Kivalina Wind-Diesel Conceptual Design Report

This report prepared for

Alaska Village Electric Cooperative

by

WHPacific

and

V3 Energy LLC

This report was written by Douglas Vaught, P.E. of V3 Energy, LLC under contract to WHPacific, Inc. for development of wind power in the village of Kivalina, Alaska. This analysis is part of a wind energy feasibility project for Northwest Arctic Borough, NANA Regional Corporation and Alaska Energy Authority.

Contents

Introduction

Alaska Village Electric Cooperative (AVEC) is the electric utility for the City of Kivalina. WHPacific is working with Northwest Arctic Borough and NANA Regional Corporation to consider renewable energy options in Kivalina. WHPacific has contracted V3 Energy, LLC to help prepare this conceptual design report. The primary focus is to evaluate wind power options at the met tower site for the village at its present location. A secondary focus is to model the wind resource at Kisimigiuktuk Hill, which is the planned new location for the village after relocation, and consider wind power options in that location. Additionally, an electrical distribution intertie has been proposed to connect between Red Dog Port and Kivalina. Should this connection be constructed, the presumed location for wind power development would be Red Dog Port with larger utility-scale turbines. This scenario is evaluated in this report.

Project Management

Alaska Village Electric Cooperative, Key Accounts Department, has executive oversight over development of wind power in Kivalina. AVEC, Northwest Arctic Borough, NANA Regional Corporation, and the City of Kivalina wish to install wind turbines in Kivalina primarily to reduce diesel fuel consumption and save money, but also to:

- Reduce long-term dependence on outside sources of energy
- Reduce exposure to fuel price volatility
- Reduce air pollution resulting from less fossil fuel combustion
- Reduce possibility of spills from fuel transport & storage
- Reduce Northwest Arctic Borough's carbon footprint and its contribution to climate change.

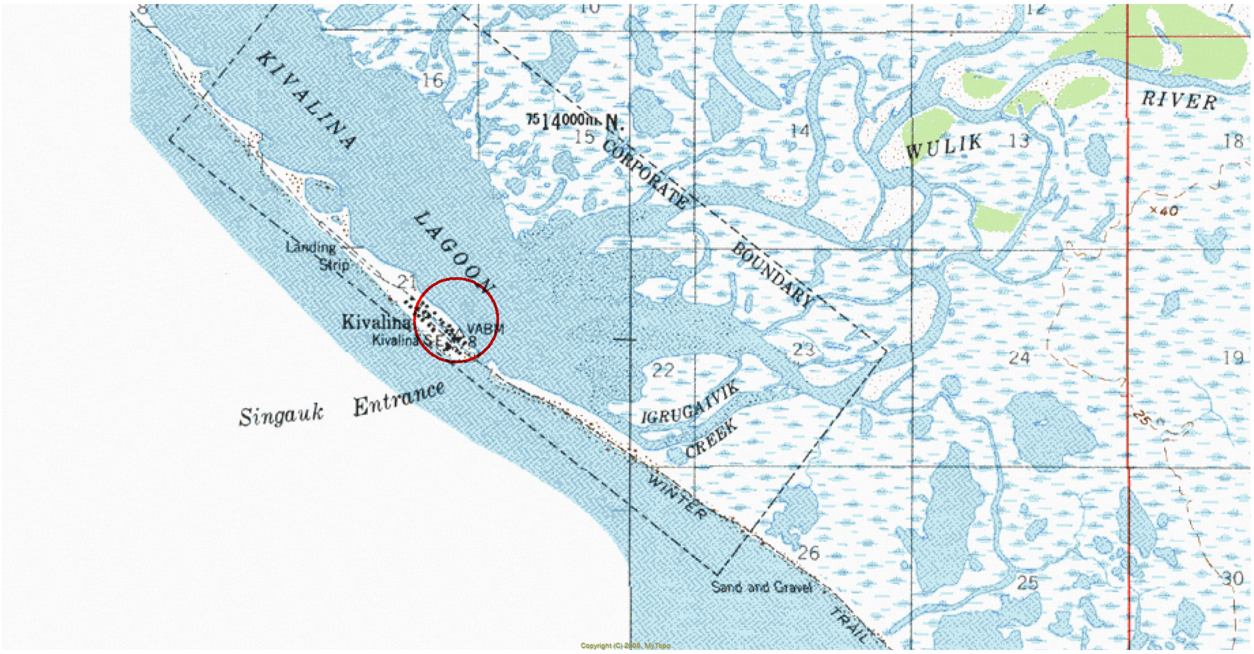
Kivalina

Kivalina is at the tip of an 8-mile barrier reef located between the Chukchi Sea and Kivalina River. It lies 80 air miles northwest of Kotzebue. It lies in the transitional climate zone, which is characterized by long, cold winters and cool summers. The average low temperature during January is -15 °F; the average high during July is 57 °F. Temperature extremes have been measured from -54 to 85 °F. Annual snowfall averages 57 inches, with 8.6 inches of precipitation per year. The Chukchi Sea is ice-free and open to boat traffic from mid-June to the first of November.

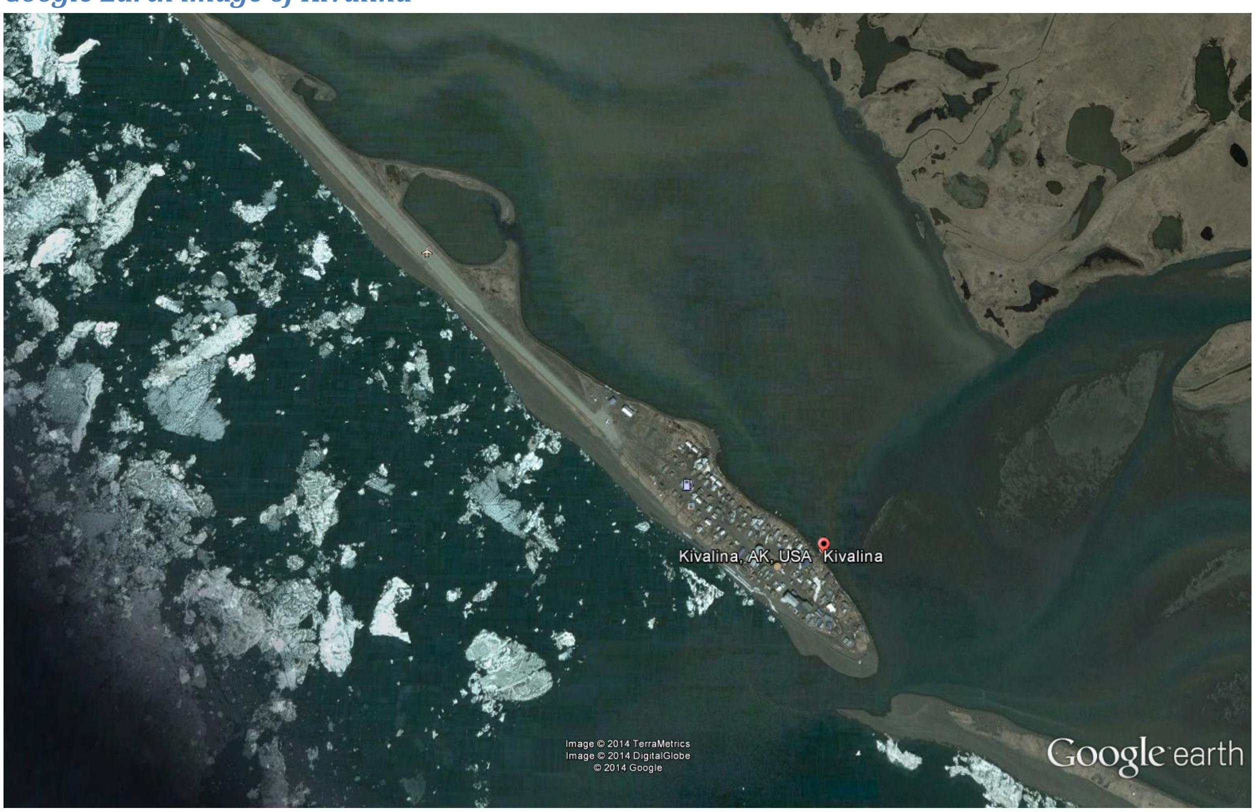
Kivalina has long been a stopping-off place for seasonal travelers between Arctic coastal areas and Kotzebue Sound communities. It is the only village in the Northwest Arctic Borough region where people hunt the bowhead whale. At one time, the village was located at the north end of the Kivalina Lagoon. It was reported as "Kivualinagmut" in 1847 by Lt. Zagoskin of the Russian Navy. Lt. G.M. Stoney of the U.S. Navy reported the village as "Kuveleek" in 1885. A post office was established in 1940. An airstrip was built in 1960 using metal mattings. Kivalina incorporated as a city in 1969. During the 1970s, new houses, a new school, and an electric system were constructed in the village. Prior to 1976, high school students from Noatak would attend school in Kivalina and board with local families. Due to severe erosion and wind-driven ice damage, the city intends to relocate to a new site 2.5 miles away. Relocation alternatives have been studied, and a new site has been designed and engineered.

Kivalina is a traditional Inupiat Eskimo village. Subsistence activities, including whaling, provide most food sources.

Topographic map of Kivalina



Google Earth image of Kivalina



Kivalina Power Plant

The Kivalina powerplant is owned and operated by AVEC. Operating personnel are village residents and employed by AVEC. The following information was obtained by WHPacific in 2011 and for this report is considered current.

Equipment Data

Unit	Engine Mfr	Engine	Generator	Generator Model	Set Rating
1	Detroit Diesel	DDEC3-S60	Kato	6P4-1025	229
2	Caterpillar	D353	Kato	6P4-1700	337
3	Cummins	LTA 10	Kato	4P3-1475	203
4	Detroit Diesel	DDEC4-S60	Newage	HCI504C	363

Generating voltage: 480Y/277

The Kivalina power plant is currently equipped with two peak load generator sets, each capable of individually meeting the current peak load requirements. The highest output unit is a relatively high-efficiency 1800 rpm Detroit Diesel Series 60. The next highest output unit, a Caterpillar D353, is no longer manufactured. The Kivalina power plant is also equipped with two remote radiators on the 1800 rpm Detroit Diesel Series 60 which provide redundant cooling capacity along with a heat exchanger and hydronic heating system for transfer of heat to the plant structures.

The Kivalina tank farm has adequate useable fuel storage capacity to meet the annual requirements of the next two-year period. Major system improvements completed for the Kivalina distribution system include replacement of the remaining URD (underground residential distribution) sections of the distribution system with overhead lines. Major systems improvements planned for the Kivalina generation system include replacement of rusted powerplant step-up transformers.

Existing features

- Low system losses in 2004, 2006 and 2008
- Two redundant peak load generator sets
- One fireproof generator set module
- Three redundant remote radiators
- Welded fuel fill line
- Impermeable liner underneath tank farm
- New bulk fuel storage tank bottoms
- Slightly excess fuel storage capacity
- Two state-of-the-art electronically timed diesel sets
- High overall operating efficiency in 1998, 2002, 2006 and 2010
- Relatively high generating efficiency

Powerplant shortcomings

- High station energy consumption
- Undeveloped wind energy potential
- One remaining non-manufactured Cat D353
- No engine jacket water heat recovery system
- Low 208 volt generation
- Three year pattern of increasing average outage time; many outages in 2010
- No blending system for used lubricating oil
- No fence around power plant site
- Fluctuating system losses and station energy consumption
- Fluctuating overall adjusted operating efficiency
- Fluctuating adjusted generating efficiency
- Large fuel adjustment in 2010
- Five year pattern of increasing fuel costs
- Power plant and tank farm located adjacent to beach potentially subject to erosion
- Tank farm located far from power plant
- Remote location of tank farm requires long transfers of fuel
- Fuel transfers increase spill risk
- Declining unadjusted generating efficiency

Existing features	Powerplant shortcomings
	• Unrealistically high adjusted generating efficiency • Larger fuel adjustments since tank farm was located to a remote location from previous tank farm

Wind-Diesel Philosophy

Installing wind turbines and creating a wind-diesel power system in an Alaskan village is a demanding challenge. At first glance, the benefits of wind power are manifest: the fuel is free and it is simply a manner of capturing it. The reality of course is more complicated. Wind turbines are complex machines and integrating them into the diesel power system of a small community is complicated. With wind-diesel, a trade-off exists between fuel savings and complexity. A system that is simple and inexpensive to install and operate will displace relatively little diesel fuel, while a wind-diesel system of considerable complexity and sophistication can achieve very significant fuel savings.

The ideal balance of fuel savings and complexity is not the same for every community and requires careful consideration. Not only do the wind resource, electric and thermal load profiles, and powerhouse suitability vary between villages, so does technical capacity and community willingness to accept the opportunities and challenges of wind power. A very good wind-diesel solution for one village may not work as well in another village, for reasons that go beyond design and configuration questions. Ultimately, the electric utility and village residents must consider their capacity, desire for change and growth, and long-term goals when deciding the best solution to meets their needs.

The purpose of this conceptual design report is to introduce and discuss the viability of wind power in Kivalina. Many options are possible, ranging from a very simple low penetration system to a highly complex, diesels-off configuration potentially capable of displacing 50 percent or more of fuel usage in the community. It is possible that AVEC and Kivalina residents ultimately will prefer a simple, low penetration wind power system, or alternatively a very complex high penetration system, but from past discussions and work it appears that a moderate approach to wind power in Kivalina is preferable, at least initially.

With a moderately complex project design framework in mind, a configuration of relatively high wind turbine capacity with no electrical storage and no diesels-off capability was chosen. This provides sufficient wind capacity to make a substantive impact on fuel usage but does not require an abrupt transition of Kivalina's power generation from low to high complexity. Although conceptually elegant, there is a trade-off to consider with this approach. Installing a large amount of wind power (200 to 300 kW of wind capacity are recommended) is expensive, but without electrical or thermal storage some of the benefits of this wind power capacity may not always be used to best advantage.

The thermodynamics of energy creation and use dictates that wind power is more valuable when used to offset fuel used by diesel generators to generate electricity than fuel used in fuel oil boilers to serve thermal loads. Referring to the energy production summaries for the turbine configurations under *Modeling Results*, one can see that the wind turbines are expected to produce relatively small amounts of excess electricity, even at 85 percent turbine availability. This excess electricity, although minimal, must be shunted via a secondary load controller to the diesel generator heat recovery loop or simple radiation heaters to avoid curtailing wind turbines during periods of high wind and relatively light electrical load.

Although perhaps not readily apparent in the report, this compromise of wind capacity versus complexity is contained within the economic benefit-to-cost tables. This compromise, which is endemic to wind-diesel, results in high capital costs, but usage of the energy generated is imperfect from an efficiency point of view. The most efficient usage of wind energy from a technical point of view – offset of electrical power, may be too expensive from a cost-benefit perspective.

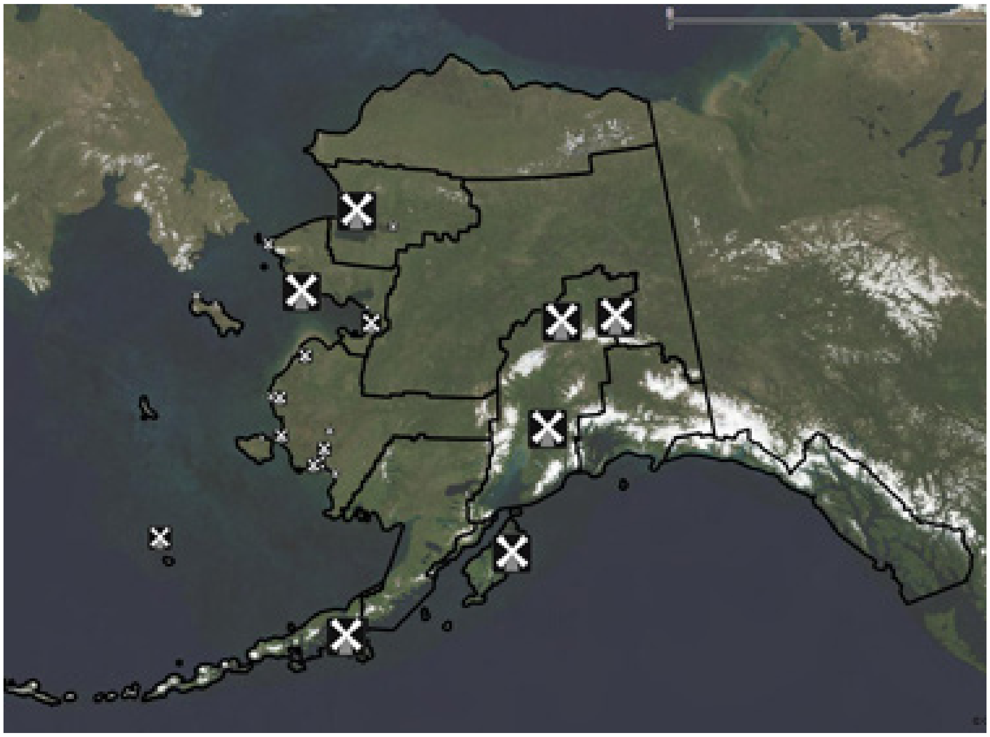
It is important not to focus strictly on benefit-to-cost ratio of a particular configuration design or particular turbine option, but also consider a wider view of the proposed wind project for Kivalina. Installing 200 to 300 kW wind power capacity has considerable short-term benefit with reduction of diesel fuel usage, but more importantly it would provide a platform of sustainable renewable energy growth in Kivalina for many years to come. This could include enhancements such as additional thermal load offset, battery storage and/or use of a flywheel to enable diesels-off capability, creation of deferred heat loads such as water heating, and installation of distributed electrical home heat units (Steffis heaters or similar) controlled by smart metering. The latter, presently operational to a limited extent in the villages of Kongiganak, Kwigillingok, Tuntutuliak, has enormous potential in rural Alaska to not only reduce the very high fuel oil expenses borne by village residents, but also to improve the efficiency and cost benefit of installed and future wind power projects. These opportunities and benefits are tangible and achievable, but their cost benefit was not modeled in this report.

Lastly, it must be acknowledged that a wind power project in Kivalina will provide benefits that are not easily captured by economic modeling. These are the *externalities* of economics that are widely recognized as valuable, but often discounted because they are considered by some as soft values compared to the hard numbers of capital cost, fuel quantity displaced, etc. These include ideals such as long-term sustainability of the village, independence from foreign-sourced fuel, reduction of Kivalina's carbon footprint, and opportunities for education and training of local residents. Beyond these somewhat practical considerations, there is the simple moral argument that renewable energy is the right thing to do, especially in a community such as Kivalina that is in the vanguard of risk from climate change due to global warming.

Wind-Diesel Hybrid System Overview

There are now over twenty-four wind-diesel projects in the state, making Alaska a world leader in wind-diesel hybrid technology. There are a variety of system configurations and turbine types in operation and accordingly there is a spectrum of success in all of these systems. As experience and statewide industry support has increased so has overall system performance. The following figure illustrates the locations of installed wind projects in Alaska.

Alaska wind-diesel projects

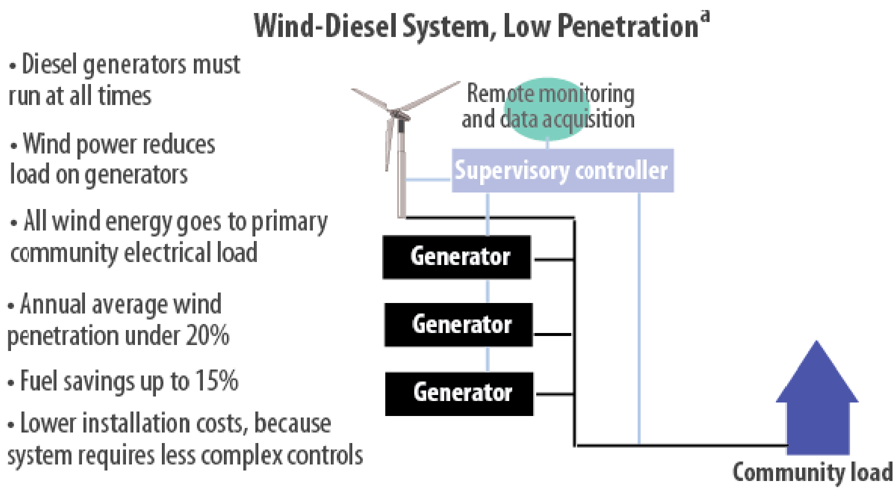


Wind-diesel Design Options

Wind-diesel power systems are categorized based on their average penetration levels, or the overall proportion of wind-generated electricity compared to the total amount of electrical energy generated. Commonly used categories of wind-diesel penetration levels are low penetration, medium penetration, and high penetration. The wind penetration level is roughly equivalent to the amount of diesel fuel displaced by wind power. Note however that the higher the level of wind penetration, the more complex and expensive a control system and demand-management strategy is required. This is a good compromise between of displaced fuel usage and relatively minimal system complexity and is the preferred system configuration of Alaska Village Electric Cooperative (AVEC). AVEC is Alaska's leading utility developer of wind-diesel power systems, and a useful guide for North Slope Borough.

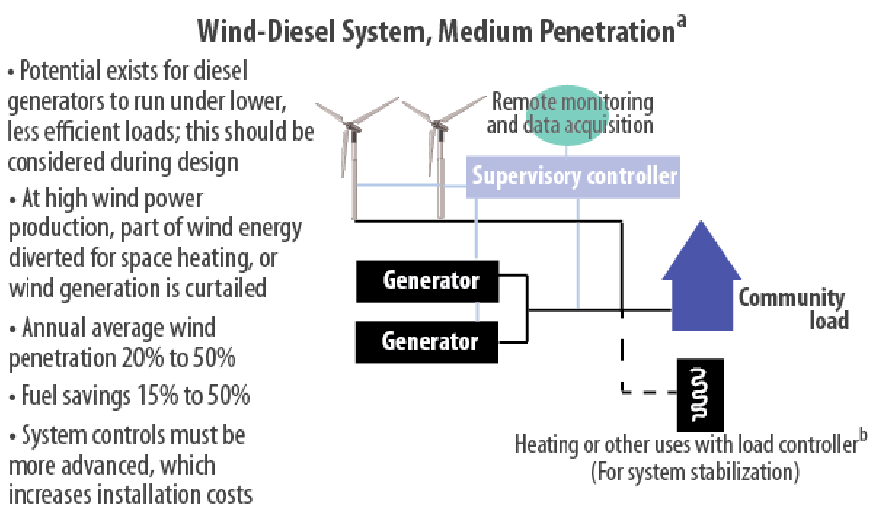
Low Penetration Configuration

Low-penetration wind-diesel systems require the fewest modifications to the existing system. However, they tend to be less economical for village installations due to the limited annual fuel savings compared to the total wind system installation costs.



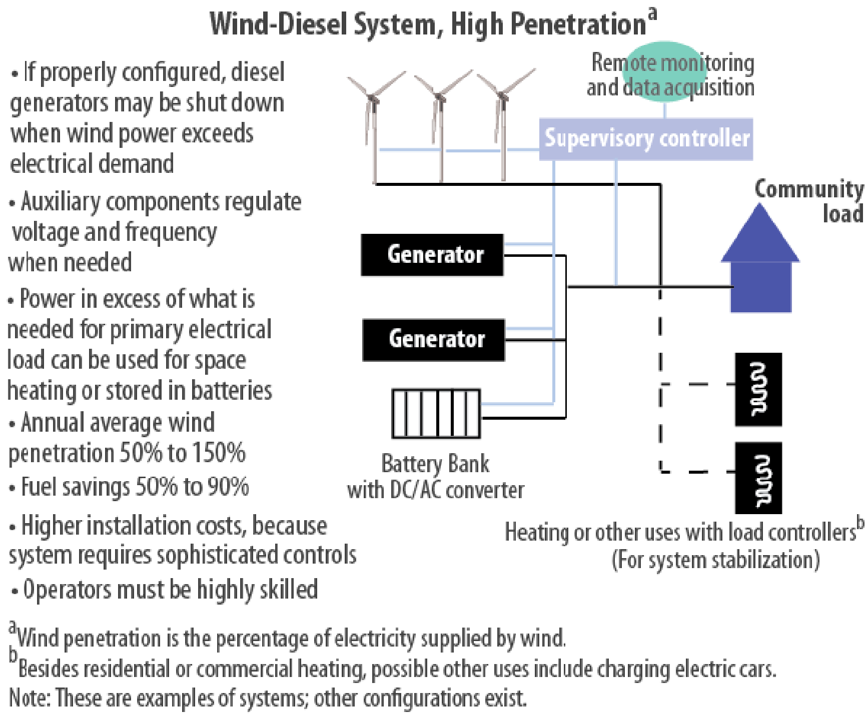
Medium Penetration Configuration

Many of the AVEC communities, Toksook Bay for example, have 24% of their energy from wind. The figure below indicates the configuration and key points on using a medium penetration, wind-diesel system.



High Penetration Configuration

Other communities, such as Kokhanok, are more aggressively seeking to offset diesel used for thermal and electrical energy. They are using configurations which will allow for the generator sets to be turned off and use a significant portion of the wind energy for various heating loads. The potential benefit of these systems is the highest, however currently the commissioning for these system types due to the increased complexity, can take longer. The figure below indicates the configuration and key points on using a high-penetration, wind-diesel system.



The above system descriptions can be summarized in the table below. The level of instantaneous penetration is important for power quality design considerations. The annual amount of wind energy on the system is considered the average penetration level and helps to provide a picture of the overall economic benefit.

Categories of wind-diesel penetration levels

Penetration Category	Wind Penetration Level		Operating Characteristics and System Requirements
	Instantaneous	Average	
Very Low	<60%	<8%	• Diesel generator(s) runs full time • Wind power reduces net load on diesel • All wind energy serves primary load • No supervisory control system
Low	60 to 120%	8 to 20%	• Diesel generator(s) runs full time • At high wind power levels, secondary loads are dispatched to insure sufficient diesel loading, or wind generation is curtailed • Relatively simple control system
Medium	120 to 300%	20 to 50%	• Diesel generator(s) runs full time • At medium to high wind power levels, secondary loads are dispatched to insure sufficient diesel loading • At high wind power levels, complex secondary load control system is needed to ensure heat loads do not become saturated • Sophisticated control system

Penetration Category	Wind Penetration Level		Operating Characteristics and System Requirements
	Instantaneous	Average	
High (Diesels-off Capable)	300+%	50 to 150%	• At high wind power levels, diesel generator(s) may be shut down for diesels-off capability • Auxiliary components required to regulate voltage and frequency • Sophisticated control system

Wind-Diesel System Components

Listed below are the main components of a medium to high-penetration wind-diesel system:

- Wind turbine(s), plus tower and foundation
- Supervisory control system
- Secondary load (plus controller)
- Deferrable load
- Interruptible load
- Storage
- Synchronous condenser

Wind Turbine(s)

Village-scale wind turbines are generally considered to be 50 kW to 500 kW rated output capacity. This turbine size once dominated with worldwide wind power industry but has long been left behind in favor of much larger 1,500 kW plus capacity turbines. Conversely, many turbines are manufactured for home or farm application, but generally these are 10 kW capacity or less. Consequently, few new village size-class turbines are on the market, although a large supply of used and/or remanufactured turbines are available. The latter typically result from repowering older wind farms in the United States and Europe with new, larger wind turbines.

Supervisory Control System

Medium- and high-penetration wind-diesel systems require fast-acting real and reactive power management to compensate for rapid variation in village load and wind turbine power output. A wind-diesel system master controller, also called a supervisory controller, would be installed inside the Kivalina power plant or in a new module adjacent to it. The supervisory controller would select the optimum system configuration based on village load demand and available wind power.

Synchronous Condenser

A synchronous condenser, also referred to as a synchronous compensator, is a specialized synchronous-type electric motor with an output shaft that spins freely. Its excitation field is controlled by a voltage regulator to either generate or absorb reactive power as needed to support grid voltage or to maintain the grid power factor at a specified level. A synchronous condenser or similar device is needed to operate in diesels-off mode with wind turbines equipped with asynchronous (induction) type generators. This is to provide the reactive power necessary for operation of the asynchronous generator.

Synchronous condenser at the Kokhonak, AK powerplant

Secondary Load

A secondary or "dump" load during periods of high wind is required for a wind-diesel hybrid power system to operate reliably and economically. The secondary load converts excess wind power into thermal power for use in space and water heating through the extremely rapid (sub-cycle) switching of heating elements, such as an electric boiler imbedded in the diesel generator jacket water heat recovery loop. As seen in Figure 16, a secondary load controller serves to stabilize system frequency by providing a fast responding load when gusting wind creates system instability.

An electric boiler is a common secondary load device used in wind-diesel power systems. An electric boiler (or boilers), coupled with a boiler grid interface control system, could be installed in Kivalina to absorb excess instantaneous energy (generated wind energy plus minimum diesel output exceeds electric load demand). The grid interface monitors and maintains the temperature of the electric hot water tank and establishes a power setpoint. The wind-diesel system master controller assigns the setpoint based on the amount of unused wind power available in the system. Frequency stabilization is another advantage that can be controlled with an electric boiler load. The boiler grid interface will automatically adjust the amount of power it is drawing to maintain system frequency within acceptable limits.

Deferrable Load

A deferrable load is electric load that must be met within some time period, but exact timing is not important. Loads are normally classified as deferrable because they have some storage associated with them. Water pumping is a common example - there is some flexibility as to when the pump actually operates, provided the water tank does not run dry. Other examples include ice making and battery charging. A deferrable load operates second in priority to the primary load and has priority over charging batteries, should the system employ batteries as a storage option.

Interruptible Load

Electric heating either in the form of electric space heaters or electric water boilers could be explored as a means of displacing stove oil with wind-generated electricity. It must be emphasized that electric heating is only economically viable with excess electricity generated by a renewable energy source such as wind and not from diesel-generated power. It is typically assumed that 40 kWh of electric heat is equivalent to one gallon of heating fuel oil.

Storage Options

Electrical energy storage provides a means of storing wind generated power during periods of high winds and then releasing the power as winds subside. Energy storage has a similar function to a secondary load but the stored, excess wind energy can be converted back to electric power at a later time. There is an efficiency loss with the conversion of power to storage and out of storage. The descriptions below are informative but are not currently part of the overall system design.

Flywheels

A flywheel energy system has the capability of short-term energy storage to further smooth out short-term variability of wind power, and has the additional advantage of frequency regulation. The smallest capacity flywheel available from Powercorp (now ABB), however, is 500 kW capacity, so it is only suitable for large village power generation systems.

Batteries

Battery storage is a generally well-proven technology and has been used in Alaskan power systems including Fairbanks (Golden Valley Electric Association), Wales and Kokhanok, but with mixed results in the smaller communities. Batteries are most appropriate for providing medium-term energy storage to allow a transition, or bridge, between the variable output of wind turbines and diesel generation. This "bridging" period is typically 5 to 15 minutes long. Storage for several hours or days is also possible with batteries, but this requires higher capacity and cost. In general, the disadvantages of batteries for utility-scale energy storage, even for small utility systems, are high capital and maintenance costs and limited lifetime. Of particular concern to rural Alaska communities is that batteries are heavy and expensive ship and most contain hazardous substances that require special removal from the village at end of service life and disposal in specially-equipped recycling centers.

There are a wide variety of battery types with different operating characteristics. Advanced lead acid and zinc-bromide flow batteries were identified as "technologically simple" energy storage options appropriate for rural Alaska in an Alaska Center for Energy and Power (ACEP) July, 2009 report on energy storage. Nickel-cadmium (NiCad) batteries have been used in rural Alaska applications such as the Wales wind-diesel system. Advantages of NiCad batteries compared to lead-acid batteries include a deeper discharge capability, lighter weight, higher energy density, a constant output voltage, and much better performance during cold temperatures. However, NiCads are considerably more expensive than lead-acid batteries and one must note that the Wales wind-diesel system had a poor operational history and has not been functional for over ten years.

Because batteries operate on direct current (DC), a converter is required to charge or discharge when connected to an alternating current (AC) system. A typical battery storage system would include a bank of batteries and a power conversion device. The batteries would be wired for a nominal voltage of roughly 300 volts. Individual battery voltages on a large scale system are typically 1.2 volts DC. Recent advances in power electronics have made solid state inverter/converter systems cost effective and preferable a power conversion device. The Kokhanok wind-diesel system is designed with a 300 volts DC battery bank coupled to a grid-forming power converter for production of utility-grade real and reactive power. Following some design and commissioning delays, the solid state converter system in Kokhanok should be operational by late 2013 and will be monitored closely for reliability and effectiveness.

Kivalina-based Wind Power Project

This section examines the options for a wind project based in or near Kivalina and serving only electric and thermal loads in the village.

Wind Resource Assessment - Kivalina

The wind resource measured in Kivalina is good, with measured power class 3 to 4 winds. In addition to high annual mean wind speed and wind power density, Kivalina experiences directional prevailing winds, low turbulence and calculations indicate low extreme wind speed probability.

A 30 meter met tower was installed in May 2011 about two miles south of Kivalina near the Wulik River at the planned re-location site for the village. The met tower datalogger failed in May 2012 and the met tower itself collapsed in a severe wind storm with accompanying flooding in autumn 2012. The met tower debris was removed from the site in August 2013 and remaining rebar guy wires anchors were cut-off at ground level in February 2014. The complete Kivalina wind resource report, dated June 2012, is included in Appendix A of this report.

Met tower data synopsis

Data dates	May 9, 2011 to May 18, 2012 (12.3 months)
Site number	9750
Site location (NAD83)	N 67° 43’ 26.64”; W 164° 26’ 25.38”
Wind power class	Class 3 to Class 4
Wind power density mean, 30 m	325 W/m^2
Wind speed mean, 30 m	5.84 m/s
Max. 10-min wind speed average	26.7 m/s
Maximum 2-sec. wind gust	33.6 m/s (November, 2011)
Weibull distribution parameters	k = 1.65, c = 6.51 m/s
Wind shear power law exponent	Not determined due to faulty 20 m anemometer
Roughness class	Not determined due to faulty 20 m anemometer
IEC 61400-1, 3rd ed. classification	Class III-C
Turbulence intensity, mean	0.075 (at 15 m/s)
Calm wind frequency (at 33 m)	35% (< 4 m/s)

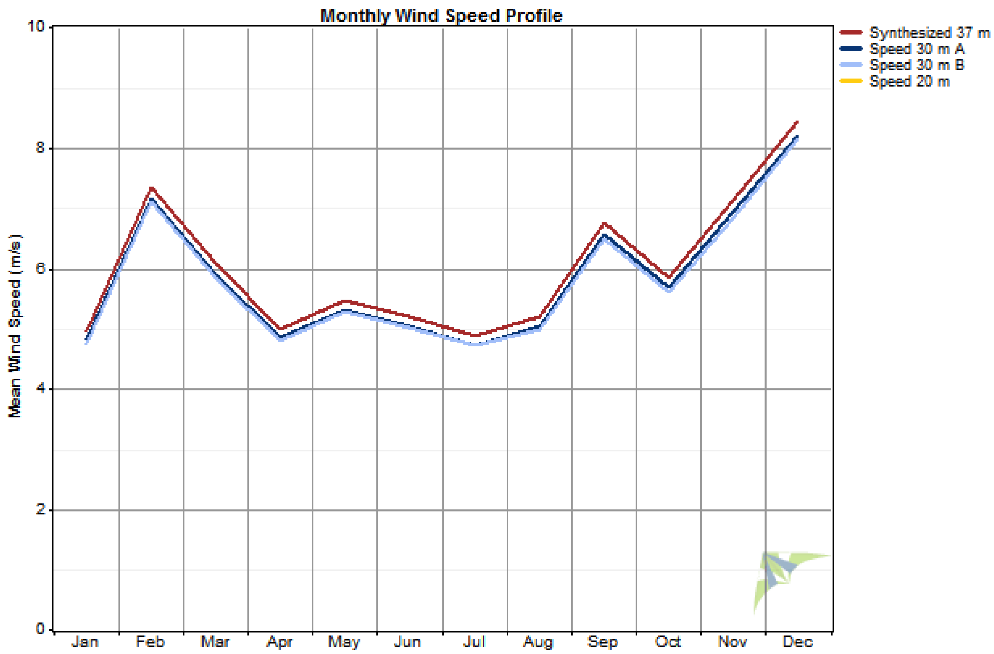
Wind Speed

Anemometer data obtained from the met tower, from the perspectives of both mean wind speed and mean wind power density, indicate a good wind resource. Mean wind speeds are greater at higher elevations on the met tower as one would expect. Note that the cold mean annual air temperature in Kivalina contributed to a higher wind power density than otherwise expected for the mean wind speeds. With an assumed power law exponent (α) value of 0.12, wind speed was extrapolated to 37 meters for use elsewhere in this report. Not that α could not be calculated from the data set due to data quality problems with the 20 meter level anemometer.

Anemometer data summary

Variable	Speed 30 m A	Speed 30 m B	Speed 37 m synthesized
Measurement height (m)	30	30	37
Mean wind speed (m/s)	5.84	5.79	6.02
Max 10-min avg wind speed (m/s)	26.7	26.7	27.5
Max gust wind speed (m/s)	33.2	33.6	
Weibull k	1.65	1.61	1.65
Weibull c (m/s)	6.51	6.44	6.71
Mean power density (W/m²)	323	321	353
Mean energy content (kWh/m²/yr)	2,830	2,810	3,090
Energy pattern factor	2.43	2.48	2.43

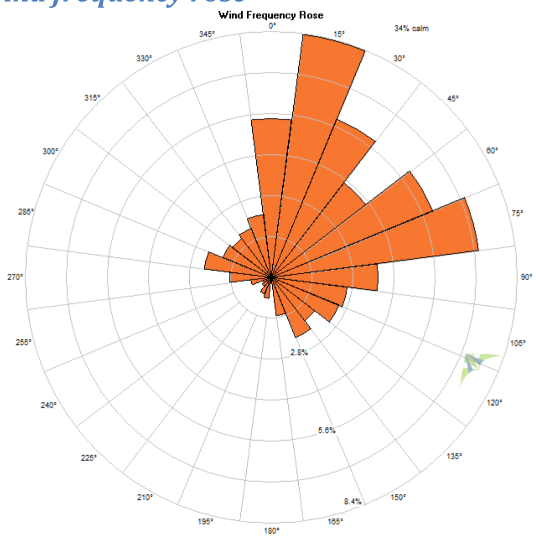
Wind speed profile



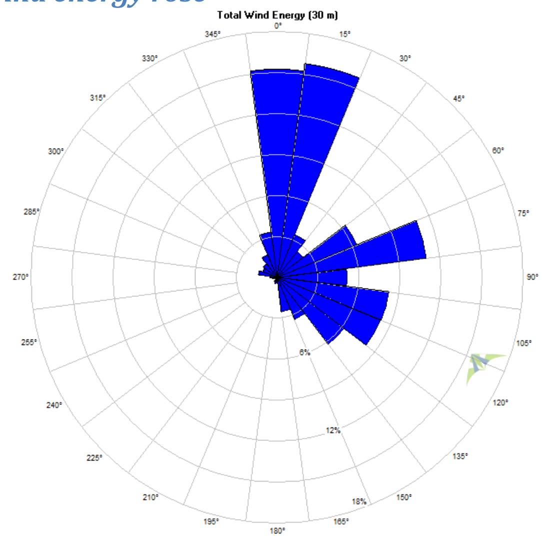
Wind Rose

Wind frequency rose data indicates that winds at Kivalina are relatively directional, with north-northeasterly and east-northeasterly predominating. The mean value rose indicates that infrequent southeasterly winds, when they do occur, are of high energy and hence likely are storm winds. The wind energy rose indicates that winds for wind turbine operations power-producing are northerly and southeasterly dominant. Calm frequency (percent of time that winds at the 30 meter level are less than 4 m/s) was 34 percent during the met tower test period.

Wind frequency rose



Wind energy rose



Temperature

Kivalina has an exceptionally cold climate with a below freezing mean annual temperature and a minimum measured temperature during the test period of -48.7° C (-55.7° F). Summer temperatures can be quite warm however.

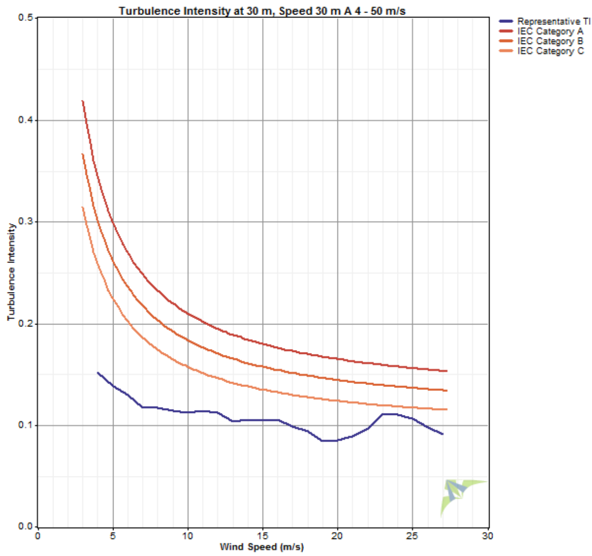
Kivalina temperature data

Month	Mean (°C)	Mean (°F)	Min (°C)	Min (°F)	Max (°C)	Max (°F)
Jan	-30.7	-23.2	-44.5	-48.1	-8.9	16.0
Feb	-15.9	3.3	-48.7	-55.7	2.7	36.9
Mar	-20.2	-4.4	-34.5	-30.1	-7.4	18.7
Apr	-7.9	17.7	-28.4	-19.1	10.6	51.1
May	1.8	35.2	-15.4	4.3	25.0	77.0
Jun	12.2	54.0	0.7	33.3	28.1	82.6
Jul	12.9	55.2	2.6	36.7	28.9	84.0
Aug	11.3	52.4	0.4	32.7	23.5	74.3
Sep	6.8	44.3	-5.1	22.8	19.3	66.7
Oct	-3.5	25.8	-17.6	0.3	8.7	47.7
Nov	-16.5	2.2	-31.5	-24.7	1.8	35.2
Dec	-15.5	4.0	-35.0	-31.0	0.5	32.9
Annual	-5.4	22.3	-48.7	-55.7	28.9	84.0

Turbulence Intensity

Turbulence intensity (TI) at the Kivalina met tower site is well within acceptable standards with an IEC 61400-1, 3rd edition (2005) classification of turbulence category C, which is the lowest defined. The mean TI at 15 m/s is 0.075 and the representative TI at 15 m/s is 0.105 (30 m A anemometer), both which can be considered very low and hence very desirable for wind turbine operations.

Turbulence intensity, 30 m A anemometer, all direction sectors



Extreme Winds

A modified Gumbel distribution analysis, based on monthly maximum winds vice annual maximum winds, was used to predict extreme winds at the Kivalina met tower site. Industry standard reference of extreme wind is the 50 year probable (50 year return period) ten-minute average wind speed, referred to as V_{ref}. For Kivalina, this calculates to 35.8 m/s (at 30 meters), which qualifies as an International Electrotechnical Commission (IEC) 61400-1, 3rd edition criteria Class III site, the lowest defined. All wind turbines are designed for IEC 61400-1 Class III conditions.

Extreme wind probability table, 30 m A data

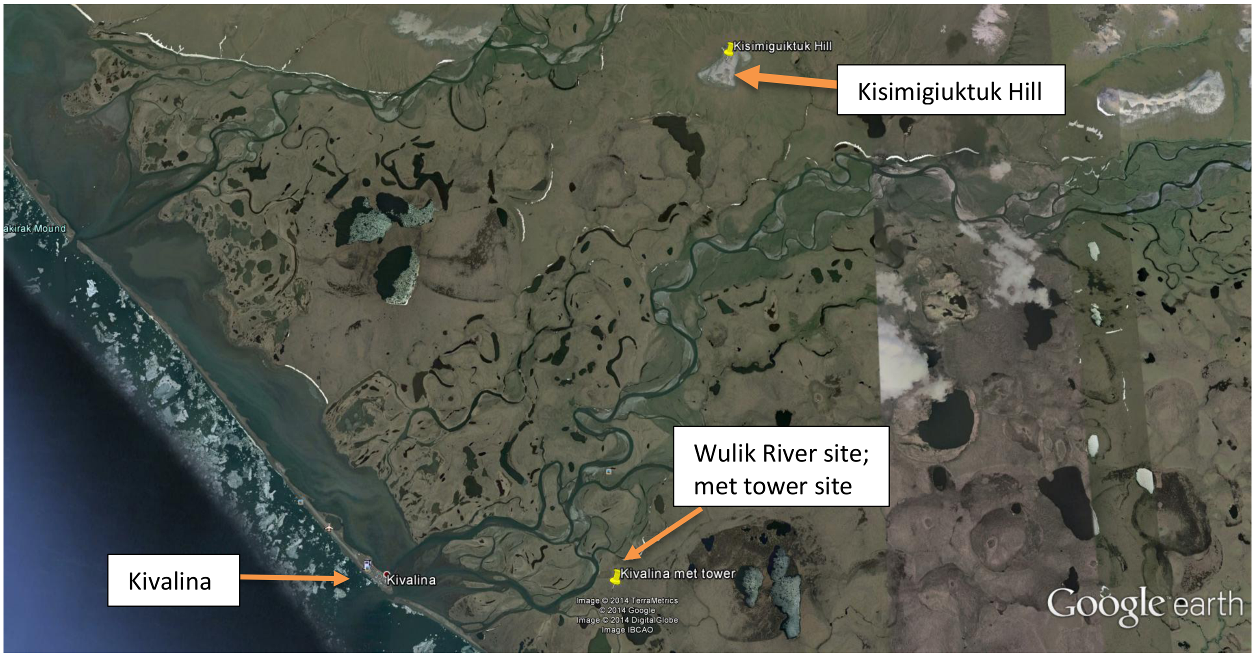
Period (years)	V_{ref} (m/s)	Gust (m/s)	IEC 61400-1, 3rd ed. Class	V_{ref}, m/s
3	26.8	32.8	I	50.0
10	30.7	37.5	II	42.5
20	32.9	40.2	III	37.5
30	34.2	41.8	S	designer-specified
50	35.8	43.8		
100	38.0	46.5		

Kivalina Wind Site Options

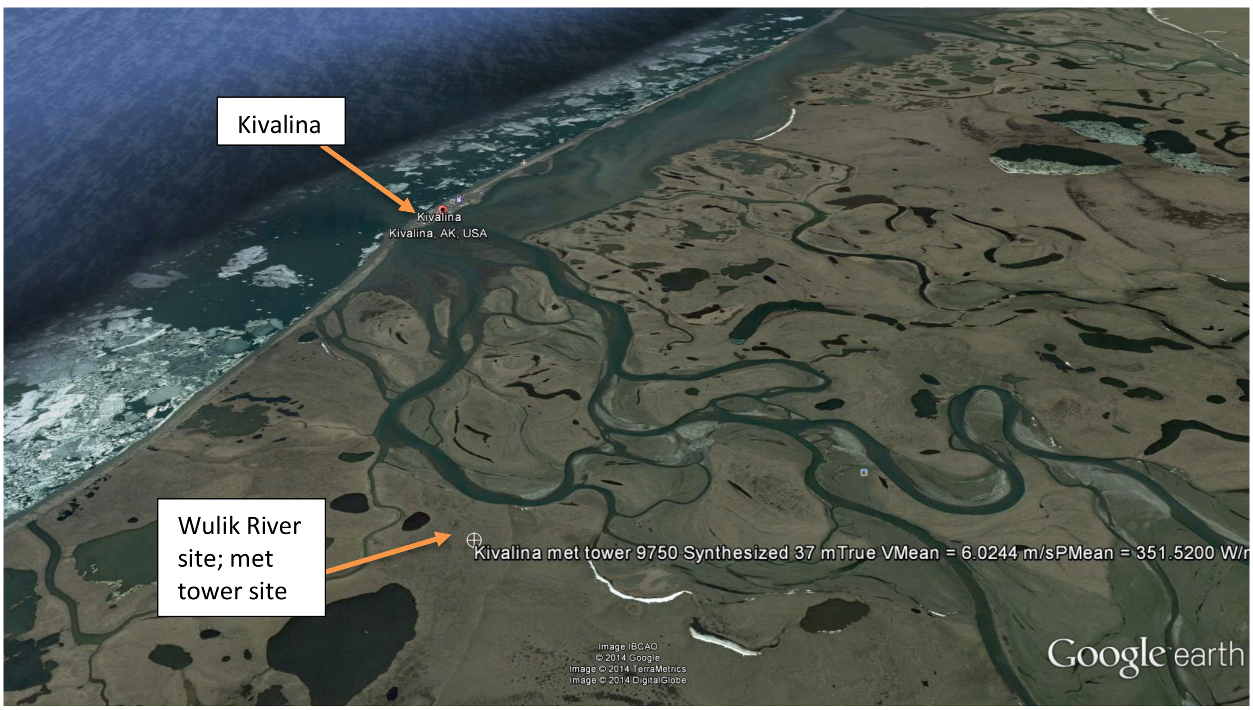
The primary difficulty in identifying and selecting a wind turbine site in Kivalina is the status of the village. Wind turbines in or very near Kivalina are not possible due to the very confined nature of the community and the alignment of the runway which precludes large structures near the village. But, due to the ever-increasing erosion of the barrier island that Kivalina occupies which separates the community from Kivalina Lagoon and the Bering Sea, the village may move to a more secure location.

Several years ago the preferred new location was one mile up the Wulik River (about two miles from the present village site), very near the site of the Kivalina met tower. This location, however, was deemed unsuitable by the U.S. Army Corps of Engineers due to flooding risk, hence a site on the east slope of Kisimigiuktuk Hill ("stands alone"; also *Kisimiguiqtuq*) was chosen for re-location of the village. Kisimigiuktuk Hill is seven miles northeast of Kivalina and would require construction of a causeway across Kivalina Lagoon and a substantial road construction project to cross several miles of marshy tundra. Kisimigiuktuk Hill is stable and dry upland terrain and suitable for construction of infrastructure.

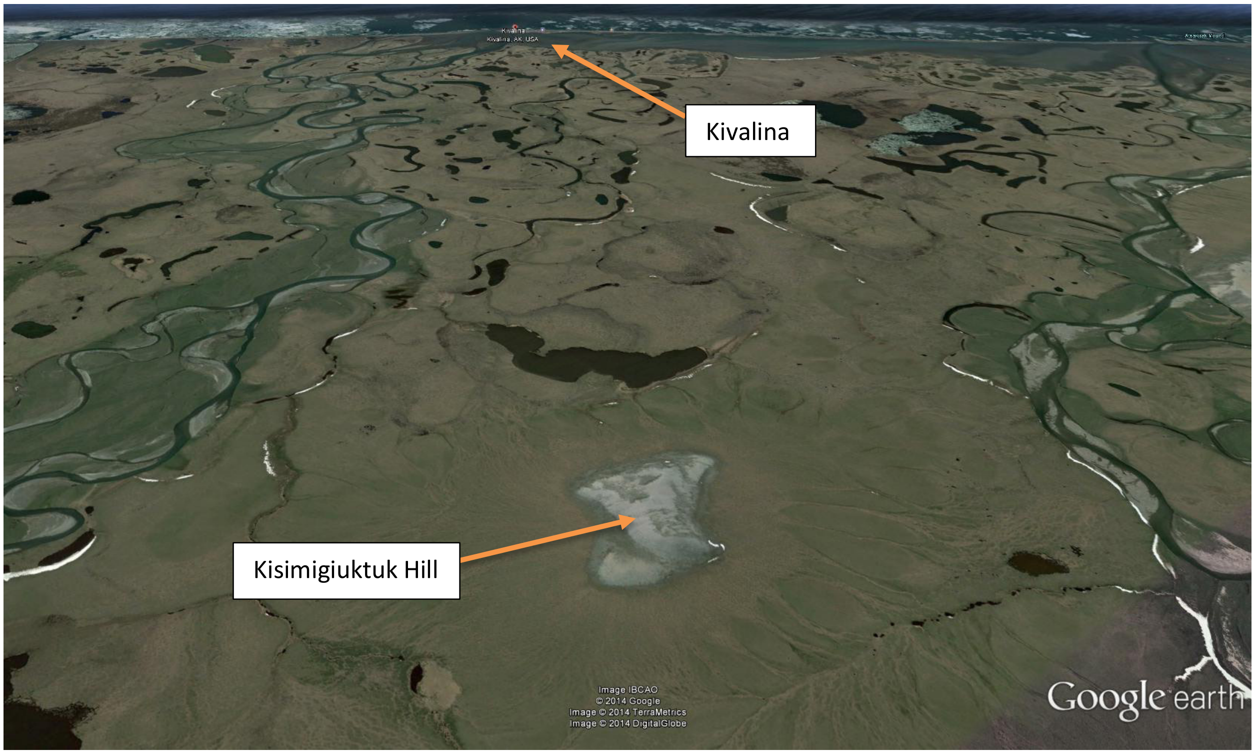
Kivalina site options



Wulik River site, view to west



Kisimigiuktuk Hill, view to west



Kivalina wind turbine site options table

Wind Turbine Site	Advantages	Disadvantages
Wulik River	• Near the existing village location • Site large enough to accommodate several wind turbines with sufficient room for future expansion • Sufficient distance from the Kivalina airport to allay air traffic operations concerns	• Two miles of new distribution line required; complicated distribution line route with water crossing • This site is no longer the preferred location for the re-location of Kivalina • Marshy permafrost site; expensive foundation; substantial fill required • Summer access undeveloped; would require improved boat landing on the Wulik River • Winter construction required
Kisimigiuktuk Hill	• Area of the preferred site for re-location of Kivalina • Very good wind exposure • Rocky eroded mountain geotech; ballast type foundation possible • Site large enough to accommodate several wind turbines with sufficient room for future expansion	• Presumes re-location of Kivalina without which this turbine site is not viable • Road must be constructed to top of Kisimigiuktuk Hill (presuming preceding construction of road from Kivalina to Kisimigiuktuk Hill

Wind Turbine Site	Advantages	Disadvantages
	• Presuming Kivalina airport is not relocated from the barrier island, no turbine height limitations • Dry site; likely good geotech conditions for turbine foundations	

WAsP Modeling

WAsP (acronym for *Wind Atlas and Application Program*) is a PC-based software to predict wind climate, wind resource and power production for wind turbines and wind farms. WAsP modeling was used in this conceptual design report to predict the wind resource on Kisimigiuktuk Hill with the Kivalina met tower as the wind resource reference point.

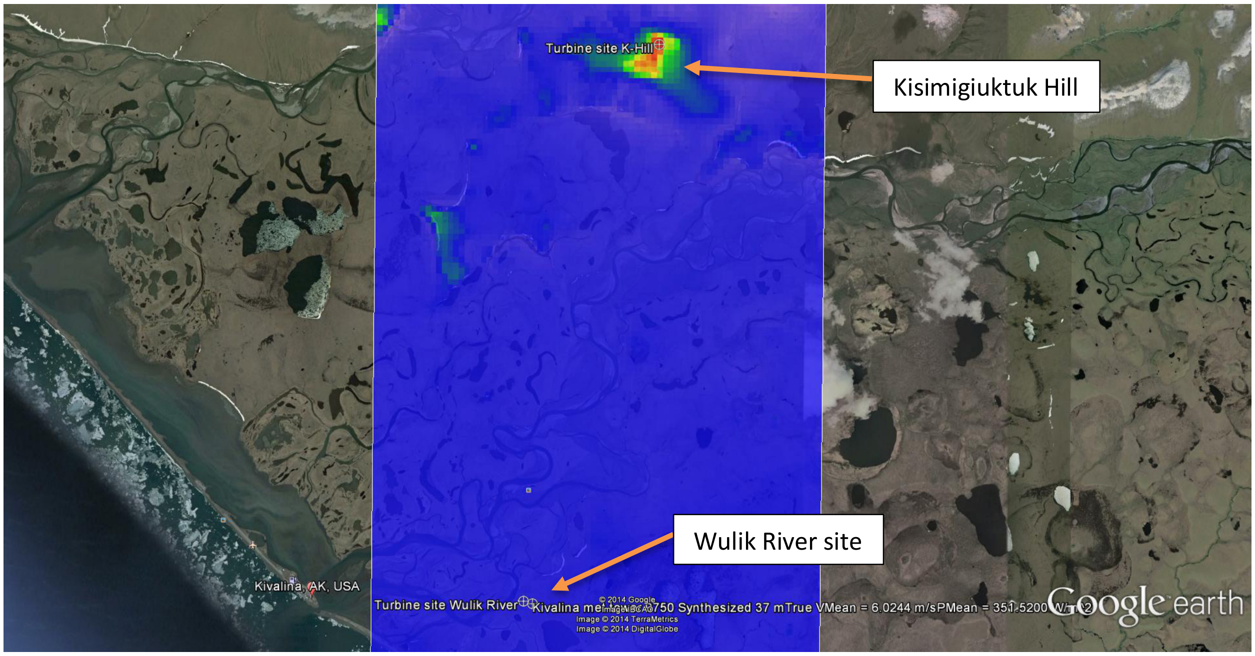
WAsP modeling begins with import from the National Elevation Dataset of a digital elevation map (DEM) of the subject site and surrounding area and conversion of coordinates to Universal Transverse Mercator (UTM). UTM is a geographic coordinate system that uses a two-dimensional Cartesian coordinate system to identify locations on the surface of Earth. UTM coordinates reference the meridian of its particular zone (60 longitudinal zones are further subdivided by 20 latitude bands) for the easting coordinate and distance from the equator for the northing coordinate. Units are meters. Elevations of the DEMs are converted to meters if necessary for import into WAsP software. Kivalina is within the boundary of new, high resolution elevation data with modern datum geographic reference. This new data was used for the WAsP analysis in this report.

Once converted for use in WAsP software, a met tower reference point is added to the DEM, wind turbine locations identified, and a wind turbine type selected to perform the calculations. WAsP considers the orographic (terrain) effects on the wind (plus surface roughness and obstacles) and calculates wind flow increase or decrease at each node of the DEM grid. The mathematical model has a number of limitations, including the assumption that wind regime of the turbine site is similar to that of the met tower reference site, prevailing weather conditions are stable over time, and the surrounding terrain at both sites is sufficiently gentle and smooth to ensure laminar, attached wind flow. WAsP software is not capable of modeling turbulent wind flow resulting from sharp terrain features such as mountain ridges, canyons, shear bluffs, etc. Turbulent flow modeling requires computation fluid dynamics methods.

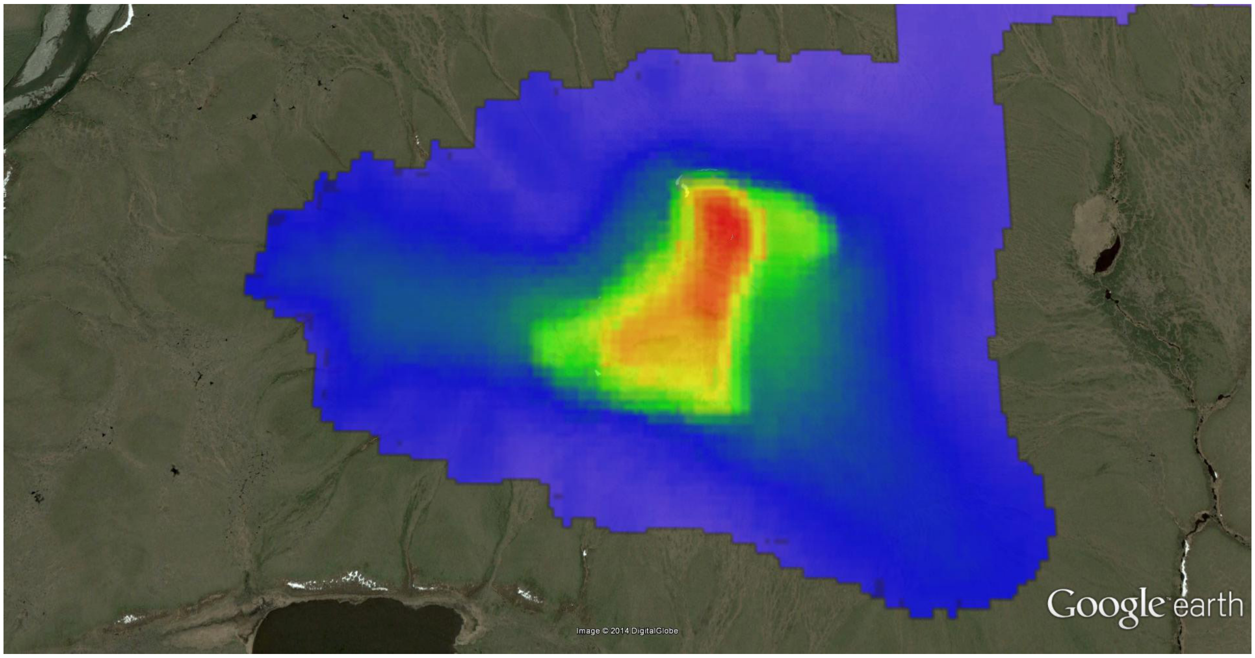
Turbine Site Options

As previously described, there are two site options: the Wulik River site at or near the met tower location, and on the summit of Kisimigiuktuk Hill, presuming eventual relocation of the village of Kivalina to this area due to the accelerating trend and increasing risk of erosion and coastal flooding.

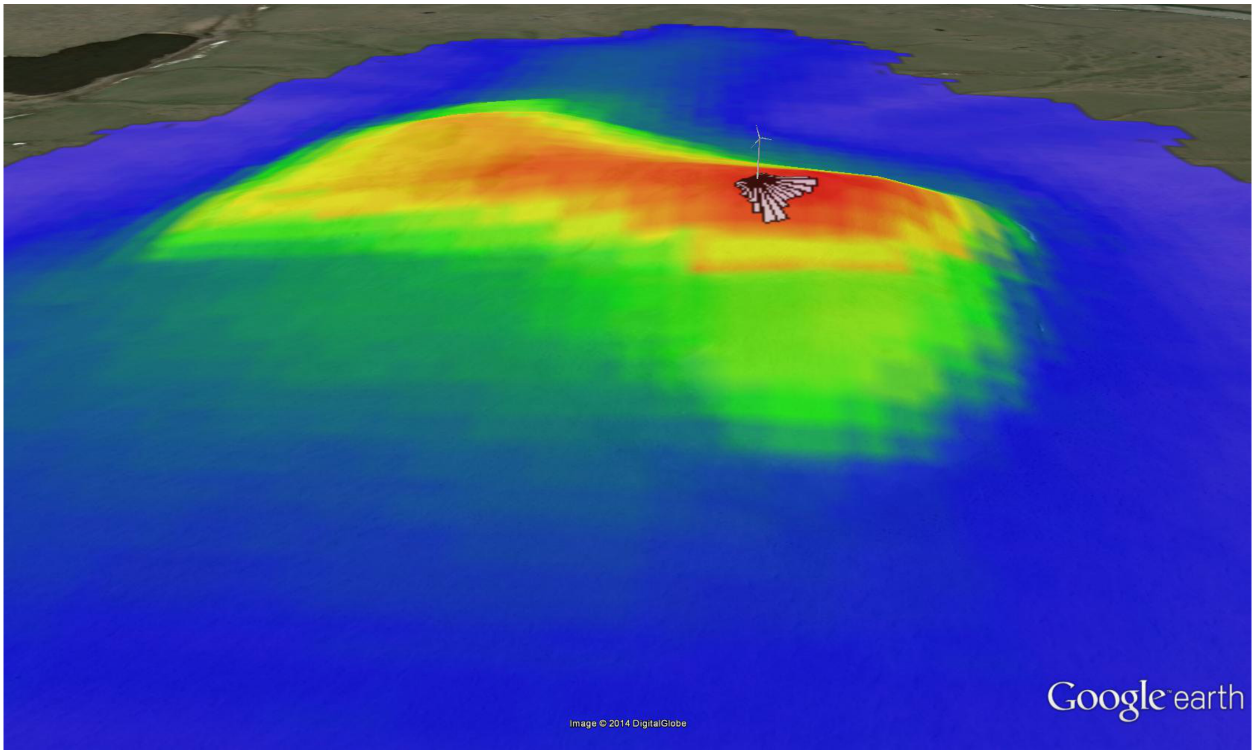
WAsP wind speed overlay, Wulik River site and Kisimigiuktuk Hill



WAsP wind speed overlay, Kisimigiuktuk Hill site area



WAsP wind speed overlay with wind rose, Kisimigiuktuk Hill Site, view to the west

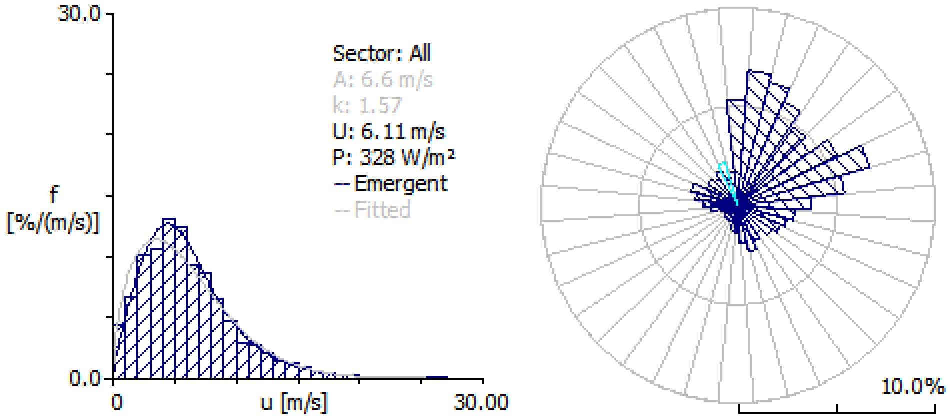


Comparative prediction of Kivalina met tower and wind turbine sites

Location	Wind Speed (annual mean), (m/s)	Power Density, (annual mean), (W/m^2)	Weibull k	Weibull A, (m/s)	IEC 61400-1 classif.
Kivalina met tower (30 m A measured with synthesis)	5.84	323	1.65	6.71	III-C
Kivalina met tower (37 m extrapolated, α=0.14)	6.02	353	1.65	6.71	
Kivalina met tower (37 m WAsP observed wind climate)	6.11	328*	1.57	6.60	
Wulik River site (37 m WAsP predicted)	6.14	331	1.68	6.90	III-C
Kisimigiuktuk Hill site (37 m WAsP predicted)	8.28	830	1.60	8.70	II-C**

*WAsP wind power density calculation does not consider temperature/air density
**predicted/assumed

WAsP observed wind climate (37 m extrapolated), from Windographer data file



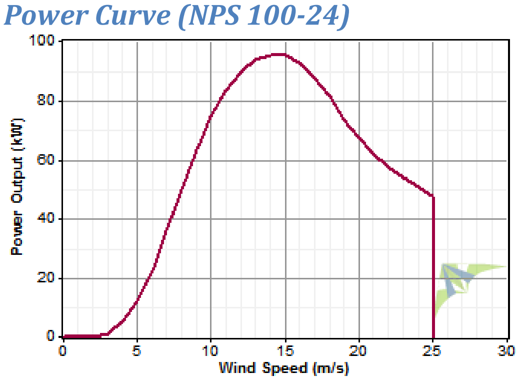
Wind Turbine Options, Kivalina

The wind power options for a Kivalina-based project are limited to robust turbines in the approximately 100 kW capacity range. For the Wulik River site, these are the Northern Power NPS 100-24 and the Vestas V20. Given the prediction of much higher wind speeds at the Kisimigiuktuk Hill site, the Northern Power NPS 100-21 and the Vestas V17 are a more conservative consideration and likely more appropriate with respect to IEC classification of extreme wind speed probability.

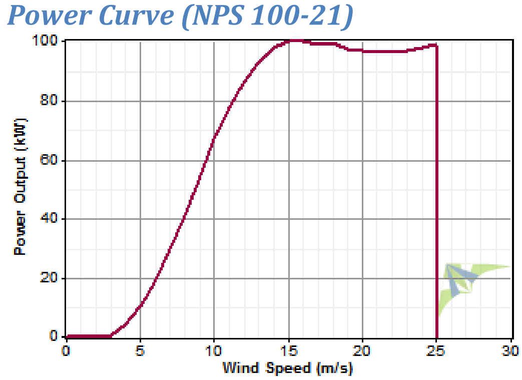
Northern Power Systems 100 (NPS 100)

At 100 kilowatts of rated power, the Northern Power 100 (previously known as the Northwind 100) is an innovative wind turbine with gearless direct drive design, permanent magnet generator, best-in-class reliability, and pleasing aesthetics. The turbine is marketed in two versions: the NPS 100 for temperature climates and the NPS 100 Arctic for cold climates such as Alaska. Differences between the two include heaters and insulation for the Arctic version, plus certification that metal used in the tower and nacelle frame are appropriate for operation to -40° C (-40° F).

Power Curve (NPS 100-24)



Power Curve (NPS 100-21)



Basic NPS 100 turbine features, beyond those noted above, are a 21 meter rotor for IEC Class II wind environments and a 24 meter rotor (21 meter rotor blades with blade root extenders) for IEC Class III/s wind environments. In a suitable wind regime, the NPS 100-24 can generate 10 to 15 percent more energy per year than the NPS 100-21. Northern Power noted that new full span blades (no blade extenders) for the NPS 100-24 will be available soon that will boost energy production even further, perhaps by additional 12 percent over the present NPS 100-24 configuration. The NPS 100 turbine is normally available on 23, 30 and 37 meter tubular towers. A future option of a 48 meter lattice tower is planned.

The generator and rotor of the NPS 100 are directly coupled and rotate at the same speed. By eliminating the gearbox, Northern Power has simplified the drivetrain design by significantly reducing the number of moving parts and wear items. This gearless design results in a high reliability turbine with lower operating costs. The turbine's relatively simple design allows owners and operators to perform their own O&M functions (with factory training), saving service calls and increasing wind plant availability and performance.

The proprietary permanent magnet generator is central to the design of the NPS 100 drivetrain. Permanent magnet generators offer high efficiency energy conversion, particularly at partial load, and require no separate field excitation system. Permanent magnet generators are lighter, more efficient, and require less assembly labor than competing designs.

The Northern Power permanent magnet generator was designed in conjunction with its power converter to create an optimized solution tailored for high energy capture and low operating costs. The NPS 100-21 generator is passively cooled directly by the wind with no requirement for auxiliary fans or air transfer through the generator. The new NPS 100-24 configuration uses active fan cooling to ensure full system output during the warmer summer months, and/or during extended periods of high energy production.

A key element of Northern Power's direct drive wind turbine design is the power converter used to connect the permanent magnet generator output to the local power system. Northern Power designs and manufactures power converters for its wind turbines in-house, with complete hardware, control design, and software capabilities.

In 2006, the American Wind Energy Association (AWEA) awarded its annual Technical Achievement Award to Northern Power's Chief Engineer, Jeff Petter. It recognized his expertise and leadership in the development of Northern Power Systems' FlexPhase™ power converter for mega-watt scale wind turbine applications. The FlexPhase power converter combines a unique, patent-pending circuit design with a high bandwidth control system to provide unique generator management, power quality, and grid support features. The FlexPhase converter platform offers a modular approach with a very small footprint and 20-year design life.

The Northern Power System NPS 100 wind turbine is manufactured by Northern Power Systems in Barre, Vermont. The NPS 100 turbine is rated at 100 kW, is stall-regulated and operates upwind with active yaw control, has a direct-drive permanent magnet synchronous generator, comes equipped with a 21 meter or 24 meter diameter rotor, and is available on 30 and 37 meter tubular steel monopole towers, or on a 48 meter four-leg lattice tower.

The NPS 100-21 is the most represented village-scale wind turbine in Alaska with a significant number of installations in the Yukon-Kuskokwim Delta region of the state, and also in Gambell and Savoonga on St. Lawrence Island. More information can be found at: http://www.northernpower.com/.

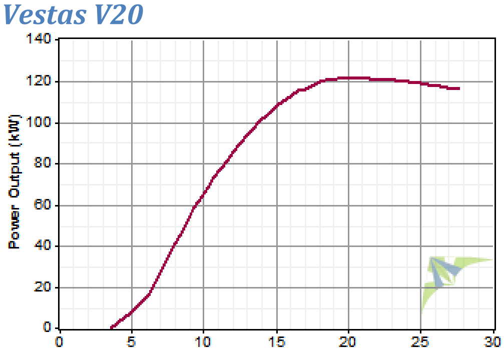
Design class of the NPS 100-21 (21 meter rotor) is IEC (International Electrotechnical Commission) Class II-A (air density 1.225 kg/m^3, average wind speed below 8.5 m/s, and 50-year peak gust below 59.5 m/s).

Northern Power Systems 100 wind turbines, Toksook Bay, Alaska

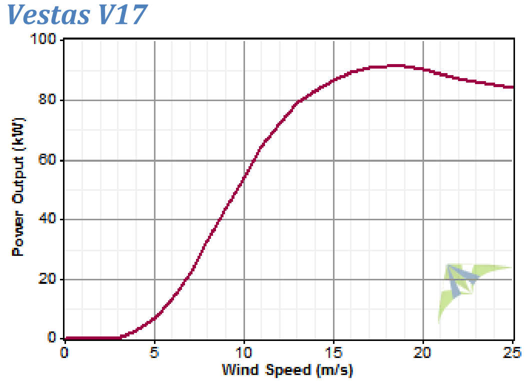
Vestas V20 and V17

The Vestas V20 and V17 wind turbines were originally manufactured by Vestas Wind Systems A/S in Denmark and are no longer in production. They are, however, available as remanufactured units from Halus Power Systems in California (represented in Alaska by Marsh Creek, LLC). The V20 is similar to the V17 but designed for lower wind speed environments. The drivetrain and control system of the two turbines are identical, but the V20 is equipped with dissimilar rotor blades (not just blade root extenders) from the V17. The V20 and V17 turbines are equipped fixed-pitch, stall-regulated rotor coupled to asynchronous (induction) generators via gearbox drives. The original turbine designs included low speed and high speed generators in order to optimize performance at low and high wind speeds. The two generators are connected to the gearbox with belt drives and a clutch mechanism. In some installations though – especially sites with a high mean wind speeds – the low speed generator is removed to eliminate a potential failure point.

Vestas V20



Vestas V17



Vestas began mass production of wind turbines in the mid 1980's with a 55 kW model. Thousands of Vestas turbines were installed in California in the 1980's and most of these turbines are still operational. Vestas is the largest wind turbine manufacturer in the world and the only major Danish pioneer wind turbine manufacturer still in business. Although the sub-megawatt Vestas turbine models offered by Halus Power have not been manufactured for a number of years, Vestas still sells new parts for these units, enabling easier operations and maintenance than with turbines from manufacturers who no longer in business.

For the fixed pitch V17 and V20, Halus manufactures an after-market controllers as replacements for Vestas' original turbine controllers. Unlike PLC-based controllers with generic PLC's designed for a wide variety of industrial control systems, Halus' microprocessor-based controllers are designed specifically for stall-regulated wind turbines. As a result, according to Halus, the new controllers enable more functionality and are easier to troubleshoot than a PLC-based controller. Some of the controller features:

- Advanced soft-start motor control with user-definable thyristor trigger angle and cut-in slope
- Automatic motor start support for two-generator (low speed/high speed) designs, common on many wind turbines
- Power factor control including user-definable delay for capacitor connection and capacitor discharging time
- User-definable grid frequency, voltage, and current ranges
- Remote monitoring and control system (similar to SCADA systems used by wind farm operators)
- Optional relay protection system to meet utility interconnection IEEE standards
- Pre-mounted on galvanized steel stand to minimize labor time in the field

If desired by the client, Halus offers remote monitoring and control of their turbine models (the turbine can be accessed by the customer as well). Some of the available remote functions are: monitoring of voltage, current, power, energy, frequency, wind speed, generator and rotor rpm, temperature, and system status, modification of controller limits, sending commands to the turbine, reading and resetting the error list, and generating power curves. This type of functionality may be more suitable, however, may be more suitable for utility-connected stand-alone turbines that for isolated grid applications.

Remanufactured Vestas turbines installed in cold climates are equipped with heaters controlled by digital temperature controllers that have network connectivity options, extra insulation of components, and application of black coatings to absorb heat.

Tower options include tubular, lattice, tower extensions, and custom colors. For remote locations where turbine erection by crane is not possible, tilt-up installation is possible on select turbine models. Additionally, customer logos on the turbine nacelle cover or (tubular) tower are possible. The logos are high-quality outdoor vinyl with ten-plus year life.

Vestas V17 wind turbines in Kokhanok, Alaska

Cold Climate Considerations of Wind Power

Kivalina's harsh climate condition is an important consideration should wind power be developed in the community. The principal challenges with respect to turbine selection and subsequent operation is severe cold and icing. Many wind turbines in standard configuration are designed for a lower operating temperature limit of -4° C (-20° F), which clearly would not be suitable for Kivalina. A number of wind turbine manufacturers offer their turbine in an "arctic" configuration which includes verification that structural and other system critical metal components are fatigue tested for severe cold capability and/or a proven history of extensive cold climate operations. In addition, arctic-rated turbines are fitted with insulation and heaters in the nacelle and power electronics space to ensure proper operating temperatures. With an arctic rating, the lower temperature operating limit generally extends to -40° C (-40° F). On occasion during winter Kivalina may experience temperatures colder than -40° C which would signal the wind turbines to curtail. Temperatures below -40° C are relatively infrequent however and when they do occur, are generally accompanied by lighter winds.

A second aspect of concern regarding Kivalina's arctic climate is icing conditions. Atmospheric icing is a complex phenomenon characterized by astonishing variability and diversity of forms, density, and tenacity of frozen precipitation, some of which is harmless to wind turbine operations and others highly problematic. Although highly complex, with respect to wind turbines five types of icing are recognized: clear ice, rime ice, mixed ice, frost ice, and SLD ice (www.Wikipedia.org/wiki/icing_conditions). Rime would not be expected at the sea-level Wulik River site, but possibly may occur to a limited extent on Kisimigiuktuk Hill.

- Clear ice is often clear and smooth. Super-cooled water droplets, or freezing rain, strike a surface but do not freeze instantly. Forming mostly along the stagnation point on an airfoil, it generally conforms to the shape of the airfoil.

- Rime ice is rough and opaque, formed by super-cooled drops rapidly freezing on impact. Often "horns" or protrusions are formed and project into the airflow.
- Mixed ice is a combination of clear and rime ice.
- Frost ice is the result of water freezing on unprotected surfaces. It often forms behind deicing boots or heated leading edges of an airfoil and has been a factor airplane crashes.
- SLD ice refers to ice formed in super-cooled large droplet (SLD) conditions. It is similar to clear ice, but because droplet size is large, it often extends to unprotected parts of a wind turbine (or aircraft) and forms large ice shapes faster than normal icing conditions.

SLD ice on an airplane

Wind-Diesel HOMER Model, Kivalina

Considering AVEC's goal of displacing as much diesel fuel for electrical generation as possible and yet recognizing the present limitations of high penetration wind power in Alaska and AVEC's desire to operate a highly stable and reliable electrical utility in Kivalina, only the medium penetration wind-diesel configuration scenario was modeled with HOMER software. Note that low penetration wind was not modeled as this would involve use of smaller farm-scale turbines that are not designed for severe cold climates, and low penetration would not meet AVEC's goal of significantly displacing fuel usage in Kivalina.

As previously noted, a medium penetration wind-diesel configuration is a compromise between the simplicity of a low penetration wind power and the significant complexity and sophistication of the high penetration wind. With medium penetration, instantaneous wind input is sufficiently high (at 100 plus percent of the village electrical load) to require a secondary or diversion load to absorb excess wind power, or alternatively, to require curtailment of wind turbine output during periods of high wind/low electric loads. For Kivalina only, appropriate wind turbines for medium wind penetration are generally in the 100 to 300 kW range with more numbers of turbines required for lower output machines compared to larger output models.

There are a number of comparative medium penetration village wind-diesel power systems presently in operation in Alaska. These include the AVEC villages of Toksook Bay, Chevak, Savoonga, Kasigluk, Hooper Bay, among others. All are characterized by wind turbines directly connected to the AC distribution system. AC bus frequency control during periods of high wind penetration, when diesel governor control would be insufficient, is managed by the sub-cycle, high resolution, and fast-switching capability of the secondary load controller (SLC). Ideally, the SLC is connected to an electric boiler serving a thermal load as this will enhance overall system efficiency by augmenting the operation of the fuel oil boiler(s) serving the thermal load.

Kivalina Powerplant

AVEC powerplant configuration information indicates that four diesel generators are in use, as presented in the table below. Should the village relocate to the Kisimigiuktuk Hill area, it is possible that new diesel generators would be installed in the new powerplant. Given the likelihood of an upgraded powerplant for Kivalina prior to development of wind power, diesel generator fuel consumption is modeled as equivalent for all four units for this study.

Diesel generator HOMER modeling information

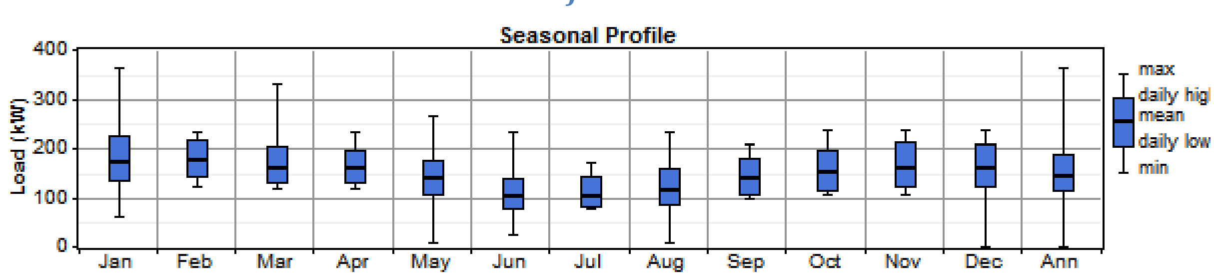
Diesel generator	DD S60D3	Cat D353	CMS LTA10	DD S60K4
Power output (kW)	229	337	250	363
Intercept coeff. (L/hr/kW)	0.04	0.04	0.04	0.04
Slope (L/hr/kW output)	0.22	0.22	0.22	0.22
Minimum electric load (%)	15.0% (35kW)	15.0% (51 kW)	15.0% (37 kW)	15.0% (55 kW)
Heat recovery ratio (% of generator waste heat energy available to serve the thermal load; when modeled)	35	35	35	35

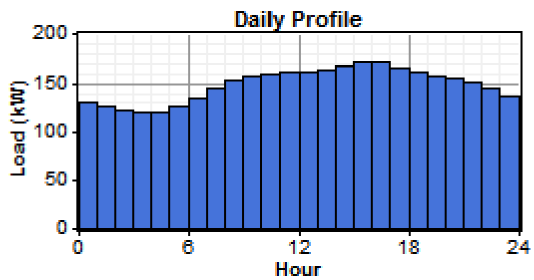
Notes: Intercept coefficient – the no-load fuel consumption of the generator divided by its capacity
Slope – the marginal fuel consumption of the generator

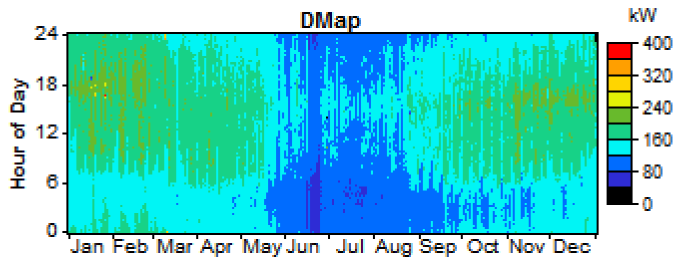
Electric Load

AVEC monitors Kivalina with a data logger that records energy demand on 15 minute intervals. With some data processing, Homer can import this data as hourly or 15 minute data points. For this report, the 15 minute interval was used as it is more granular than hourly. Data interval obtained from AVEC was December 23, 2012 to December 29, 2013. Additionally, data from August 17, 2012 to August 24, 2012 was used as most data of that time period in 2013 was missing due to a telephone communications problem in Kivalina. Excel software was used to combine the data into a representative year for transfer to Homer software.

Kivalina 15 min. interval electric load data from AVEC







Kivalina electric load data

	Baseline	Scaled
Average (kWh/d)	3,553	3,553
Average (kW)	148	148
Peak (kW)	362	283
Load factor	0.523	0.523

Thermal Load

At present, there is not an operational recovered heat system in Kivalina, hence thermal loads are not modeled. Jacket water heat is dissipated to the atmosphere by the radiators in the powerplant. Should wind turbines be installed at the Wulik River site to serve Kivalina in its present location, excess wind energy could be diverted to thermal loads such as the school or water plant via a secondary load controller and electric boiler configured as a remote node. The thermal load demand of these facilities, however, is unknown at present. Should the village of Kivalina be re-located to the Kisimigiuktuk Hill site area, presumably the new powerplant would be constructed with recovered heat capability to serve thermal energy demand in the new community, but estimating that load is beyond the scope of this report.

Wind Turbine Configuration Options

AVEC's goals with their wind-diesel systems is to offset a significant percentage of fuel used in the powerplant, but not create a highly complex system with significant thermal offset and/or electrical storage capability. This philosophy dictates a medium penetration design approach where wind power is approximately one-third of the annual electric energy demand, but at least one diesel generator is always online to provide spinning reserve. Medium penetration design, though, means that instantaneous wind power will at times be well over 100 percent of the load. This may result in unstable grid frequency, which can occur when electrical power generated exceeds the load demand. In a wind-diesel power system without electrical storage, there are two options to prevent this possibility:

1. Curtail one or more wind turbines to prevent instantaneous wind penetration from exceeding 100 percent (one must also account for minimum loading of the diesel generator).
2. Install a secondary load controller with a resistive heater. The secondary load controller is the fast-acting switching mechanism commanding heating elements to turn on and off to order to maintain stable frequency. The resistive heater can be as simple as a heater ejecting energy to the atmosphere or an interior air space or, more desirably, a boiler serving one or more thermal

loads. The boiler can be installed in the powerplant heat recovery loop and operated in parallel with fuel oil boilers.

In either case, system frequency control features are necessary in medium penetration design as, generally speaking, the diesel generator paralleled with the wind turbines during periods of high wind energy input may not have sufficient inertia to control frequency by itself. This design philosophy is typical of most wind-diesel systems presently operational in Alaska and provides a solid compromise between the minimal benefit of low penetration wind systems and the cost and complexity of high penetration wind systems.

Many utilities prefer to install more than one wind turbine in a village wind power project to provide redundancy and continued renewable energy generation should one turbine be out-of-service for maintenance or other reasons. Referencing the medium wind power penetration design philosophy discussed above, the Northern Power NPS 100 and the Vestas V17 and V20 turbines are considered for a Kivalina-based wind power project. Turbine types are not mixed, however, as it is assumed that AVEC will select only one type of wind turbine.

System Modeling and Technical Analysis

Installation of wind turbines in medium penetration mode is evaluated in this report to demonstrate the economic impact of these turbines with the following configuration philosophy: turbines are connected to the electrical distribution system to serve the electrical load and a secondary load controller and an electric heater or boiler to divert excess electrical power to offset thermal load(s) via a secondary load controller.

HOMER energy modeling software was used to analyze the Kivalina power generation system. HOMER was designed to analyze hybrid power systems that contain a mix of conventional and renewable energy sources, such as diesel generators, wind turbines, solar panels, batteries, etc. and is widely used to aid development of Alaska village wind power projects. The following wind-diesel system configurations were modeled for this conceptual design report.

Modeled wind-diesel configurations

Site	Turbine	No. Turbines	Installed kW	Tower Type	Hub Height (meters)
Wulik River	Northern Power NPS 100-24	2	200	Monopole	37
	Vestas V20	2	240	Monopole	30
Kisimigiuktuk Hill	Northern Power NPS 100-21	2	200	Monopole	37
		3	300		
	Vestas V17	2	180	Monopole	30
		3	270		

Modeling assumes that wind turbines constructed in Kivalina would operate in parallel with the diesel generators. Although excess energy will serve thermal loads via a secondary load controller and electric boiler that would augment the existing jacket water heat recovery system, it is not modeled as such to conform to AEA's methods with use of the ISER cost model spreadsheet. Installation cost of this turbine project assumes three-phase upgrade of the distribution system to the wind turbine site.

Technical modeling assumptions

Operating Reserves	
Load in current time step	10%
Wind power output	50% (diesels always on)
Fuel Properties (no. 2 diesel for powerplant)	
Heating value	46.8 MJ/kg (140,000 BTU/gal)
Density	830 kg/m^3 (6.93 lb./gal)
Fuel Properties (no. 1 diesel to serve thermal loads)	
Heating value	44.8 MJ/kg (134,000 BTU/gal)
Density	830 kg/m^3 (6.93 lb./gal)
Diesel Generators	
Efficiency	13.6 kWh/gal (FY2013 PCE report data)
Minimum load	15%
Schedule	Optimized
Wind Turbines	
Net capacity factor	85% (adjusted by reducing mean wind speed in Homer software)
Turbine hub height	37 m (NPS 100); 30 m (V20 and V17)
Wind speed – Wulik River	5.84 m/s at 30 m level at met tower site; wind speed scaled to 5.26 m/s for 85% turbine net AEP
Wind speed – Kisimigiuktuk Hill	8.01 m/s at 30 m level at met tower site; wind speed scaled to 6.70 m/s for 85% turbine net AEP
Density adjustment	Density not adjusted (i.e., STP turbine power curves)
Energy Loads	
Electric	3,467 kWh/day mean annual electrical load
Thermal	Not modeled but possible with remote node to absorb excess energy
Fuel oil boiler efficiency	85% (not modeled)
Electric boiler efficiency	100%

Model Results – Wulik River Site

The Wulik River site wind resource is nearly identical to that measured by the met tower. This site likely is not height restricted, hence large wind turbines and/or high hub heights are possible, although given Kivalina's modest electric load, turbines larger than 100 kW class are considered impractical at the present time. Note that turbine energy production is modeled at 85 percent net.

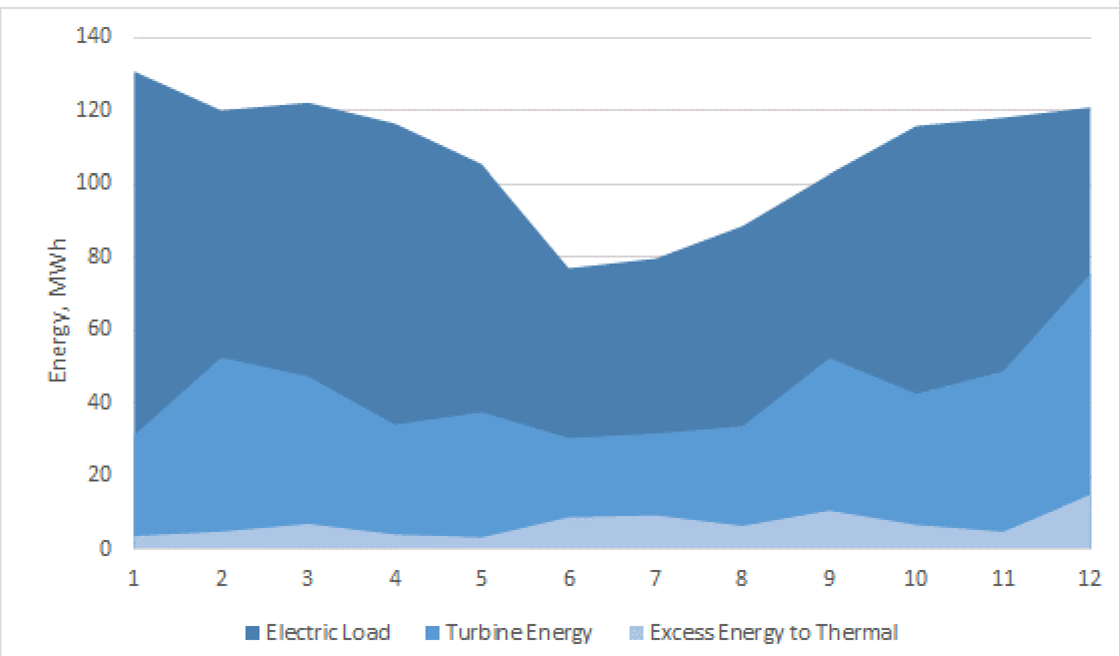
Northern Power NPS 100-24, two (2) turbines

This configuration models two Northern Power NPS 100-24 wind turbines at Wulik River site at a 37 meter hub height and generating 85 percent of maximum annual energy production.

Two NPS 100-24's, Wulik River, 37 m hub height, 85% net AEP

Month	Electric Load	Turbine Energy	Energy Generated	Turbine Energy to E. Load	Wind Penetra-tion	Excess Energy to Thermal	Excess Energy to Thermal
	kWh	kWh	kWh	kWh	%	kWh	%
1	130,706	31,287	134,385	27,608	23.3%	3,679	2.5%
2	120,024	52,611	124,903	47,733	42.1%	4,879	3.5%
3	122,140	47,413	129,152	40,401	36.7%	7,012	4.5%
4	116,441	34,171	120,540	30,071	28.3%	4,100	2.7%
5	105,313	37,600	108,628	34,285	34.6%	3,315	2.6%
6	76,898	30,498	85,716	21,680	35.6%	8,817	7.2%
7	79,555	31,744	88,887	22,413	35.7%	9,331	7.2%
8	88,480	33,766	94,956	27,291	35.6%	6,475	5.1%
9	102,637	52,438	113,284	41,790	46.3%	10,648	7.6%
10	115,766	42,638	122,493	35,911	34.8%	6,727	4.5%
11	118,042	48,795	122,901	43,936	39.7%	4,860	3.4%
12	120,850	75,516	135,717	60,648	55.6%	14,867	9.5%
Annual	1,296,852	518,477	1,381,562	433,767	37.5%	84,710	5.0%

Chart, two NPS 100-24 turbines, Wulik River



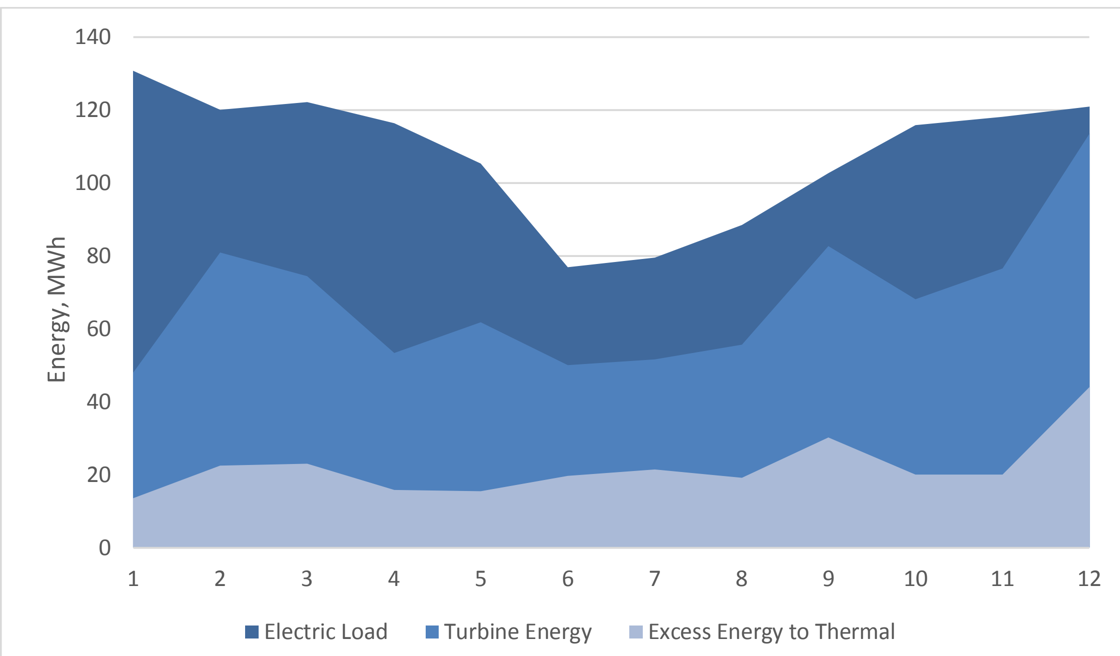
Vestas V20, two (2) turbines

This configuration models two Northern Power NPS 100-24 wind turbines at Wulik River site at a 37 meter hub height and generating 85 percent of maximum annual energy production.

Two V20's, Wulik River, 30 m hub height, 85% net AEP

Month	Electric Load	Turbine Energy	Energy Generated	Turbine Energy to E. Load	Wind Penetra-tion	Excess Energy to Thermal	Excess Energy to Thermal
	kWh	kWh	kWh	kWh	%	kWh	%
1	130,706	28,977	136,371	23,312	21.2%	5,665	3.1%
2	120,024	49,329	128,324	41,029	38.4%	8,300	5.0%
3	122,140	39,226	128,211	33,154	30.6%	6,071	3.7%
4	116,441	29,340	120,613	25,167	24.3%	4,173	2.5%
5	105,313	27,243	106,703	25,852	25.5%	1,390	1.2%
6	76,898	22,603	83,063	16,438	27.2%	6,165	5.1%
7	79,555	23,616	85,596	17,576	27.6%	6,041	5.0%
8	88,480	24,452	92,108	20,824	26.5%	3,628	3.0%
9	102,637	43,338	111,504	34,470	38.9%	8,867	5.9%
10	115,766	34,183	121,292	28,657	28.2%	5,525	3.5%
11	118,042	44,183	125,324	36,900	35.3%	7,282	4.2%
12	120,850	70,725	137,208	54,366	51.5%	16,359	9.6%
Annual	1,296,852	437,213	1,376,317	357,747	31.8%	79,465	4.3%

Chart, two V20 turbines, Wulik River



Model Results – Kisimigiuktuk Hill Site

The projected wind resource at the top of Kisimigiuktuk Hill was modeled with WAsP software and transferred to Homer software for wind-diesel energy balance modeling. Compared to the Wulik River site, turbine options were modified to the NPS 100-21 and the V17, both of which are more suitable for the presumed high energy, potentially IEC 61400-1 Class I or II wind resource at the top of Kisimigiuktuk Hill. Note that turbine energy production is modeled at 85 percent net.

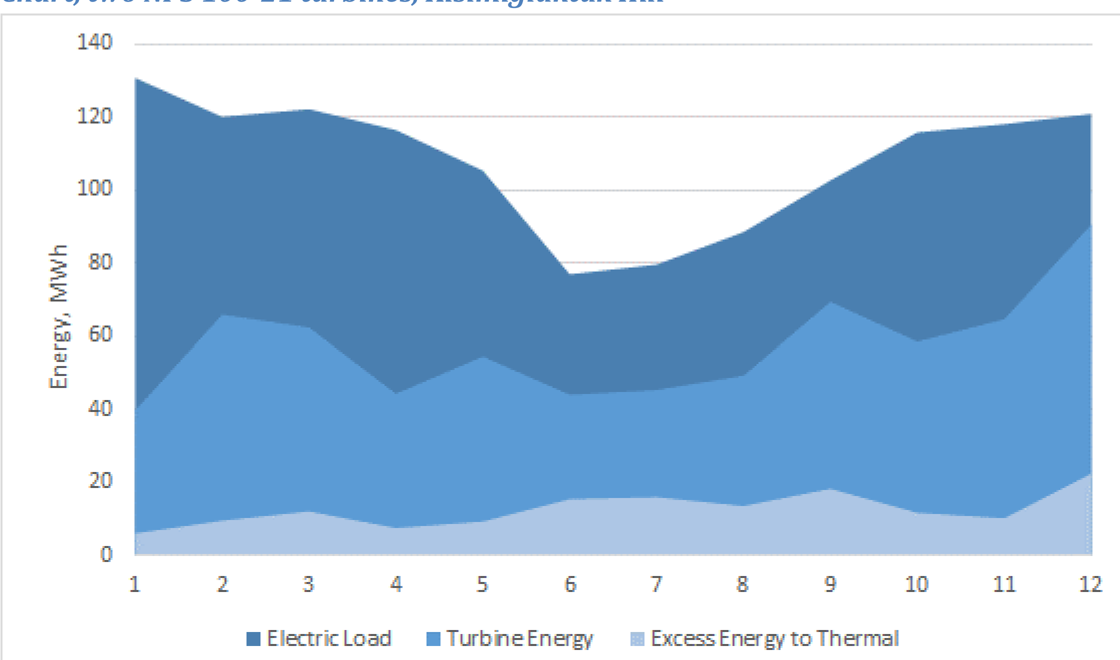
Northern Power NPS 100-21, two (2) turbines

This configuration models two Northern Power NPS 100-21 wind turbines at Kisimigiuktuk Hill at a 37 meter hub height and generating 85 percent of maximum annual energy production.

Two NPS 100-21's, Kisimigiuktuk Hill, 37 m hub height, 85% net AEP

Month	Electric Load	Turbine Energy	Energy Generated	Turbine Energy to E. Load	Wind Penetra-tion	Excess Energy to Thermal	Excess Energy to Thermal
	kWh	kWh	kWh	kWh	%	kWh	%
1	130,706	39,847	136,768	33,785	29.1%	6,062	3.8%
2	120,024	65,998	129,566	56,456	50.9%	9,542	6.4%
3	122,140	62,477	134,219	50,398	46.5%	12,080	7.5%
4	116,441	44,428	123,965	36,904	35.8%	7,524	4.8%
5	105,313	54,611	114,624	45,300	47.6%	9,311	6.5%
6	76,898	44,153	92,334	28,717	47.8%	15,436	12.0%
7	79,555	45,450	95,526	29,480	47.6%	15,970	11.5%
8	88,480	49,359	102,029	35,811	48.4%	13,548	9.9%
9	102,637	69,483	120,904	51,215	57.5%	18,268	12.3%
10	115,766	58,591	127,455	46,902	46.0%	11,689	7.3%
11	118,042	64,697	128,238	54,501	50.5%	10,196	6.7%
12	120,850	90,671	143,287	68,234	63.3%	22,437	13.5%
Annual	1,296,852	689,767	1,448,916	537,703	47.6%	152,064	8.5%

Chart, two NPS 100-21 turbines, Kisimigiuktuk Hill



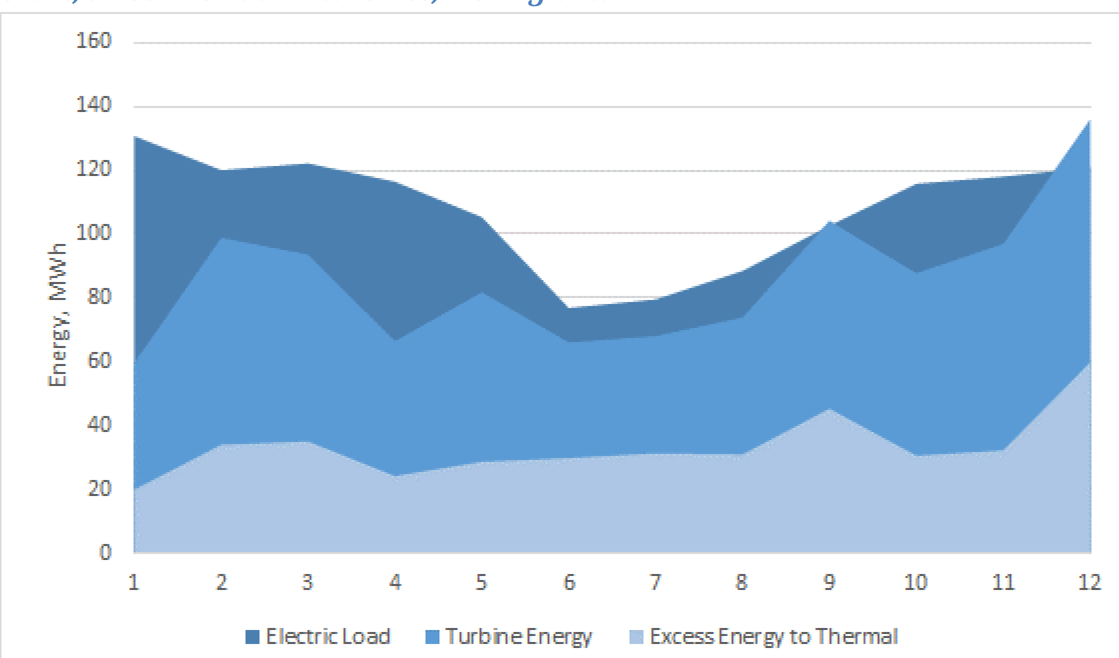
Northern Power NPS 100-21, three (3) turbines

This configuration models three Northern Power NPS 100-21 wind turbines at Kisimigiuktuk Hill at a 37 meter hub height and generating 85 percent of maximum annual energy production.

Three NPS 100-21's, Kisimigiuktuk Hill, 37 m hub height, 85% net AEP

Month	Electric Load	Turbine Energy	Energy Generated	Turbine Energy to E. Load	Wind Penetration	Excess Energy to Thermal	Excess Energy to Thermal
	kWh	kWh	kWh	kWh	%	kWh	%
1	130,706	59,770	150,707	39,769	39.7%	20,001	9.0%
2	120,024	98,997	154,071	64,950	64.3%	34,047	16.8%
3	122,140	93,716	157,236	58,620	59.6%	35,096	16.5%
4	116,441	66,643	140,705	42,378	47.4%	24,264	11.6%
5	105,313	81,917	134,043	53,187	61.1%	28,730	15.9%
6	76,898	66,229	106,808	36,319	62.0%	29,910	19.5%
7	79,555	68,175	110,948	36,783	61.4%	31,392	18.4%
8	88,480	74,038	119,521	42,998	61.9%	31,041	18.5%
9	102,637	104,225	148,009	58,852	70.4%	45,373	23.8%
10	115,766	87,886	146,394	57,258	60.0%	30,628	14.9%
11	118,042	97,046	150,343	64,745	64.6%	32,301	16.2%
12	120,850	136,007	180,738	76,118	75.3%	59,889	26.6%
Annual	1,296,852	1,034,650	1,699,523	631,979	60.9%	402,671	17.3%

Chart, three NPS 100-21 turbines, Kisimigiuktuk Hill



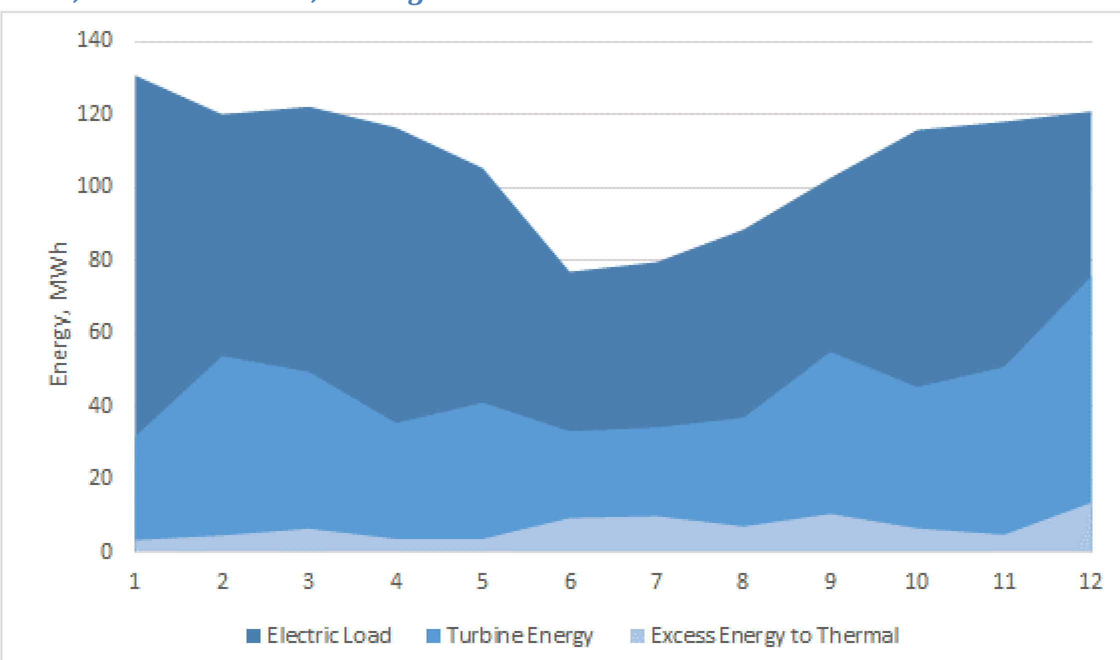
Vestas V17, two (2) turbines

This configuration models two Northern Power NPS 100-24 wind turbines at Wulik River site at a 37 meter hub height and generating 85 percent of maximum annual energy production.

Two V17's, Kisimigiuktuk Hill, 30m hub height, 85% net AEP

Month	Electric Load	Turbine Energy	Energy Generated	Turbine Energy to E. Load	Wind Penetra-tion	Excess Energy to Thermal	Excess Energy to Thermal
	kWh	kWh	kWh	kWh	%	kWh	%
1	130,706	31,907	134,097	28,516	23.8%	3,391	2.3%
2	120,024	53,968	124,694	49,297	43.3%	4,670	3.4%
3	122,140	49,600	128,680	43,060	38.5%	6,540	4.4%
4	116,441	35,590	120,166	31,865	29.6%	3,725	2.6%
5	105,313	41,178	109,044	37,446	37.8%	3,732	2.9%
6	76,898	33,336	86,345	23,889	38.6%	9,447	8.0%
7	79,555	34,367	89,501	24,421	38.4%	9,946	7.8%
8	88,480	37,053	95,631	29,902	38.7%	7,151	5.8%
9	102,637	55,110	113,219	44,527	48.7%	10,583	7.7%
10	115,766	45,462	122,364	38,864	37.2%	6,598	4.6%
11	118,042	51,014	122,928	46,127	41.5%	4,886	3.5%
12	120,850	75,723	134,455	62,118	56.3%	13,605	8.9%
Annual	1,296,852	544,307	1,381,125	460,034	39.4%	84,273	5.2%

Chart, two V17 turbines, Kisimigiuktuk Hill



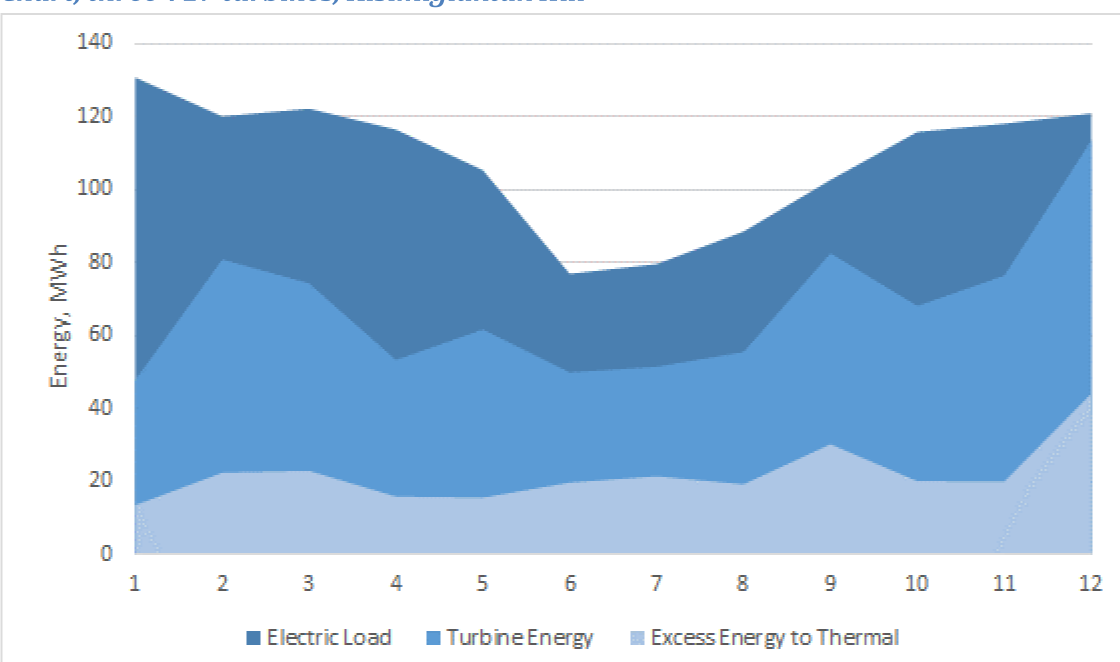
Vestas V17, three (3) turbines

This configuration models two Northern Power NPS 100-24 wind turbines at Wulik River site at a 37 meter hub height and generating 85 percent of maximum annual energy production.

Three V17's, Kisimigiuktuk Hill, 30m hub height, 85% net AEP

Month	Electric Load	Turbine Energy	Energy Generated	Turbine Energy to E. Load	Wind Penetra-tion	Excess Energy to Thermal	Excess Energy to Thermal
	kWh	kWh	kWh	kWh	%	kWh	%
1	130,706	47,860	144,234	34,332	33.2%	13,528	6.6%
2	120,024	80,951	142,439	58,536	56.8%	22,415	12.1%
3	122,140	74,401	145,083	51,457	51.3%	22,943	11.7%
4	116,441	53,385	132,329	37,497	40.3%	15,888	8.2%
5	105,313	61,766	120,877	46,202	51.1%	15,564	9.7%
6	76,898	50,004	96,628	30,274	51.7%	19,729	14.0%
7	79,555	51,550	100,987	30,118	51.0%	21,432	13.7%
8	88,480	55,580	107,731	36,330	51.6%	19,250	12.5%
9	102,637	82,665	132,857	52,444	62.2%	30,221	17.2%
10	115,766	68,193	135,875	48,085	50.2%	20,109	10.6%
11	118,042	76,521	138,029	56,533	55.4%	19,988	11.0%
12	120,850	113,585	164,920	69,515	68.9%	44,070	21.2%
Annual	1,296,852	816,461	1,561,990	551,323	52.3%	265,138	12.4%

Chart, three V17 turbines, Kisimigiuktuk Hill



Economic Analysis

Modeling assumptions are detailed in the table below. Many assumptions, such as project life, discount rate, operations and maintenance (O&M) costs, etc. are AEA default values. Other assumptions, such as diesel overhaul cost and time between overhaul are based on general rural Alaska power generation experience. The base or comparison scenario is the Kivalina powerplant with its present configuration of diesel generators and the existing thermal loads connected to the heat recovery loop.

Fuel Cost

A fuel price of $6.11/gallon was chosen for the economic analysis by reference to *Alaska Fuel Price Projections 2013-2035*, prepared for Alaska Energy Authority by the Institute for Social and Economic Research (ISER), dated June 30, 2013 and the *2013_06_R7Prototype_final_07012013* Excel spreadsheet, also written by ISER. This price reflects the average value of all fuel prices between the 2016 (the assumed project start year) fuel price of $5.00/gallon and the 2035 (20 year project end year) fuel price of $7.26/gallon using the medium price projection analysis with an average CO_2-equivalent allowance cost of $0.59/gallon included.

By comparison, the fuel price for Kivalina reported to Regulatory Commission of Alaska for the 2013 PCE report is $4.17/gallon, without inclusion of the CO_2-equivalent allowance cost. Assuming a CO_2-equivalent allowance cost of $0.40/gallon (ISER *Prototype* spreadsheet, 2013 value), the 2013 Kivalina fuel price was $4.57/gallon.

Heating fuel displacement by excess energy diverted to thermal loads is valued at $7.16/gallon as an average price for the 20 year project period. This price was determined by reference to the *2013_06_R7Prototype_final_07012013* Excel spreadsheet where heating oil is valued at the cost of diesel fuel (with CO_2-equivalent allowance cost) plus $1.05/gallon, assuming heating oil displacement between 1,000 and 25,000 gallons per year.

Kivalina fuel cost table, CO_2-equivalent allowance cost included

ISER med. projection	2015 (/gal)	2034 (/gal)	Average (/gallon)
Diesel Fuel	$5.00	$7.26	$6.11
Heating Oil	$6.05	$8.31	$7.16

Wind Turbine Project Costs

Construction cost for wind turbine installation and integration with the diesel power plant will be accurately defined during the design phase of the project. Project costs are estimated in this conceptual design report in order to provide comparative valuation. The Wulik River and Kisimigiuktuk Hill site options are presented separately, both with start years of 2016. It is recognized, however, that although possible for Wulik River, re-locating the village of Kivalina to Kisimigiuktuk Hill and initiating a wind project by 2016 is unrealistic. But, for purposes of comparative consistency, 2016 is retained as the project start date for the Kisimigiuktuk Hill site option.

Economic modeling assumptions

Economic Assumptions	
Project life	20 years (2016 to 2035)
Discount rate for NPV	3% (ISER spreadsheet assumption)
System fixed capital cost (plant upgrades required to accommodate wind turbines)	Included in turbine project cost
Fuel Properties (no. 2 diesel for powerplant)	
Price (20 year average; ISER 2013, medium projection plus social cost of carbon)	$6.11/gal
Fuel Properties (no. 1 diesel to serve thermal loads)	
Price (20 year average; ISER 2013, medium projection plus social cost of carbon)	$7.16/gal
Diesel Generators	
Generator capital cost	$0 (already installed)
O&M cost	$0.02/kWh (ISER spreadsheet assumption)
Efficiency	13.6 kWh/gal (Homer model)
Wind Turbines	
Net capacity factor	85% (adjusted by reducing mean wind speed in Homer software)
O&M cost	$0.049/kWh (ISER spreadsheet assumption)

Wind Turbine Project Costs, Wulik River Site

Config-uration	No. Turbs	Wind Capacity (kW)	Estimated Cost (in $millions) Turbine	Freight	Install	Civil	Distribu-tion	Power-plant	Project Cost	Cost/ kW
NPS 100-24	2	200	0.70	0.40	0.80	1.00	0.70	0.20	3.80	19,000
Vestas V20	2	240	0.28	0.30	0.70	1.00	0.70	0.20	3.18	13,300

Wind Turbine Project Costs, Kisimigiuktuk Hill Site

Config-uration	No. Turbs	Wind Capacity (kW)	Estimated Cost (in $millions) Turbine	Freight	Install	Civil	Distribu-tion	Power-plant	Project Cost	Cost/ kW
NPS 100-21	2	200	0.66	0.40	0.60	0.70	0.30	0.10	2.76	13,800
	3	300	0.99	0.60	0.85	0.95	0.30	0.10	3.79	12,600
Vestas V17	2	180	0.26	0.30	0.55	0.65	0.30	0.10	2.16	12,000
	3	270	0.39	0.45	0.80	0.80	0.30	0.10	2.84	10,500

Economic Model Results

Economic benefit-to-cost is shown by the ISER method. This method does *not* account for heat loss from the diesel engines due to reduced loading and subsequent impact on heating fuel usage to serve the thermal loads. ISER cost modeling assumptions are noted above or are discussed in the 2013_06_R7Prototype_final_07012013 Excel spreadsheet. Net annual energy production of the wind turbines was assumed at 85 percent to reflect production losses due to operations and maintenance down time, icing loss, wake loss, hysteresis, etc.

As one can in the tables below, it is anticipated that developing wind power at the Kisimigiuktuk Hill site has a significant economic advantage over development of the Wulik River site. This is readily understandable from the higher (projected) wind speeds and lower project development costs at the Kisimigiuktuk Hill site compared to Wulik River. But, this presupposes that an access road to Kisimigiuktuk Hill is developed and that the residents of Kivalina commit to moving their village to the slopes of Kisimigiuktuk Hill. The Kisimigiuktuk Hill site electrical distribution connection, for instance, is assumed to be the short distance from the Kisimigiuktuk Hill site to the planned new village location on the east slope of the hill, not the seven mile distance to the existing village location on the barrier island.

Economic valuation table, Wulik River site

Configuration	Wind Turbine Capacity (kW)	Project Cost	(in $ millions) NPV Benefits	NPV Costs	B/C	Diesel Fuel Saved (gal/yr)	Heating Oil Saved (gal/yr)	Petroleum Fuel Saved (gal/yr)
NPS 100-24	200	3.80	2.60	3.38	0.77	32,371	2,165	34,536
Vestas V20	240	3.18	1.98	2.83	0.70	26,698	2,031	28,729

Economic valuation table, Kisimigiuktuk Hill site

Configuration	Wind Turbine Capacity (kW)	Project Cost	(in $ millions) NPV Benefits	NPV Costs	B/C	Diesel Fuel Saved (gal/yr)	Heating Oil Saved (gal/yr)	Petroleum Fuel Saved (gal/yr)
NPS 100-	200	2.76	3.34	2.45	1.36	40,127	3,887	44,014
21	300	3.79	5.25	3.37	1.56	65,865	3,887	69,752
Vestas	180	2.16	2.51	1.92	1.31	34,331	2,154	36,485
V17	270	2.84	3.37	2.52	1.34	41,144	6,778	47,921

Red Dog Port-based Wind Power Project

This section assesses the possibility of a wind power project based at Port of Red Dog with the port as the major electrical energy load and Kivalina served via an intertie, which must be constructed. A WHPacific and V3 Energy, LLC report titled *Red Dog Port to Kivalina Transmission Line* was submitted to Alaska Village Electric Cooperative in May 2014. This report details right of way considerations, required environmental documentation, power needs and alternatives, and permitting requirements for construction of an electrical intertie connecting Kivalina, 25 miles distant, from Red Dog Port. In this scenario, all electric power – diesel and wind-generated – would be located at Red Dog Port and supplied to Kivalina. The Kivalina powerplant would no longer function as a primary generating station and would be transitioned to a standby facility for use in the event of loss of power from Red Dog Port.

Given the larger electrical load at Red Dog Port and its industrial nature and greater support, larger wind turbines are possible. This is advantageous as larger wind turbines generally are lower cost per kilowatt of installed capacity. This is due to the cost of the turbine itself and also lower costs for foundations, roads and pads, distribution connections, and overall construction time.

Wind Resource Assessment – Red Dog Port

A 33 meter Rohn lattice-type communications tower at Red Dog Port was equipped with wind measurement sensors in 2008 and data was collected for a 34 month period. The Rohn tower, located about two miles inland from the coast on the connecting road to Red Dog Mine, is near the primary prospective wind turbine site and was outfitted with sensors as a substitute for erection of a met tower. The complete Red Dog Port wind resource report, dated September 2011, is included in Appendix B of this report.

Met tower data synopsis

Data dates	October 10, 2008 to August 10, 2011 (34 months)
Wind power class	Class 4 to 5 (good to excellent)
Wind power density mean, 33 m	574 W/m^2
Wind speed mean, 33 m	6.05 m/s
Max. 10-min wind speed average	38.5 m/s
Maximum 2-sec. wind gust	43.5 m/s (January, 2009)
Weibull distribution parameters	k = 1.24, c = 6.52 m/s
Wind shear power law exponent	0.180 (moderate)
Roughness class	0.73 (lawn grass)
IEC 61400-1, 3rd ed. classification	Class II-C
Turbulence intensity, mean	0.119 (at 15 m/s)
Calm wind frequency (at 33 m)	45% (< 4 m/s)

Data Recovery

Data quality was very good with data recovery of all four anemometers greater than 96 percent and data recovery of the wind vane greater than 95 percent. Data loss is limited to winter months only and is attributable to icing events which are characterized by non-variant output of the anemometer at the minimum offset value (essentially zero) and by non-variant output of the direction vane at the last operable direction with temperatures near or less than zero degrees Centigrade and relative humidity at or near 100 percent.

Wind Speed

Anemometer data obtained from the Red Dog Port communications tower, from the perspectives of both mean wind speed and mean wind power density, indicate an excellent wind resource. Mean wind speeds are greater at higher elevations on the tower, as one would expect. Note that cold temperatures contributed to a higher wind power density than otherwise might have been expected for the mean wind speeds. Also note, as discussed in the previous section, that anemometer summary information is the table below is *post* gap-fill. Non-gap-filled mean wind speeds and power densities are slightly higher than below.

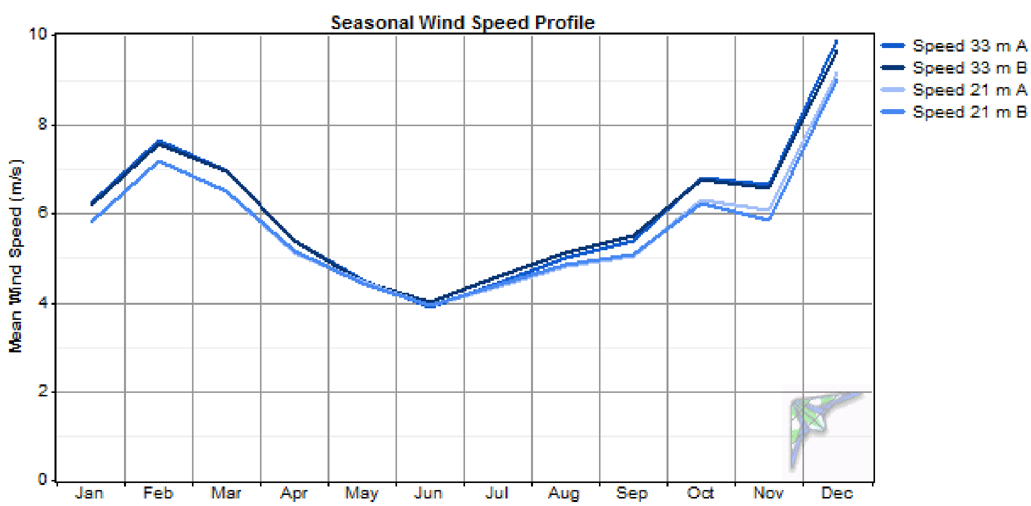
Anemometer data summary

Variable	Speed 33 m A	Speed 33 m B	Speed 21 m A	Speed 21 m B
Measurement height (m)	33	33	21	21
Mean annual wind speed (m/s)	6.02	6.02	5.71	5.68
Max 10-min avg wind speed (m/s)	38.5	36.7	36.1	34.4
Max gust wind speed (m/s)	43.5	41.8	42.0	40.5
Weibull k	1.24	1.26	1.28	1.31
Weibull c (m/s)	6.52	6.52	6.22	6.21
Mean wind power density (W/m²)	577	529	467	435
Mean energy content (kWh/m²/yr)	5,050	4,634	4,093	3,810
Energy pattern factor	4.08	3.75	3.89	3.66
Frequency of calms (%)	44.5	43.3	45.9	44.9
1-hr autocorrelation coefficient	0.945	0.942	0.941	0.940
Diurnal pattern strength	0.046	0.041	0.066	0.062
Hour of peak wind speed	15	15	15	15

MMM = mean of monthly means

Time series calculations indicate high mean wind speeds during the winter months with more moderate mean wind speeds during summer months. This correlates well with the a typical village load profile where winter months have a high electric and heat demand and summer months a lesser demand. The opposite load profile exists however at Red Dog Port where summer loads are high and winter low.

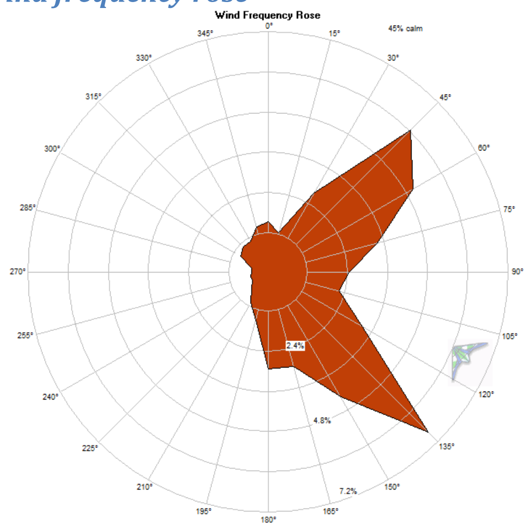
Wind speed profile



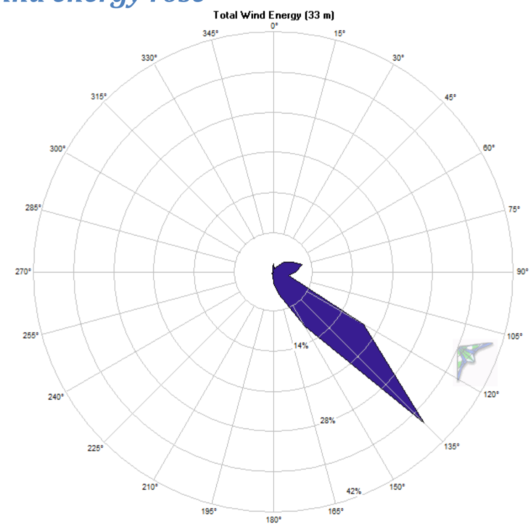
Wind Rose

Wind frequency rose data indicates that winds at Red Dog Port are highly directional, with northeasterly and southeasterly wind predominating. The mean value rose indicates that southeasterly winds, when they do occur, are of high energy and hence likely storm winds. The wind energy rose indicates that for wind turbine operations power-producing winds are very strongly southeastern dominant. Calm frequency (percent of time that winds at the 33 meter level are less than 4 m/s) was a very high 45 percent during the met tower test period.

Wind frequency rose



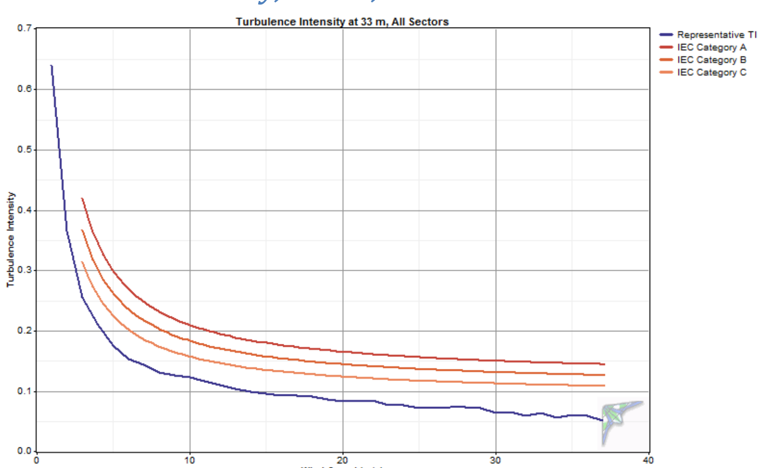
Wind energy rose



Turbulence Intensity

Turbulence intensity (TI) at the Red Dog Port test site is well within acceptable standards with an IEC 61400-1, 3rd edition (2005) classification of turbulence category C, which is the lowest defined. The mean TI at 15 m/s is 0.069 and the representative TI at 15 m/s is 0.096, both which can be considered extraordinarily low and hence very desirable for wind turbine operations.

Turbulence intensity, 33m B, all direction sectors



Extreme Winds

A modified Gumbel distribution analysis, based on monthly maximum winds vice annual maximum winds, was used to predict extreme winds at Red Dog Port. Due to the unusual seasonal variation in wind speeds at the site and in an effort to better match the monthly data Gumbel approach to the annual data approach, a modification to the analysis was made to exclude May through September data. Note below that the extreme wind analysis shows relatively energetic extreme wind probability compared to measured mean wind speed.

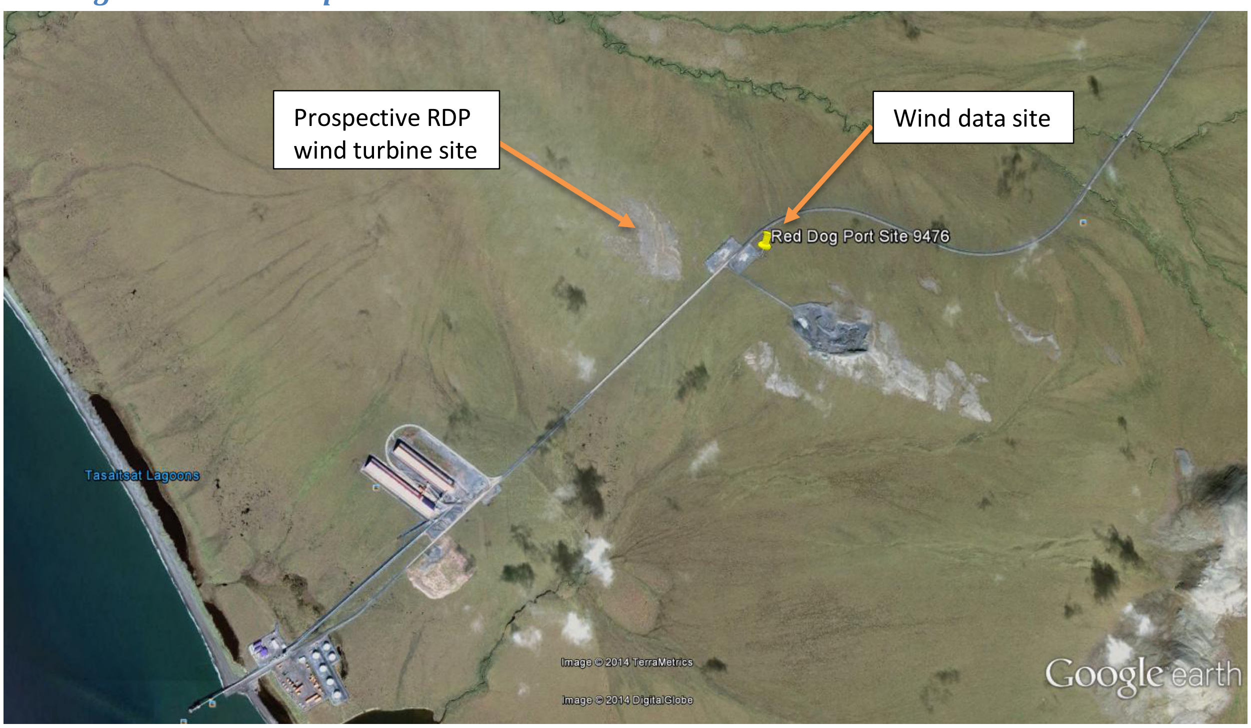
Extreme wind probability table, 33 m A data

Period (years)	V_{ref} (m/s)	Gust (m/s)	IEC 61400-1, 3rd ed. Class	V_{ref}, m/s
3	33.4	38.7	I	50.0
10	37.3	43.2	II	42.5
20	39.5	45.8	III	37.5
30	40.8	47.3	S	designer-specified
50	42.4	49.2		
100	44.6	51.7		

Red Dog Port Wind Site Options

A likely and hence presumed wind turbine site at Red Dog Port is an exposed outcropping of rock and gravel a short distance west of the communication tower that served as a met tower for the Red Dog Port wind resource study. The advantage of this site is that it is a very short distance from the Red Dog mine-port road, it would have minimal impact to tundra, and a relatively short distribution line upgrade is required. Other sites in the port area are possible though.

Red Dog Port wind site option

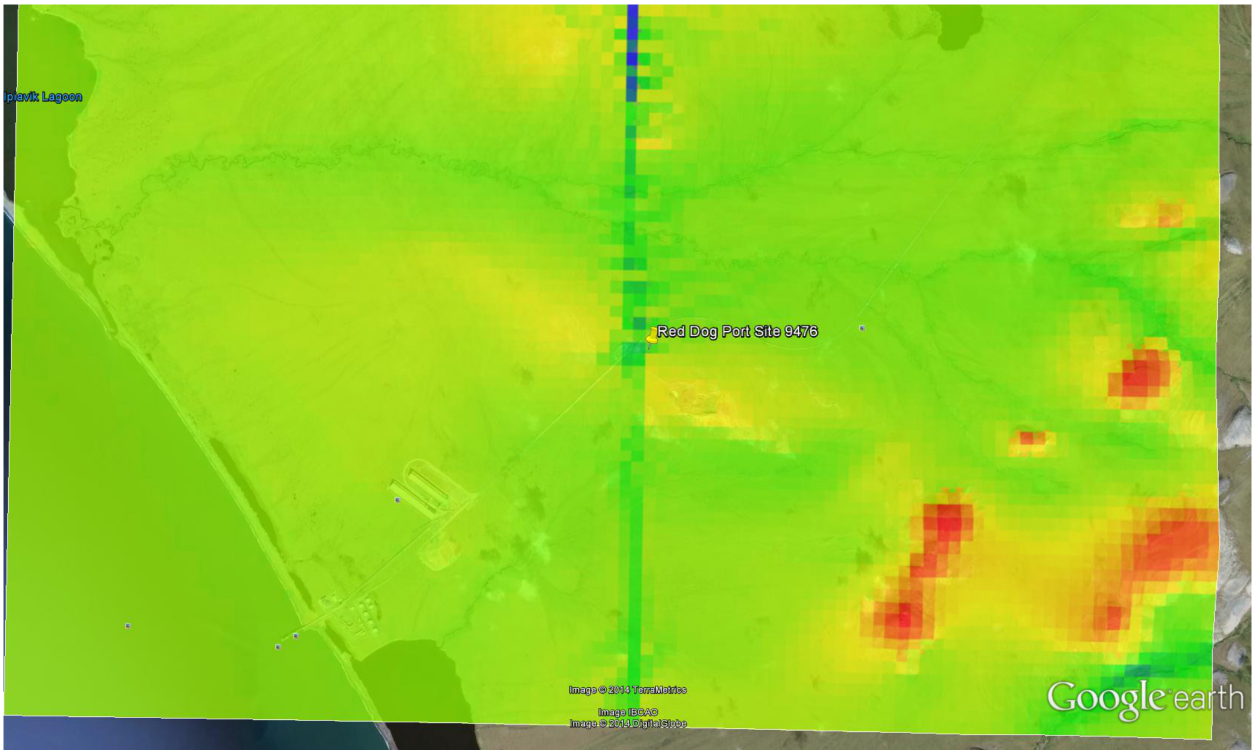


WAsP Modeling

WAsP software modeling indicates relatively consistent winds across the port area with the exposed rock and gravel outcroppings both east and west of the communication tower wind reference point (Red

Dog port Site 9476 placemark) as slightly better wind resource than the lower-lying terrain surrounding them. Wind speeds are higher, however, on the eroded mountains and hills east of the port, but installing wind turbines in this area is somewhat impractical. Note that the vertical blue and green line in the image below is an artifact of merging two digital elevation maps for use by WAsP software.

WAsP wind speed overlay, Red Dog Port area



Wind Turbine Option, Red Dog Port

For the option of wind turbines at Red Dog Port that supplies power to both Red Dog Port and Kivalina, the EWT DW 52-900 is evaluated in this report, although other wind turbines such as the 750 kW Aeronautica AW 750 and the 500 kW Vestas V39 and 600 kW Vestas V44 are highly suitable as well. Should a wind project based at Red Dog Port proceed, additional analysis to include these other turbines should be considered.

EWT DW 52-900

The DW 52/54-900 is a direct-drive, pitch-regulated wind turbine with a synchronous generator and inverter-conditioned power output. More information regarding the EWT DW 52/54-900 wind turbine is attached and available on EWT's website: http://www.ewtdirectwind.com/. The turbine boasts a track record of over 400 operating turbines in many different wind climates. At present, five DW 900 turbines have been installed in Alaska: one in Delta Junction, two in Kotzebue and two in Nome. For Red Dog Port, the 52 meter rotor version likely would be most optimal.

Type	*DW 54 / DW 52*
Rotor diameter	54.0 m / 51.5 m

Variable Rotor Speed	12 to 28 rpm
Nominal Power Output	900 kW
Cut-in wind speed	2.5 m/s
Rated wind speed	13 m/s
Cut-out wind speed (10 minute average)	25 m/s
Survival wind speed	59.5 m/s
Power output control	Pitch controlled variable speed

Type Certificate
IEC 61400 wind class IIIA (DW 54)
IEC 61400 wind class IIA (DW 52)

Drive System
Generator Synchronous air-cooled EWT-design, multi-pole, wound-rotor.
Power converter Full-power, IGBT-controlled AC-DC-AC 'back-to-back' type.

Control System
Bachman PLC control system.
Possibility for remote access via TCP / IP internet and the DMS 2.0 * SCADA system.

Tower
Type Conical tubular steel, internal ascent.
Hub heights 40, 50 and 75 meters.

Safety systems
Main brake action Individual rotor blade pitch (three independent brakes).
Fail-safe brake Individual rotor blade pitch by three independent battery-powered back-up units.

EWT DW 52-900 wind turbines in Kotzebue

Red Dog Port Powerplant

The current redundant power generation capability at Red Dog Port is 1,300 kW. This is comprised of two 650 kW generators running in parallel with one extra as backup. In order for RDP to provide full redundancy at the projected output requirement of 2,362 kW peak, two sets of one 1285 kW generator plus one 650 kW generator running in parallel are required. Hence, one new 1285 kW generator would be required. Future provisions in the existing distribution equipment exist for this; however, the current-carrying capacity of the generator paralleling power system is insufficient at 3000 amps.

A total new Red Dog Port station load of 2,362 kW equates to 3,552 amps at 0.80 power factor. The existing distribution equipment would need to be upgraded to at least 4000 amps with the addition of the new 1285 kW generator mentioned above. Should the potential addition of mining equipment or infrastructure become necessary in the future, taking a long range view on the power distribution equipment would justify upgrading the distribution equipment to 6000 amps now to prevent additional down time.

Diesel generator HOMER modeling information

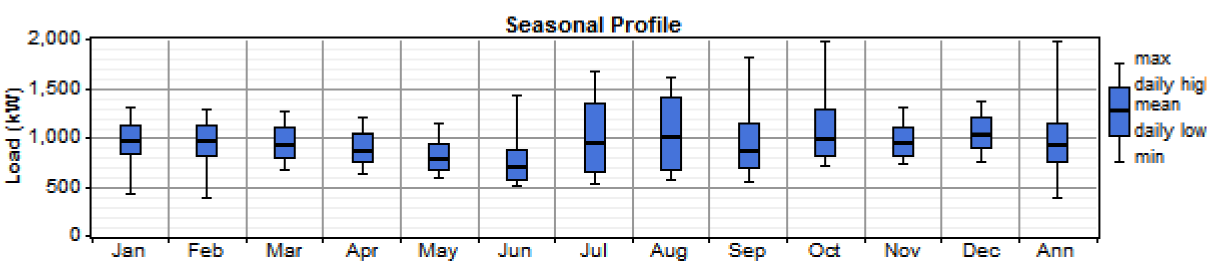
Diesel generator	Gen 1	Gen 2	Gen 3	Gen 4
Power output (kW)	1,285	650	650	650
Intercept coeff. (L/hr/kW)	0.04	0.04	0.04	0.04
Slope (L/hr/kW output)	0.22	0.22	0.22	0.22
Minimum electric load (%)	15.0% (193 kW)	15.0% (98 kW)	15.0% (98 kW)	15.0% (98 kW)

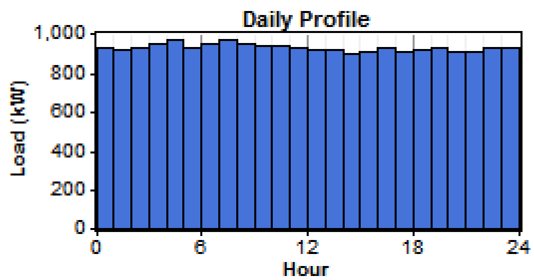
Notes: Intercept coefficient – the no-load fuel consumption of the generator divided by its capacity
Slope – the marginal fuel consumption of the generator

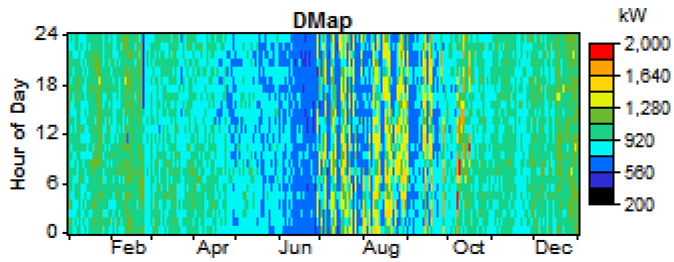
Electric Load

Red Dog Port electric load data was obtained from Teck Alaska in 2011 for a wind power review project. Loads may have changed since that time, although it is believed that no major system upgrades have occurred since 2011, hence the 2011 load profile is modeled as current in this report. Note that counter to a typical village or city seasonal load profile that has higher loads during the cold winter months, highest load demand at Red Dog Port occurs during the summer months when the port is ice-free. It is during this period that the ore is loaded onto barges and ships.

Red Dog Port electric load data from Teck Alaska





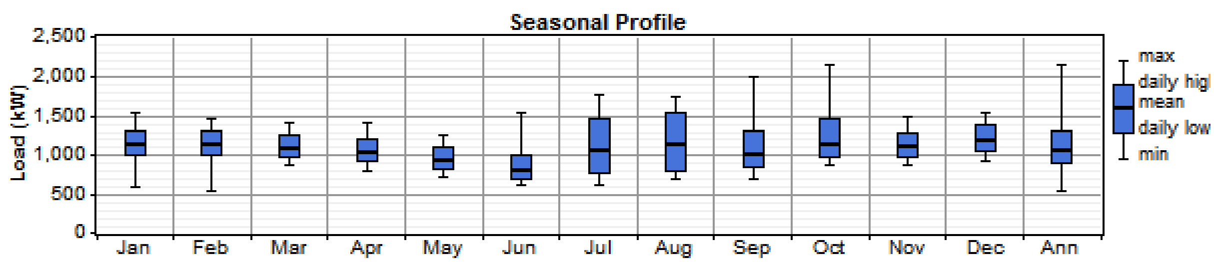


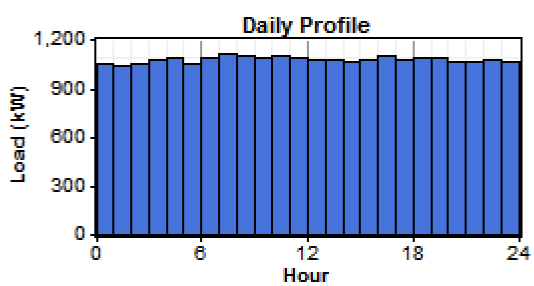
Red Dog Port electric load data

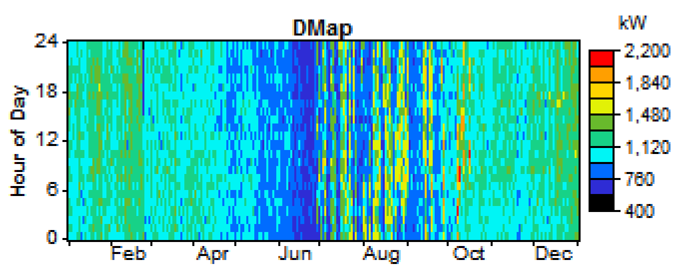
	Baseline	Scaled
Average (kWh/d)	22,296	22,296
Average (kW)	929	929
Peak (kW)	1,988	1,988
Load factor	0.467	0.467

Shown below is the Red Dog Port electric load profile and Red Dog Port electric load combined with that of Kivalina. The latter is used in the wind turbine analysis in this section of this report.

Red Dog Port and Kivalina combined electric loads







Red Dog Port-Kivalina combined electric load data

	Baseline	Scaled
Average (kWh/d)	25,849	25,849
Average (kW)	1,077	1,077
Peak (kW)	2,151	2,151
Load factor	0.501	0.501

Thermal Load

Although Teck Alaska makes extensive use of waste heat from the Red Dog Port powerplant recovered heat system to supply thermal loads in the facility, these thermal loads are not defined and hence are not specifically modeled in this report. If wind turbine(s) are installed at Port of Red Dog to serve the facility and Kivalina, excess wind energy could be absorbed by the recovered heat loop or be diverted to a remote thermal load at the Port or in Kivalina.

System Modeling and Technical Analysis

Installation of wind turbines in medium penetration mode is evaluated in this report to demonstrate the economic impact of these turbines with the following configuration philosophy: turbines are connected to the electrical distribution system to serve the electrical load and a secondary load controller and an electric heater or boiler to divert excess electrical power to offset thermal load(s) via a secondary load controller.

HOMER energy modeling software was used to analyze the Red Dog Port power generation system. HOMER was designed to analyze hybrid power systems that contain a mix of conventional and renewable energy sources, such as diesel generators, wind turbines, solar panels, batteries, etc. and is widely used to aid development of Alaska village wind power projects. The following wind-diesel system configurations were modeled for this conceptual design report.

Modeled wind-diesel configurations

Site	Turbine	No. Turbines	Installed kW	Tower Type	Hub Height (meters)
Red Dog Port	EWT DW 52-900	1	900	Monopole	75
	EWT DW 52-900	2	1,800	Monopole	75

Modeling assumes that wind turbines constructed in Kivalina would operate in parallel with the diesel generators. Although excess energy will serve thermal loads via a secondary load controller and electric boiler that would augment the existing jacket water heat recovery system, it is not modeled as such to conform to AEA's methods with use of the ISER cost model spreadsheet. Installation cost of this turbine project assumes three-phase upgrade of the distribution system to the wind turbine site.

Technical modeling assumptions

Operating Reserves	
Load in current time step	10%
Wind power output	50% (diesels always on)
Fuel Properties (no. 2 diesel for powerplant)	
Heating value	46.8 MJ/kg (140,000 BTU/gal)
Density	830 kg/m^3 (6.93 lb./gal)
Fuel Properties (no. 1 diesel to serve thermal loads)	
Heating value	44.8 MJ/kg (134,000 BTU/gal)
Density	830 kg/m^3 (6.93 lb./gal)
Diesel Generators	
Efficiency	13.8 kWh/gal (Homer model)
Minimum load	15%
Schedule	Optimized
Wind Turbines	

Net capacity factor	90% (adjusted by reducing mean wind speed in Homer software)
Turbine hub height	75 meters
Wind speed	6.02 m/s at 33 m level at met tower site; wind speed scaled to 5.60 m/s for 90% turbine net AEP
Power law exponent	0.123
Density adjustment	Density not adjusted (i.e., STP turbine power curves)
Energy Loads	
Electric	25,849 kWh/day mean annual electrical load
Thermal	Not modeled but possible with remote node to absorb excess energy
Fuel oil boiler efficiency	85% (not modeled)
Electric boiler efficiency	100%

Model Results – Red Dog Port

The wind resource at the presumed Red Dog Port wind turbine site is nearly identical to that measured on the nearby communications tower. This site will not be height restricted, hence large wind turbines and/or high hub heights are possible. Note that the DW 52-900 annual energy production is modeled at 90 percent net compared to 85 percent net for the NPS 100 and Vestas turbines in the Kivalina only option. This is due to the sophistication of the larger EWT turbine and a presumed enhanced operational focus of a wind turbine at an industrial facility compared to a village setting.

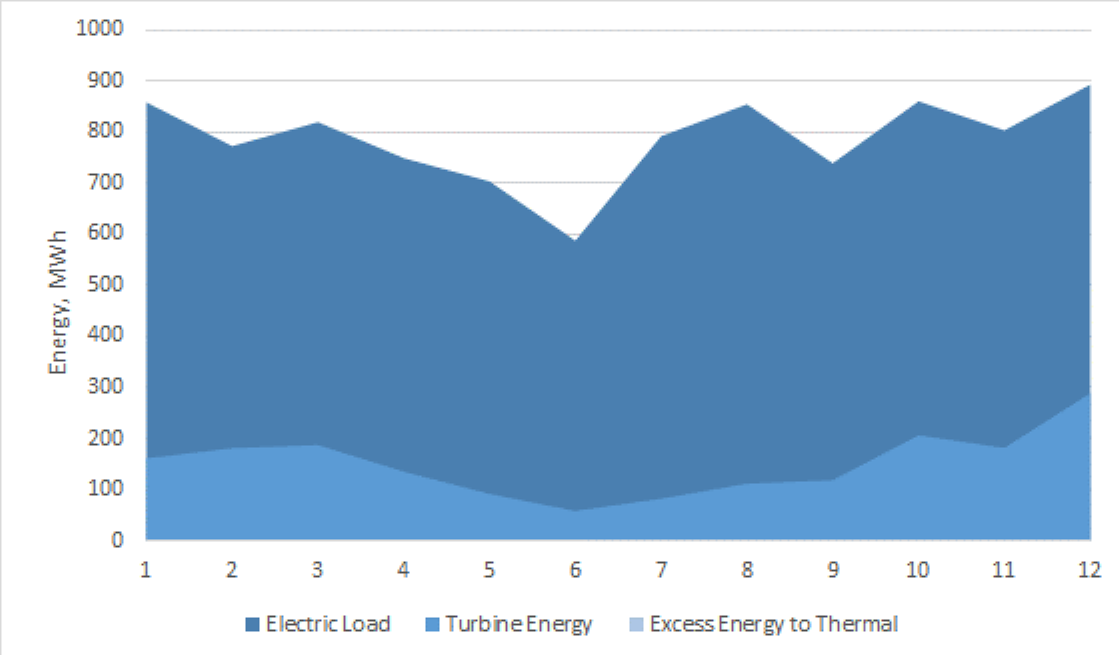
EWT DW 52-900, one (1) turbine, 75 m hub height, 90% net AEP

This configuration models one EWT DW 52-900 wind turbine at Red Dog Port (prospective site) at a 75 meter hub height and generating 90 percent of maximum annual energy production.

One DW 52-900, Red Dog Port, 75 m hub height, 90% net AEP

Month	Electric Load	Turbine Energy	Energy Generated	Turbine Energy to E. Load	Wind Penetra-tion	Excess Energy to Thermal	Excess Energy to Thermal
	kWh	kWh	kWh	kWh	%	kWh	%
1	858,271	162,421	858,531	162,161	18.9%	260	0.0%
2	772,986	182,357	774,499	180,845	23.5%	1,512	0.2%
3	819,735	188,663	821,829	186,569	23.0%	2,094	0.3%
4	749,274	136,467	750,336	135,404	18.2%	1,062	0.1%
5	703,608	92,944	704,059	92,493	13.2%	451	0.1%
6	587,705	59,504	588,793	58,416	10.1%	1,088	0.2%
7	792,258	83,525	792,895	82,887	10.5%	637	0.1%
8	854,746	112,930	856,442	111,234	13.2%	1,696	0.2%
9	739,069	119,908	740,057	118,920	16.2%	988	0.1%
10	860,465	207,665	861,568	206,562	24.1%	1,103	0.1%
11	803,579	183,052	804,853	181,778	22.7%	1,274	0.2%
12	893,169	289,933	893,821	289,281	32.4%	652	0.1%
Annual	9,434,865	1,819,368	9,447,682	1,806,551	19.3%	12,817	0.1%

Chart, one DW 52-900 turbine, Red Dog Port



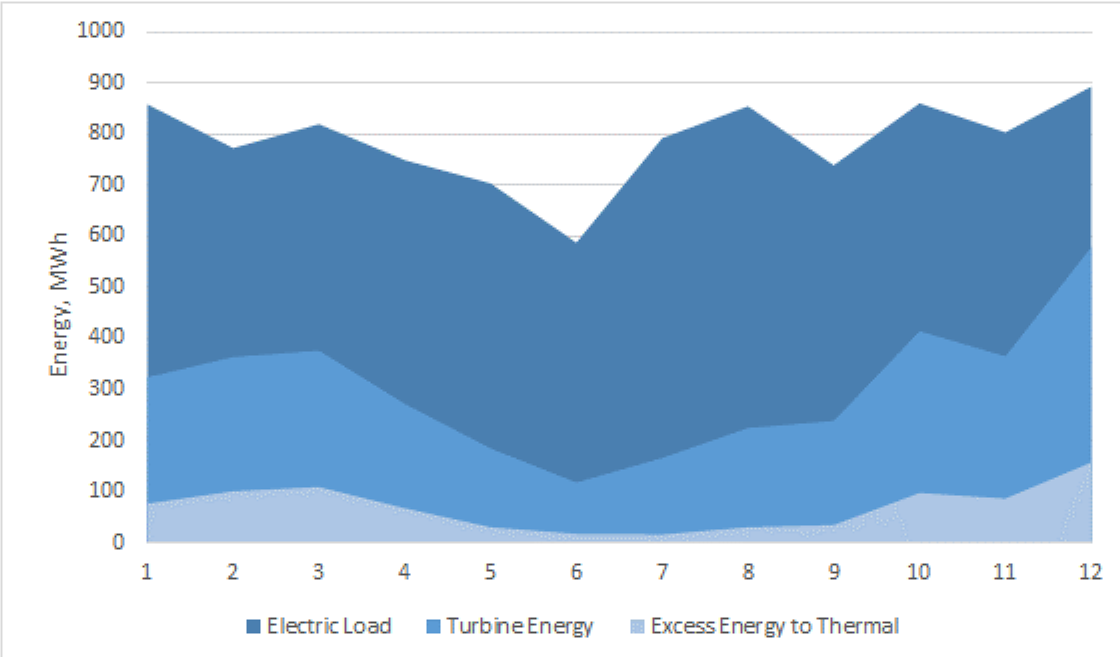
EWT DW 52-900, two (2) turbines

This configuration models two EWT DW 52-900 wind turbines at Red Dog Port (prospective site) at a 75 meter hub height and generating 90 percent of maximum annual energy production.

Two DW 52-900's, Red Dog Port, 75 m hub height, 90% net AEP

Month	Electric Load	Turbine Energy	Energy Generated	Turbine Energy to E. Load	Wind Penetra-tion	Excess Energy to Thermal	Excess Energy to Thermal
			kWh	kWh	%		%
1	858,271	324,841	935,408	247,703	34.7%	77,138	5.9%
2	772,986	364,715	874,500	263,201	41.7%	101,514	8.5%
3	819,735	377,326	929,428	267,634	40.6%	109,693	8.3%
4	749,274	272,933	817,532	204,675	33.4%	68,258	5.6%
5	703,608	185,887	734,666	154,829	25.3%	31,058	2.7%
6	587,705	119,008	605,602	101,111	19.7%	17,897	1.8%
7	792,258	167,049	809,070	150,237	20.6%	16,812	1.5%
8	854,746	225,860	885,608	194,997	25.5%	30,862	2.7%
9	739,069	239,817	774,344	204,542	31.0%	35,275	3.2%
10	860,465	415,330	958,409	317,386	43.3%	97,944	7.7%
11	803,579	366,103	890,505	279,177	41.1%	86,926	7.0%
12	893,169	579,867	1,050,942	422,094	55.2%	157,773	11.9%
Annual	9,434,865	3,638,736	10,266,015	2,807,586	35.4%	831,150	5.5%

Chart, two DW 52-900 turbines, Red Dog Port



Economic Analysis

Modeling assumptions are detailed in the table below. Many assumptions, such as project life, discount rate, operations and maintenance (O&M) costs, etc. are AEA default values. Other assumptions, such as diesel overhaul cost and time between overhaul are based on general rural Alaska power generation experience. The base or comparison scenario is the Red Dog Port powerplant with its present configuration of diesel generators and the existing thermal loads connected to the heat recovery loop.

Fuel Cost

A fuel price of $5.03/gallon was chosen for the economic analysis by reference to *Alaska Fuel Price Projections 2013-2035*, prepared for Alaska Energy Authority by the Institute for Social and Economic Research (ISER), dated June 30, 2013 and the *2013_06_R7Prototype_final_07012013* Excel spreadsheet, also written by ISER. This price reflects the average value of all fuel prices between the 2016 (the assumed project start year) fuel price of $4.08/gallon and the 2035 (20 year project end year) fuel price of $6.02/gallon using the medium price projection analysis with an average CO_2-equivalent allowance cost of $0.59/gallon included. Because fuel costs for Teck Alaska are not available, the ISER fuel cost tables of nearby Kotzebue are used as stand-in data for economic valuation.

Heating fuel displacement by excess energy diverted to thermal loads is valued at $6.08/gallon as an average price for the 20 year project period. This price was determined by reference to the *2013_06_R7Prototype_final_07012013* Excel spreadsheet where heating oil is valued at the cost of diesel fuel (with CO_2-equivalent allowance cost) plus $1.05/gallon, assuming heating oil displacement between 1,000 and 25,000 gallons per year.

Red Dog Port (Kotzebue cost reference) fuel cost table, CO_2-equivalent allowance cost included

ISER med. projection	2015 (/gal)	2034 (/gal)	Average (/gallon)
Diesel Fuel	$4.08	$6.02	$5.03
Heating Oil	$5.13	$6.07	$6.08

Wind Turbine Project Costs

Construction cost for wind turbine installation and integration with the diesel power plant will be accurately defined during the design phase of the project. Project costs are estimated in this conceptual design report in order to provide comparative valuation. The Wulik River and Kisimigiuktuk Hill site options are presented separately, both with start years of 2016. It is recognized, however, that although possible for Wulik River, re-locating the village of Kivalina to Kisimigiuktuk Hill and initiating a wind project by 2016 is unrealistic. But, for purposes of comparative consistency, 2016 is retained as the project start date for the Kisimigiuktuk Hill site option.

Economic modeling assumptions

Economic Assumptions	
Project life	20 years (2016 to 2035)
Discount rate for NPV	3% (ISER spreadsheet assumption)
System fixed capital cost (plant upgrades required to accommodate wind turbines)	Included in turbine project cost
Fuel Properties (no. 2 diesel for powerplant)	
Price (20 year average; ISER 2013, medium projection plus social cost of carbon)	$5.03/gal
Fuel Properties (no. 1 diesel to serve thermal loads)	
Price (20 year average; ISER 2013, medium projection plus social cost of carbon)	$6.08/gal
Diesel Generators	
Generator capital cost	$0 (already installed)
O&M cost	$0.02/kWh (ISER spreadsheet assumption)
Efficiency	13.8 kWh/gal (Homer model)
Wind Turbines	
Net capacity factor	90% (adjusted by reducing mean wind speed in Homer software)
O&M cost	$0.049/kWh (ISER spreadsheet assumption)

Wind Turbine Project Costs, Red Dog Port and Kivalina

Config-uration	No. Turbs	Wind Capacity (kW)	Estimated Cost (in $millions)							
			Turbine	Freight	Install	Civil	Distribu-tion	Power-plant	Project Cost	Cost/ kW
DW 900	1	900	1.85	0.50	1.50	1.80	0.50	0.30	6.45	7,200
	2	1,800	3.70	0.90	2.80	2.20	0.60	0.30	10.50	5,800

Economic Model Results

Economic benefit-to-cost is shown by the ISER method. This method does *not* account for heat loss from the diesel engines due to reduced loading and subsequent impact on heating fuel usage to serve the thermal loads. ISER cost modeling assumptions are noted above or are discussed in the 2013_06_R7Prototype_final_07012013 Excel spreadsheet. Net annual energy production of the wind turbines was assumed at 85 percent to reflect production losses due to operations and maintenance down time, icing loss, wake loss, hysteresis, etc.

As one can see in the table below, EWT DW 52-900 wind turbines, in both one and two turbine configurations, are projected to be economically beneficial over a 20 year project life. Note however that this economic evaluation does not include construction cost of an electrical distribution intertie between Red Dog Port and Kivalina, at either its present location on the barrier island or at Kisimigiuktuk Hill. The projected distribution cost only assumes connection from the wind turbine(s) to the Red Dog Port powerplant or nearest three-phase connection point.

Economic valuation table, Red Dog Port and Kivalina

Config-uration	Wind Turbine Capacity (kW)	Project Cost	(in $ millions) NPV Benefits	NPV Costs	B/C	Diesel Fuel Saved (gal/yr)	Heating Oil Saved (gal/yr)	Petroleum Fuel Saved (gal/yr)
DW 900	900	6.45	7.46	5.73	1.30	123,736	328	124,064
	1,800	10.50	13.26	9.33	1.42	192,300	21,246	213,546

Development Considerations

Given that a Kivalina-only wind power development scenario is most likely with Kisimigiuktuk Hill as the project site, geotechnical, environmental and permitting will focus on it alone. Some of these considerations will apply to Red Dog Port as well, but because an electrical intertie must be constructed for this wind power development scenario to be possible, geotechnical, environmental and permitting for Red Dog Port won't be addressed in this report.

Geology

Kisimigiuktuk Hill is a semi-isolated, low, rounded knob located approximately seven miles inland (northeast) from the village of Kivalina. The elevation of the peak is approximately 460 feet above sea level. The upper elevations, above the vegetated areas, are quite steep, but at the lower elevations, the slopes are generally less than ten percent grade.

The hill is characterized by exposed limestone subcrop and rock rubble at the surface. The surface rocks have been frost-fractured to a depth of approximately three feet. While no large outcrops of limestone were observed, it is anticipated that below the surface larger frost-fractured rocks and boulders may exist. The slopes on all sides of Kisimigiuktuk Hill are mantled with limestone rubble, which terminates abruptly at the toe of the hill. The transition to tundra, which has well-developed tussocks, takes place within 100 to 150 feet.

The surface rock observed is composed of fine- to medium-grained crystalline limestone. The limestone is occasionally oolitic (limestone comprised of minute rounded concretions resembling fish roe), emits a fetid (hydrocarbon) odor upon breaking, and reacts strongly to dilute HCL. Further exploration and testing will be required to identify the depths, extents, and quality of the underlying bedrock.

At this point it appears that a driven pile foundation system, as was proposed for the Buckland Wind Turbine project, might be an appropriate turbine foundation. Alternatively, a conventional concrete foundation tied back to bedrock with rock anchors may be feasible. However, this will need to be confirmed with a geotechnical investigation to determine the depth, type, and strength of the bedrock at the hill.

Environmental Review

This environmental review addresses issues of concern with respect to flora and fauna of the area.

Vegetation

Terrestrial vegetation in the vicinity of the Kisimigiuktuk Hill is expected to transition from wet tundra at the base of the hill to sparsely vegetated uplands near the top of the hill. The soils on the upper reaches of the hill are thin and the area is exposed creating habitat supporting a sparse sub-alpine type vegetation regime characterized as dryas-sedge dwarf shrub tundra.

Avian Resources

Birds are numerous in the Kivalina vicinity, and include many migratory species such as Canada Goose, Sandhill Crane, White-fronted Goose, Tundra Swan, all four species of loon (Yellow-billed, Common, Pacific, Red-throated), and both Steller's Eider and Spectacled Eider. The area around Kivalina is a staging area for migratory waterfowl in the spring and fall (USEPA 2009). The Red Dog Mine EIS (USEPA 2009) states that the adjacent areas are high quality habitat for breeding and molting Canada geese. Tundra provides critical breeding, feeding and molting habitat for many different species of migratory birds. Lagoons, wetlands and barrier islands provide important nesting, molting and staging habitat (North Slope Borough 2006). Bird species are especially sensitive in nesting and molting areas. Because of their federal status, Yellow-billed loon, Steller's eider, and Spectacled eider are species of particular concern in the Kivalina area and in relation to the proposed evacuation route.

Yellow-billed Loon

Kivalina is included in the breeding range for Yellow-billed Loon, however the highest concentrations are on the North Slope (USFWS 2006). Yellow-billed loons nest in coastal and inland low-lying tundra with permanent fish-bearing lakes and forage in nearshore and offshore waters near their breeding grounds during summer (USFWS 2009). Migration routes are thought to be primarily marine (USFWS 2006), but during spring and fall migration these birds use coastal waters, rivers, and large inland bodies of water (Audubon).

The yellow-billed loon is a candidate for federal listing under the Endangered Species Act. Breeding is thought to be limited by available habitat (USFWS 2006). These birds are shy and will flee their nest if disturbed, leaving eggs or young vulnerable to predation (Audubon). Gravel extraction and road construction are two of the main conservation concerns for YBLO, and their habitat is sensitive to infrastructure development disturbance, wetland filling, hydrology alterations or thermokarst action (USFWS 2006). Interviews with Kivalina residents and Kivalina Subsistence Committee (7/9/2012) suggest that YBLO are seen on occasion in the Kivalina Lagoon, but occurrences are typically sporadic and likely associated with migrations or transient individuals.

Steller's and Spectacled Eiders

Kivalina is not within the breeding, molting or wintering range of the Steller's eider, or Spectacled eiders, both of which are federally listed as. Kivalina is within the historic breeding range of the spectacled eider (USFWS 2012). The breeding ranges for both species are far to the north of the Kivalina area and the molting and wintering ranges are far to the south. However, they could be in the project area at times and will require Section 7 consultation. Both species of eiders are not typically observed inland preferring to remain close to shore or over open water (Jewell Bennett personal interview 2014, USFWS).

Bats

No bat species are known to range in the vicinity of Kivalina.

Other Mammals

Mammals that may occur in the Kivalina area include caribou (Rangifer tarandus granti), Muskox (Ovibos moschatus), moose (Alces alces), brown bear (Ursus arctos horribilis), grey wolf (Canis lupus), wolverine (Gulo gulo), and small fur-bearing animals such as fox, hair, marmot, beaver, muskrat and voles (Red Dog Mine EIS, 2009). Many of these terrestrial mammals are hunted for subsistence, primarily caribou and furbearers. The species listed here have generally healthy population numbers, and are not federally listed as species of concern in Alaska. Polar bears (Ursus maritimus) are considered marine mammals and are listed under the Federal Endangered Species Act.

Fisheries

The Wulik River and the Kivalina River are listed anadromous streams by the Alaska Department of Fish and Game (ADFG 2011). The Wulik River supports chum salmon (Oncorynchus keta), coho salmon (O. kisutch), Chinook salmon (O. tshawytscha), pink salmon (O. gorbuscha), sockeye salmon (O. nerka), Dolly Varden (Salvelins malma), and whitefish species (Coregonus spp., Prosopium cylindraceum). The Kivalina River supports Chinook, coho, sockeye, chum, and pink salmon, Dolly Varden, broad whitefish, Arctic grayling (Thymallus arcticus), and possibly least ciscoes (Coregonus sardinella). The Kivalina Lagoon contains coho, chum, Chinook, pink, sockeye, Dolly Varden, and undifferentiated whitefish. The Wulik River is also the main source of freshwater for the village.

Threatened and Endangered Species

Species most at risk from wind development projects varieties of birds with habitat in the project vicinity. The United States Fish and Wildlife Service (USFWS) lists three species including the Steller's eider, spectacled eider and the yellow-billed loon as federally listed species with habit potentially ranging through the project area. Both the Steller's eider and the spectacled eider are federally listed as threatened species and the yellow-billed loon is a federally listed candidate species.

Other listed species are present in the region; however, they are marine or terrestrial species that would likely not be impacted by the proposed project, or bird species with no range in the area. These include the short tailed albatross, polar bear (discussed above), Kittlitz's murrelet, Pacific walrus, bearded seal and ring seal. The project area is within polar bear critical habitat, as both Barrier Island Critical Habitat and Sea Ice Critical Habitat extend 25 miles inland.

Cultural Resources

Kivalina has remained a traditional Inupiat Eskimo village, relying on an understanding of the environment for subsistence activities such as hunting, fishing, berry picking and egg gathering for many food and cultural resources. Caribou are the largest part of the subsistence diet in Kivalina with marine mammals also representing a significant component as does the fall and late spring fisheries for Dolly Varden in the Kivalina Lagoon and Wulik River.

The first recorded history of the village occurred in 1847 when Lt. Zagoskin of the Russian Navy noted the small community at the northern end of Kivalina Lagoon, he wrote the name of the village as "Kivualinagmut" (City of Kivalina 2012). According to the City of Kivalina website, the original population consisted of survivors of aboriginal Kivalinarmuit Society as well as refugees from the Shishmaref, Noatak, and Kotzebue regions (City of Kivalina 2012).

Historically, the Kivalina area was a stopping place and meeting area for trade, to gather food and for communication for people living on the mainland, or traveling by land or by sea (Northwest Arctic Borough 2009). The current village site was established in 1905 when a federal school was established. The forced migration to the barrier island in order for the children to go to school caused a lot of stress in the early population. The population of Kivalina was decimated by disease and starvation in the early 20th century (City of Kivalina 2012). Missionaries came to Kivalina in the early 20th century and the Episcopal Church ordained at least two residents as ministers in early years. The first post office in Kivalina was established in 1940; the first airstrip was built in 1960; and Kivalina was incorporated as a city in 1969. The 1970's brought a new school, new houses, and a modern electric system. The Alaska Native Claims Settlement Act (ANCSA) established the regional corporations in 1971 (City of Kivalina 2012). NANA Regional Corporation is the area corporation (State of Alaska 2012).

The majority of the city currently does not have modern plumbing. Water is collected from the Wulik River during months when the river and ground are not frozen, and at times of lower turbidity. This water is stored in large tanks in the center of town, where villagers collect for household use (Personal communication with Kivalina Village, 7/9/2012).

Permitting and Agency Consultation Requirements

The environmental permitting requirements listed below are discussed in Alaska Wind Energy Development: Best Practices Guide to Environmental Permitting and Consultations, a study prepared by URS Corporation for the Alaska Energy Authority in 2009.

Wetlands and Waterways

Kisimigiuktuk Hill is an upland area and does not have any wetlands or "Waters of the United States" that would require permits in order to place fill. The project area is, however, surrounded by a vast area of wetlands associated with the Wulik and the Kivalina Rivers. As stated, the Wulik and Kivalina Rivers are located in the vicinity of the project area.

Alaska Pollution Discharge Elimination System

State regulations (18 AAC 83) require that all discharges to surface waters, including storm water runoff, be permitted under the Alaska Pollution Discharge Elimination System (APDES). The goal of the program is to reduce or eliminate pollution and sediments in stormwater and other discharges to surface water. Under the state APDES program, projects that disturb one or more acre of ground are subject to the terms of the Alaska Construction General Permit (CGP) and are required to develop a project Storm Water Pollution Prevention Plan (SWPPP) outlining measures to control or eliminate pollution and sediment discharges. A wind project in Kivalina is likely to disturb more than one acre of ground during the construction of wind turbines, supporting infrastructure and access roads and would be subject to the requirements of the CGP. Prior to construction, the contractor would be required to file a Notice of Intent (NOI) with the Alaska Department of Environmental Conservation (ADEC) prior to submitting the project SWPPP. ADEC would issue an APDES permit following the public comment period.

US. Fish and Wildlife Service/National Marine Fisheries Service

Although the project is not a Federal action and effects on bird and animal species will likely be minor, consultation with the USFWS is necessary to insure there are no unintended impacts as a result of the project. Consultation will also establish post construction monitoring guidelines, if determined to be necessary, to comply with the Migratory Bird Treaty Act (MBTA) and/or the Bald and Golden Eagle Protection Act.

USFWS regulations and guidance under the MBTA prohibits the taking of active bird nests, eggs and young. In their Advisory: Recommended Time Periods for Avoiding Vegetation Clearing in Alaska in order to protect Migratory Birds, USFWS has developed “bird windows” statewide that prohibit clearing activity. The bird window for the Northern region of Alaska, including Kivalina is June 1st – July 31st for shrub and open type habitats (tundra and wetlands) and May 20th – September 15th for nesting seabird colonies. The clearing window for black scoter habitat is through August 10th. Clearing prior to these dates is allowed. If clearing has already occurred then construction may proceed during these dates.

USFWS Wind Turbine Guidelines Advisory Committee developed guidelines and recommendations for wind power projects to avoid impacts to birds and bats. These recommendations have been released to the public as draft U.S. Fish and Wildlife Service Land-Based Wind Energy.

Federal Aviation Administration

Prior to turbine construction an FAA Notice of Proposed Construction or Alteration (Form 7460-1) is required to be completed. Filing a 7460-1 may result in additional discussions with the FAA regarding turbine siting and appropriate lighting requirements that would need to be incorporated into the project specifications.

U.S. Army Corps of Engineers

The US Army Corps of Engineers (USACE) requires a permit for the placement of fill in “waters of the United States”, including wetlands and streams, under Section 404 of the Clean Water Act (CWA). The proposed Kisimigiuktuk Hill turbine site is no likely to be wetlands as there is exposed bedrock at the site. If, however, some component of infrastructure or access road is determined to be within waters of the U.S. a Section 404 permit from the Alaska District USACE and an accompanying U.S. Environmental Protection Agency (EPA) Section 401 Water Quality Certification would need to be obtained. Currently, Individual Permits and Nationwide 12 permits are being issued for wind power projects in Alaska. An individual permit would be required for activities related to the construction of access roads or pads in wetlands. A Nationwide 12 Permit would be appropriate for activities related to utility installation (i.e. power lines). Depending on the site selection and potential impacts, a jurisdictional determination (wetland delineation) may be necessary to obtain a Section 404 permit. WHPacific, Inc. and V3 Energy, LLC 1 May 2014

Alaska Department of Fish and Game

The Alaska Department of Fish and Game (ADF&G) oversees activities that may have an impact on fish habitat and anadromous fish streams. An ADF&G Title 16 Fish Habitat Permit would be required if the proposed project includes construction of access roads and infrastructure that may impact fish habitat or would involve installing a culvert in a fish stream.

State Historic Preservation Office

Consultation with the State Historic Preservation Office (SHPO) for State of Alaska-funded projects is required under the State Historic Preservation Act. The act requires that all state projects be reviewed for potential impacts to cultural and historic resources. During the permitting phase of the project prior to construction, consultation with the SHPO would be initiated to determine if the project may impact these resources. The extent of needed infrastructure (pads and new roads) and the presence of known archaeological sites in the vicinity of the project area may trigger the SHPO to recommend an archaeological survey of the site.

Discussion

For this conceptual design report, only proven and robust wind turbines were considered for evaluation, hence any of the evaluated configurations can be designed and operated to meet expectations of high performance and reliability. Integration requirements will vary depending on the type of electrical generator in the turbine (synchronous vs. asynchronous), inverter-conditioning, soft-start or other similar grid stability control features, VAR support if necessary, minimum loading levels of the diesel generators as a percentage of the electric load, secondary load controller resolution and response time, among others. These design elements are beyond the scope of this conceptual design project, but the technology is mature enough to be assured that the wind turbines operating in a medium penetration/non-storage mode in Kivalina are controllable.

With these issues in mind, the primary deciding factors for selection of wind turbine(s) for Kivalina will be cost, aesthetics, redundancy, support, and commonality.

Cost

The highest benefit-to-cost ratio wind turbine configuration calculated in this conceptual design is the Northern Power NPS 100-21 turbine at the Kisimigiuktuk Hill site, although the projected benefit-to-cost ratio of Vestas V17 turbines is high as well. Note however that the cost estimates in this report were not produced at the same level of precision and accuracy as will occur during the design phase and so should be considered with a level of caution. Also note that many cost parameters such as operations and maintenance costs over the life of the project are estimated using Alaska Energy Authority default values and may not be realistic for a particular turbine configuration option.

Aesthetics

This is a highly subjective consideration that may elicit strong and conflicting opinions. Ultimately, Kivalina residents must collectively agree on the aesthetic impact of wind turbines in their community, especially at Kisimigiuktuk Hill as the turbines will be near the new community and easily visible on a prominent landmark. Should an intertie to Red Dog Port be constructed to supply electrical power to Kivalina, wind turbines at Red Dog Port would not be visible from Kivalina and would only present an aesthetic consideration for Teck Alaska. Given the industrial nature of the port facility, aesthetic objections to wind turbine(s) at Red Dog Port are unlikely.

Redundancy

A single wind turbine would be redundant in the sense that diesel generation will continue to exist to meet electrical load demand should the turbine be off-line for maintenance or a fault condition. On the other hand, a single wind turbine is not redundant with respect to wind generation itself. Should the turbine be out of service for an extended period of time, wind power would not be generated during the outage and the community would revert to a diesels-only mode of operation.

Support

Manufacturer warranty and support will be a primary consideration of AVEC given its responsibility as electrical utility for Kivalina. The Borough must have confidence that the turbine manufacturer and/or its representatives will be available throughout the life of the project. This is a matter of trust and ultimately a value that AVEC must determine for itself.

Commonality

This is a practical consideration in that several AVEC communities are equipped with Northern Power wind turbines, which can be considered to be AVEC's "fleet" turbine. There are many desirable aspects of a fleet turbine of value to AVEC: a single supplier and point of contact, a common control system for all turbines in the fleet, common parts, and technicians that must learn only one turbine, not two or more. On the other hand, AVEC has at times expressed interest in working with other wind turbine suppliers and developing alternative wind power configurations.

Recommendation

The configuration of two Northern Power 100-21 wind turbines at the Kisimigiuktuk Hill site is recommended as the AVEC's best option for wind power development in Kivalina, assuming a Kivalina-only configuration. This recommendation is based on the following considerations:

- Cost – Development of wind power at the Kisimigiuktuk Hill site is recommended, but as noted elsewhere in this report, this assumes relocation of the village to the Kisimigiuktuk Hill area. This recommendation also assumes that relocation costs will be borne by other funding sources. This report does not recommend development of wind power at Kisimigiuktuk Hill to served Kivalina at its present location on the barrier island.

  With respect to development of wind power for Kivalina in its present location, although this is possible at the Wulik River site, this option is not cost effective with the evaluated wind turbines, and is not recommended. Note that should wind turbines be installed at the Wulik River site to serve Kivalina and then the village subsequently re-located to Kisimigiuktuk Hill, the turbines would be orphaned in an undesirable location.

- Aesthetics – Presuming the relocation of Kivalina to Kisimigiuktuk Hill area and wind power development on Kisimigiuktuk Hill, undeniably wind turbines will be have an aesthetic impact. This can be perhaps be partially mitigated by microsite decisions regarding view angles and exact turbine location. Should an intertie to Red Dog Port be constructed and wind power developed at the port, aesthetic considerations will be a moot point for Kivalina residents.

- Redundancy – Installing at least two wind turbines enables continuity of wind power production should one turbine be out of service for an extended period of time and is recommended for a Kivalina-only wind power project. Should an intertie be constructed and wind power developed at Red Dog Port, redundancy considerations will be the province of Teck Alaska to decide, although two or more wind turbines would be recommended for Red Dog Port for the same reason they are recommended for a Kivalina-only option: continuity of wind power should one turbine be off-line.

- Support – All three (two when considering Kivalina-only options) turbine manufacturers evaluated in this conceptual design report are professional companies with extensive depth and capability to provide warranty and continuing support over time with both factory personnel and Alaska-based representatives. But, given AVEC's long history with Northern Power Systems, continuation of this relationship in Kivalina is recommended.

- Commonality – Given AVEC's long history with Northern Power Systems, NPS 100 turbines would be most straightforward for AVEC to integrate into its operations department.

It must be emphasized that for this report the wind resource at Kisimigiuktuk Hill was modeled by reference to only one year of met tower data collected five miles distant at the Wulik River site. With that in mind, a met tower should be installed on Kisimigiuktuk Hill to verify the wind resource modeled in this report. At publication of this report, it was reported that WHPacific, AVEC, Alaska Energy

Authority, and NANA Regional Corp. are working to accomplish that goal during the summer 2014 field season.

Appendix A – Kivalina Wind Resource Report

Kivalina Wind Resource Report

Kivalina aerial photo by Doug Vaught, July 2011

June 27, 2012

Douglas Vaught, P.E.
dvaught@v3energy.com
V3 Energy, LLC
Eagle River, Alaska

Purpose

The Kivalina wind resource report is a component of a larger feasibility study to install wind turbines in either Kivalina or at the Red Dog Port facility located 27 km (17 miles) to the southeast. The feasibility study includes an analysis of a potential electrical intertie connecting Kivalina to Red Dog Port. A follow-on version of this wind resource report will include a comparison of wind data being collected at Red Dog Port.

Summary

The wind resource measured at the Kivalina met tower site is good with measured wind power class 4 (description: good) if considering power density and wind power class 3 (description: fair) if considering only mean wind speed. Given the cold temperatures in Kivalina, higher wind density results in a higher power density than at standard temperature and pressure. In other respects, Kivalina's wind characteristics are ideal with exceptionally low turbulence and low wind shear. Kivalina experiences very cold winter temperatures, which will increase energy production of both variable pitch and stall-regulated wind turbines, but the low elevation of the site keeps it free of problematic rime icing problems that have been noted elsewhere in northern Alaska.

The Kivalina wind resource study was funded by the Alaska Energy Authority and managed by WHPacific for the Alaska Village Electric Cooperative (AVEC). WHPacific contracted V3 Energy, LLC to write this wind resource report. AVEC and WHPacific points of contact, respectively, are Brent Petrie, Key Accounts Manager (bpetrie@avec.org), and Katherine Keith, Distributed Energy Specialist (kkeith@whpacific.com).

Met tower data synopsis

Data dates	May 9, 2011 to May 18, 2012 (12.3 months); status: operational
Wind power class	Class 3 to Class 4
Wind power density mean, 30 m	325 W/m^2
Wind speed mean, 30 m	5.87 m/s
Max. 10-min wind speed average	26.7 m/s
Maximum 2-sec. wind gust	33.6 m/s (November, 2011)
Weibull distribution parameters	k = 1.66, c = 6.56 m/s
Wind shear power law exponent	0.194 (moderate) (see report for notes)
Roughness class	2.11 (few trees) (see report for notes)
IEC 61400-1, 3rd ed. classification	Class III-C
Turbulence intensity, mean	0.075 (at 15 m/s)
Calm wind frequency (at 33 m)	34% (< 4 m/s)

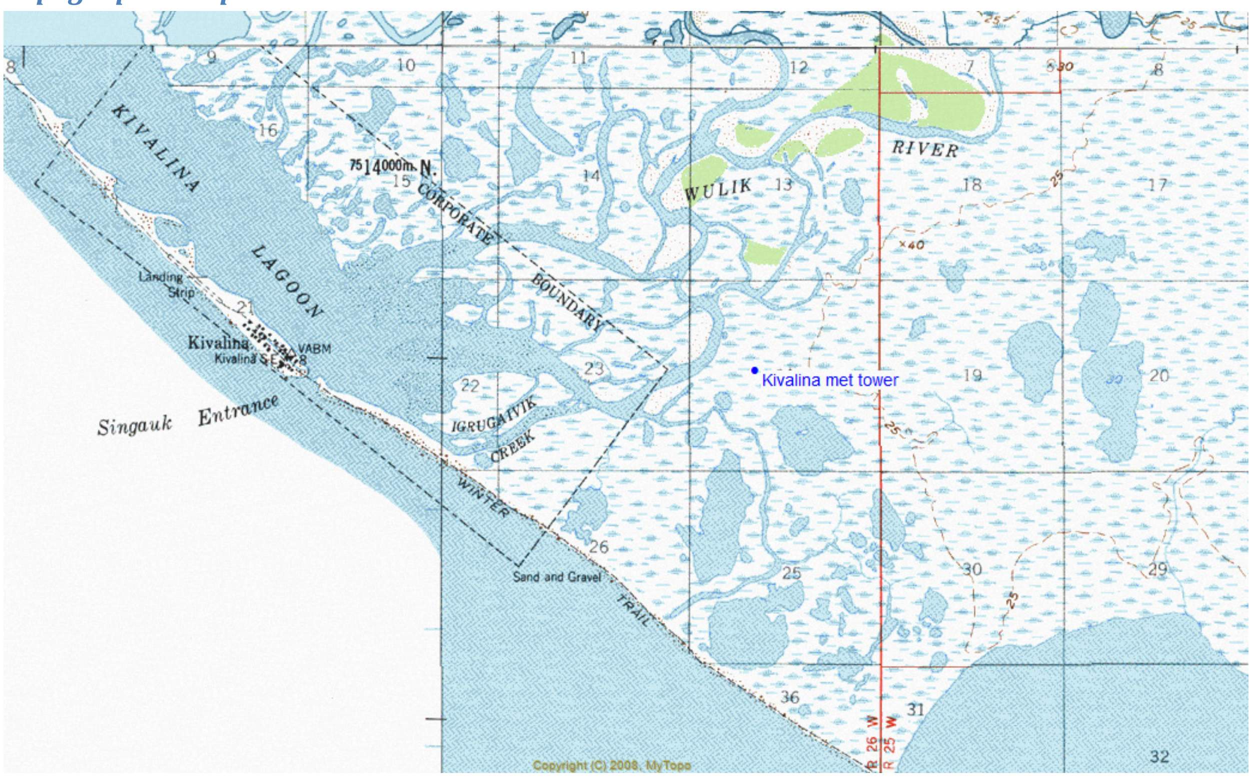
Test Site Location

Wind measurement instrumentation was installed on a six-inch diameter 30 meter NRG tubular Tall Tower (met tower) approximately three kilometers (two miles) east of the village of Kivalina and approximately 1.5 km (1 mile) from the Chukchi Sea coast. The tower is located on open tundra in the general vicinity of the new Kivalina town site should the village be relocated due to continuing erosion and flooding risk at the existing village location, which is on an exposed coastal barrier island. The met tower was installed on May 6, 2011 by Echelon Energy Corp. of San Jose, California.

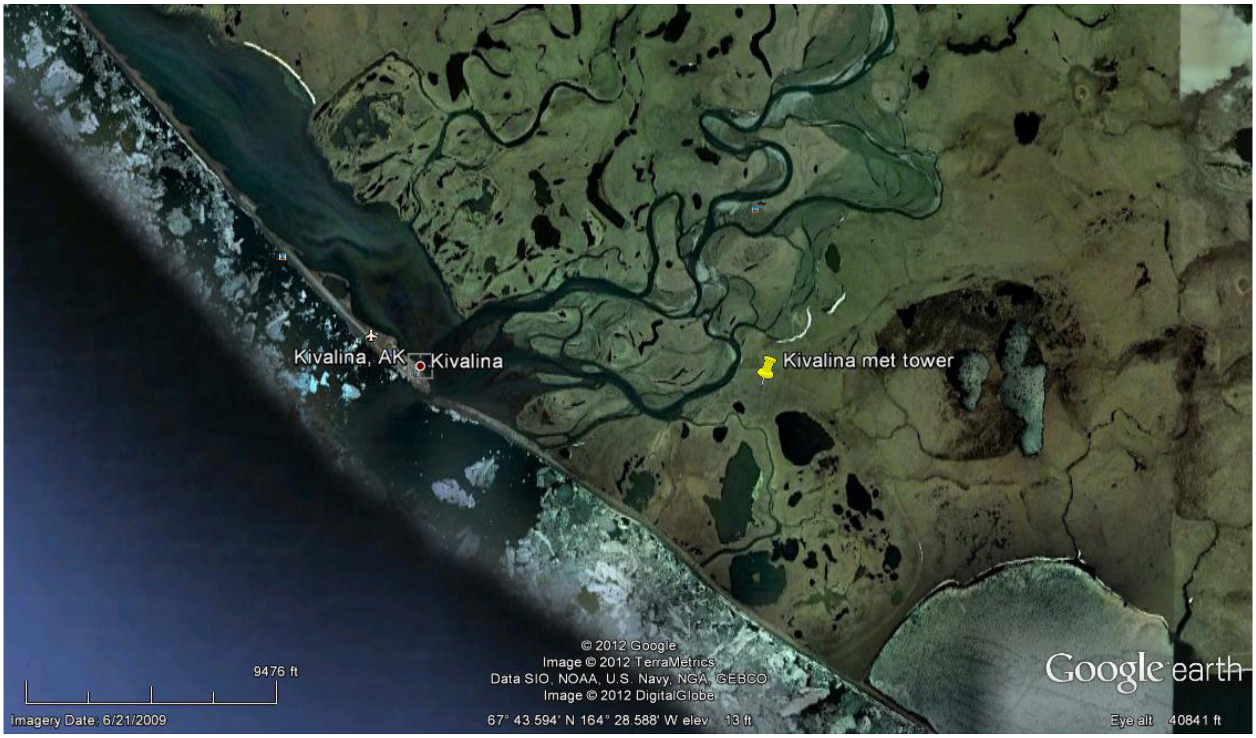
Site information

Site number	9750
Latitude/longitude	N 67° 43’ 29.64” W 164° 26’ 25.38”, NAD 83
Site elevation	3 meters (10 ft)
Datalogger type	NRG Symphonie, 10 minute time step
Tower type	NRG Tall Tower, 30 meters, six-inch diameter

Topographic map



Google Earth image



Tower sensor information

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	30 m A	0.765	0.35	north
2	NRG #40 anemometer	30 m B	0.765	0.35	south
3	NRG #40 anemometer	20 m	0.765	0.35	north
7	NRG #200P wind vane	29 m	0.351	351	351° T
9	NRG #110S Temp C	3 m	0.138	-86.3	north

Tower sensors photo (view to the southwest)

Data Quality Control

Data quality is generally very good for the 30 meter level anemometers, excellent for the wind vane and temperature sensor, and very poor for the 20 meter level anemometer. An installation error with the 20 meter anemometer resulted in it being located directly in line with the north-facing third-level guy wire, resulting in fouling of the sensor in the wire after the tower settled in the tundra a bit and the guy wires slackened. In the data analysis, a filter was used to remove 20 meter anemometer data significantly divergent from 30 meter A anemometer data, but that is not a precise tool and it is not possible to definitively determine all times that the 20 m anemometer was fouled. Recovered 20 m level anemometer data is not usable by itself for wind speed or other data, but it is usable, with qualification, for calculation of the wind shear coefficient.

Data loss due to icing conditions was very infrequent in Kivalina compared to coastal sites in western Alaska. This may be due to the extremely cold winter of 2011/2012 and the otherwise normal extensive sea ice offshore of Kivalina and resulting low moisture content in the air. Icing conditions in the anemometer data are characterized by output of the anemometer at the minimum offset value of 0.4 m/s, standard deviation of zero, and temperatures less than 1 degree Centigrade. For wind direction data, icing is characterized by non-variant output at the last operable wind direction (standard deviation of zero) and temperature less than 1 degree Centigrade.

In addition to icing, 30 meter level anemometer data was filtered for tower shadow using an algorithm that identifies wind from a 30 degree sector opposite the anemometer and filters that data. With frequent northerly winds, the south-facing 30 m B anemometer was filtered more frequently than the north-facing 30 m A anemometer.

Data recovery summary table

Sensor	Units	Height	Possible Records	Valid Records	Recovery Rate (%)
Speed 30 m A	m/s	30 m	54,018	51,676	95.7
Speed 30 m B	m/s	30 m	54,018	47,240	87.5
Speed 20 m	m/s	20 m	54,018	15,965	29.6
Direction 29 m	°	29 m	54,018	53,408	98.9
Temperature	°C		54,018	53,868	99.7

Anemometer and wind vane data recovery

Year	Month	30 m A Recovery Rate (%)	30 m B Recovery Rate (%)	20 m Recovery Rate (%)	Vane Recovery Rate (%)	Temp Recovery Rate (%)
2011	May	88.6	92.2	43.7	95.5	100.0
2011	Jun	93.9	88.5	9.7	100.0	100.0
2011	Jul	93.7	95.5	5.7	100.0	100.0
2011	Aug	94.5	96.2	15.3	100.0	100.0
2011	Sep	96.2	81.4	25.8	100.0	100.0
2011	Oct	99.3	90.5	25.0	98.3	100.0

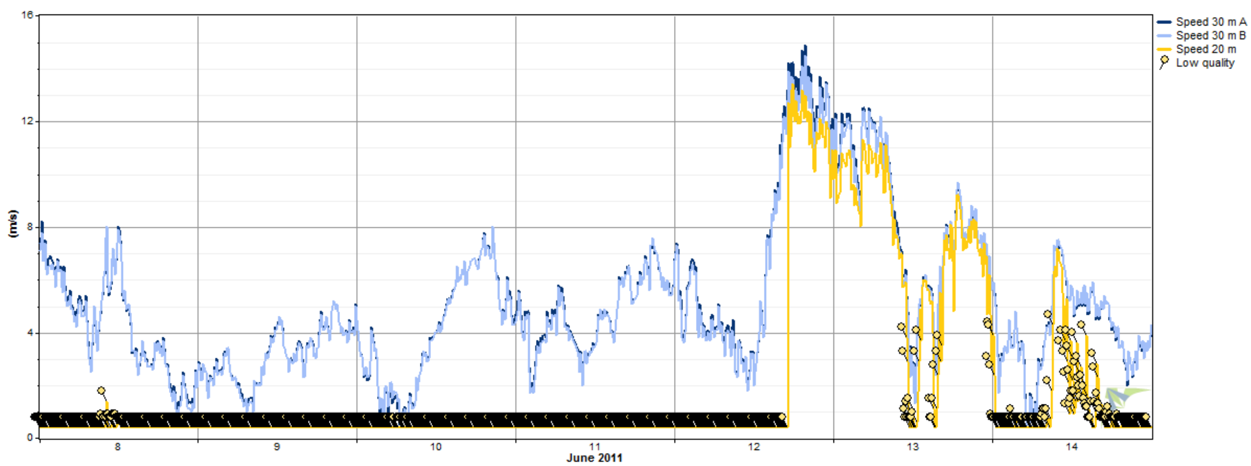
Year	Month	30 m A Recovery Rate (%)	30 m B Recovery Rate (%)	20 m Recovery Rate (%)	Vane Recovery Rate (%)	Temp Recovery Rate (%)
2011	Nov	99.4	85.5	18.5	100.0	100.0
2011	Dec	90.8	80.5	57.2	91.4	96.8
2012	Jan	98.0	87.2	54.7	100.0	100.0
2012	Feb	97.8	84.3	44.0	100.0	100.0
2012	Mar	99.3	74.8	27.0	100.0	100.0
2012	Apr	94.7	93.0	26.0	100.0	100.0
2012	May	96.0	89.1	39.8	99.8	99.8
All Data		95.7	87.5	29.6	98.9	99.7

Data flag statistics

Anemometer	Possible Records	Icing %	Low quality %	Tower shading %
Speed 30 m A	54,018	0.4%	0.0%	3.6%
Speed 30 m B	54,018	0.4%	0.0%	11.4%
Speed 20 m	54,018	24.4%	68.6%	0.0%

Note: low quality and icing flags of 20 m anemometer often overlap.

Fouled 20 meter anemometer



Wind Speed

Anemometer data obtained from the met tower, from the perspectives of both mean wind speed and mean wind power density, indicate a good wind resource. Mean wind speeds are greater at higher elevations on the met tower as one would expect. Note that the cold mean annual air temperature in Kivalina contributed to a higher wind power density than otherwise expected for the mean wind speeds.

Anemometer data summary

Variable	Speed 30 m A	Speed 30 m B
Measurement height (m)	30	30
Mean wind speed (m/s)	5.87	5.52
Median wind speed (m/s)	5.20	5.00
Max 10-min avg wind speed (m/s)	26.7	26.7
Max gust wind speed (m/s)	33.2	33.6
Weibull k	1.66	1.62
Weibull c (m/s)	6.56	6.15
Mean power density (W/m²)	325	274
Mean energy content (kWh/m²/yr)	2,845	2,398
Energy pattern factor	2.41	2.47
Frequency of calms (%)	34.4	37.3

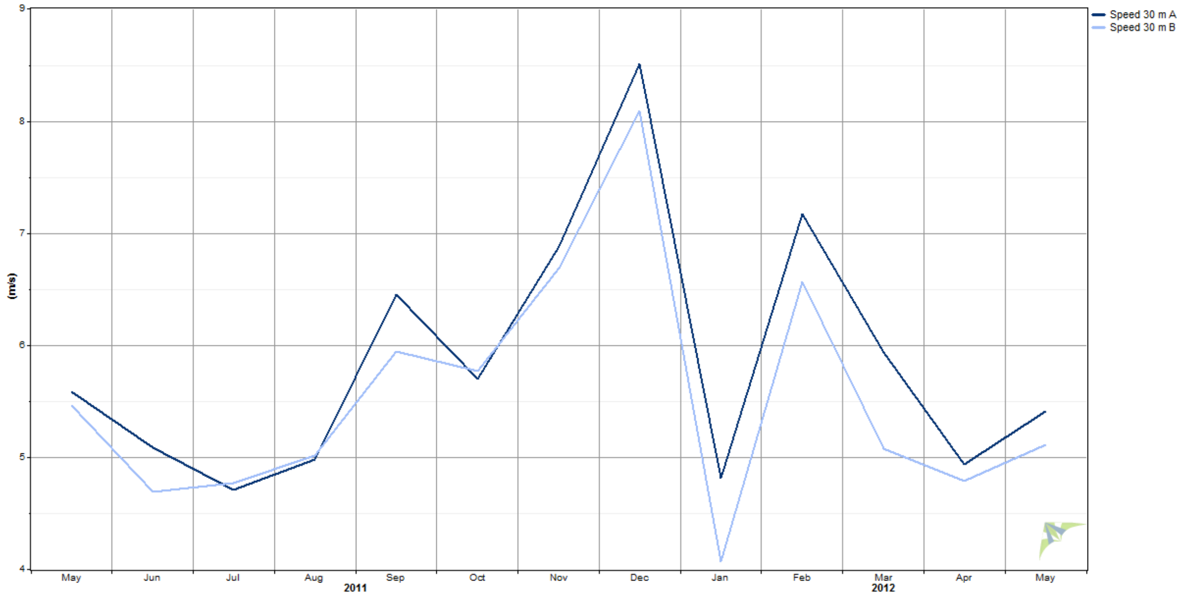
Time Series

Time series calculations indicate high mean wind speeds during the winter months with more moderate mean wind speeds during summer months. This correlates well with the typical village load profile where winter months have a high electric and heat demand and summer months a lesser demand. The a diurnal profile indicates remarkably stable wind speeds throughout the day with a minor "valley" of wind speeds during the morning hours and a minor "peak" of wind speeds during late afternoon.

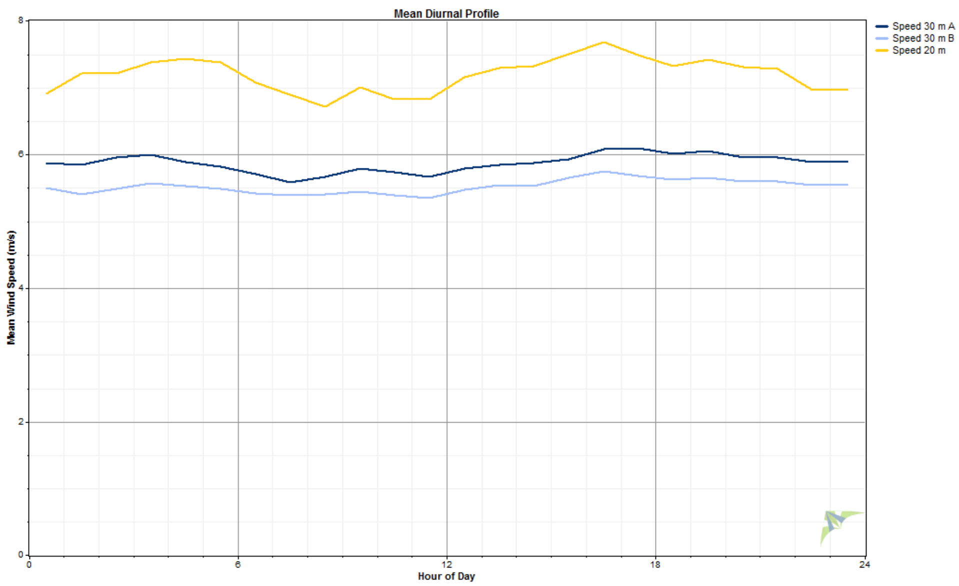
30 m A anemometer data summary

Year	Month	Mean (m/s)	Max 10-min (m/s)	Max Gust (m/s)	Std. Dev. (m/s)	Weibull k (-)	Weibull c (m/s)
2011	May	5.58	14.0	17.2	2.83	2.04	6.29
2011	Jun	5.09	14.9	18.3	2.70	1.95	5.73
2011	Jul	4.71	13.8	17.9	2.53	1.92	5.29
2011	Aug	4.98	12.5	15.6	2.35	2.19	5.60
2011	Sep	6.45	17.8	22.9	3.14	2.15	7.28
2011	Oct	5.69	18.5	22.9	3.08	1.92	6.42
2011	Nov	6.88	26.7	33.2	4.08	3.55	10.12
2011	Dec	8.51	21.2	25.6	4.19	2.14	9.60
2012	Jan	4.81	24.7	27.1	4.24	1.17	5.08
2012	Feb	7.17	21.2	24.8	4.43	1.64	8.00
2012	Mar	5.94	16.7	19.5	3.47	1.71	6.63
2012	Apr	4.94	17.6	22.9	3.87	1.21	5.24
2012	May	5.41	13.5	16.1	2.60	2.19	6.10
All Data		5.87	26.7	33.2	3.63	1.66	6.56
Mean of monthly means		5.88					

Wind speed time series graph



Diurnal profile

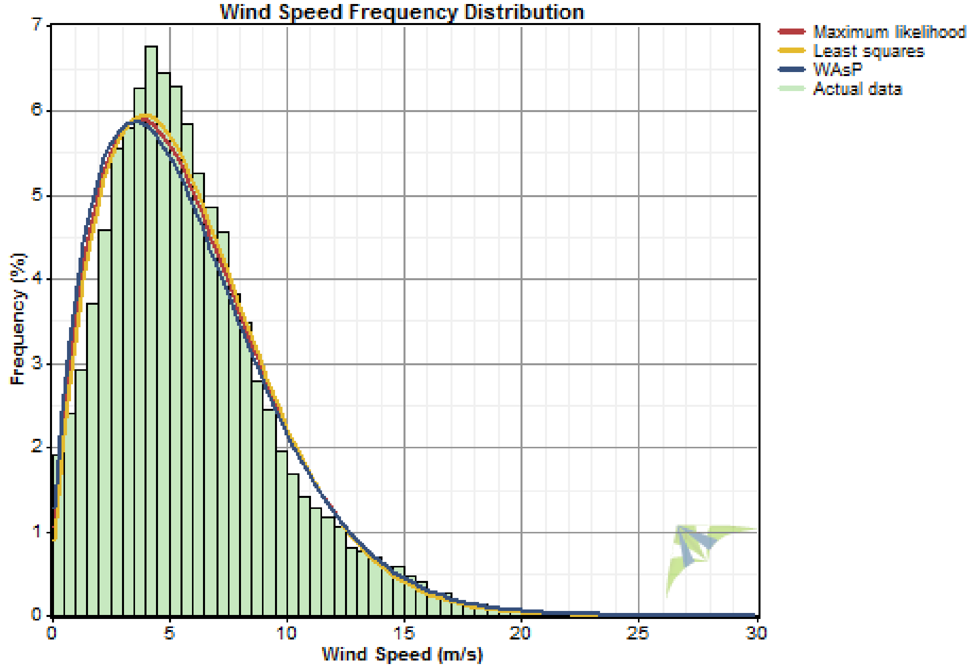


Note: disregard the Speed 20 m curve due to problems with data recovery

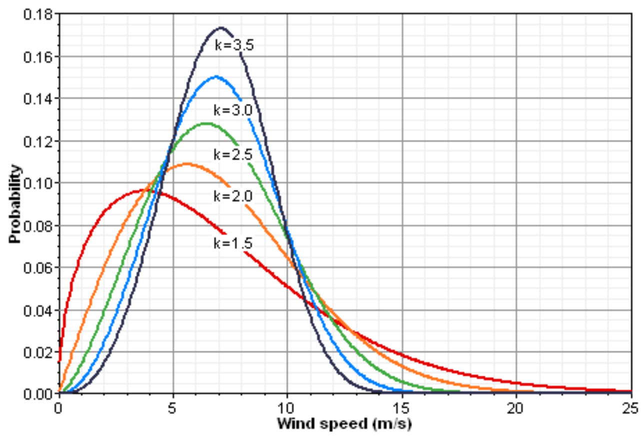
Wind Speed Distribution

The probability distribution function (PDF), or histogram, of Kivalina wind speed data indicates a shape curve somewhat dominated by lower wind speeds, as opposed to a "normal" shape curve, known as the Rayleigh distribution (Weibull k = 2.0), which is defined as the standard wind distribution for wind power analysis. As one can see in the PDF of 30 meter A anemometer, the most frequently occurring wind speeds are between 4 and 6 m/s with very few wind events exceeding 25 m/s (the cutout speed of most wind turbines; see following wind speed statistical table).

Wind speed distribution of 30 m A anemometer



Weibull k shape curve table



Weibull comparison table

Algorithm	Weibull k (-)	Weibull c (m/s)	Mean (m/s)	Proportion Above 5.872 m/s	Power Density (W/m2)	R Squared (-)
Maximum likelihood	1.660	6.560	5.864	0.435	291.8	0.977
Least squares	1.704	6.586	5.875	0.439	283.8	0.980
WAsP	1.603	6.496	5.823	0.427	299.2	0.970
Actual data	(51,676 time steps)		5.872	0.427	299.2	

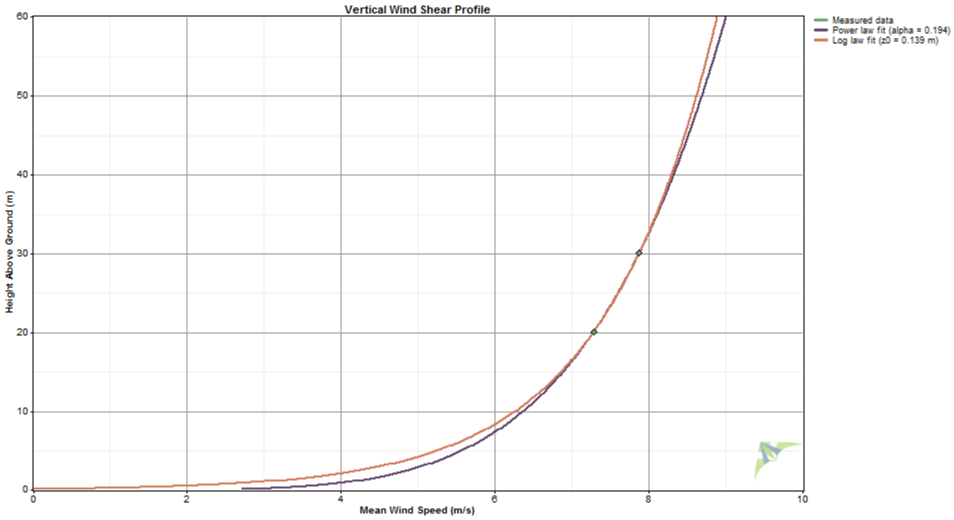
Occurrence by wind speed bin

Bin Endpoints (m/s)		Occurrences		Bin Endpoints (m/s)		Occurrences	
Lower	Upper	No.	Percent	Lower	Upper	No.	Percent
0	1	2,224	4.5%	14	15	604	1.2%
1	2	3,420	6.9%	15	16	443	0.9%
2	3	5,226	10.5%	16	17	287	0.6%
3	4	6,219	12.5%	17	18	180	0.4%
4	5	6,821	13.7%	18	19	122	0.2%
5	6	6,261	12.6%	19	20	78	0.2%
6	7	5,213	10.5%	20	21	37	0.1%
7	8	4,327	8.7%	21	22	18	0.0%
8	9	3,236	6.5%	22	23	13	0.0%
9	10	2,271	4.6%	23	24	17	0.0%
10	11	1,610	3.2%	24	25	22	0.0%
11	12	1,270	2.5%	25	26	25	0.1%
12	13	962	1.9%	26	27	13	0.0%
13	14	757	1.5%	all		49,817	100.0%

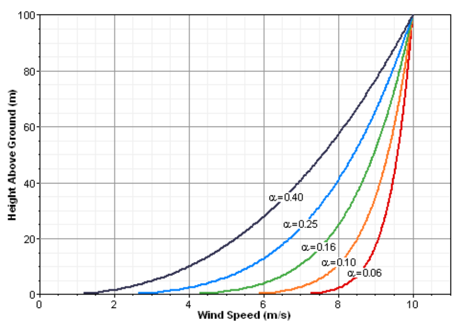
Wind Shear and Roughness

A wind shear power law exponent (α) of 0.194 indicates moderate wind shear at the site. Related to wind shear, a calculated surface roughness of 0.114 meters (indicating the height above ground level where wind velocity would be zero) indicates moderately rough terrain (roughness description: few trees) surrounding the met tower. This data is comprised however by very poor data recovery from the 20 meter level anemometer, which was installed such that it was often fouled in the third level north-facing guy wire. The power law exponent is calculated only with time step data with valid anemometer data from the selected sensors (the 30 m A anemometer and the 20 meter anemometer); in this case only 28 percent of the time steps qualified. This is a statistically sufficient amount of data except that filtering of the 20 meter data to remove the time steps where the anemometer was fouled is not precise and some data that should have been filtered was undoubtedly retained. Although the power law exponent and roughness length are generally reasonable, one might expect both values to be lower considering the flat, featureless, and typically snow-covered terrain surrounding the met tower.

Vertical wind shear profile



Comparative wind shear profiles



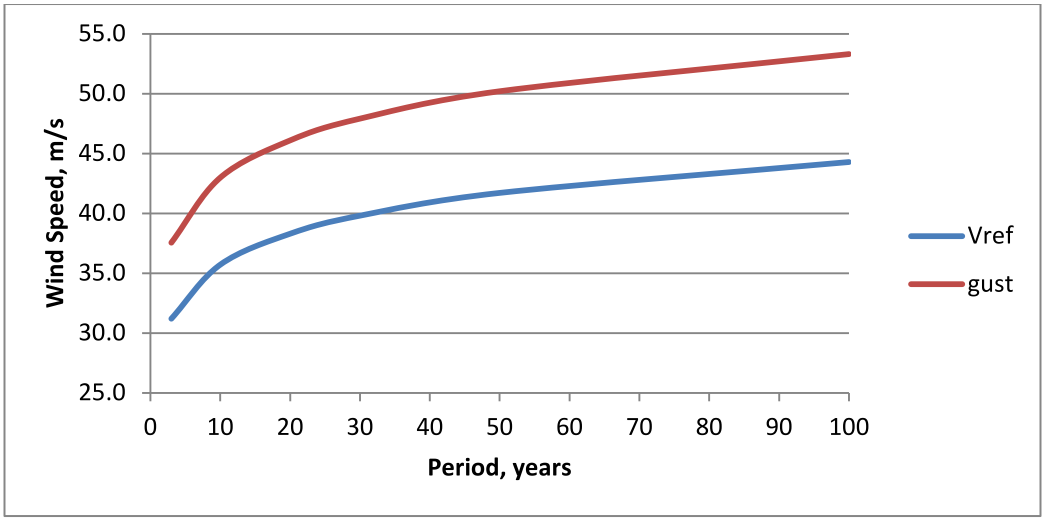
Extreme Winds

A modified Gumbel distribution analysis, based on monthly maximum winds vice annual maximum winds, was used to predict extreme winds at the Kivalina met tower site. Industry standard reference of extreme wind is the 50 year probable (50 year return period) ten-minute average wind speed, referred to as V_{ref}. For Kivalina, this calculates to 35.8 m/s (at 30 meters), which qualifies as an International Electrotechnical Commission (IEC) 61400-1, 3rd edition criteria Class III site, the lowest defined. All wind turbines are designed for IEC 61400-1 Class III conditions.

Extreme wind probability table, 30 m A data

Period (years)	V_{ref} (m/s)	Gust (m/s)	IEC 61400-1, 3rd ed. Class	V_{ref}, m/s
3	26.8	32.8	I	50.0
10	30.7	37.5	II	42.5
20	32.9	40.2	III	37.5
30	34.2	41.8	S	designer-specified
50	35.8	43.8		
100	38.0	46.5		

Extreme wind graph



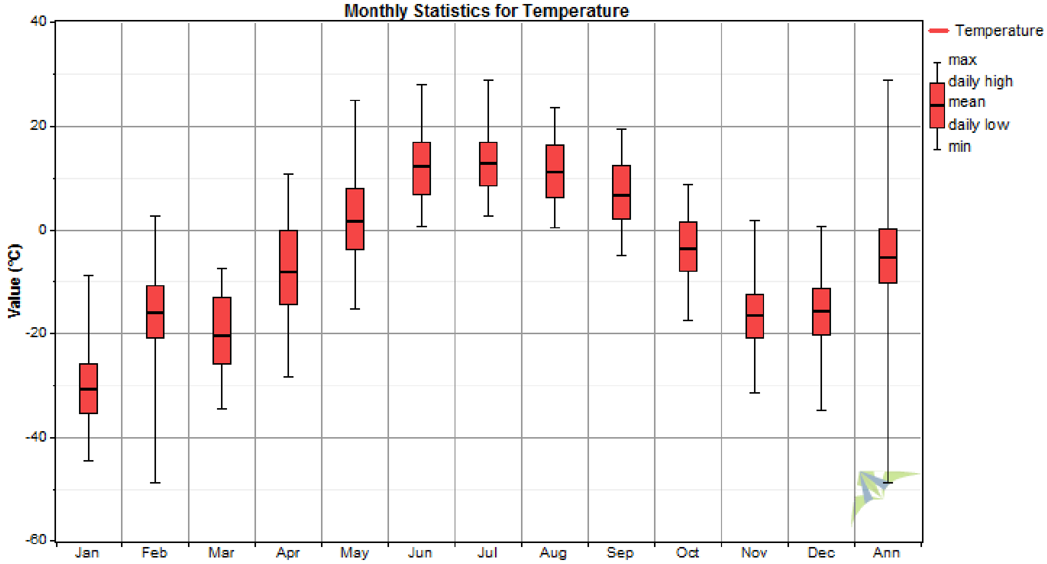
Temperature and Density

Kivalina experiences cool summers and very cold winters with resulting higher than standard air density. Calculated annual mean air density during the met tower test period exceeds by 7.8 percent the 1.225 kg/m^3 standard air density at a 3 meter elevation. This is advantageous in wind power operations as wind turbines typically produce more power at low temperatures/high air density than at standard temperature and density.

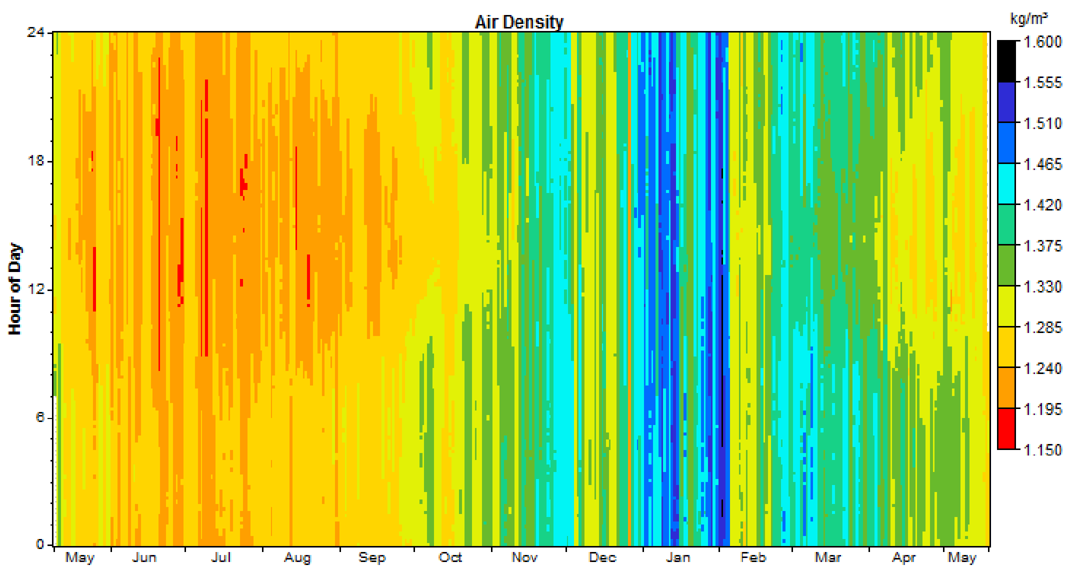
Temperature and density table

	Temperature			Density		
Month	Mean (°C)	Min (°C)	Max (°C)	Mean (kg/m³)	Min (kg/m³)	Max (kg/m³)
Jan	-30.7	-44.5	-8.9	1.456	1.335	1.543
Feb	-15.9	-48.7	2.7	1.374	1.279	1.572
Mar	-20.2	-34.5	-7.4	1.395	1.327	1.478
Apr	-7.9	-28.4	10.6	1.331	1.243	1.441
May	1.8	-15.4	25.0	1.284	1.183	1.369
Jun	12.2	0.7	28.1	1.237	1.171	1.288
Jul	12.9	2.6	28.9	1.234	1.168	1.279
Aug	11.3	0.4	23.5	1.240	1.189	1.290
Sep	6.8	-5.1	19.3	1.260	1.206	1.316
Oct	-3.5	-17.6	8.7	1.308	1.252	1.380
Nov	-16.5	-31.5	1.8	1.376	1.283	1.460
Dec	-15.5	-35.0	0.5	1.367	1.224	1.481
Annual	-5.2	-48.7	28.9	1.321	1.168	1.572

Annual temperature boxplot



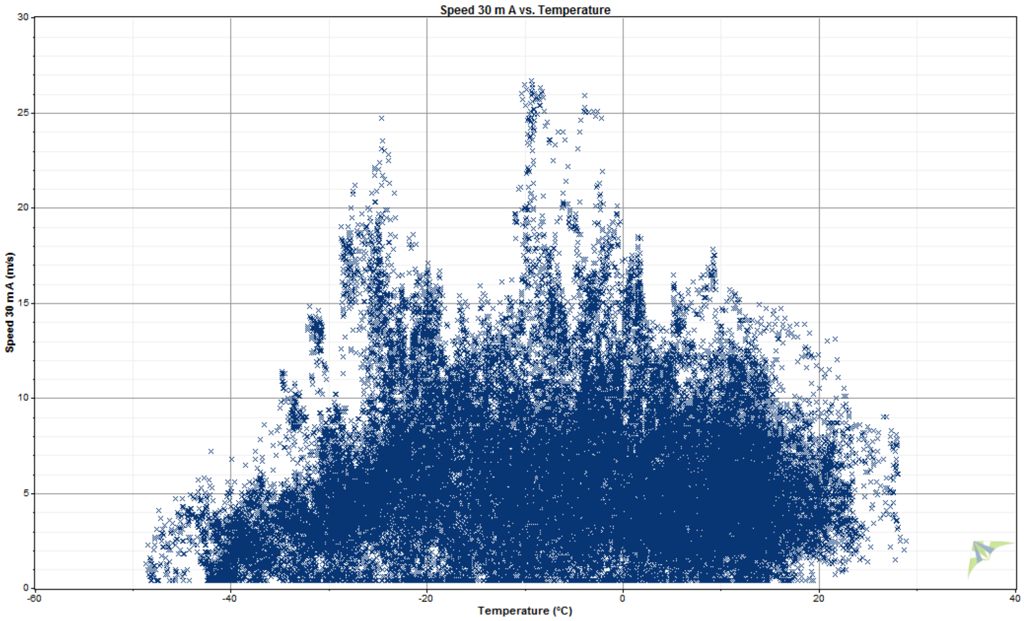
Air density DMap



Wind Speed Scatterplot

The wind speed versus temperature scatterplot below indicates that a substantial percentage of wind in Kivalina coincides with cold temperatures as one would expect. During the met tower test period, temperatures fell below -40°C, the minimum operating temperature for arctic-capable wind turbines, on a number of occasions. Wind speeds during periods of extreme cold are generally low, however, and loss of wind turbine availability during these times would not be significant. Also note that periods of high winds (wind speeds greater than 20 m/s) are characterized by cold temperatures, between 0°C and -25°C.

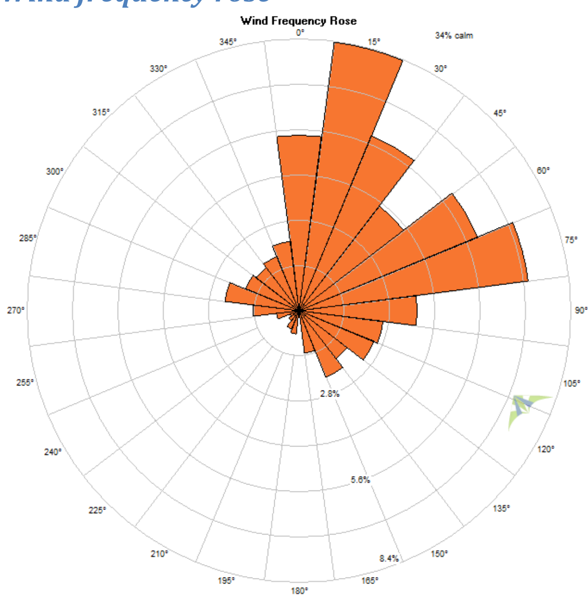
Wind speed/temperature



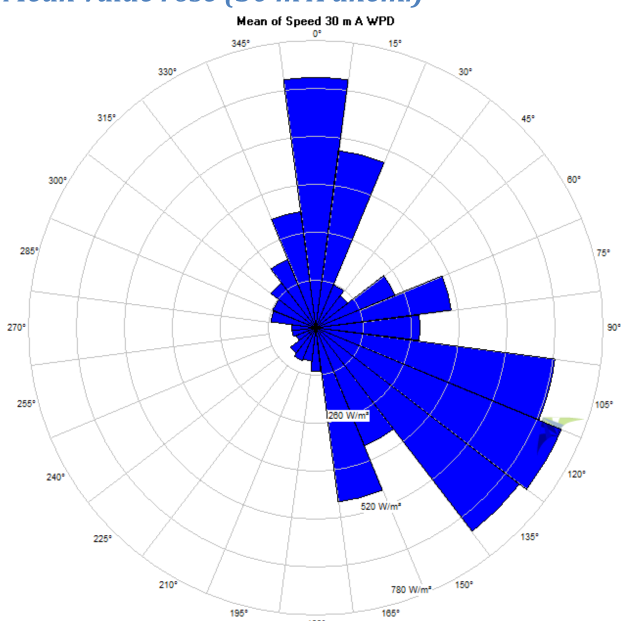
Wind Direction

Wind frequency rose data indicates that winds at Kivalina are relatively directional, with north-northeasterly and east-northeasterly predominating. The mean value rose indicates that infrequent southeasterly winds, when they do occur, are of high energy and hence likely storm winds. The wind energy rose indicates that winds for wind turbine operations power-producing are northerly and southeasterly dominant. Calm frequency (percent of time that winds at the 30 meter level are less than 4 m/s) was 34 percent during the met tower test period.

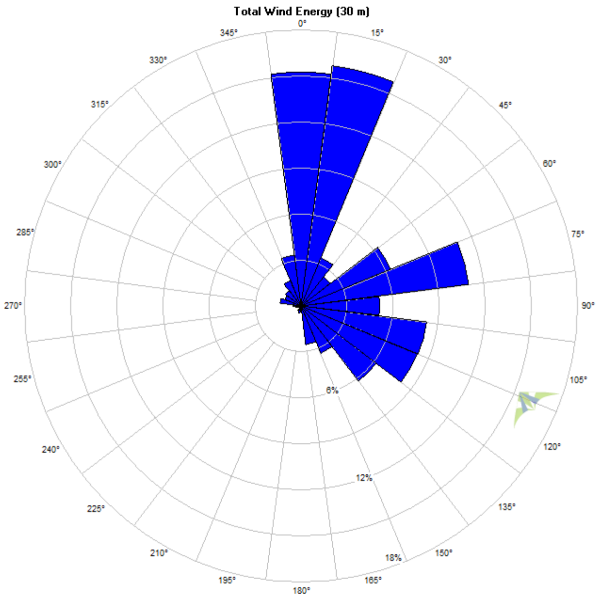
Wind frequency rose



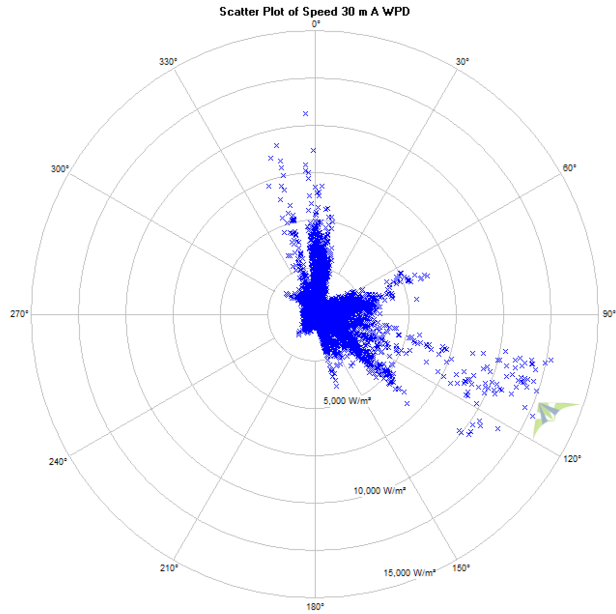
Mean value rose (30 m A anem.)



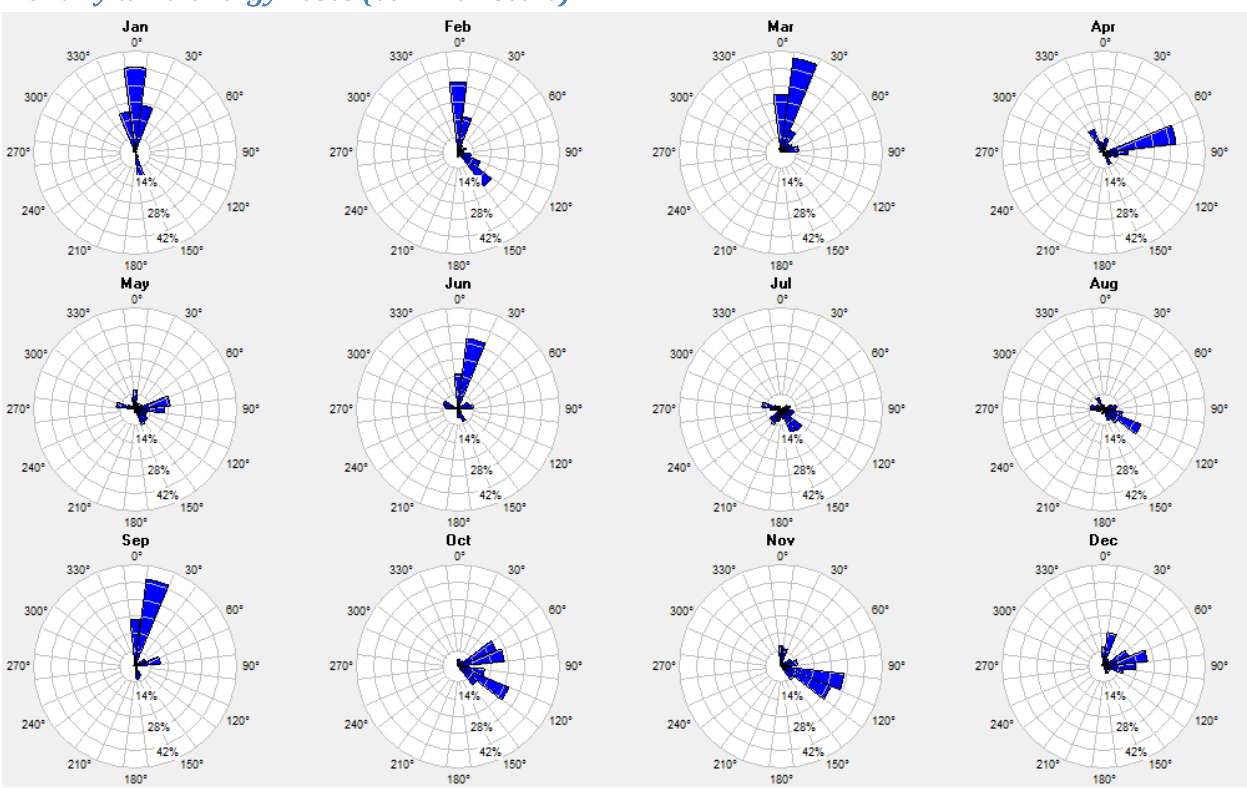
Wind energy rose (30 m A anem.)



Scatterplot rose of 30m A wind power density



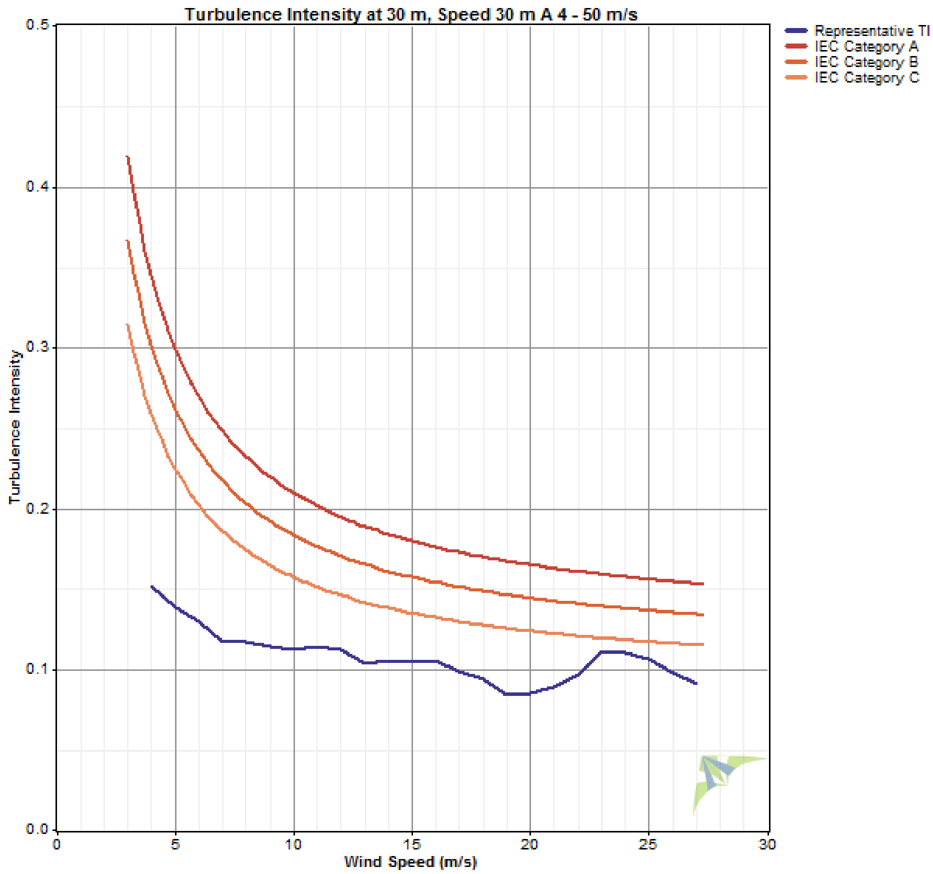
Monthly wind energy roses (common scale)



Turbulence

Turbulence intensity (TI) at the Kivalina met tower site is well within acceptable standards with an IEC 61400-1, 3rd edition (2005) classification of turbulence category C, which is the lowest defined. The mean TI at 15 m/s is 0.075 and the representative TI at 15 m/s is 0.105 (30 m A anemometer), both which can be considered very low and hence very desirable for wind turbine operations.

Turbulence intensity, 30 m A anemometer, all direction sectors



Turbulence table, 30 m A data

Bin Endpoints Lower (m/s)	Upper (m/s)	Records in Bin	Mean TI	Standard Deviation of TI	Representative TI	Peak TI
0.5	1.5	2,744	0.363	0.155	0.561	1.091
1.5	2.5	4,280	0.180	0.090	0.295	0.800
2.5	3.5	5,847	0.126	0.064	0.209	0.815
3.5	4.5	6,725	0.100	0.049	0.163	0.771
4.5	5.5	6,568	0.086	0.041	0.138	0.633
5.5	6.5	5,732	0.081	0.038	0.130	0.468
6.5	7.5	4,858	0.076	0.032	0.117	0.299
7.5	8.5	3,763	0.076	0.032	0.117	0.364
8.5	9.5	2,704	0.076	0.029	0.114	0.299

Bin Endpoints Lower (m/s)	Upper (m/s)	Records in Bin	Mean TI	Standard Deviation of TI	Representative TI	Peak TI
9.5	10.5	1,883	0.077	0.028	0.113	0.269
10.5	11.5	1,398	0.078	0.028	0.114	0.252
11.5	12.5	1,155	0.078	0.027	0.112	0.265
12.5	13.5	808	0.074	0.023	0.104	0.167
13.5	14.5	662	0.076	0.023	0.105	0.174
14.5	15.5	545	0.075	0.023	0.105	0.166
15.5	16.5	347	0.076	0.023	0.105	0.167
16.5	17.5	241	0.074	0.019	0.099	0.145
17.5	18.5	151	0.073	0.016	0.094	0.120
18.5	19.5	98	0.068	0.013	0.084	0.115
19.5	20.5	58	0.069	0.012	0.085	0.100
20.5	21.5	24	0.072	0.014	0.089	0.103
21.5	22.5	16	0.078	0.015	0.097	0.103
22.5	23.5	12	0.080	0.024	0.111	0.104
23.5	24.5	17	0.090	0.016	0.110	0.120
24.5	25.5	28	0.087	0.015	0.106	0.108
25.5	26.5	20	0.090	0.006	0.097	0.104
26.5	27.5	4	0.086	0.003	0.091	0.091

Wind Turbine Performance

The selection of suitable wind turbines for a wind power project in Kivalina is beyond the scope of this report, but for initial planning purposes, predicted annual energy output and capacity factor for the 100 kW Northwind 100 B model (21 meter rotor, 37 meter hub height) is presented below.

Note that the Alaska Energy Authority considers 82 percent turbine availability (percent of time that the turbine is operational and available to produce power, irrespective of wind speed) as the default value for planning village power projects. Many wind turbines in rural Alaska operate with better than 82 percent availability, but for a number of reasons some operate with lower than 82 percent availability.

For this turbine performance analysis, adjustment of power output (from standard temperature and pressure conditions) of the NW100 turbine due to air density was not considered as Northern Power Systems has not published density-specific power curves for the turbine.

NW100B/21 at 37 m, 82% availability

Month	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Mean Net Power Output (kW)	Mean Net Energy Output (kWh/yr)	Net Capacity Factor (%)
Jan	5.03	41.1	2.6	16.1	12,001	16.1
Feb	7.48	14.6	4.8	30.1	20,242	30.1
Mar	6.17	20.3	1.9	22.9	17,036	22.9

Month	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Mean Net Power Output (kW)	Mean Net Energy Output (kWh/yr)	Net Capacity Factor (%)
Apr	5.08	38.1	2.5	17.6	12,655	17.6
May	5.60	21.2	0.0	18.5	13,758	18.5
Jun	5.26	21.0	0.1	15.4	11,071	15.4
Jul	4.93	24.5	0.0	13.4	9,993	13.4
Aug	5.27	18.7	0.0	15.2	11,272	15.2
Sep	6.87	10.8	2.7	26.2	18,896	26.2
Oct	5.95	15.7	1.7	19.9	14,817	19.9
Nov	7.22	8.8	2.2	24.9	17,928	24.9
Dec	8.76	8.2	5.5	40.4	30,036	40.4
Annual	6.10	20.4	1.9	21.5	188,215	21.5

Appendix B – Red Dog Port Wind Resource Report

Red Dog Port Wind Resource Report

Red Dog Port communication tower, view to the southeast, D. Vaught photo

September 7, 2011

Douglas Vaught, P.E.
V3 Energy, LLC
Eagle River, Alaska

V3 Energy LLC
Eagle River, Alaska 907.350.5047

Summary

The wind resource measured at the Red Dog Port communication tower (Site 5) is very good with measured wind power class 6 (outstanding) if considering power density, but wind power class 3 (fair) if considering only mean wind speed. Given the cold temperatures of Red Dog Port area, higher wind density results in a higher power density than at standard temperature and pressure. This increases wind turbine power production, but the boost is not linear. By more useful measure with respect to potential wind turbine energy production, the site would classify as Class 4 to 5 (good to excellent), depending on individual turbine performance.

In a general sense, wind classification at Red Dog Port should be viewed with caution as the statistical characteristics of the wind at this site are somewhat unusual with a wind speed probability distribution skewed toward lower wind speeds but also comprised of high wind events, the latter which strongly influence the mean annual wind power density. Intuitively, this can be grasped by considering that although the mean annual wind power density is quite high, the site experiences 45 percent calm winds (wind speeds less than four meters per second). Another indication of the periodic high winds at Red Dog Port is the extreme wind probability calculation which, depending on one's assumptions, classifies the site as IEC Class I or II.

In other respects, however, Red Dog Port wind characteristics are ideal with exceptionally low turbulence and low surface roughness. The Port experiences very cold temperatures, which will increase energy production of both variable pitch and stall-regulated wind turbines, but the low elevation of the site keeps it free of problematic rime icing problems that have been noted elsewhere in northern Alaska.

Met tower data synopsis

Data dates	October 10, 2008 to August 10, 2011 (34 months); status: operational
Wind power class	Difficult to classify; likely Class 4 to 5 (good to excellent)
Wind power density mean, 33 m	574 W/m^2
Wind speed mean, 33 m	6.05 m/s
Max. 10-min wind speed average	38.5 m/s
Maximum 2-sec. wind gust	43.5 m/s (January, 2009)
Weibull distribution parameters	k = 1.24, c = 6.52 m/s
Wind shear power law exponent	0.180 (moderate)
Roughness class	0.73 (lawn grass)
IEC 61400-1, 3rd ed. classification	Class II-C
Turbulence intensity, mean	0.119 (at 15 m/s)
Calm wind frequency (at 33 m)	45% (< 4 m/s)

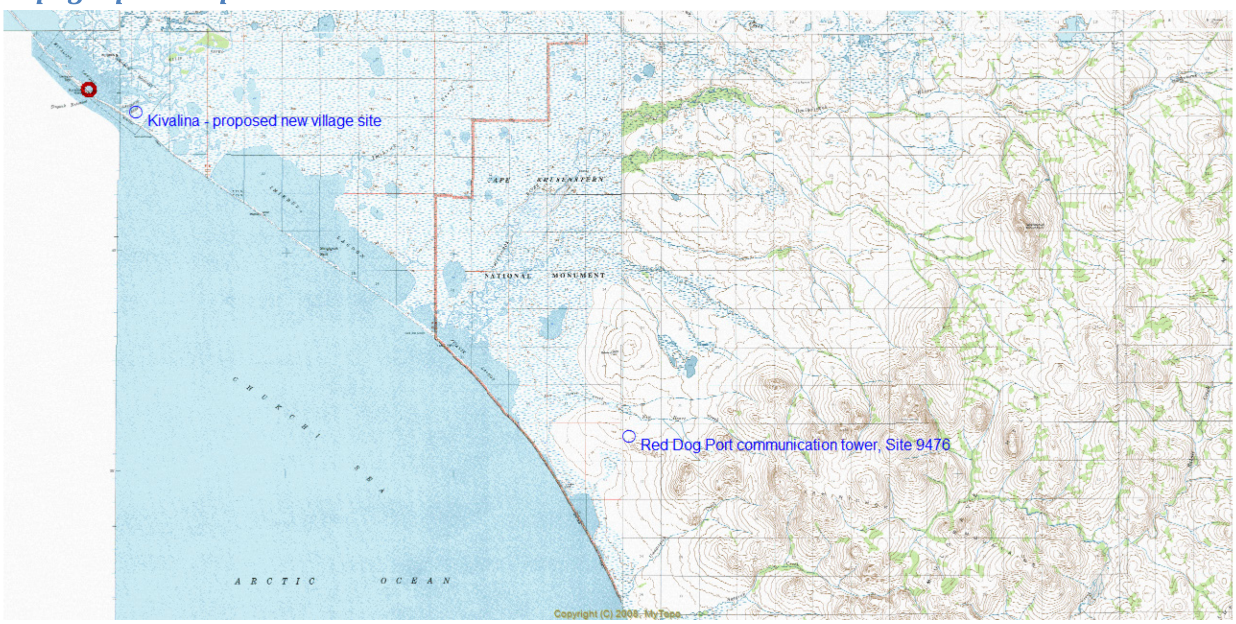
Test Site Location

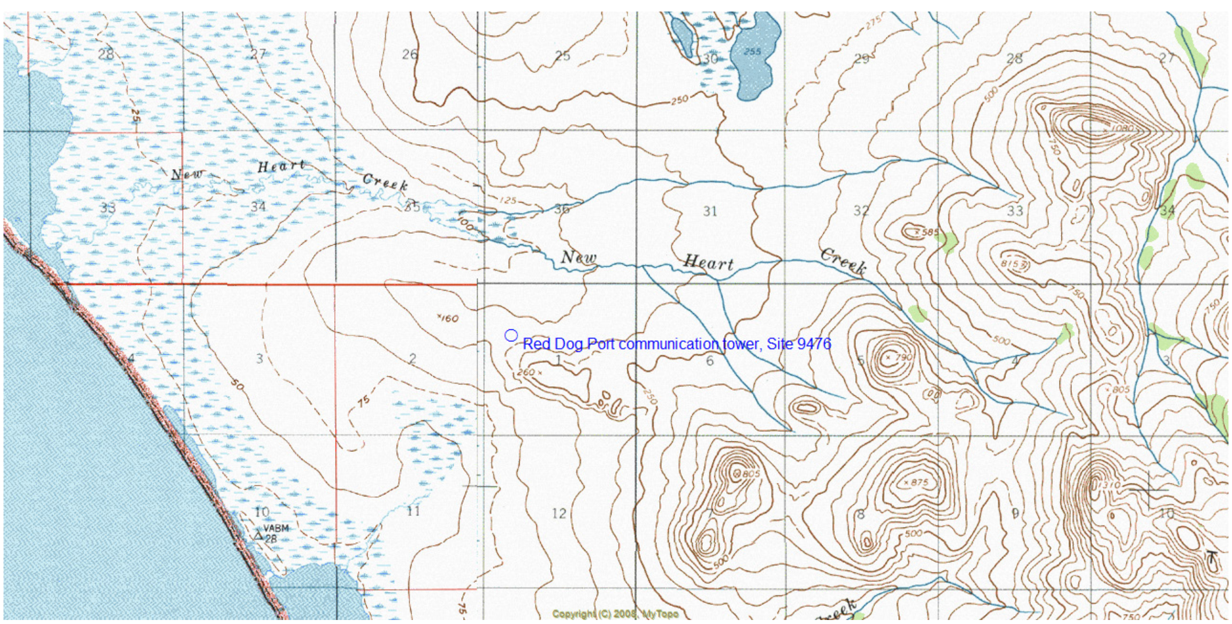
Wind measurement instrumentation was installed on an existing 33 meter Rohn lattice-type communication tower at the Red Dog Port area and approximately three kilometers (two miles) from the Chukchi Sea coast. The tower is located on a small gravel pad immediately adjacent to the haul road which connects Red Dog Mine to Red Dog Port. There is considerable area in the near vicinity of the Port complex to accommodate several or more large turbines.

Site information

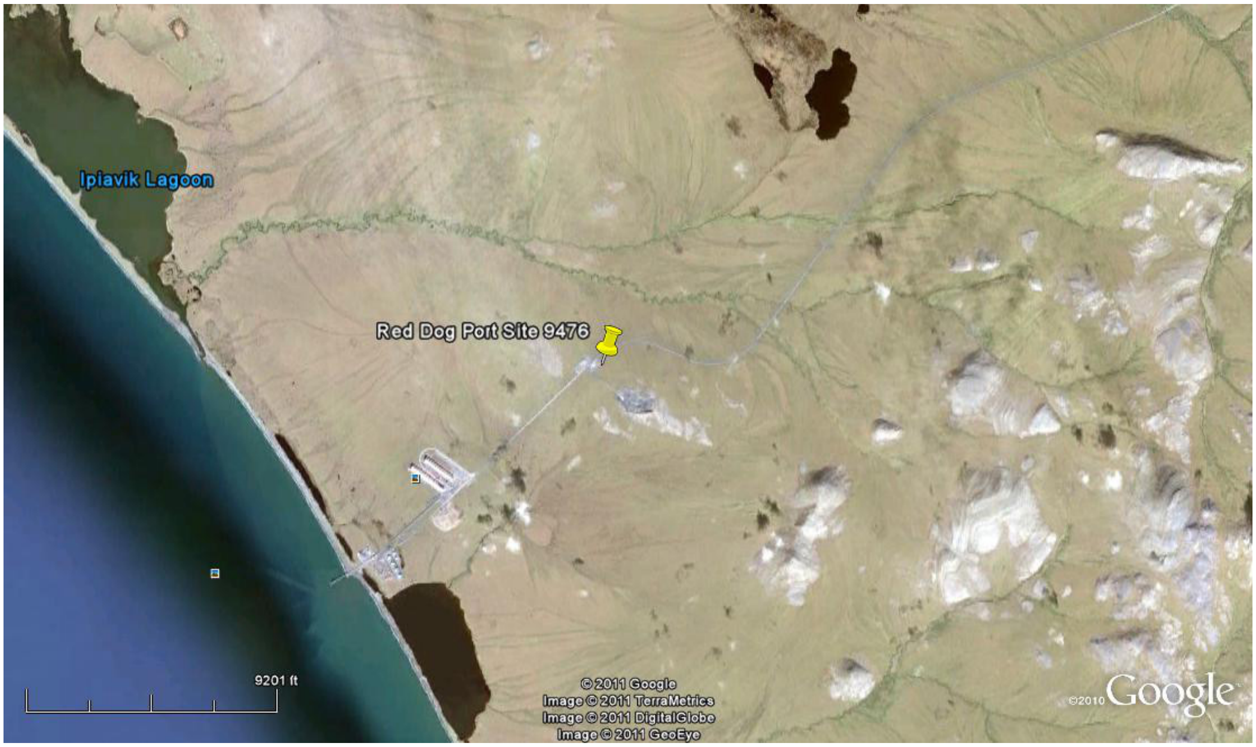
Site number	9476
Latitude/longitude	N 67° 35' 48.90" W 163° 59' 42.10", WGS 84
Site elevation	49 meters (160 ft)
Datalogger type	NRG Symphonie, 10 minute time step
Tower type	Rohn lattice tower, 33 meter height

Topographic maps





Google Earth image



Tower sensor information

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	32.6 m (33 m A)	0.760	0.36	000° T
2	NRG #40 anemometer	32.6 m (33 m B)	0.757	0.41	115° T
3	NRG #40 anemometer	20.7 m (21 m A)	0.761	0.33	000° T
4	NRG #40 anemometer	20.7 m (21 m B)	0.758	0.33	115° T
7	NRG #200P wind vane	29.0 m	0.351	180	000° T
9	NRG #110S Temp C	3 m	0.138	-86.3	N
10	iPack batter voltmeter	n/a	0.021	0	n/a
12	RH-5 relative humidity	2 m	0.098	0	N

Tower sensors photo

Data Quality Control

Data quality is very good with data recovery of all four anemometers greater than 96 percent and data recovery of the wind vane greater than 95 percent. Data loss is limited to winter months only and is attributable to icing events which are characterized by non-variant output of the anemometer at the minimum offset value (essentially zero) and by non-variant output of the direction vane at the last operable direction with temperatures near or less than zero degrees Centigrade and relative humidity at or near 100 percent.

Data recovery summary table

Label	Units	Height	Possible Records	Valid Records	Recovery Rate (%)
Speed 33 m A	m/s	32.6 m	148,962	144,189	96.8
Speed 33 m B	m/s	32.6 m	148,962	143,962	96.6
Speed 21 m A	m/s	20.7 m	148,962	144,176	96.8
Speed 21 m B	m/s	20.7 m	148,962	144,871	97.3
Direction 29 m	°	29 m	148,962	142,369	95.6
Temperature	°C		148,962	148,841	99.9
Voltmeter	volts		148,962	148,841	99.9
RH-5 Humidity %RH	%RH		148,962	148,841	99.9

Anemometer and wind vane data recovery

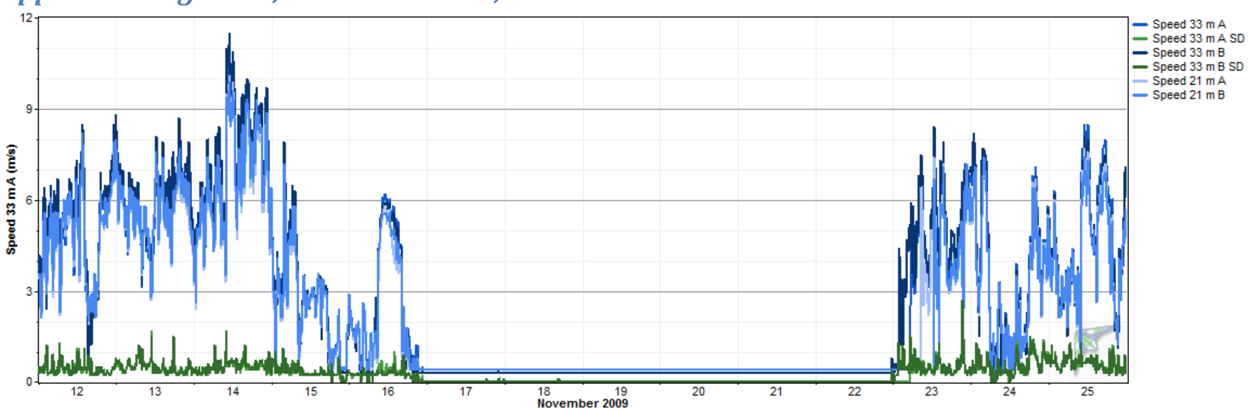
Year	Month	Possible Records	Valid Records	33 m A Recovery Rate (%)	33 m B Recovery Rate (%)	21 m A Recovery Rate (%)	21 m B Recovery Rate (%)	Vane Recovery Rate (%)
2008	Oct	3,168	2,862	90.3	90.3	89.8	90.3	76.3
2008	Nov	4,320	3,553	82.3	83.1	81.8	90.9	87.1
2008	Dec	4,464	4,188	93.8	93.8	93.8	93.8	95.1
2009	Jan	4,464	4,464	100.0	100.0	100.0	100.0	85.3
2009	Feb	4,032	4,032	100.0	100.0	100.0	100.0	100.0
2009	Mar	4,464	4,464	100.0	100.0	100.0	100.0	100.0
2009	Apr	4,320	4,200	97.2	97.2	97.2	97.2	97.2
2009	May	4,464	4,165	93.3	96.8	96.7	97.1	92.2
2009	Jun	4,320	4,320	100.0	100.0	100.0	100.0	100.0
2009	Jul	4,464	4,464	100.0	100.0	100.0	100.0	100.0
2009	Aug	4,464	4,464	100.0	100.0	100.0	100.0	100.0
2009	Sep	4,320	4,320	100.0	100.0	100.0	100.0	100.0
2009	Oct	4,464	4,157	93.1	93.1	93.1	87.4	95.7
2009	Nov	4,320	3,355	77.7	78.3	77.3	76.6	100.0
2009	Dec	4,464	3,981	89.2	89.2	89.2	89.2	100.0
2010	Jan	4,464	4,464	100.0	100.0	100.0	100.0	100.0
2010	Feb	4,032	4,032	100.0	100.0	100.0	100.0	100.0
2010	Mar	4,464	4,464	100.0	91.7	100.0	95.1	100.0
2010	Apr	4,320	4,320	100.0	100.0	100.0	100.0	84.8
2010	May	4,464	4,464	100.0	100.0	100.0	100.0	100.0
2010	Jun	4,320	4,320	100.0	100.0	100.0	100.0	100.0
2010	Jul	4,464	4,464	100.0	100.0	100.0	100.0	100.0
2010	Aug	4,464	4,464	100.0	100.0	100.0	100.0	100.0
2010	Sep	4,320	4,320	100.0	100.0	100.0	100.0	100.0
2010	Oct	4,464	4,464	100.0	100.0	100.0	100.0	100.0
2010	Nov	4,320	3,189	73.8	72.0	71.3	89.1	54.6
2010	Dec	4,464	4,464	100.0	100.0	100.0	100.0	74.7
2011	Jan	4,464	4,464	100.0	100.0	100.0	100.0	100.0
2011	Feb	4,032	4,032	100.0	100.0	100.0	100.0	100.0
2011	Mar	4,464	4,464	100.0	100.0	100.0	100.0	100.0
2011	Apr	4,320	4,320	100.0	100.0	100.0	100.0	100.0
2011	May	4,464	4,345	97.3	97.3	97.3	97.3	100.0
2011	Jun	4,320	4,320	100.0	100.0	100.0	100.0	100.0
2011	Jul	4,464	4,464	100.0	100.0	100.0	100.0	100.0
2011	Aug	1,362	1,362	100.0	100.0	100.0	100.0	100.0
All data		148,962	144,189	96.8	96.6	96.8	97.3	95.6

Icing Event

The Red Dog Port communication tower site is at an elevation of less than 50 meters; hence rime icing is not a concern. But freezing rain and other similar cold climate events do occur on occasion which can compromise anemometer and wind vane data, but are not likely to seriously impede wind turbine operations.

Apparent icing event, November 2009, temp and RH data

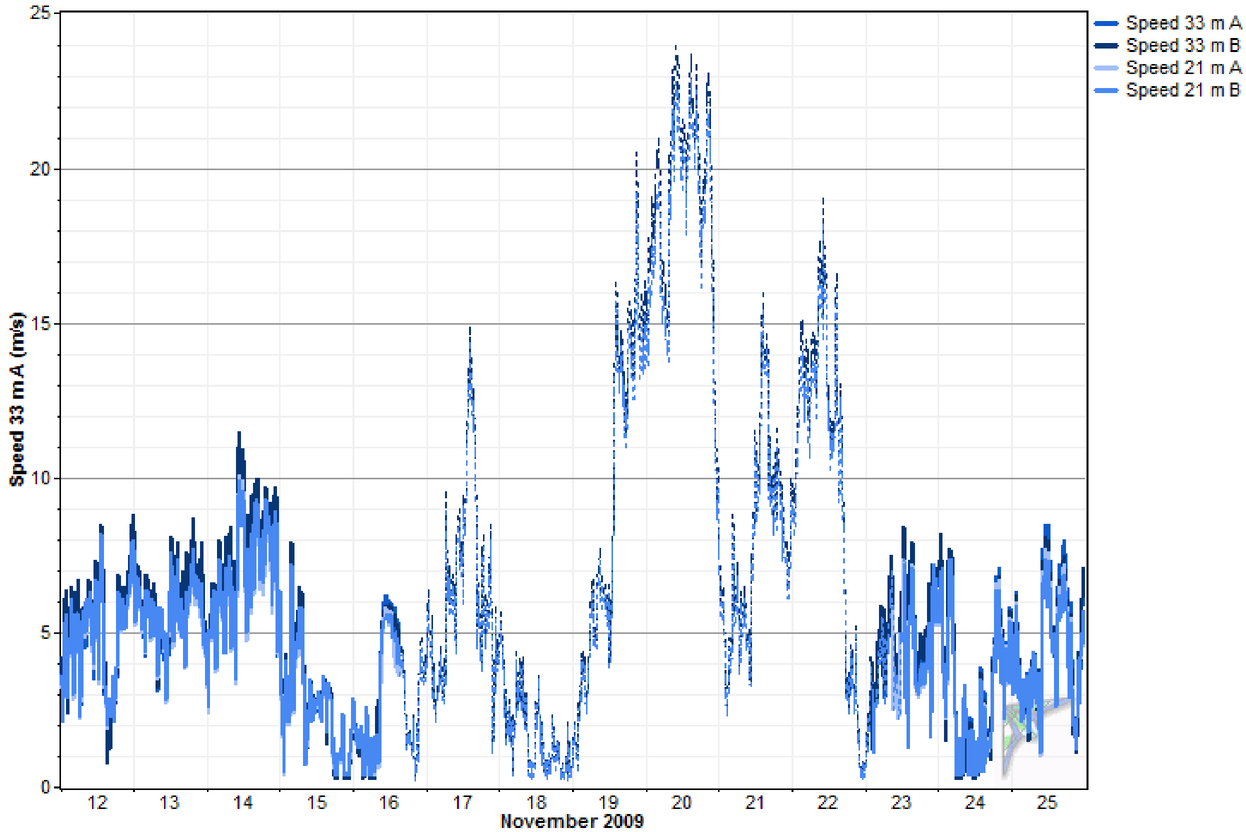
Apparent icing event, November 2009, anemometer data



Data Gap-fill

Although the overall loss of anemometer data due to icing was less than 95 percent, this includes the summer months which naturally do not experience icing conditions. Wintertime icing loss was higher, with data recovery of the anemometers in the 75 to 80 percent range in November 2011. In the quality control process, ice event data is removed from the file to avoid biasing the mean wind speed low (i.e., logging zero wind speed when the wind is likely blowing), but that can create the opposite situation, where the data set bias is high (i.e., no recorded wind speed during the ice periods, leaving just higher wind speeds in the data set). To overcome these errors, a data gap-fill algorithm contained in Windographer software was employed to synthesize missing data and create a statistically truer representation of the Red Dog Port wind resource than the data without the gaps filled. Note: dotted lines below are synthesized data.

Gap-fill of November 2009 icing event



Wind Speed

Anemometer data obtained from the met tower, from the perspectives of both mean wind speed and mean wind power density, indicate an excellent wind resource. Mean wind speeds are greater at higher elevations on the met tower, as one would expect. Note that cold temperatures contributed to a higher wind power density than otherwise might have been expected for the mean wind speeds. Also note, as discussed in the previous section, that anemometer summary information is the table below is *post* gap-fill. None gap-filled mean wind speeds and power densities are slightly higher than below.

Anemometer data summary

Variable	Speed 33 m A	Speed 33 m B	Speed 21 m A	Speed 21 m B
Measurement height (m)	33	33	21	21
Mean wind speed (m/s)	6.06	6.05	5.74	5.71
MMM wind speed (m/s)	6.02	6.02	5.71	5.68
Max 10-min avg wind speed (m/s)	38.5	36.7	36.1	34.4
Max gust wind speed (m/s)	43.5	41.8	42.0	40.5
Weibull k	1.24	1.26	1.28	1.31
Weibull c (m/s)	6.52	6.52	6.22	6.21
Mean power density (W/m²)	596	546	483	449
MMM power density (W/m²)	577	529	467	435

Mean energy content (kWh/m²/yr)	5,223	4,782	4,232	3,935
MMM energy content (kWh/m²/yr)	5,050	4,634	4,093	3,810
Energy pattern factor	4.08	3.75	3.89	3.66
Frequency of calms (%)	44.5	43.3	45.9	44.9
1-hr autocorrelation coefficient	0.945	0.942	0.941	0.940
Diurnal pattern strength	0.046	0.041	0.066	0.062
Hour of peak wind speed	15	15	15	15

MMM = mean of monthly means

Time Series

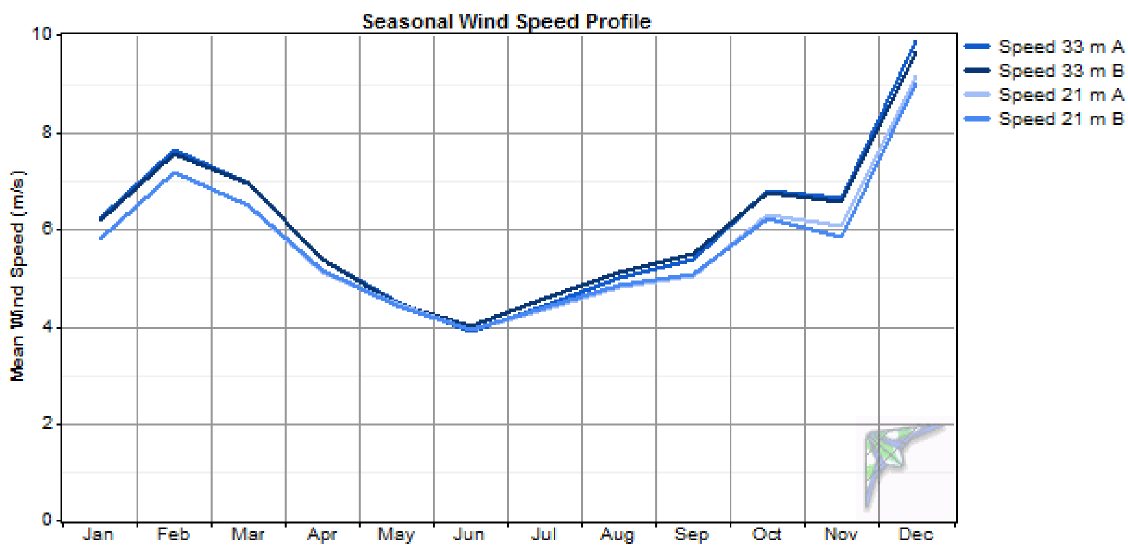
Time series calculations indicate high mean wind speeds during the winter months with more moderate mean wind speeds during summer months. This correlates well with the a typical village load profile where winter months have a high electric and heat demand and summer months a lesser demand. The opposite load profile exists however at Red Dog Port where summer loads are high and winter low.

33 m A anemometer data summary

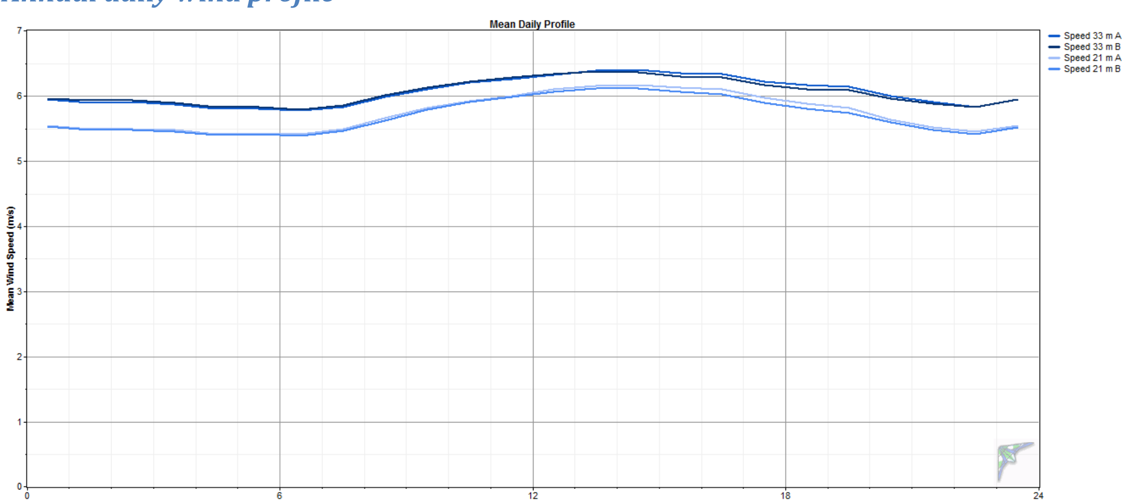
Year	Month	Mean (m/s)	Max (m/s)	Gust (m/s)	Std. Dev. (m/s)	Weibull k (-)	Weibull c (m/s)
2008	Oct	6.89	20.2	23.1	4.59	1.50	7.62
2008	Nov	6.03	18.2	20.4	3.63	1.68	6.74
2008	Dec	11.21	28.9	32.6	7.20	1.45	12.27
2009	Jan	6.18	38.5	43.5	7.11	0.96	6.05
2009	Feb	7.92	30.8	36.7	7.53	0.97	7.83
2009	Mar	9.57	31.5	36.0	6.58	1.42	10.49
2009	Apr	5.91	22.7	28.0	4.96	1.13	6.17
2009	May	4.79	21.0	27.7	3.10	1.63	5.36
2009	Jun	4.12	14.9	19.3	2.56	1.67	4.62
2009	Jul	4.60	18.4	24.6	2.83	1.67	5.15
2009	Aug	5.12	18.1	22.4	3.08	1.70	5.74
2009	Sep	5.10	15.0	17.8	2.70	1.94	5.74
2009	Oct	5.69	21.0	24.6	3.80	1.54	6.33
2009	Nov	5.20	19.1	22.7	3.77	1.37	5.68
2009	Dec	8.52	27.4	32.6	6.55	1.29	9.21
2010	Jan	5.46	23.1	26.1	5.01	1.15	5.75
2010	Feb	5.01	17.1	19.7	3.82	1.27	5.39
2010	Mar	5.25	26.1	30.3	4.97	1.15	5.54
2010	Apr	5.43	27.3	32.1	4.42	1.33	5.94
2010	May	3.62	16.4	19.7	2.52	1.57	4.06
2010	Jun	3.36	13.7	18.9	2.36	1.51	3.74
2010	Jul	4.24	12.7	16.7	2.55	1.73	4.76
2010	Aug	4.71	15.5	21.6	3.11	1.55	5.24
2010	Sep	5.64	18.0	21.2	2.99	1.96	6.35

2010	Oct	7.88	23.1	28.0	4.34	1.87	8.86
2010	Nov	8.14	20.2	25.0	5.24	1.61	9.10
2010	Dec	9.62	28.3	32.1	6.37	1.46	10.57
2011	Jan	7.00	25.9	29.5	6.74	0.97	6.92
2011	Feb	9.93	30.5	34.1	7.56	1.21	10.55
2011	Mar	5.99	25.7	29.1	6.47	0.90	5.69
2011	Apr	4.70	20.3	22.4	3.87	1.21	5.01
2011	May	5.02	19.3	21.9	3.77	1.41	5.54
2011	Jun	4.21	14.9	17.1	2.54	1.73	4.73
2011	Jul	4.47	15.4	21.6	2.72	1.70	5.01
2011	Aug	5.49	13.2	16.7	2.85	1.95	6.15
All data		6.06	38.5	43.5	5.11	1.24	6.52
MMM		6.02					

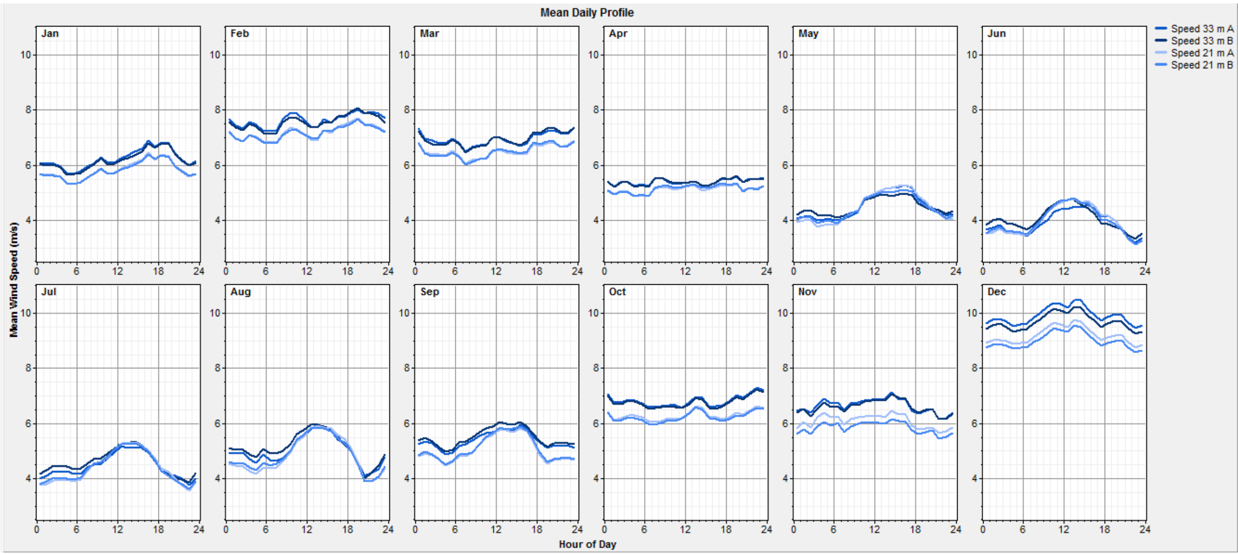
Seasonal time series graph



Annual daily wind profile



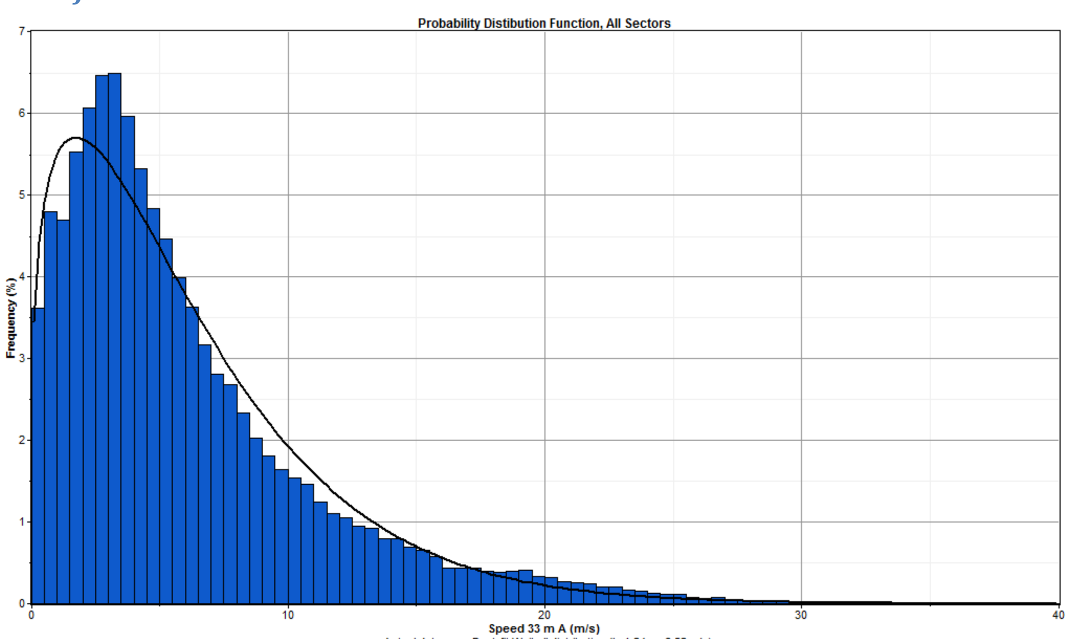
Monthly daily wind profile



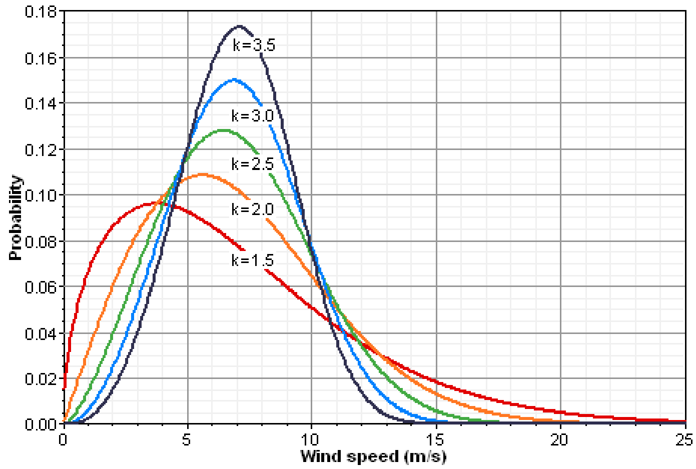
Probability Distribution Function

The probability distribution function (PDF), or histogram, of Red Dog Port wind speed indicates a shape curve dominated by lower wind speeds, as opposed to a "normal" shape curve, known as the Rayleigh distribution (Weibull k = 2.0), which is defined as the standard wind distribution for wind power analysis. As one can see in the PDF of 33 m A anemometer, the most frequently occurring wind speeds are between 2 and 5 m/s with a number of wind events exceeding 25 m/s (the cutout speed of most wind turbines; see following wind speed statistical table). Note also the Weibull k value which describes the Red Dog Port site is unusually low and indicative, as one can see, of a site dominated by calm winds but periodically exposed to high winds.

PDF of 33 m A anemometer



Weibull k shape curve table



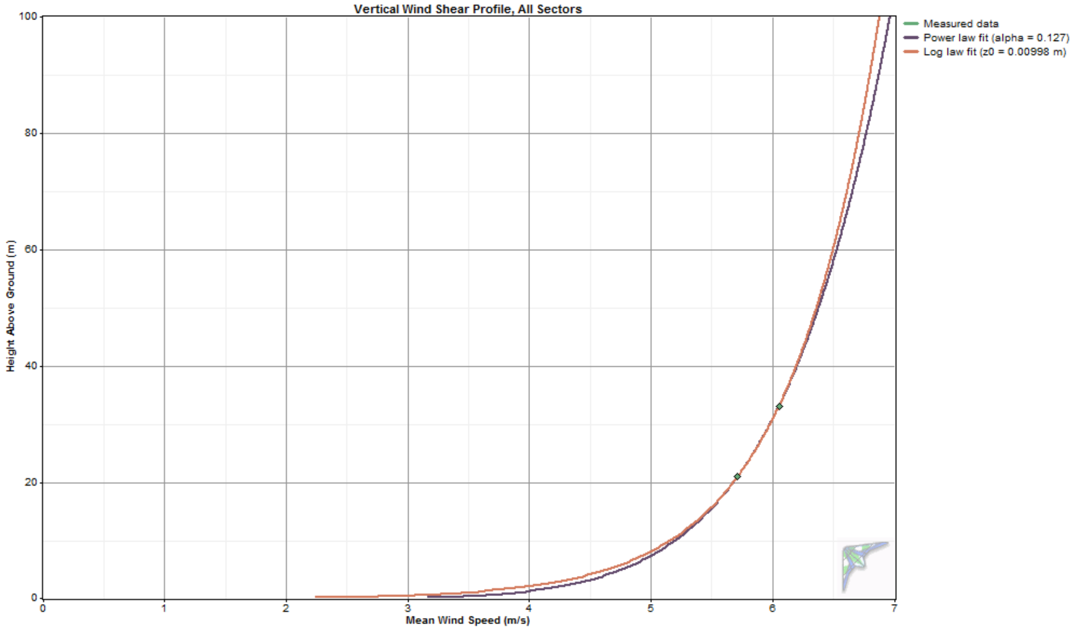
Occurrence by wind speed bin

Bin Endpoints (m/s)		Occurrences		Bin Endpoints (m/s)		Occurrences	
Lower	Upper	No.	Percent	Lower	Upper	No.	Percent
0	1	12,529	8.64%	20	21	878	0.61%
1	2	15,229	10.50%	21	22	733	0.51%
2	3	18,666	12.88%	22	23	610	0.42%
3	4	18,537	12.79%	23	24	482	0.33%
4	5	15,125	10.43%	24	25	374	0.26%
5	6	12,586	8.68%	25	26	290	0.20%
6	7	10,116	6.98%	26	27	202	0.14%
7	8	8,187	5.65%	27	28	141	0.10%
8	9	6,488	4.48%	28	29	88	0.06%
9	10	5,123	3.53%	29	30	76	0.05%
10	11	4,478	3.09%	30	31	47	0.03%
11	12	3,483	2.40%	31	32	23	0.02%
12	13	2,981	2.06%	32	33	12	0.01%
13	14	2,569	1.77%	33	34	11	0.01%
14	15	2,220	1.53%	34	35	9	0.01%
15	16	1,836	1.27%	35	36	2	0.00%
16	17	1,299	0.90%	36	37	3	0.00%
17	18	1,242	0.86%	37	38	3	0.00%
18	19	1,169	0.81%	38	39	2	0.00%
19	20	1,113	0.77%	39	40	0	0.00%

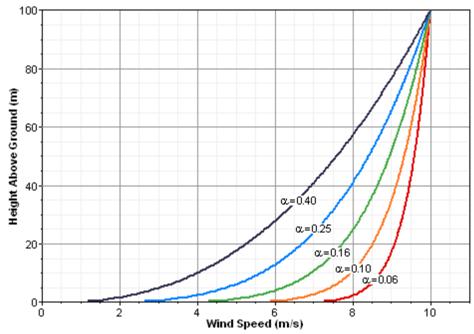
Wind Shear and Roughness

A wind shear power law exponent (α) of 0.127 indicates low to moderate wind shear at the site. Related to wind shear, a calculated surface roughness of 0.0079 meters (indicating the height above ground level where wind velocity would be zero) indicates very smooth terrain (roughness description: lawn grass) surrounding the met tower. These data indicate that it might be possible to construct turbines at a lower hub height for cost saving purposes, yet still obtain high energy production.

Vertical wind shear profile



Comparative wind shear profiles



Extreme Winds

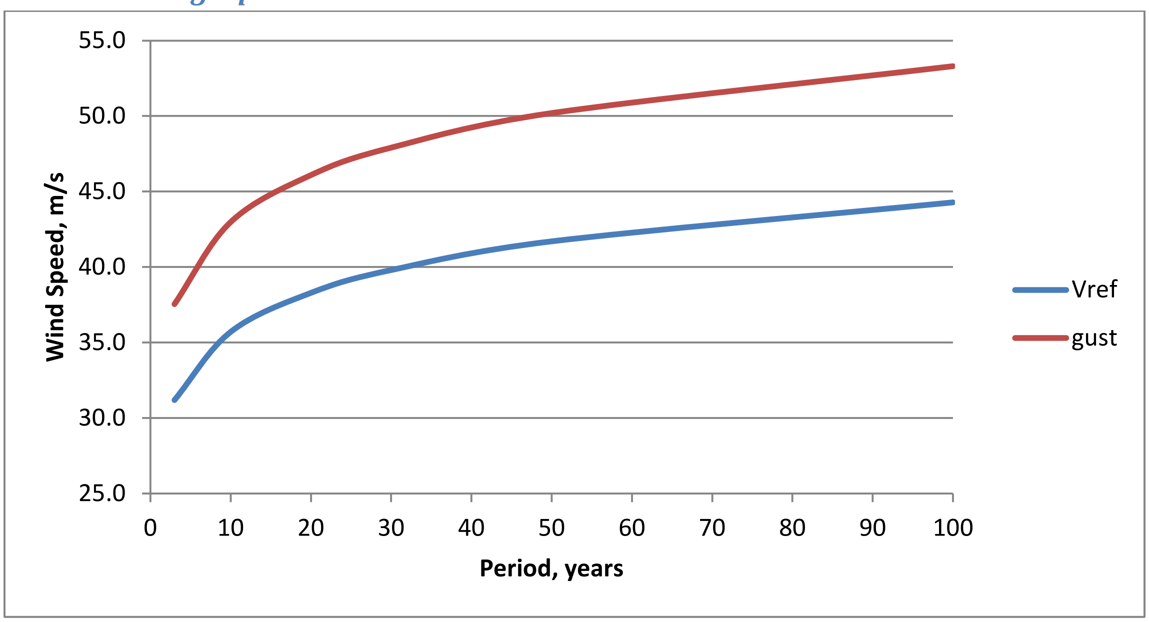
A modified Gumbel distribution analysis, based on monthly maximum winds vice annual maximum winds, was used to predict extreme winds at Red Dog Port. Due to the unusual seasonal variation in wind speeds at the site and in an effort to better match the monthly data Gumbel approach to the annual data approach, a further modification to the analysis was made to exclude May through September data.

Note below that the extreme wind analysis shows relatively energetic extreme winds compared to the measured mean wind speeds. Industry standard reference of extreme wind is the 50 year probable (50 year return period) ten-minute average wind speed, referred to as V_{ref}. For Red Dog Port, with the assumptions noted above, this calculates to 42.4 m/s (at 33 meters), which is on the threshold of International Electrotechnical Commission (IEC) 61400-1, 3rd edition criteria Class I site and possibly should be considered as such. Note that Class I or II extreme wind classifications indicate the possibility of highly energetic wind events. Not all wind turbines are designed for IEC Class I or II winds, so this *must* be considered during turbine selection.

Extreme wind probability table, 33 m A data

Period (years)	V_{ref} (m/s)	Gust (m/s)	IEC 61400-1, 3rd ed. Class	V_{ref}, m/s
3	33.4	38.7	I	50.0
10	37.3	43.2	II	42.5
20	39.5	45.8	III	37.5
30	40.8	47.3	S	designer-specified
50	42.4	49.2		
100	44.6	51.7		
average gust factor:	1.16			

Extreme wind graph



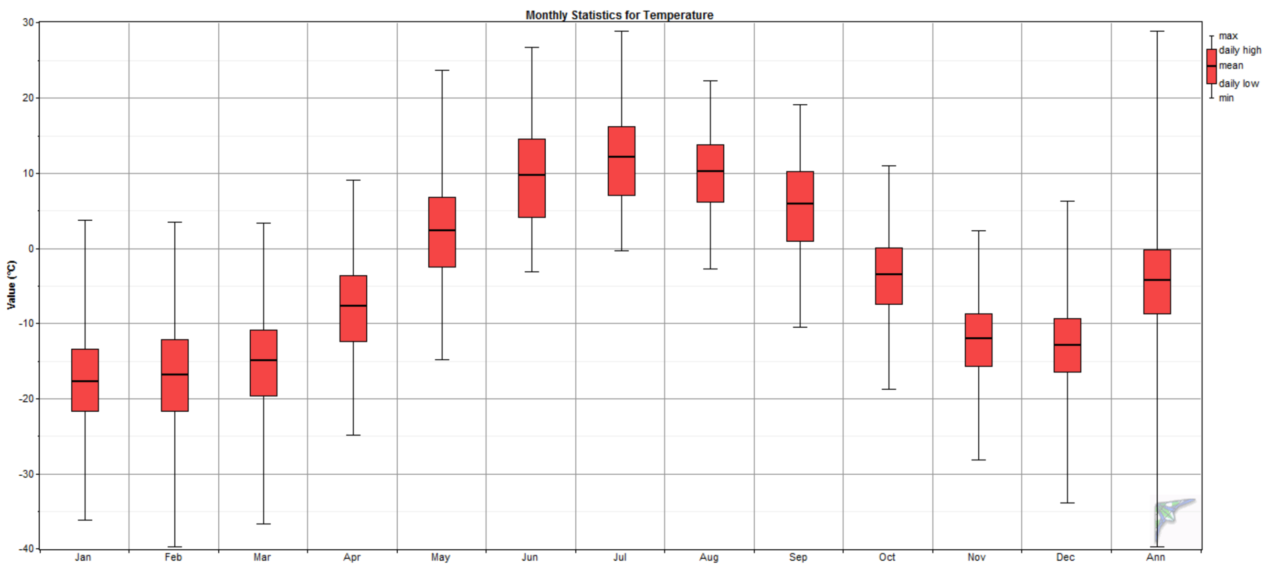
Temperature, Density, and Relative Humidity

The Red Dog Port area experiences cool summers and very cold winters with resulting higher than standard air density. Calculated mean-of-monthly-mean air density during the met tower test period exceeds the 1.219 kg/m^3 standard air density for a 49 meter elevation by 7.0 percent. This is advantageous in wind power operations as wind turbines produce more power at low temperatures (high air density) than at standard temperature and density.

Temperature and density table

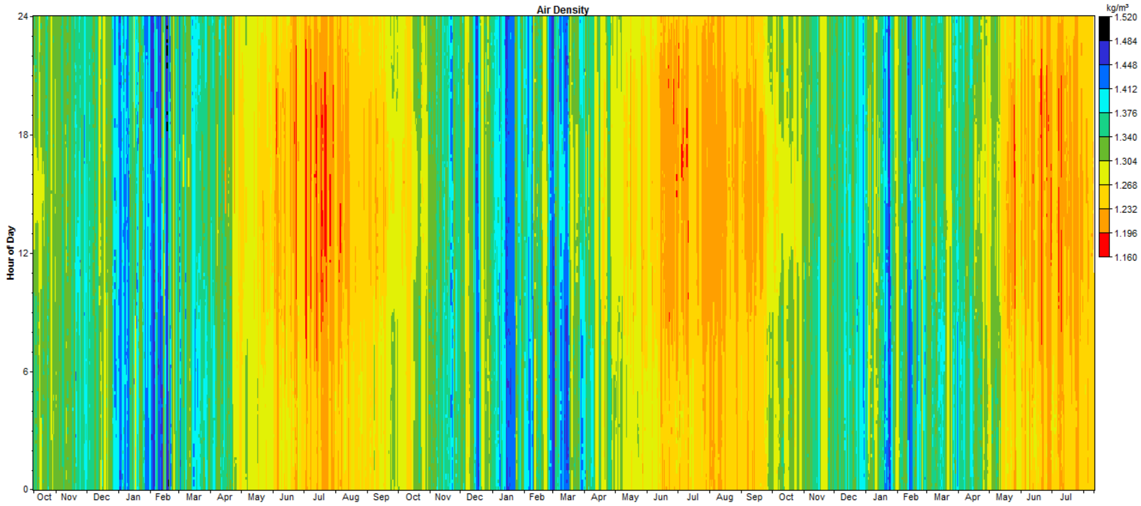
Month	Temperature Mean (°C)	Temperature Min (°C)	Temperature Max (°C)	Air Density Mean (kg/m³)	Air Density Min (kg/m³)	Air Density Max (kg/m³)
Jan	-17.6	-36.2	3.7	1.375	1.267	1.481
Feb	-16.7	-39.8	3.4	1.370	1.269	1.504
Mar	-14.9	-36.7	3.3	1.360	1.269	1.484
Apr	-7.6	-24.9	9.1	1.321	1.219	1.413
May	2.4	-14.9	23.6	1.274	1.182	1.359
Jun	9.9	-3.2	26.7	1.240	1.170	1.300
Jul	12.2	-0.4	28.8	1.230	1.162	1.286
Aug	10.4	-2.8	22.2	1.238	1.188	1.298
Sep	5.9	-10.5	19.1	1.258	1.201	1.336
Oct	-3.4	-18.8	10.9	1.301	1.219	1.379
Nov	-11.9	-28.2	2.3	1.343	1.274	1.432
Dec	-12.8	-33.9	6.3	1.348	1.256	1.466
Annual	-3.6	-39.8	28.8	1.305	1.162	1.504

Annual temperature boxplot



Temperature data, measurement period

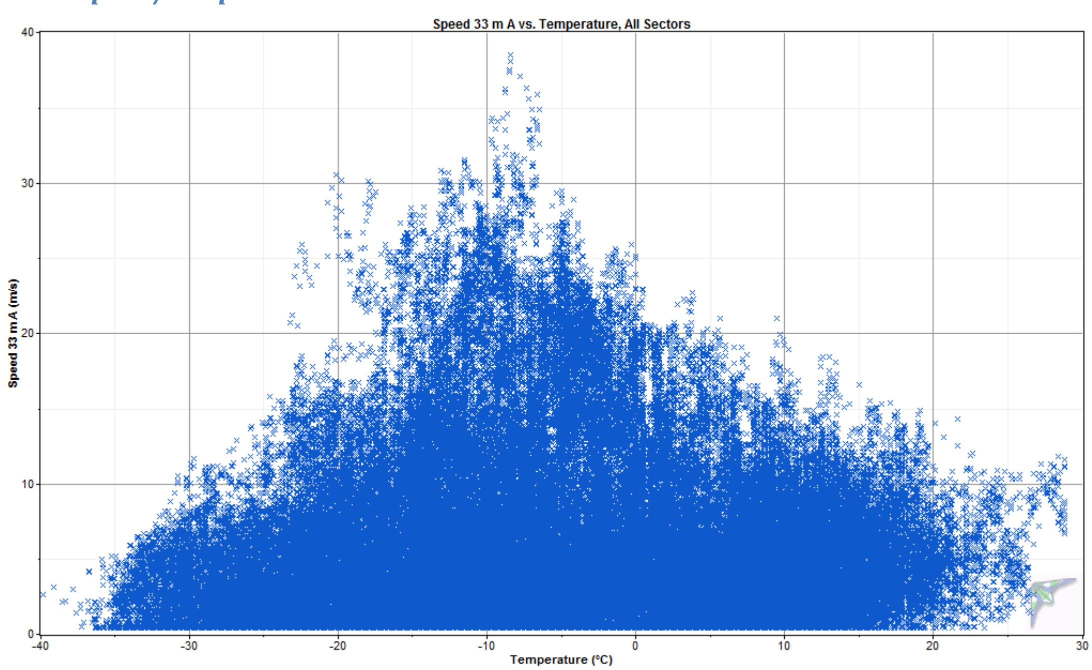
Air density DMap



Wind Speed Scatterplot

The wind speed versus temperature scatterplot below indicates that a substantial percentage of wind at Red Dog Port coincides with cold temperatures, as one would expect. However, during the met tower test periods, temperatures did not fall below -40°C, which is the minimum operating temperature for arctic-capable wind turbines, but did fall below -30°C on a substantial number of occasions, but as one can see, periods of extreme cold are characterized by relatively light winds. Also note that periods of very high winds (wind speeds greater than 30 m/s) are also characterized by cold temperatures, between -5°C and -20°C. Colder temperatures than recorded during the test period may occur during particular severe winters, but it is likely that temperatures colder than -40°C are extremely rare at the site. Hence, restrictions of wind turbine operations due to extreme cold should not be expected.

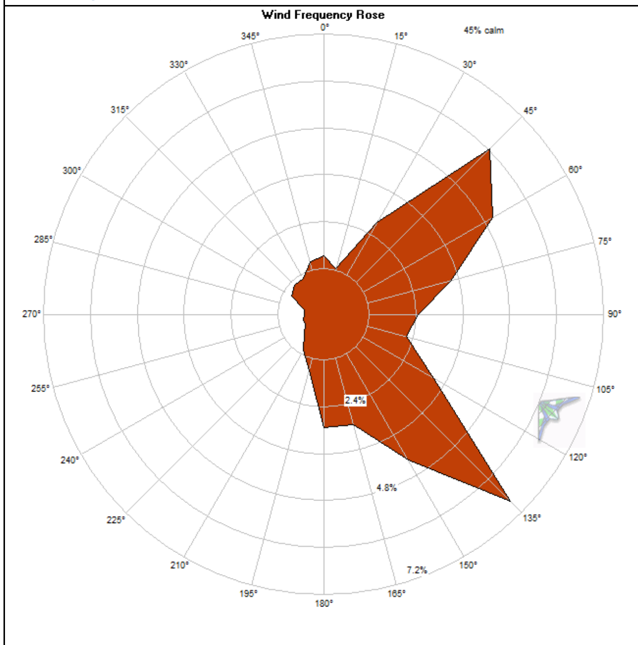
Wind speed/temperature



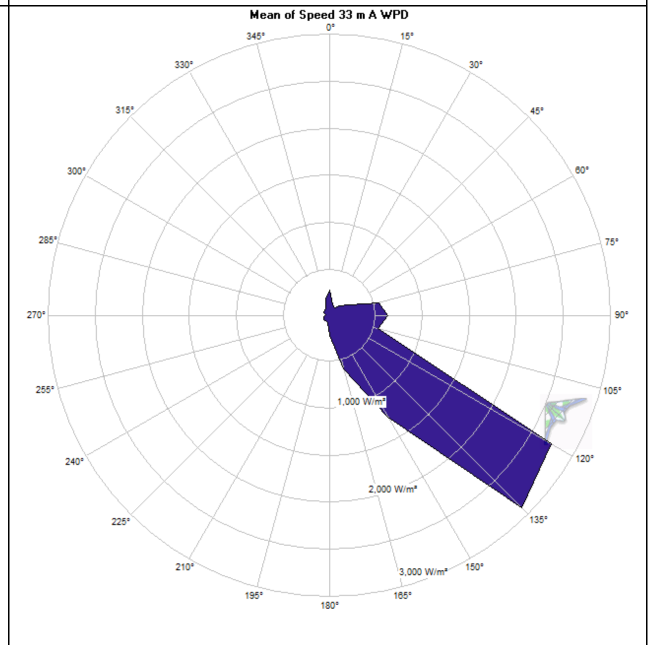
Wind Direction

Wind frequency rose data indicates that winds at Red Dog Port are highly directional, with northeasterly and southeasterly wind predominating. The mean value rose indicates that southeasterly winds, when they do occur, are of high energy and hence likely storm winds. The wind energy rose indicates that for wind turbine operations power-producing winds are very strongly southeastern dominant. Calm frequency (percent of time that winds at the 50 meter level are less than 4 m/s) was a very high 45 percent during the met tower test period.

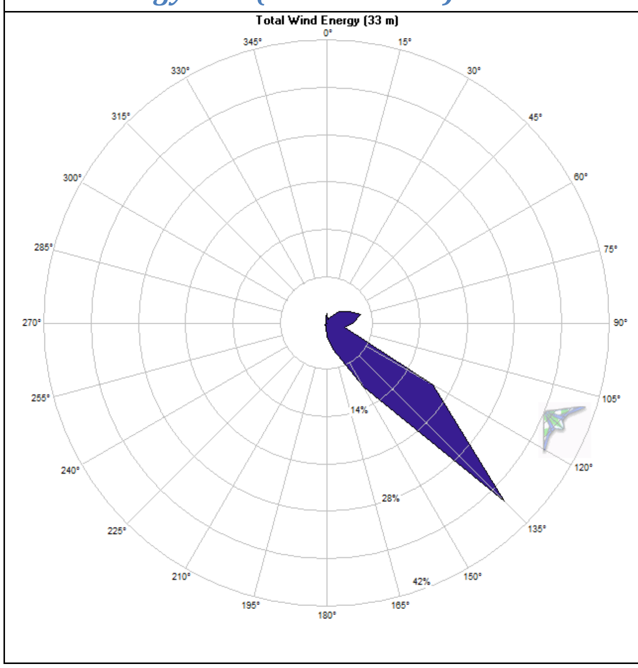
Wind frequency rose



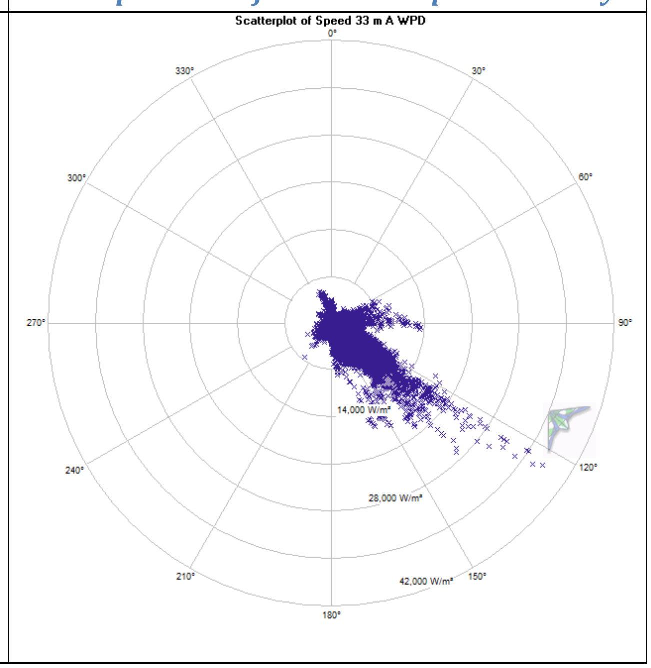
Mean value rose (33 m A anem.)



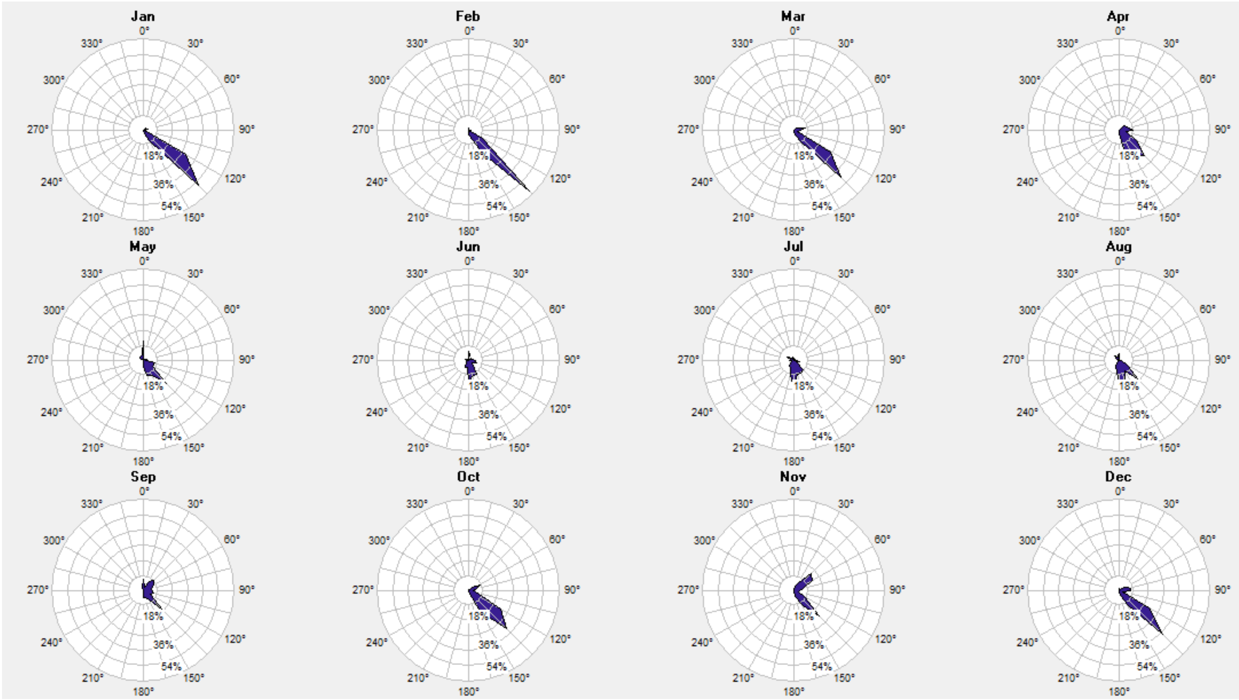
Wind energy rose (33 m A anem.)



Scatterplot rose of 33m A wind power density



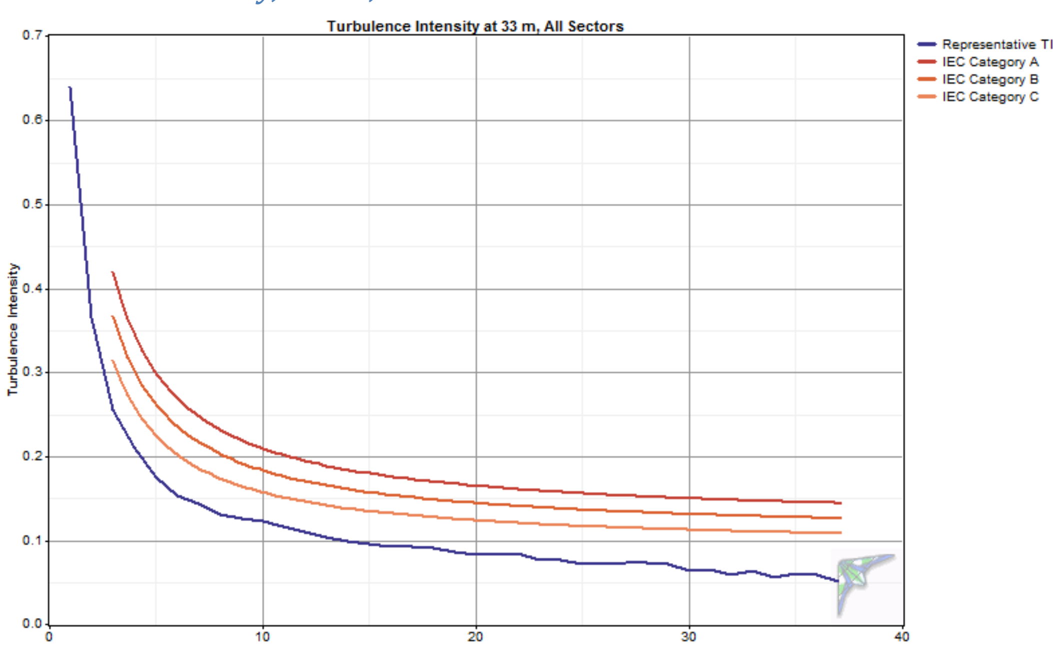
Wind density roses by month (common scale)



Turbulence

Turbulence intensity (TI) at the Red Dog Port test site is well within acceptable standards with an IEC 61400-1, 3rd edition (2005) classification of turbulence category C, which is the lowest defined. The mean TI at 15 m/s is 0.069 and the representative TI at 15 m/s is 0.096, both which can be considered extraordinarily low and hence very desirable for wind turbine operations.

Turbulence intensity, 33m B, all direction sectors



Turbulence table, 33m B data

Bin Endpoints Lower (m/s)	Upper (m/s)	Records in Bin	Mean TI	SD of TI	Representative TI	Peak TI
0.5	1.5	12,626	0.420	0.172	0.640	1.333
1.5	2.5	15,946	0.217	0.116	0.366	1.067
2.5	3.5	17,579	0.152	0.080	0.254	0.840
3.5	4.5	15,929	0.124	0.067	0.210	0.875
4.5	5.5	12,858	0.103	0.057	0.176	0.681
5.5	6.5	11,533	0.092	0.048	0.154	0.691
6.5	7.5	9,401	0.086	0.045	0.144	0.681
7.5	8.5	7,922	0.081	0.038	0.130	0.494
8.5	9.5	6,081	0.080	0.035	0.125	0.418
9.5	10.5	4,894	0.081	0.033	0.123	0.418
10.5	11.5	4,088	0.079	0.029	0.116	0.333
11.5	12.5	3,351	0.076	0.027	0.110	0.271
12.5	13.5	2,826	0.072	0.025	0.104	0.291
13.5	14.5	2,477	0.069	0.023	0.098	0.229
14.5	15.5	1,819	0.069	0.021	0.096	0.243
15.5	16.5	1,575	0.066	0.020	0.092	0.172
16.5	17.5	1,324	0.068	0.019	0.093	0.155
17.5	18.5	1,235	0.066	0.019	0.090	0.167
18.5	19.5	1,072	0.065	0.017	0.087	0.168
19.5	20.5	841	0.063	0.015	0.083	0.150
20.5	21.5	659	0.063	0.016	0.084	0.156
21.5	22.5	574	0.063	0.017	0.085	0.148
22.5	23.5	394	0.060	0.013	0.077	0.123
23.5	24.5	305	0.060	0.013	0.077	0.110
24.5	25.5	217	0.058	0.011	0.073	0.093
25.5	26.5	132	0.059	0.010	0.072	0.089
26.5	27.5	90	0.060	0.010	0.073	0.083
27.5	28.5	68	0.061	0.009	0.073	0.079
28.5	29.5	38	0.058	0.011	0.072	0.093
29.5	30.5	20	0.057	0.006	0.064	0.070
30.5	31.5	9	0.053	0.010	0.066	0.068
31.5	32.5	11	0.049	0.008	0.059	0.060
32.5	33.5	6	0.056	0.007	0.064	0.067
33.5	34.5	3	0.051	0.004	0.057	0.056
34.5	35.5	3	0.054	0.005	0.060	0.058
35.5	36.5	3	0.052	0.005	0.059	0.058
36.5	37.5	1	0.052	0.000	0.052	0.052

Appendix C – FAA Notice Criteria Tool, Wulik River Site

Federal Aviation Administration

« OE/AAA

Notice Criteria Tool

The requirements for filing with the Federal Aviation Administration for proposed structures vary based on a number of factors: height, proximity to an airport, location, and frequencies emitted from the structure, etc. For more details, please reference CFR Title 14 Part 77.9.

You must file with the FAA at least 45 days prior to construction if:

- your structure will exceed 200ft above ground level
- your structure will be in proximity to an airport and will exceed the slope ratio
- your structure involves construction of a traverseway (i.e. highway, railroad, waterway etc...) and once adjusted upward with the appropriate vertical distance would exceed a standard of 77.9(a) or (b)
- your structure will emit frequencies, and does not meet the conditions of the FAA Co-location Policy
- your structure will be in an instrument approach area and might exceed part 77 Subpart C
- your proposed structure will be in proximity to a navigation facility and may impact the assurance of navigation signal reception
- your structure will be on an airport or heliport
- filing has been requested by the FAA

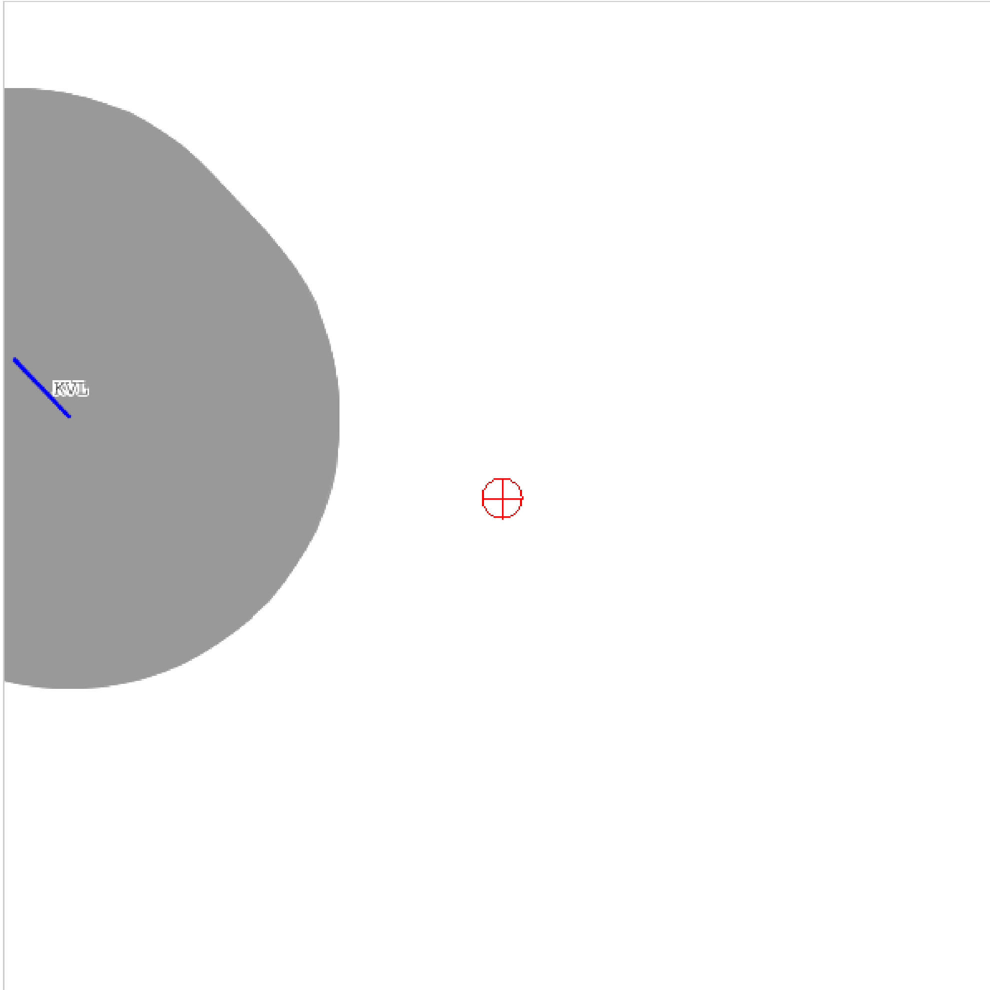
If you require additional information regarding the filing requirements for your structure, please identify and contact the appropriate FAA representative using the Air Traffic Areas of Responsibility map for Off Airport construction, or contact the FAA Airports Region / District Office for On Airport construction.

The tool below will assist in applying Part 77 Notice Criteria.

Latitude:	67 Deg 43 M 29.64 S N
Longitude:	164 Deg 26 M 25.38 S W
Horizontal Datum:	NAD83
Site Elevation (SE):	16 (nearest foot)
Structure Height (AGL):	160 (nearest foot)
Traverseway:	No Traverseway (Additional height is added to certain structures under 77.9(c))
Is structure on airport:	(•) No ( ) Yes

Results

You do not exceed Notice Criteria.


KVL

Appendix D – FAA Notice Criteria Tool, Kisimigiuktuk Hill Site

Federal Aviation Administration

« OE/AAA

Notice Criteria Tool

The requirements for filing with the Federal Aviation Administration for proposed structures vary based on a number of factors: height, proximity to an airport, location, and frequencies emitted from the structure, etc. For more details, please reference CFR Title 14 Part 77.9.

You must file with the FAA at least 45 days prior to construction if:

- your structure will exceed 200ft above ground level
- your structure will be in proximity to an airport and will exceed the slope ratio
- your structure involves construction of a traverseway (i.e. highway, railroad, waterway etc...) and once adjusted upward with the appropriate vertical distance would exceed a standard of 77.9(a) or (b)
- your structure will emit frequencies, and does not meet the conditions of the FAA Co-location Policy
- your structure will be in an instrument approach area and might exceed part 77 Subpart C
- your proposed structure will be in proximity to a navigation facility and may impact the assurance of navigation signal reception
- your structure will be on an airport or heliport
- filing has been requested by the FAA

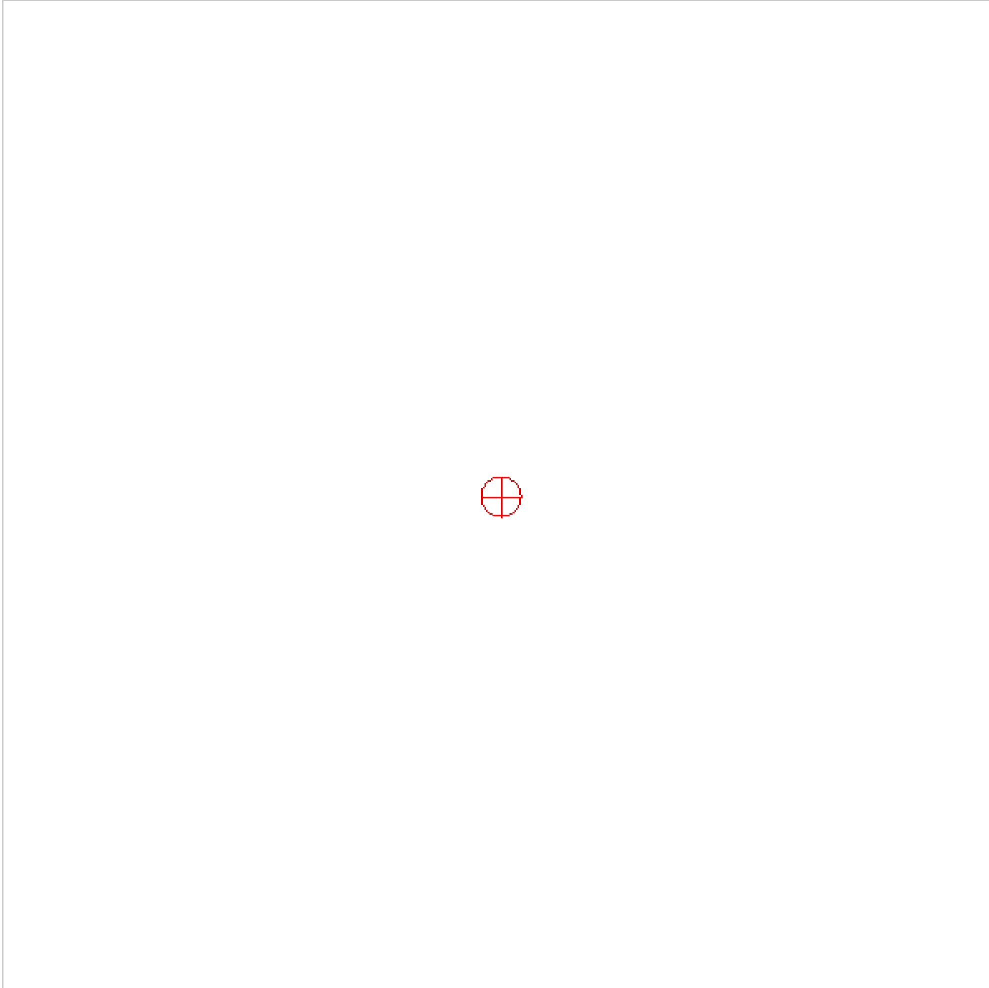
If you require additional information regarding the filing requirements for your structure, please identify and contact the appropriate FAA representative using the Air Traffic Areas of Responsibility map for Off Airport construction, or contact the FAA Airports Region / District Office for On Airport construction.

The tool below will assist in applying Part 77 Notice Criteria.

Latitude:	67 Deg 48 M 48.51 S N
Longitude:	164 Deg 23 M 11.86 S W
Horizontal Datum:	NAD83
Site Elevation (SE):	163 (nearest foot)
Structure Height (AGL):	160 (nearest foot)
Traverseway:	No Traverseway (Additional height is added to certain structures under 77.9(c))
Is structure on airport:	(•) No ( ) Yes

Results

You do not exceed Notice Criteria.



Appendix E – FAA Notice Criteria Tool, Red Dog Port Site

Federal Aviation Administration

« OE/AAA

Notice Criteria Tool

The requirements for filing with the Federal Aviation Administration for proposed structures vary based on a number of factors: height, proximity to an airport, location, and frequencies emitted from the structure, etc. For more details, please reference CFR Title 14 Part 77.9.

You must file with the FAA at least 45 days prior to construction if:

- your structure will exceed 200ft above ground level
- your structure will be in proximity to an airport and will exceed the slope ratio
- your structure involves construction of a traverseway (i.e. highway, railroad, waterway etc...) and once adjusted upward with the appropriate vertical distance would exceed a standard of 77.9(a) or (b)
- your structure will emit frequencies, and does not meet the conditions of the FAA Co-location Policy
- your structure will be in an instrument approach area and might exceed part 77 Subpart C
- your proposed structure will be in proximity to a navigation facility and may impact the assurance of navigation signal reception
- your structure will be on an airport or heliport
- filing has been requested by the FAA

If you require additional information regarding the filing requirements for your structure, please identify and contact the appropriate FAA representative using the Air Traffic Areas of Responsibility map for Off Airport construction, or contact the FAA Airports Region / District Office for On Airport construction.

The tool below will assist in applying Part 77 Notice Criteria.

Latitude:	67 Deg 35 M 49 S N
Longitude:	163 Deg 59 M 42.89 S W
Horizontal Datum:	NAD83
Site Elevation (SE):	163 (nearest foot)
Structure Height (AGL):	335 (nearest foot)
Traverseway:	No Traverseway (Additional height is added to certain structures under 77.9(c))
Is structure on airport:	(●) No ( ) Yes

Results

You exceed the following Notice Criteria:

77.9(a) by 135 ft.

The FAA requests that you file