Buckland Wind-Diesel Hybrid Feasibility Study Report

Final Report

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This report was prepared under contract to WHPacific for a Northwest Arctic Borough project to assess the technical and economic feasibility of installing wind turbines in a wind-diesel hybrid power system design for the village of Buckland, Alaska.

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Executive Summary

Buckland has a well-run powerplant ideally suited for integration of wind turbines and associated control systems, very expensive fuel, and a strong desire to incorporate wind power to reduce their energy costs. Two wind studies have been conducted in Buckland, one near the village and the other in the hills approximately five miles to the west. The wind resource is characterized by a lower wind classification near the village and a moderate wind classification in the west hills. Fortunately with respect to the west hills site area, an existing road to a gravel quarry leads nearly to the site. This wind resource and distance relationship leads to a tradeoff of options – greater distance and higher capital costs but superior wind resource – for wind power development in Buckland.

Wind-diesel configuration options considered in this report are low penetration with minimal wind power input, medium penetration with much higher wind power input but no electrical energy storage, and high penetration with high wind power input and electrical energy storage to draw against during periods of calm winds. An economic analysis of the options concludes that medium to high penetration configurations have positive benefit-to-cost ratios with fuel prices in the medium to high projection range as determined by UAA's Institute for Social and Economic Research in the 2011 Alaska petroleum fuels cost study. Although this study indicates that a near-village site is possibly more advantageous cost-wise, the difference is not dramatic and further study may be necessary, along with community and utility input, to select the final site for construction of wind turbines.

At present, the City of Buckland and Kotzebue Electric Association desire a medium penetration system as this configuration is most common in Alaska and provides an excellent compromise between significant offset of diesel fuel-generated electricity and relatively low system complexity compared to high penetration designs. This report demonstrates, however, that because fuel costs in Buckland are so expensive, a high penetration configuration that maximizes the displacement of diesel fuel for electrical generation is highly beneficial as well.

Introduction

Northwest Alaska is an area with abundant wind energy resources. In 2007, the U.S. Department of Energy's Tribal Energy Program awarded NANA Regional Corporation (NRC) grant #DE-FG36-07GO17076 to fund a Wind Resource Assessment Project (WRAP) for the NANA region. Although a wind study was underway at the time at a site immediately adjacent to the southern border of the village, a new site for a met tower was chosen on the first significant rise above a rock quarry about 4.5 miles west of Buckland. A met tower owned by the Alaska Energy Authority was installed at this location in August 2008 as part of the NANA WRAP study efforts and was removed in May 2011.

In 2009, AEA (with approval from the state legislature) awarded a $10,750,000 Renewable Energy Fund grant to the Northwest Arctic Borough (NWAB) for design and construction of wind-diesel projects in Deering, Buckland, and Noorvik. The feasibility study/conceptual design phase of this grant began in September 2010.

Village of Buckland

Buckland is an Inupiat Eskimo located on the west bank of the Buckland River, about 75 miles southeast of Kotzebue. The village comprises 1.2 square miles of land and 0.2 square miles of water. Buckland is located in the transitional climate zone, which is characterized by long, cold winters and cool summers. The average low temperature during January is -18 °F. The average high during July is 63 °F. Temperature extremes from a low of -60° F to a high of 85 °F have been measured. Annual snowfall averages 40 inches, and total precipitation averages 9 inches per year. Kotzebue Sound is ice-free from early July until mid-October.

Buckland residents have moved from one site to another along the river at least five times in recent memory, to places known as Elephant Point, Old Buckland, and New Site. The presence of many fossil finds at Elephant Point indicates prehistoric occupation of the area. The Inupiat depend on reindeer, beluga whales, and seal for survival. The Buckland city government was incorporated in 1966.

A federally-recognized tribe is located in the community, the Native Village of Buckland. The population of the village is primarily Inupiat Eskimo and subsistence activities are an important focus of the community. The sale and importation of alcohol is banned in the village.

According to Census 2010, there were 101 housing units in the community and 98 were occupied. The population is 95.4 percent Alaska Native, 2.6 percent white, and 1.9 percent of the residents have multi-racial backgrounds.

Residents depend on a subsistence lifestyle for most food sources. Employment is primarily with the school, city, health clinic, and stores. Some mining also occurs. In 2010, one resident held a commercial fishing permit. The community is interested in developing a Native food products and crafts manufacturing facility to produce reindeer sausage, berry products, Labrador tea, and ivory and wood carving.

Water is pumped from the Buckland River, treated in the washeteria building, and stored in a 100,000 gallon tank. Residents haul their own water. The city pumps flush/haul waste tanks or hauls honey buckets to the sewage lagoon. A flush/haul system has been problematic on the south side of town where it will occasionally freeze and fail during winter. Only eight homes and the school have functioning plumbing; 74 homes are not served. Individuals dispose of residential solid waste in dumpsters, which are hauled to the landfill. Electricity is provided by City of Buckland. There is one school located in the community with 164 students. The Tigautchiaq Amainiq Health Clinic in Buckland is the only local healthcare facility.

Potential Alternative Energy Resources

At present, all of Buckland's electrical power is generated with diesel generators, all of its space and water heating (thermal) needs are supplied by heating oil (diesel fuel), and all mechanized transportation powered by diesel or gasoline internal combustion engines, making the village one hundred percent dependent on the import of fossil fuel for its energy supply.

A 1979 study by the U.S. Department of Energy concluded that there are no potential hydroelectric sites near enough to Buckland to develop for village power needs. This conclusion was reaffirmed with the NANA Strategic Energy Plan in 2008, which also discounted the possibility of geothermal energy for Buckland because the nearest hot springs are located 45 miles south at Granite Mountain.

Solar energy would not be practical for utility-scale power/heat generation in Buckland due to the high cost of installing solar PV/thermal panels and little or no solar resource during winter, the time of year with peak electrical and heat demand. However, solar PV/thermal may be a feasible energy source for end-user (residential and light commercial) efficiency improvement.

Electrical intertie with another village, although possible, is thought at present impractical as the nearest community, Deering, is approximately 50 miles distant across both high ridges and bottomland, making an intertie very complicated and expensive to construct.

A coal resource is located 40 miles west of Buckland Chicago Creek, but several studies have indicated that the resource would be very costly to develop and it would not be economically viable at a small scale.

Wind energy has therefore been identified as the only viable renewable energy resource available for Buckland. The wind resource data collected from 2005 to 2008 near the village and from 2008 to 2010 at the hills west of Buckland indicate that wind power for the community is possible.

Buckland's Electric Power System

Electric power (comprised of the diesel power plant and the power distribution system) is provided by the City of Buckland, which acts as its own utility, although in that capacity it receives support under contract from Kotzebue Electric Association. The power plant is relatively new and by all indications is well managed and operated. At this time there are no identified operational issues that would hinder or argue against development of wind power for the community.

The power plant is adjacent to the water treatment plant and washeteria facility which are connected to the plant via the recovered heat system. The power plant was constructed in 2007 to replace an outdated power plant. Two large diesel generators and one smaller diesel generator are installed as prime units, although at present the smaller Caterpillar C-9 generator is not used often due to an unresolved software problem in the supervisory controller.

The power plant, designed by the Alaska Energy Authority, incorporates switchgear manufactured by Controlled Power, Inc. that is intended to be adaptable to wind power integration. An Allen-Bradley programmable logic controller (PLC) functions as the supervisory controller and is designed to automate operation of the power plant, including dispatch of the appropriate available diesel generator based on load demand.

The village-wide electrical distribution system consists of two three-phase feeders: one labeled "east" and the other labeled "west".

The Alaska Energy Authority's statistical reports of the Power Cost Equalization (PCE) program are an excellent resource for basic power plant operational data. Information for the Buckland utility in the FY2010 and FY2009 reports appears to be in error, so with reference to the FY2008 PCE statistical report, the Buckland power plant burned 148,600 gallons of diesel fuel in FY2008 to generate 1,546 MWh of electricity. This equates to a 176 kW average load and an average fuel efficiency of 10.4 kWh/gallon. The reported cost of fuel in the FY2010 PCE statistical report was $6.53/gallon ($1.72/liter).

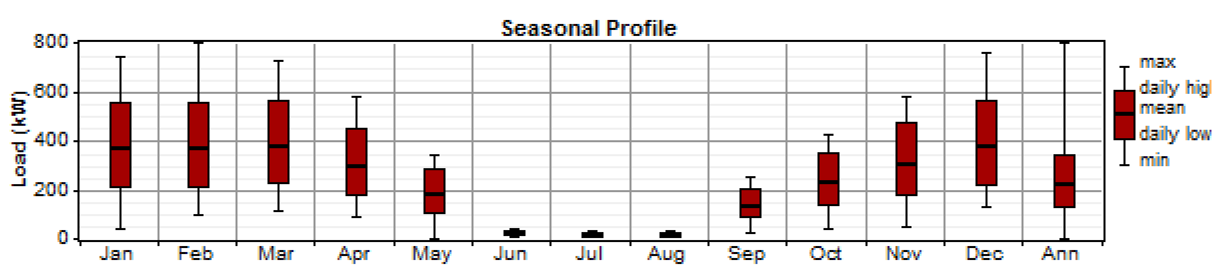
Buckland powerplant diesel generators

Generator	Capacity	Diesel Engine Model, Serial No.	Generator Model, Serial No.
1	475 kW	Caterpillar 3456	
2	475 kW	Caterpillar 3456	
3	175 kW	Caterpillar C-9, C9J00154	

Heat Demand

Heating oil (diesel fuel) is the primary source of energy for space and water heating in Buckland. In general, Buckland consumes more diesel fuel oil for thermal (space and water heating) needs than for electric power generation. Although discussed in greater detail later in this study, below is the Buckland thermal load profile (data from Alaska Energy Authority).

Buckland thermal load serviced by recovered heat



Wind Power System Configurations and Equipment

Wind-diesel power systems are categorized based on their average energy penetration levels, or the proportion of wind-produced electric energy (in kWh) generated compared to the total amount of electric energy (in kWh) supplied by the system. Commonly used categories of wind-diesel penetration levels are low, medium, and high (diesels-off capable), as summarized in Table 5. The average wind penetration level is roughly equivalent to the overall amount of diesel fuel saved. In general, the higher the level of wind penetration that the system is designed for, the more complex and expensive a control system and demand-management strategy is required. One should keep in mind though a distinction between instantaneous wind penetration, which is wind-supplied power (in kW) compared to system power (in kW) at any moment. Average penetration, as referenced above, is wind-supplied energy (in kWh) compared to system-supplied energy (in kWh) over a specified period of time, typically one year.

Choosing the ideal wind penetration for a community depends on a number of factors, including technical capability and experience of the utility and its employees, load profile of the community, wind resource, construction challenges, cost, etc. There is no one "right" answer and the most optimal wind-diesel system for a village may not be always be one that displaces the most fuel, nor even one that has the highest estimated benefit-to-cost ratio.

Categories of wind-diesel penetration levels

Penetration Category	Penetration Level		Operating characteristics and system requirements
	Instantaneous power (kW)	Average energy (kWh)	
Low	0% to 50%	Less than 20%	Diesel generator(s) run full time at greater than recommended minimum loading level. Requires minimal changes to existing diesel control system. All wind energy generated supplies the primary load.
Medium	0% to 100+%	20% to 50%	Diesel generator(s) run full time at greater than manufacturer's recommended minimum loading level. Requires new control system with automation of set-point control, and a secondary load such as an electric boiler. At high wind power levels, secondary (thermal) loads are dispatched to absorb energy not used by the primary (electric) load, or alternatively, wind generation is curtailed.
High (Diesels-off Capable)	0% to 150+%	Greater than 50%	Diesel generator(s) can be turned off during periods of high wind power levels. Requires sophisticated new control system, significant wind turbine capacity, a secondary load, and additional components (including demand-managed devices and more advanced controls to regulate grid voltage and frequency). At high wind power levels, secondary loads and/or demand-managed devices are dispatched to absorb energy not used by the primary load.

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.

Battery storage is a well-proven technology and has been used in Alaskan power systems including Fairbanks (Golden Valley Electric Association), Wales and Kokhanok. Kotzebue Electric Association will be installing an innovative 500 kW battery storage system in 2011.

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 between 5 and 15 minutes. Storage for several hours or days is also possible with batteries, but requires more capacity and higher 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 hence expensive to transport to the site, and many contain toxic material that requires disposal as hazardous waste at the end of a battery's useful life.

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 480 volts. Individual battery voltage on a large scale system is typically 1.2 VDC. Recent advances in power electronics have made solid state converter (inverter/rectifier) systems cost effective and hence the preferable power conversion device. The Kokhanok wind-diesel hybrid system is designed with a 300 VDC battery bank coupled to a "grid-forming" converter for production of utility-grade real and reactive power. The solid state converter system in Kokhanok will be commissioned in the spring of 2011 and will be monitored for reliability and effectiveness.

Wind-diesel Integration Controls

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. This is accomplished with a master controller, also referred to as a supervisory controller. The existing Allen-Bradley PLC likely can be modified for this purpose. If not, a new supervisory controller will be installed and will replace all functions presently controlled by the Allen-Bradley PLC. The supervisory controller would select the optimum system configuration based on village load (demand) and available wind power.

Two examples of a wind-diesel system supervisory controller are the Powercorp control system and the Sustainable Automation control system. Both are pre-configured to operate with multiple diesel gen-sets, wind systems, and demand-managed devices.

The Powercorp system is broken into several layers of operation, with each controller device in communication with the others:

- Station Controller: schedules each of the lower units, performs remote control functions and stores collected system data
- Generation Controller: monitors and controls a single diesel generator
- Demand Controller: monitors, controls, and schedules demand-managed devices such as a synchronous condenser or electric boiler, to insure that sufficient generation capacity is online.

- Feeder Monitor: monitors vital statistics of the distribution feeder, including ground fault information
- Wind Turbine Controller: monitors the wind turbine it is connected to, and dispatches wind turbines depending on the wind-diesel's system's overall load, and the availability of wind energy.

The Sustainable Automation control system uses many similar components as the Powercorp system. Functions of the Sustainable Automation Hybrid Power System Supervisory Controller include:

- Diesel dispatch: starting and stopping the diesel generator(s) according to the diesel capacity required
- Wind turbine dispatch: allow/inhibit wind turbine operation as necessary
- Secondary load dispatch: determining the required amount of power sent to the secondary load at any given instant
- Diesel status monitoring
- Wind turbine status monitoring
- Performance data logging: kWh and run-time totals, alarms, etc., fault detection and annunciation, and provide for remote access via dialup or internet connection

Several Alaskan electrical engineering and construction firms have also been involved with wind-diesel power systems, including Electric Power Systems of Anchorage who has been working with Kotzebue Electric Association on their large wind diesel project and with Cordova electric on a hydro-diesel project and Marsh Creek, LLC of Anchorage who designed and developed with Kokhanok wind-diesel project.

Wind Project Sites

Buckland has two wind power site options to consider: one at (or close to) sea level generally near the village (the general area of the original met tower study, Site 5062), and the other at 540 ft. (165 m) elevation on the first major rise of the west hills approximately five miles (8 km) west of the village (the site of the second met tower study, Site 5063).

The village wind power site would not need to be exactly at the location of the Site 5062 met tower study on the south side of the village, but likely would be located somewhat near the village as, given the topography of the landscape, there does not appear to be a significant increase in wind resource potential until one is at the west hills site (met tower Site 5063). A village-location wind power site south of the runway center, near what appears to be a construction staging area or possibly the village landfill, appears to be a good location to consider.

The west hills site is defined by the location of the Site 5063 met tower, which is immediately west of and above a borrow pit on the west end of a 4.5 mile (7.3 km) access road that crosses the marshy terrain of the Buckland River valley. The Site 5063 met tower was located on the easternmost high point flat enough to accommodate two or more wind turbines. This site is very well exposed to northerly, easterly and southerly winds, and relatively exposed as well to westerly winds. The west hills met tower site is at 540 ft. (165 m) elevation. Moving west about one mile (1.6 km) from the site, a ridge connects to a 727 ft. (222 m) elevation hill that could accommodate wind turbines. Beyond that in a westerly direction, it is an additional one mile (1.6 km) to a higher and much broader ridge line.

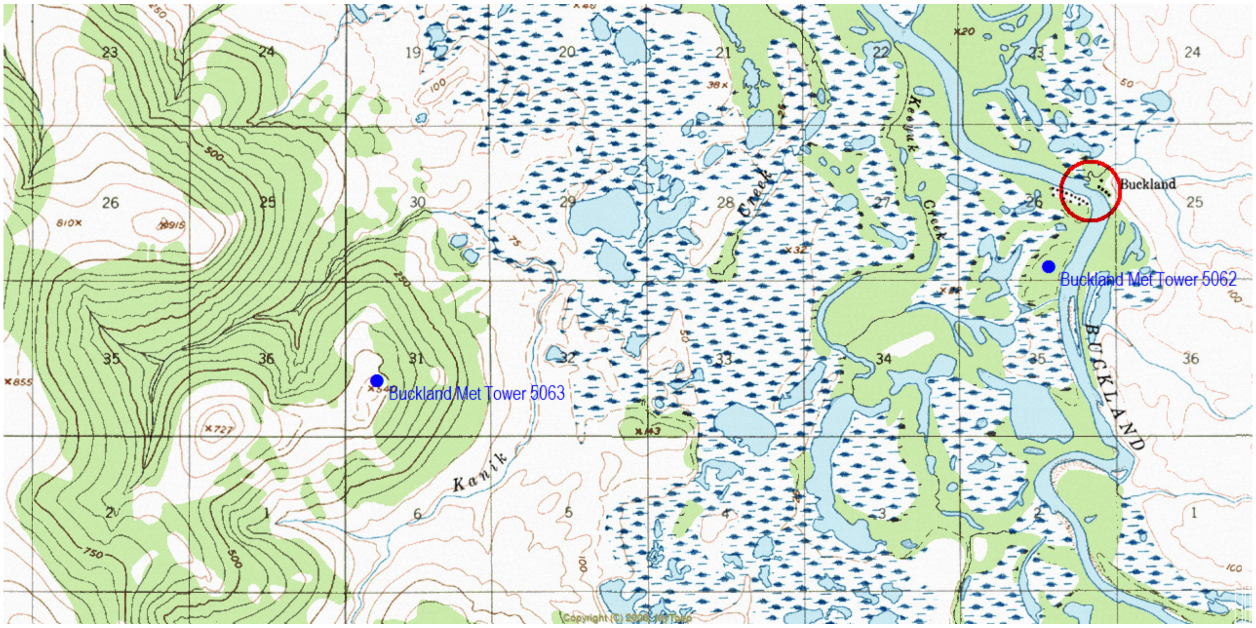
Buckland met tower sites

Buckland village site

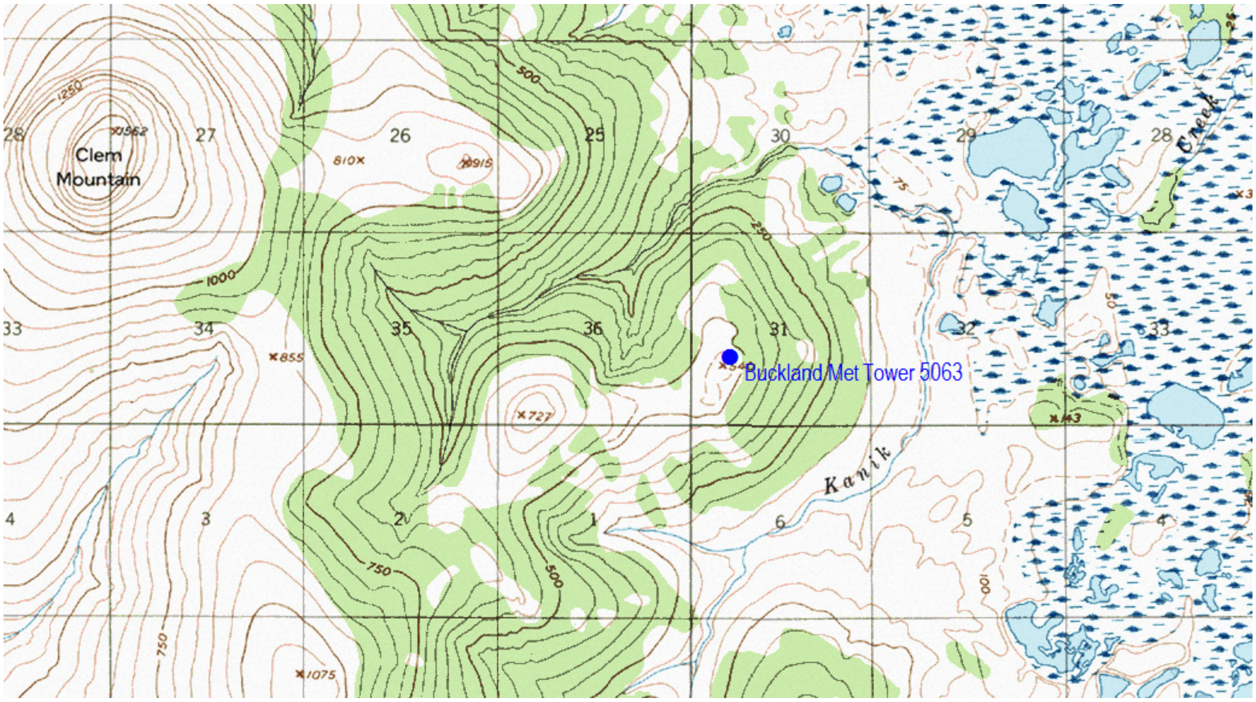
West hills site

West hills site, oblique view

Topographic map of wind power sites



West hills site topographic map



Wind Resource

Note that there are two wind resources to consider in Buckland: the first near the village and measured by a met tower operational from 2005 to 2007 and the second in the west hills and measured by a met tower operational from 2008 to 2011.

Village Site

The wind resource at the Buckland village area Site 5062 met tower site is documented by a V3 Energy LLC report entitled *Buckland, Alaska Wind Resource Report*, which is attached in Appendix A. As a brief summary, the site classifies as wind power class 2 (marginal) with a mean annual wind speed of 4.60 m/s and a mean annual wind power density of 177 W/m^2 (at 30 meters elevation). The site experiences low turbulence and wind shear conditions and classifies as International Electrotechnical Commission (IEC) 61400-1, 3rd edition class III-c.

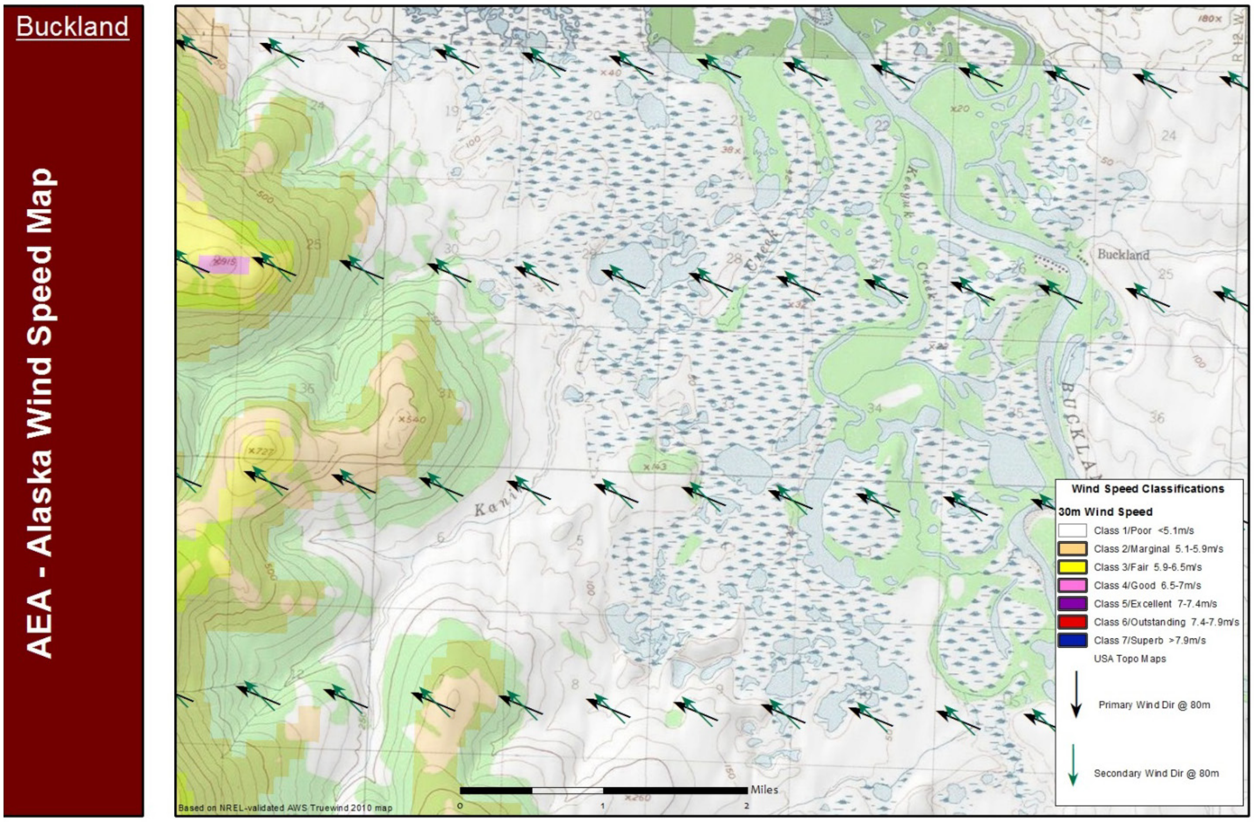
West Hills Site

The wind resource at the Buckland west hills Site 5063 met tower site is documented by a V3 Energy LLC report entitled *Buckland Wind Resource Report*, which is attached in Appendix B. As a brief summary, the site classifies as mid-wind power class 3 (fair) with a mean annual wind speed of 5.58 m/s and a mean annual wind power density of 302 W/m^2 (at 30 meters elevation). The site experiences low turbulence and wind shear conditions and classifies as IEC 61400-1, 3rd edition class II-c.

Wind Modeling

Wind map modeling (NREL-validated AWS Truewind) confirms met tower data collected at the village and west hills sites, although possibly one wind class less than actual. The wind model, as shown below, suggests that marginal winds exist on the valley floor, than increase significantly with elevation at the west hills met tower site and higher. Anecdotal evidence suggests that several mounds or high points on the valley floor experience wintertime wind scouring and drifting that may indicate a higher-than-expected wind resource, but AWS Truewind modeling does not flag those locations as notable.

AWS Truewind Map



Development of a Village Site

Installation of wind turbines at a village site will require consultation with FAA, geotech consultants, and landowners to identify an optimal location that is available for use, has relatively good foundation potential, and does not interfere with flight operations at the airport. As previously mentioned, a site south of the runway center may present fewer concerns to FAA.

Presuming that an acceptable site can be identified near the village, it is likely that a short access road will be required with a distribution line extension to service the site.

Village Site Geotechnical Considerations

The open terrain surrounding Buckland is overlain, except where disturbed by development, an intact, insulating cover of tundra vegetation. By all visual indications and with reference to prior geotechnical studies for past construction projects in Buckland, these tundra areas are underlain by continuous permafrost.

Development of the West Hills Site

Installation of wind turbines at the west hills site presents a greater access and development challenge. The road at present terminates at the borrow pit and transitions to an ATV trail to reach the Site 5063 met tower site. This trail would require significant improvement to accommodate construction equipment necessary to erect wind turbines at the site.

Development of the west hills site will require extension of the Buckland power distribution system to the site. At present power distribution extends no further than the start of the quarry access road. The line extension will be approximately 4.5 miles long, three-phase, and presumably can follow the existing road for ease of construction.

West Hills Site Geotechnical Considerations

Geotechnical conditions at the west hills site are considerably different than the permafrost-underlain tundra at and near the village. The surface of the west hills site consists of gravel, sand, some soil and vegetation, with occasional rock outcroppings in places. Permafrost is not likely and was not encountered during installation of anchors for the met tower. A key consideration is depth to bedrock at the met tower site and other sites on the ridge which possibly might host wind turbines.

Preliminary Geotechnical Review

During the design phase of the project the NWAB team will sub-contract with a geotechnical engineering company to conduct a geotechnical analysis of the preferred turbine site(s) and a review of the aggregate supply available in Buckland. The analysis will include a survey of known geotechnical conditions in Buckland and possibly on-site drilling to determine precise conditions required to support foundation design. A reconnaissance of concrete aggregate sources will be conducted and will include a review of available pit documentation resources, but presumably the borrow pit at the terminus of the road leading to the west hills met tower site will be the primary source of aggregate for a wind power construction project.

Environmental Review

The environmental permitting steps 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.

Alaska Pollution Discharge Elimination System

State regulations (18 AAC 83) require that all discharges, including storm water runoff, to surface waters be permitted under the Alaska Pollutant Discharge Elimination System (APDES) permit program. This program aims to reduce or eliminate storm water runoff that might contain pollutants or sediments from a project site during construction. The construction in Buckland of one or more wind turbines, and the possible construction of a connecting access road and power line, would likely disturb one acre or more of soil, and thus must be permitted under the State of Alaska's Construction General Permit (CGP) and an accompanying Storm Water Pollution Prevention Plan (SWPPP) must be written. The construction contractor must submit a Notice of Intent (NOI) to Alaska Department of Environmental

Conservation (DEC) before submitting a SWPPP. The DEC issues the final APDES permit for the project after a public comment period and their review.

U.S. Fish and Wildlife Service

Several of the fourteen species on the Threatened and Endangered Species List for Alaska are known to inhabit or visit the broader Buckland area. This includes the polar bear, the short tailed albatross, king and spectacled eiders, the Eskimo curlew, the Kittlitz's murrelet, and three species of whale. A discussion with the U.S. Fish and Wildlife Service (USFWS) will be initiated and at a minimum, a letter and a map sent requesting their opinion regarding level of consultation needed to proceed with construction of the project.

USFWS regulations and guidance under the Migratory Bird Treaty Act 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 Seward Peninsula, which includes Buckland, is May 20 to July 20. For black scoter habitat the window is May 20 to August 10. Clearing before or after these dates is allowed. If clearing has already taken place before the bird window, construction may proceed during the window.

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 Guidelines* and will be referred to during design and construction of a wind turbine project in Buckland.

Federal Aviation Administration

Although a temporary permit was obtained for installation of the met tower, turbine construction at either the met tower site or the alternate site will require that FAA Form 7460-1 (Notice of Proposed Construction or Alteration) be filed. FAA approval is never certain and it is possible that the permitting process may require changes to the site or initial turbine construction plan. It is recognized that obstruction lighting on the wind turbines is likely to be required and they would be so equipped as standard equipment.

Alaska Department of Natural Resources

The Alaska Department of Natural Resources (ADNR)-administered Alaska Coastal Management Program (ACMP) evaluates projects within the coastal zone of Alaska, which includes Buckland (ACMP Map: Candle #35), for consistency with statewide standards and other local Coastal District enforceable policies. The ACMP consistency review is a coordination process involving all federal and state permitting authorities within the Northwest Arctic Coastal Zone Resource Service Area where Buckland is located.

The project design team, on behalf of the NWAB and the City of Buckland, will submit a Coastal Project Questionnaire (CPQ) and consistency evaluation form and to ADNR's Division of Coastal and Ocean

Management (DCOM). After a public comment and review period, DCOM will issue a final consistency determination.

US 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). Proposed wind turbine site(s) in Buckland may be located on wetlands if a near-village site is selected. The project must receive a Section 404 permit from the Alaska District USACE.

Proposed Conceptual Designs of Buckland Wind-Diesel Systems

In consideration of the wind power development options for Buckland, four configuration scenarios were modeled with HOMER software:

- Scenario 1: Low penetration wind, village site
- Scenario 2: Medium penetration wind, village site
- Scenario 3: Medium penetration wind, west hills site
- Scenario 4: High penetration wind, west hills site

Scenario 1, Low Penetration Wind, Village Site

The low penetration system configuration option is the simplest and easiest to construct and operate as there is no secondary load controller, no energy storage, and no substantive system control configuration changes, but as one would expect, the ensuing avoided diesel fuel usage is minimal compared to higher penetration options. One or more wind turbines in the 10 to 49 kW output range would be directly connected to the distribution grid with appropriate inverters and transformers as necessary and would operate independently of power plant controls. The wind turbine generators would be alternating current, preferably permanent magnet direct-drive, although induction is suitable as well. Although a three phase wind turbine connection is most desirable, for small turbines single or two phase connections are acceptable and would connect to the weakest phase(s).

In a low-penetration wind-diesel scenario for Buckland, multiple small wind turbines would be installed at a site very near the village to minimize the need for a distribution line extension or road access improvements. No additional controls or communications would be needed in the Buckland powerplant. The wind turbines would operate independently of the powerplant and power produced by the turbines would be seen as reduced (or negative) load by the diesel generator(s). It is assumed that a short distance power distribution extension line will be needed for a low penetration installation.

A target wind turbine capacity for the low penetration scenario is approximately 45 kW. For Buckland, this equates to approximately 50% or less of the minimum projected load. This should mitigate concerns regarding power quality and minimum generator loading.

Low Penetration Comparison Project

A comparative low penetration village wind-diesel system in Alaska is the village of Perryville which has a load profile about half of Buckland's and is presented equipped with ten Skystream 3.7 (2.4 kW rated) wind turbines all directly connected to an AC distribution line. The Perryville wind-diesel configuration has no secondary (or diversion) load and no energy storage capabilities.

Scenario 2, Medium Penetration Wind, Village Site

Medium penetration wind configuration is a compromise between the absolute simplicity of the low penetration scenario and the significant complexity and sophistication of a high penetration scenario. With medium penetration, instantaneous wind input is sufficiently high (at 100 percent or more of the village electrical load) to require a secondary or diversion load to absorb excess wind power, or alternatively, require curtailment of wind turbine output during periods of high wind/low electric loads. For Buckland, appropriate wind turbines for medium wind penetration are in the 10 to 100 kW range with more numbers of turbines required for the lower output machines compared to the larger output models.

Similar to Scenario 1, medium penetration wind at a village site would consist of multiple smaller turbines or just one or two larger turbines at a site near the village to minimize the need for a distribution line extension or road access improvements.

Medium Penetration Comparison Projects

There are a number of comparative medium penetration village wind-diesel power systems now in operation in Alaska. These include the AVEC villages of Toksook Bay, Chevak, Savoonga, Kasigluk, among others. All are characterized by wind turbines directly connected to the AC distribution bus and use of a secondary load controller (SLC) connected to an electric boiler (serving a thermal load) to absorb excess wind energy and to control AC bus frequency with SLC's sub-cycle, high resolution, fast-switching capability.

Scenario 3, Medium Penetration Wind, West Hills Site

This scenario is identical to Scenario 2 in concept and configuration design, except that the turbine site is at the west hills location instead of a near-village site. This will require construction of a 4.5 mile electrical distribution line to connect wind turbines to the village grid system and will also require a short distance road improvement from the borrow pit to the turbine sites.

Scenario 4, High Penetration Wind, West Hills Site

High penetration wind configuration builds on the design aspects of the medium penetration approach by adding short to longer term energy storage such as batteries. Other storage options, such as a flywheel, exist in the market but are of an unsuitable scale for Buckland's small load. With high penetration, instantaneous wind power will often be well above 100 percent (compared to system load) and average wind penetration sufficiently high that energy storage is required to avoid curtailing wind turbines or wasting excess energy, hence the need for batteries.

In a high penetration wind-diesel scenario for Buckland, three or more larger wind turbines would be installed and connected at the west hills site. Significant power plant upgrades would be required, including a modified SCADA, a secondary load controller and boiler, a battery bank for electric energy storage with converter, and possibly new diesel generator controls. Wind turbine operation would be controlled by the SCADA with capability to curtail one or more wind turbines if necessary. With turbines located at west hills site, a 4.5 mile distribution line extension would be necessary to connect to existing distribution on the west side of the village.

High Penetration Comparison Projects

There are only two comparative high penetration village wind-diesel power systems in Alaska and neither is fully functional at present. The Wales system was constructed in the late 1990's and has never functioned satisfactorily. Reportedly this is more due to operational than design issues, although turbulence at the wind turbine site has been noted as a problem. The Kokhanok high penetration wind-diesel system, designed and constructed by Marsh Creek LLC of Anchorage, is new this year and as of this writing has not been fully tested and commissioned. Both the Wales and Kokhanok designs enable diesels-off operation with battery storage. In other respects, they are similar to the medium penetration designs and are characterized by wind turbines directly connected to the AC distribution bus and use of a secondary load controller connected to an electric boiler (serving a thermal load) to divert excess wind energy and control bus frequency.

Wind Turbines

The wind market supports a large number of manufacturers, but most turbines are either not suitable for an Alaska village wind project or are not available for any number of reasons. For the purposes of this report, the turbines to be considered for Buckland were restricted to rated outputs of 10 kW on the low end and 100 kW on the high end. This eliminates the small battery-charging turbines that are simply too small to be useful for village power needs and the very larger hub-community to utility-scale turbines that would overwhelm the Buckland power system. The primary criteria for wind turbines suitable for Buckland are:

- Alternating current (AC) generator; synchronous and asynchronous are acceptable
- Cold-climate capable with appropriate use of materials, lubricants and heaters
- Tilt-up tower availability for turbines 25 kW and less; preferably of monopole construction but lattice-type are acceptable as well
- Preferably optimized for lower class wind regimes (mean annual < 6 m/s)
- Existing Alaska dealer or supplier with warranty and repair/maintenance support
- A "known" turbine with an existing track record of installed operation; in other words, no experimental turbines or turbines brand new to the market

10 to 49 kW Range Turbines

With reference to previously listed criteria, the following turbines have been identified as potentially suitable for a low to medium-penetration wind-diesel project in Buckland.

Bergey Excel

The Bergey Excel is an American made turbine manufactured in Oklahoma by Bergey Windpower, a well-established company. This upwind fixed pitch, furling-regulated turbine has been recently redesigned for better low wind performance, is rated at 10 kW, and is equipped with a direct drive, permanent magnet generator capable of 3 phase output. In Alaska, the Bergey Excel is available through AWI and Marsh Creek, LLC. An estimated cost to install one Bergey Excel turbine in Buckland at a 24 meter hub height is $100,000; multiple turbines in the HOMER model are valued at 95 percent of the single turbine cost. More information can be found at http://www.bergey.com/.

Gaia-Wind 133-11 kW

The Gaia-Wind 133-11 is a Danish-made downwind turbine rated at 11 kW power output, has an induction generator, a solid background of independent third-party testing, and is equipped with two rotor blades and a large swept area, giving the turbine very good power recovery at low wind speeds. In Alaska, the Gaia-Wind 133-11 is available through AWI. An estimated cost to install one Gaia Wind 133-11 kW turbine in Buckland at an 18 meter hub height is $149,000; multiple turbines in the HOMER model are valued at 95 percent of the single turbine cost. Higher hub heights if available would cost more per turbine. More information can be found at http://www.gaia-wind.com/.

MC Energy 31/15

The MC Energy 31/15 is manufactured by MC Energy, an American company based in Washington State. The turbine is rated at 15 kW and has a direct-drive permanent magnet synchronous generator and is designed to perform best in higher wind, gusty conditions. It is mounted on a hinged monopole for ease of installation. MC Energy is a new company and the turbines have not yet been third party verified. In Alaska, The MC Energy 31/15 is available through AWI. An estimated cost to install one MC Energy 31/15 turbine in Buckland at a 24 meter hub height is $130,000; multiple turbines in the HOMER model are valued at 95 percent of the single turbine cost. More information can be found at http://www.trustinwind.com/.

Renewegy VP-20

The Renewegy VP-20 turbine is manufactured by Renewegy, an American company based in Wisconsin. The turbine is rated at 20 kW, is variable pitch regulated, active yaw, and equipped with a 6:1 gearbox with an induction generator. It is mounted on a tilt-up, hinged 30 meter monopole for ease of installation. In Alaska, the Renewegy turbine is available through Susitna Energy Systems. An estimated cost to install one Renewegy VP-20 turbine in Buckland at a 30 meter hub height is $225,000; multiple turbines in the HOMER model are valued at 95 percent of the single turbine cost. More information can be found at http://www.renewegy.com/index.html.

50 to 100 kW Range Turbines

With regard to Buckland electric load, larger turbines in the 50 to 100 kW size range are most suitable in a high penetration scenario with battery storage, but possibly one or two turbines could be employed in a medium penetration scenario considering that Buckland has a relatively large thermal load demand to absorb excess wind energy. At times of low electric and thermal energy demand, a large capacity turbine would have to be curtailed or the excess power dumped or wasted to continue operating.

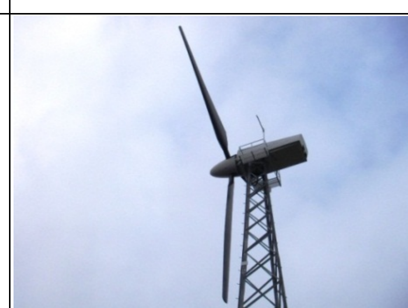
Northern Power Systems Northwind 100

The Northwind 100 (NW100) is manufactured by Northern Power Systems, an American manufacturer based in Vermont. This turbine is stall-regulated, has a direct-drive permanent magnet synchronous generator, active yaw control and is rated at 100 kW. The turbine is fully arctic-climate certified and is the most common village turbine operating in Alaska at present with a significant number of projects in the Yukon-Kuskokwim Delta area. Without geotechnical information of the project site, estimating construction cost is tentative at best, but an installed per turbine cost of $900,000 is likely approximate. Multiple turbines in the HOMER model are valued at 95 percent of the single turbine cost. More information can be found at: http://www.northernpower.com/.

Vestas V15 and V17

The Vestas V15 and V17 turbines are highly robust machines, were originally manufactured in Denmark twenty plus years ago, and are only available used or remanufactured. All remanufactured Vestas turbines presently installed in Alaska were remanufactured by Halus Power Systems of California. These two particular Vestas turbines are stall-regulated, have active yaw control, and are outfitted with two-stage induction generators. The V15 is rated at 65 kW and the V17 at 90 kW. In most respects the turbines are similar and are typically available with 23.5 meter lattice towers (26 m hub height). Given the relatively large output of the Vestas turbines compared to Buckland's electrical load, a synchronous generator or capacitors may be required to provide sufficient VAR support and control of power factor. Without geotechnical information of the project site, estimating construction cost is tentative at best, but an installed per turbine cost of $550,000 is likely approximate. Multiple turbines in the HOMER model are valued at 95 percent of the single turbine cost.

Wind turbine photos

		
Bergey Excel (10 kW)	Gaia-Wind 133-11 (11 kW)	MC Energy 31/15 (15 kW)
		
Renewegy VP-20 (20 kW)	Northern Power NW100/21 B model (100 kW)	Vestas V17 (90 kW)

Wind Turbine Performance Comparison

Wind turbines are designed to achieve optimal performance in certain wind regimes, which can vary from low wind to high mean wind speeds and from low to high turbulence conditions. Other design considerations are cold climate rating, control features, etc. Of most relevance from a strict perspective of comparing wind turbine performance in a given wind regime is the swept area of the turbine in relation to its power output rating. Because Buckland's wind resource is relatively low at both sites, turbines optimized for lower wind resource environments will be advantageous.

In the table below is an analysis of turbine output and capacity factor performance of the turbines profiled above, with comparisons of manufacturer rated output power and actual maximum output power from the turbine power curve, 100% and 80% turbine availability, and to normalize the analysis, all turbines at a common hub height of 30 meters, which was the upper anemometer sensor level of the Buckland met tower at both locations monitored. Turbine performance in the Buckland wind regime varies considerably among the turbines which most readily may be attributed to the swept area of the turbine and the wind regime it is optimized for. Turbines optimized for high energy wind regimes will handle strong, gusty winds well but are less efficient at lower wind speeds, while the opposite is true of turbines optimized for low energy wind regimes. They will efficiently extract energy during periods of low wind speeds, but either significantly spill energy or must be curtailed during higher wind conditions. The best performing turbine from a maximum capacity factor perspective is highlighted in green for both category sizes of turbines examined in this feasibility study. As one can see, the Gaia 11 and the NW100 have the highest capacity factors in the 10-49 kW and the 49-100 kW categories respectively with the Gaia 11 superior to all.

Turbine capacity factor comparison, village site

				100% avail.				80% avail.	
Output Range	Manufacturer	Turbine	Rated Turbine Output (kW)	CF of rated power (%)	Max. Turbine Output (kW)	CF of max. power (%)	Annual Energy (KWh)	CF of max. power (%)	Annual Energy (KWh)
10-49 kW	Bergey	Excel	10	15.6	12.6	12.5	13,703	10.0	10,962
	Gaia-Wind	Gaia 11	11	23.7	10.9	24.0	22,871	19.2	18,297
	MC Energy	31/15	15	18.3	17	16.2	24,070	12.9	19,256
	Renewegy	VP-20	20	13.4	20	13.4	23,435	10.7	18,748
49-100 kW	Northern Pwr	NW100	100	16.3	100	16.3	142,483	13.0	113,986
	Vestas	V17	90	13.8	91	13.6	108,677	10.9	86,942
Note: all turbines compared at a **common 30 meter** hub height!									

Turbine capacity factor comparison, west hills site

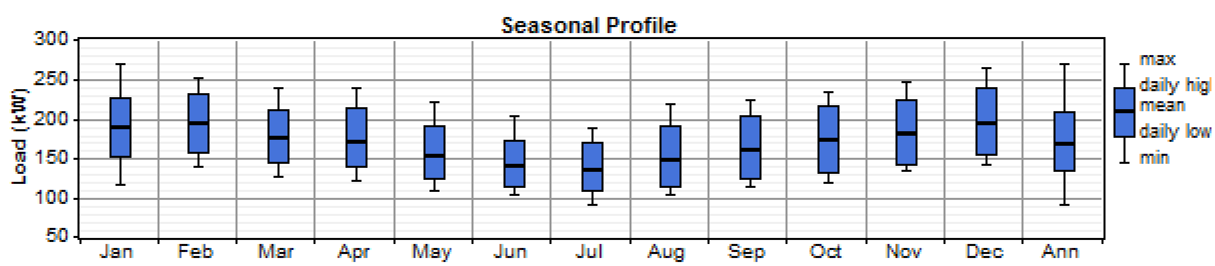
West hills wind site									
				100% avail.				80% avail.	
Output Range	Manufacturer	Turbine	Rated Turbine Output (kW)	CF of rated power (%)	Max. Turbine Output (kW)	CF of max. power (%)	Annual Energy (KWh)	CF of max. power (%)	Annual Energy (KWh)
49-100 kW	Northern Pwr	NW100	100	24.2	100	24.2	212,055	19.4	169,644
	Vestas	V17	90	21.0	91	20.7	165,318	16.6	132,254
Note: all turbines compared at a **common 30 meter** hub height!									

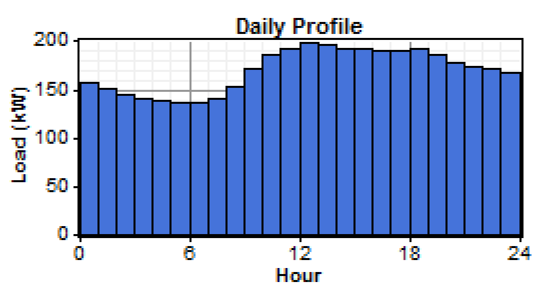
HOMER Modeling

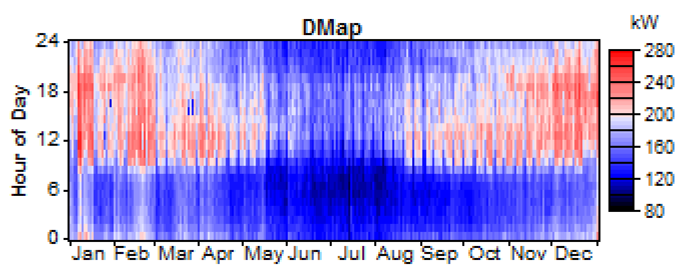
Wind turbine and system performance modeling of wind-diesel configurations in Buckland was accomplished with HOMER software. This software enables static modeling of a power system to demonstrate energy balances and fuel displacement with introduction of wind power. A limitation of the software is that it is not suitable for dynamic modeling. In other words, it cannot model voltage and frequency perturbations and power system dynamics, although it will provide a warning for systems that are potentially unstable. Basic modeling assumptions for this feasibility study are a 20 year project life, a three percent discount rate, an annual utility fixed operations and maintenance (O&M) cost of $300,000, and 100 percent wind turbine availability.

Electric Load

The Buckland electric load was synthesized with the Alaska Electric Load Calculator Excel program written in 2006 by Mia Devine of the Alaska Energy Authority. This spreadsheet allows one to create a "virtual" village load in one hour increments, suitable for import into HOMER software. For this feasibility study, 2009 PCE data of reported gross kWh generated, average power, fuel usage, and powerplant efficiency was used with the Alaska Load Calculator to synthesize a 169 kW average load with a 269 kW peak load, approximate 80 kW minimum load and with a calculated 6.0% day-to-day and 5.3% time step-to-time step random variability. Graphical representations of the electric load are shown below.



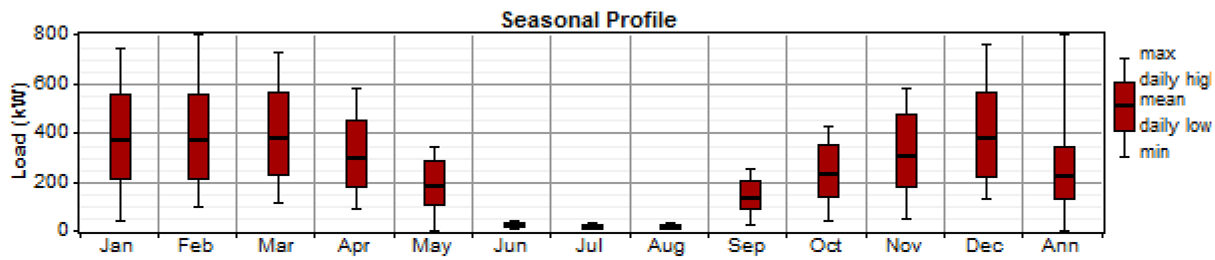


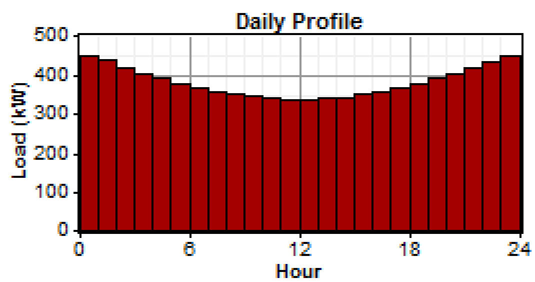


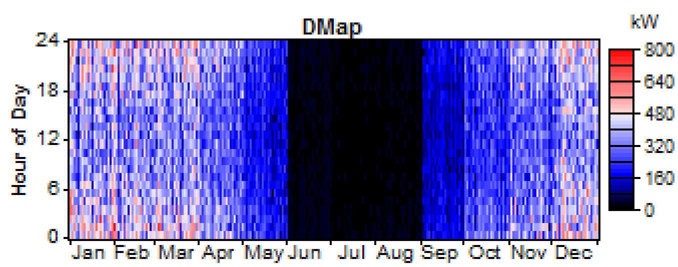
Thermal Load

The thermal load available to the diesel generator heat recovery system is well documented by modeling that AEA conducted prior to re-construction of the Buckland power plant in 2007. This thermal load demand was sent to V3 Energy LLC by David Lockard of Alaska Energy Authority via an Excel spreadsheet file entitled BUCK-HEAT RECOVERY. The spreadsheet estimates an average heat demand by hour by month as a total for all Buckland buildings (attached to the recovered heat system) in MBH (thousand British thermal unit hours). This unit was converted to metric units of kWh for use in the HOMER software.

For modeling purposes 18% diesel generator energy is assumed to be available for thermal loads via the heat recovery system (this assumption was provided by David Lockard at AEA and verified by other calculations). Graphical representations of the thermal load are shown below. Note though that KEA engineers have stated that Buckland has a greater summer (June, July, and August) thermal load than documented in the AEA spreadsheet. This discrepancy was not resolved for this report, but will be investigated and addressed in further study should this project proceed to conceptual design/design.







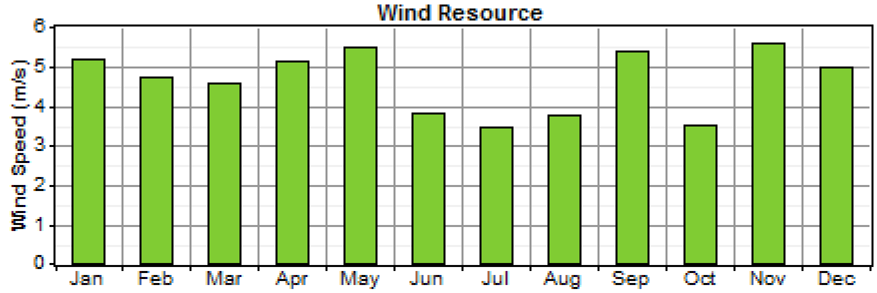
Future Load Growth

A piped water supply and sewer system is presently being constructed in Buckland by the Alaska Department of Environmental Conservation's Village Safe Water Program. This new system is expected to add a significant electrical and thermal load demand to Buckland. Note that this new load growth was not quanitified for this feasibility study.

Wind Resource

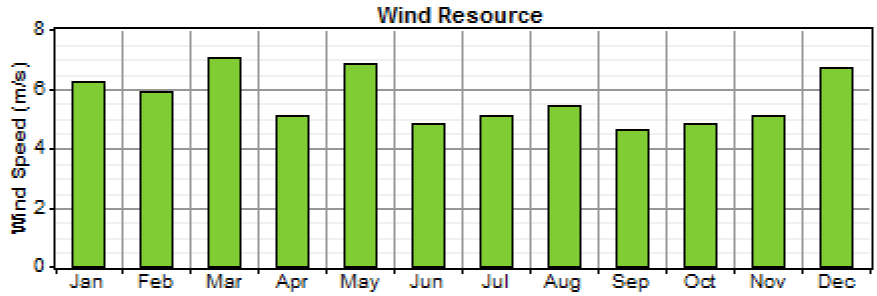
The wind resource at the Buckland village area Site 5062 was measured with a 30 meter met tower in Appendix A. The site is low wind power class 2 (description: marginal) with a mean annual wind speed of 4.60 m/s, a Weibull k of 1.34, and is dominated exclusively by easterly winds with a lesser component of westerly winds.

Buckland Site 5062 wind histogram



The wind resource at the Buckland village area Site 5062 was measured with a 30 meter met tower in Appendix A. The site is low wind power class 2 (description: marginal) with a mean annual wind speed of 4.60 m/s, a Weibull k of 1.34, and is comprised primarily of westerly and southeasterly winds with a lesser component of southwesterly winds.

Buckland Site 5063wind histogram



Diesel Generators

The HOMER model was constructed with Buckland's three diesel generators: a 475 kW output rated Caterpillar 3456, a second 475 kW Caterpillar 3456, and a 175 kW Caterpillar C-9 marine. For planning purposes, AEA assumes a generator O&M cost of $0.020/kWh. This was converted to $3.38/operating hour (for each diesel generator) for use in HOMER software (based on Buckland's modeled average electrical load of 169 kW.

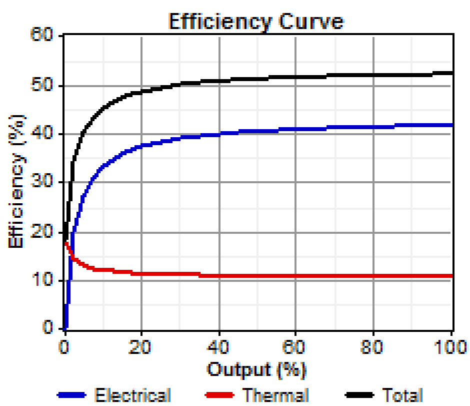
For all four scenarios, manufacturer fuel curves for each diesel generator, provided by David Lockard of AEA in an Excel file entitled *Cat C9M C18M 3508 3512 3456 Mar 20081,* were used in the HOMER models. In addition, the diesel engines in the modeling runs were set to "optimize", which HOMER interprets as use of the most efficient diesel generator whenever possible. This may not be entirely realistic given standard operating procedures at most rural power plants. In Buckland, reports indicate that the Caterpillar C-9 is often not used, even when it could be, because of some operational issues. Those problems are ignored in the HOMER modeling as it is assumed that they will be corrected as part of a wind-diesel construction project and hence the C-9 generator will operate in automatic mode and be employed in an optimally efficient manner.

Diesel generator HOMER modeling information

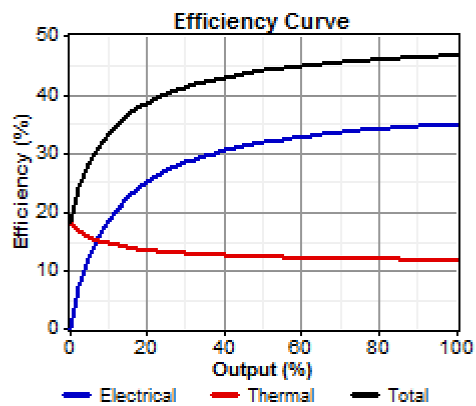
Scenario(s)	all	all	all
Diesel generator	Caterpillar 3456	Caterpillar 3456	Caterpillar C-9 marine
HOMER model identification	Gen 1	Gen 2	Gen 3
Power output (kW)	475	475	175
Intercept coeff. (L/hr/kW rated)	0.00692	0.00692	0.02875
Slope (L/hr/kW output)	0.2379	0.2379	0.2629
Minimum electric load (%)	0.30	0.30	0.30
Heat recovery ratio (%)	18	18	18

Diesel generator fuel efficiency curves

Caterpillar 3456



Caterpillar C-9 marine



Technical and Economic Analysis

As discussed earlier, four configuration scenarios were modeled with HOMER software:

- Scenario 1: Low penetration wind, village site, minimal site preparation, no powerplant upgrade
- Scenario 2: Medium penetration wind, village site, minimal site preparation, installation of a secondary load controller and boiler to augment the heat recovery system
- Scenario 3: Medium penetration wind, west hills site, 4.5 mile distribution line extension, installation of a secondary load controller and boiler to augment the heat recovery system
- Scenario 4: High penetration wind, west hills site, 4.5 mile distribution line extension, installation of a secondary load controller and boiler to augment the heat recovery system, installation of battery storage with converter (inverter/rectifier)

A Buckland wind-diesel hybrid village model was initially developed for the low penetration village site Scenario 1 and then adjusted to the more complex Scenarios 2, 3 and 4. A fuel price of $9.29/gallon

($2.46/Liter) was chosen for the HOMER analysis by reference to ISER in their July 2011 spreadsheet update to Alaska diesel fuel costs for the Renewable Energy Fund Round V analysis spreadsheet, entitled *Fuel_price_projection_2011-2035_workbook_final*. The $9.29 price reflects the median value of the 2013 (assumed project start year) price of $7.78/gallon and 2032 (20 year project end year) of $10.81/gallon, using the medium projection 3-year moving average (MA3) fuel price estimate worksheet.

Additional fuel price analysis for the medium penetration scenarios at both the village and west hills sites are included; one with ISER's low projection MA3 fuel price estimate and the other with ISER's high projection MA3 fuel price estimate. As with the medium fuel price projection scenario, the low and high fuel price projections assume a 2013 project start year and a 2032 project end year. For low projection MA3, the 2013 price of $5.48/gallon and the 2032 price of $3.52/gallon results in an average price (needed for HOMER modeling) of $4.50/gallon ($1.18/Liter). For high projection MA3, the 2013 price of $9.12/gallon and the 2032 price of $17.16/gallon results in an average price (needed for HOMER modeling) of $13.14/gallon ($3.47/Liter). These additional low and high projection fuel price analyses are included in the following tables only for medium penetration scenarios 2 and 3.

In the modeling simulations, wind turbine availability is 100 percent. Turbine availability in Alaska is less however, typically in the 80 to 90 percent range for village wind-diesel projects. An analysis with variable turbine availability could be accomplished with an additional software analysis, but for this feasibility study all technical and economic analyses were conducted with HOMER software which sets wind turbine availability at a fixed 100 percent. Note that in actual usage smaller wind turbines typically experience very high availability, so the 100 percent availability assumption is not unrealistic for medium penetration modes (with smaller turbines). HOMER modeling assumptions are listed in the table below.

Other modeling assumptions

Economic Assumptions	
Project life	20 years
Discount rate	3%
System fixed O&M cost	$300,000/year (assumed based on village population; fixed O&M cost is not available in PCE records)
Operating Reserves	
Load in current time step	10%
Wind power output	50%
Fuel Price	
Diesel arctic (generators)	$9.29/gal ($2.46/Liter)
Heating oil (thermal boilers)	$9.29/gal ($2.46/Liter)
Fuel Properties (both types)	
Heating value	42.5 MJ/kg
Density	820 kg/m^3
Diesel Generators	
O&M cost	$3.38/hour
Operating life	unlimited

Schedule	Optimized
Wind Turbines	
Availability	100%
O&M cost	$0.0469/kWh (translated to $/year with site average turbine CF's for use by HOMER)
• Bergey Excel	• $615/year/turbine
• Gaia-Wind 11 kW	• $900/year/turbine
• MC Energy 31/15	• $1,050/year/turbine
• Renewegy VP-20	• $1,150/year/turbine
• Northern NW100	• $7,000/year/turbine
• Vestas V-17	• $4,900/year/turbine

Scenario-specific Cost Assumptions

Scenario 1 is low penetration wind at a near-village site. A fixed system capital cost of $100,000 is assumed to cover a minimal amount of site preparation with no upgrades or changes in the power plant. Four wind turbines in the 10 to 49 kW rated output range are modeled for fuel displacement and project net present value and presented in the following section of this report, but note that other similar size wind turbines may be suitable for use in Buckland as well.

Scenario 2 is medium penetration wind at a near-village site. The fixed system capital cost of $100,000 is retained for site development purposes plus an additional $125,000 fixed system capital cost for a secondary load controller and SCADA improvements to accommodate the higher penetration of wind power. Two wind turbines in the 10 to 49 kW range and two wind turbines in the 50 to 100 kW range are considered.

Because the Scenario 3 site changes to the west hills location, it includes a cost assumption of $250,000 per mile for the 4.5 mile three-phase distribution line extension from Buckland. The $100,000 site development cost in Scenarios 1 and 2 is deleted but the $125,000 cost for a secondary load controller and SCADA improvements is retained. In this scenario, site development costs are included in turbine cost assumptions.

In Scenario 4 all assumptions of Scenario 3 are maintained but batteries and a converter (inverter and rectifier) are added to enable storage of excess electrical power. The batteries are assumed to cost $100,000 and the converter to cost $25,000. As in Scenario 3, site development costs are included in turbine cost assumptions. Because this scenario includes the capability of electrical storage, more turbines are assumed than in Scenario 3 and hence a discount per additional turbine of ten percent is assumed, versus five percent in other scenarios.

Synopsis of scenario-specific cost assumptions

Scenario	Cost Assumptions
1	• Site development: $100,000 • Additional turbines at 95% of first turbine
2	• Site development: $100,000 • SLC and SCADA upgrade: $125,000 • Additional turbines at 95% of first turbine
3	• SLC and SCADA upgrade: $125,000 • Distribution line extension: $1,125,000 ($250K/mile, 4.5 miles) • Additional turbines at 95% of first turbine
4	• SLC and SCADA upgrade: $125,000 • Distribution line extension: $1,125,000 ($250K/mile, 4.5 miles) • Batteries and converter: $125,000 • Additional turbines at 90% of first turbine

Scenario 1, Village Site, Low Penetration Wind, ISER 2011 Medium Projection MA3 Fuel Price

Bergey Excel, 24 meter hub height

No. Excel	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
0	$0	1,859,126	$27,659,102	0.782	0.00	388,042	233,713	621,755	164,485	0	0.9	2.6	1.000
1	$200,000	1,854,020	$27,783,128	0.788	0.01	385,406	234,023	619,429	163,870	615	0.9	2.6	0.996
2	$290,000	1,849,096	$27,799,880	0.788	0.02	382,876	234,302	617,178	163,275	1,211	0.9	2.6	0.995
3	$380,000	1,844,195	$27,816,958	0.789	0.03	380,352	234,583	614,935	162,681	1,804	0.9	2.6	0.994
4	$470,000	1,839,295	$27,834,066	0.790	0.03	377,838	234,856	612,694	162,088	2,397	0.9	2.6	0.994
5	$560,000	1,834,505	$27,852,802	0.791	0.04	375,383	235,114	610,497	161,507	2,978	1.0	2.6	0.993

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Gaia-Wind 11 kW, 18 meter hub height

No. Gaia 11 kW	Initial capital cost	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
0	$0	1,859,126	$27,659,102	0.782	0.00	388,042	233,713	621,755	164,485	0	0.9	2.5	1.000
1	$250,000	1,851,052	$27,788,970	0.788	0.01	383,931	234,176	618,107	163,520	965	0.9	2.6	0.995
2	$385,000	1,843,276	$27,808,286	0.789	0.03	379,981	234,599	614,580	162,587	1,898	0.9	2.5	0.995
3	$520,000	1,835,637	$27,829,636	0.790	0.04	376,104	235,005	611,109	161,669	2,816	1.0	2.5	0.994
4	$655,000	1,827,997	$27,850,982	0.791	0.06	372,246	235,391	607,637	160,751	3,735	1.0	2.5	0.993
5	$790,000	1,820,284	$27,871,222	0.792	0.07	368,349	235,787	604,136	159,824	4,661	1.0	2.5	0.992

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

MC Energy 31/15, 24 meter hub height

No. MC 31/15	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
0	$0	1,859,126	$27,659,102	0.782	0.00	388,042	233,713	621,755	164,485	0	0.9	2.5	1.000
4	$581,000	1,824,294	$27,721,884	0.785	0.06	370,259	235,629	605,888	160,288	4,198	0.9	2.6	0.998
3	$464,000	1,832,829	$27,731,864	0.785	0.05	374,613	235,172	609,785	161,319	3,167	0.9	2.6	0.997
2	$347,000	1,841,457	$27,743,232	0.786	0.03	379,013	234,706	613,719	162,360	2,126	1.0	2.6	0.997
1	$230,000	1,850,132	$27,755,292	0.786	0.02	383,441	234,231	617,672	163,405	1,080	1.0	2.6	0.997

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Renewegy VP-20, 30 meter hub height

No. VP-20	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
0	$0	1,859,126	$27,659,102	0.782	0.00	388,042	233,713	621,755	164,485	0	0.9	2.6	1.000
1	$325,000	1,849,905	$27,846,912	0.790	0.02	383,285	234,255	617,540	163,370	1,115	0.9	2.6	0.993
2	$527,500	1,840,947	$27,916,138	0.794	0.03	378,684	234,746	613,430	162,283	2,202	0.9	2.6	0.991
3	$730,000	1,832,129	$27,987,456	0.797	0.05	374,148	235,230	609,378	161,211	3,274	1.0	2.5	0.988

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Scenario 2, Village Site, Medium Penetration Wind, ISER 2011 Medium Projection MA3 Fuel Price

Gaia-Wind 11 kW, 18 meter hub height

No. Gaia 11 kW	Initial capital cost	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
0	$0	1,859,126	$27,659,102	0.782	0.00	388,042	233,713	621,755	164,485	0	0.9	2.5	1.000
3	$645,000	1,830,986	$27,885,440	0.792	0.04	377,125	232,093	609,218	161,169	3,317	1.9	2.9	0.992
6	$1,050,000	1,806,925	$27,932,480	0.794	0.08	366,608	231,732	598,340	158,291	6,194	2.5	2.8	0.990
9	$1,455,000	1,782,715	$27,977,296	0.796	0.12	355,220	232,181	587,401	155,397	9,088	2.9	2.7	0.989
12	$1,860,000	1,758,520	$28,022,340	0.798	0.16	343,612	232,856	576,468	152,505	11,981	3.2	2.7	0.987

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Renewegy VP-20, 30 meter hub height

No. VP-20	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
0	$0	1,859,126	$27,659,102	0.782	0.00	388,042	233,713	621,755	164,485	0	1.0	3.0	1.000
2	$652,500	1,836,728	$27,978,376	0.796	0.03	379,376	232,339	611,715	161,829	2,656	1.6	2.9	0.989
4	$1,057,500	1,818,195	$28,107,646	0.802	0.06	371,298	231,948	603,246	159,589	4,897	2.2	2.9	0.984
6	$1,462,500	1,799,875	$28,240,092	0.808	0.09	362,886	231,979	594,865	157,372	7,114	2.6	2.8	0.979
8	$1,867,500	1,781,391	$28,370,102	0.814	0.12	354,350	232,066	586,416	155,137	9,349	3.0	2.8	0.975
10	$2,272,500	1,763,436	$28,507,970	0.820	0.15	346,855	231,326	578,181	152,958	11,528	3.7	2.7	0.970

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

NW100/21, 37 meter hub height

No. NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
0	$0	1,859,126	$27,659,102	0.782	0.00	388,042	233,713	621,755	164,485	0	0.9	2.6	1.000
2	$1,935,000	1,742,102	$27,853,070	0.791	0.10	337,752	230,741	568,493	150,395	14,090	4.5	2.8	0.993
1	$1,125,000	1,797,852	$27,872,502	0.792	0.19	362,080	231,922	594,002	157,143	7,342	2.7	2.8	0.992
3	$2,745,000	1,693,847	$27,945,170	0.795	0.27	323,139	222,897	546,036	144,454	20,031	9.1	3.2	0.990

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Vestas V17, 26 meter hub height

No. V17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
3	$1,765,000	1,736,262	$27,596,188	0.779	0.20	338,218	227,617	565,835	149,692	14,794	6.0	2.9	1.002
2	$1,270,000	1,773,318	$27,652,490	0.782	0.14	350,931	231,959	582,890	154,204	10,282	2.7	2.8	1.000
0	$0	1,859,126	$27,659,102	0.782	0.00	388,042	233,713	621,755	164,485	0	0.9	2.6	1.000
1	$775,000	1,814,024	$27,763,096	0.787	0.07	369,459	231,970	601,429	159,108	5,377	4.8	2.8	0.996

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Scenario 2, Village Site, Medium Penetration Wind, ISER 2011 Low Projection MA3 Fuel Price

NW100/21, 37 meter hub height

No. NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
0	$0	1,061,935	$15,798,909	0.490	0.00	388,042	233,713	621,755	164,485	0	0.9	2.6	1.000
1	$1,125,000	1,037,530	$16,560,832	0.524	0.10	362,080	231,922	594,002	157,143	7,342	2.7	2.8	0.954
2	$1,935,000	1,014,431	$17,027,164	0.545	0.19	337,752	230,741	568,493	150,395	14,090	4.5	2.8	0.928
3	$2,745,000	994,921	$17,546,914	0.569	0.27	323,139	222,897	546,036	144,454	20,031	9.1	3.2	0.900

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Vestas V17, 26 meter hub height

No. V17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
0	$0	1,061,935	$15,798,909	0.490	0.00	388,042	233,713	621,755	164,485	0	0.9	2.6	1.000
1	$775,000	1,044,195	$16,309,985	0.513	0.07	369,459	231,970	601,429	159,108	5,377	2.3	2.9	0.969
2	$1,270,000	1,027,219	$16,552,421	0.524	0.14	350,931	231,959	582,890	154,204	10,282	3.3	2.8	0.954
3	$1,765,000	1,011,993	$16,820,906	0.536	0.20	338,218	227,617	565,835	149,692	14,794	5.0	2.9	0.939

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Scenario 2, Village Site, Medium Penetration Wind, ISER 2011 High Projection MA3 Fuel Price

NW100/21, 37 meter hub height

No. NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
3	$2,745,000	2,245,344	$36,150,044	0.973	0.27	323,139	222,897	546,036	144,454	20,031	9.1	3.2	1.022
2	$1,935,000	2,316,279	$36,395,388	0.984	0.19	337,752	230,741	568,493	150,395	14,090	4.5	2.8	1.015
1	$1,125,000	2,397,794	$36,798,116	1.003	0.10	362,080	231,922	594,002	157,143	7,342	2.7	2.8	1.004
0	$0	2,483,144	$36,942,908	1.019	0.00	388,042	233,713	621,755	164,485	0	0.9	2.6	1.000

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Vestas V17, 26 meter hub height

No. V17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
3	$1,765,000	2,307,755	$36,098,560	0.971	0.20	338,218	227,617	565,835	149,692	14,794	5.0	2.9	1.023
2	$1,270,000	2,362,037	$36,411,136	0.985	0.14	350,931	231,959	582,890	154,204	10,282	3.3	2.8	1.015
1	$775,000	2,421,467	$36,800,316	1.003	0.07	369,459	231,970	601,429	159,108	5,377	2.3	2.9	1.004
0	$0	2,483,144	$36,942,908	1.019	0.00	388,042	233,713	621,755	164,485	0	0.9	2.6	1.000

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Scenario 3, West Hills Site, Medium Penetration Wind, ISER 2011 Medium Projection MA3 Fuel Price

NW100/21, 37 meter hub height

No. NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
0	$0	1,856,322	$27,617,388	0.780	0.00	388,172	232,443	620,615	164,184	0	0.9	2.6	1.000
3	$3,770,000	1,610,512	$27,730,350	0.785	0.38	297,245	215,016	512,261	135,519	28,665	15.5	5.0	0.996
2	$2,960,000	1,679,678	$27,949,358	0.795	0.28	314,654	228,463	543,117	143,682	20,502	7.5	3.4	0.988
1	$2,150,000	1,760,997	$28,349,182	0.813	0.15	345,984	233,035	579,019	153,180	11,004	2.8	2.6	0.974

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Vestas V17, 26 meter hub height

No. V17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
0	$0	1,856,322	$27,617,388	0.780	0.00	388,172	232,443	620,615	164,184	0	0.9	2.6	1.000
3	$2,790,000	1,673,331	$27,684,944	0.783	0.29	316,134	224,123	540,257	142,925	21,259	9.6	3.8	0.998
2	$2,295,000	1,725,624	$27,967,922	0.796	0.20	332,084	231,418	563,502	149,075	15,109	4.7	2.9	0.987
1	$1,800,000	1,787,839	$28,398,534	0.815	0.10	358,034	232,751	590,785	156,292	7,892	2.3	2.6	0.972

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Scenario 3, West Hills Site, Medium Penetration Wind, ISER 2011 Low Projection MA3 Fuel Price

NW100/21, 37 meter hub height

No. NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
0	$0	1,061,935	$15,798,909	0.490	0.00	388,172	232,443	620,615	164,184	0	0.9	2.6	1.000
1	$2,150,000	1,019,852	$17,322,816	0.559	0.15	345,984	233,035	579,019	153,180	11,004	2.8	2.6	0.912
2	$2,960,000	984,487	$17,606,684	0.572	0.28	314,654	228,463	543,117	143,682	20,502	7.5	3.4	0.897
3	$3,770,000	954,817	$17,975,268	0.588	0.38	297,245	215,016	512,261	135,519	28,665	15.5	5.0	0.879

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Vestas V17, 26 meter hub height

No. V17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
0	$0	1,061,935	$15,798,909	0.490	0.00	388,172	232,443	620,615	164,184	0	0.9	2.6	1.000
1	$1,800,000	1,031,635	$17,148,120	0.551	0.10	358,034	232,751	590,785	156,292	7,892	2.3	2.6	0.921
2	$2,295,000	1,004,341	$17,237,060	0.555	0.20	332,084	231,418	563,502	149,075	15,109	4.7	2.9	0.917
3	$2,790,000	981,802	$17,396,734	0.562	0.29	316,134	224,123	540,257	142,925	21,259	9.6	3.8	0.908

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Scenario 3, West Hills Site, Medium Penetration Wind, ISER 2011 High Projection MA3 Fuel Price

NW100/21, 37 meter hub height

No. NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
3	$3,770,000	2,127,896	$35,427,720	0.941	0.38	297,245	215,016	512,261	135,519	28,665	15.5	5.0	1.043
2	$2,960,000	2,228,226	$36,110,380	0.972	0.28	314,654	228,463	543,117	143,682	20,502	7.5	3.4	1.023
0	$0	2,483,144	$36,942,908	1.009	0.00	388,172	232,443	620,615	164,184	0	0.9	2.6	1.000
1	$2,150,000	2,345,806	$37,049,672	1.014	0.15	345,984	233,035	579,019	153,180	11,004	2.8	2.6	0.997

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Vestas V17, 26 meter hub height

No. V17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
3	$2,790,000	2,218,991	$35,802,980	0.958	0.29	316,134	224,123	540,257	142,925	21,259	9.6	3.8	1.032
2	$2,295,000	2,294,761	$36,435,244	0.986	0.20	332,084	231,418	563,502	149,075	15,109	4.7	2.9	1.014
0	$0	2,483,144	$36,942,908	1.009	0.00	388,172	232,443	620,615	164,184	0	0.9	2.6	1.000
1	$1,800,000	2,384,532	$37,275,812	1.024	0.10	358,034	232,751	590,785	156,292	7,892	2.3	2.6	0.991

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Scenario 4, West Hills Site, High Penetration Wind, ISER 2011 Medium Projection MA3 Fuel Price

NW100/21, 37 meter hub height

No. NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
5	$5,155,000	1,425,161	$26,357,798	0.723	0.59	219,404	214,426	433,830	114,770	49,414	20.3	6.8	1.048
4	$4,435,000	1,489,394	$26,593,426	0.734	0.51	235,110	227,204	462,314	122,305	41,879	12.9	4.1	1.039
3	$3,715,000	1,567,972	$27,042,466	0.754	0.42	258,088	238,262	496,350	131,310	32,874	5.7	2.6	1.022
0	$0	1,857,154	$27,629,760	0.781	0.00	388,172	232,443	620,615	164,184	0	0.9	2.6	1.000

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Vestas V17, 26 meter hub height

No. V17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction of elec. load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
5	$3,685,000	1,529,735	$26,443,592	0.727	0.47	251,682	228,111	479,793	126,929	37,254	11.6	3.9	1.045
4	$3,245,000	1,584,672	$26,820,918	0.744	0.40	267,818	235,784	503,602	133,228	30,956	6.4	2.7	1.030
3	$2,805,000	1,647,809	$27,320,230	0.767	0.31	289,977	240,622	530,599	140,370	23,814	2.2	2.1	1.011
0	$0	1,857,154	$27,629,760	0.781	0.00	388,172	232,443	620,615	164,184	0	0.9	2.6	1.000

Note: Base option of 0 turbines assumes present conditions with no improvements to plant, site, or electrical distribution system

Discussion and Recommendations

Development of alternative or renewable energy sources in Buckland to mitigate the very high cost of energy in the community is a challenge, but achievable. Due to isolation and difficult barge access, fuel prices in Buckland are quite expensive – much more so than in other similar-size Alaska villages – which supports the prospects of renewable energy development in that the value of displaced fuel usage is very high. On the other hand, renewable energy options for the community are limited in options. Earlier studies have concluded that wind power is the most feasible renewable energy resource available locally. Two wind studies in the Buckland area have demonstrated that the local wind resource is somewhat modest in comparison to windier coastal communities, but this is countered by Buckland's much higher fuel costs. Noting that the Buckland power plant is modern, efficient and well supported by KEA, plant improvements, while always possible, are not likely to lead to dramatic efficiency gains. With conservation measures, wind power is the most feasible option available in Buckland to mitigate the high cost of energy.

Four wind project configuration scenario options were evaluated and with assumptions stated in this report, all exceed or are near a benefit-to-cost (B/C) ratio of 1.0. There is of course a tradeoff of construction cost and wind resource to consider between the two sites evaluated. At the village area site, the wind resource is marginal but development costs are fairly low with minimal access road and distribution line improvements required. At the west hills site, the wind resource is much improved, but some access road construction and a 4.5 mile distribution line extension are necessary for development. Comparing Scenarios 2 and 3, both medium penetration designs with Scenario 2 at a village site and Scenario 3 at the west hills site, at ISER's medium projection fuel price the initial economic screening presented in this report indicates that both sites are about equal with respect to B/C ratio over the project life. This advantage tilts a bit in favor of the west hills site with high projection fuel price. The true cost advantage appears to be with high penetration configuration and multiple turbines at the west hills site. Even with the medium projection fuel price, it is clearly advantageous to operate wind turbines in high penetration mode as this configuration maximizes the amount of fuel saved. Although not evaluated in this report, these savings would increase even more with high projection fuel prices. This is truly a consequence of Buckland's high fuel costs and indicates the utility of maximizing the input of wind power to minimize overall fuel costs.

KEA and the City of Buckland have stated that they wish to maximize the potential of wind power in Buckland but are not yet ready to commit at this time to a highly complex high penetration design. With that objective in mind, a medium penetration configuration option – Scenario 2 or 3 – is recommended for development of wind power in Buckland. The question, however, of whether to develop a village site or the west hills site, will be deferred to the conceptual design phase of this project where the opportunity exists to solicit community input, consider utility objectives, and develop more accurate cost estimates. It is also likely at that time that configuration options will be considered and the clear advantages of a high penetration configuration with electrical storage may be viewed very favorably.

With respect to selection of a turbine, KEA wishes to consider only larger turbines in the near-100 kW range as their experience in Kotzebue has taught them several or more smaller turbines are more problematic and less efficient overall then two or three (or more) larger turbines. With that in mind, it is likely that only the Vestas V17 and Northwind 100 turbines will be evaluated in the conceptual design phase of this project, although possibly an even larger turbine such as a Vestas V27 or Aeronautica 29-225 may be considered, especially if a high penetration configuration is viewed favorably by the utilities and the community.

Appendix A, Buckland, Alaska Wind Resource Report (Village, Site 5062)

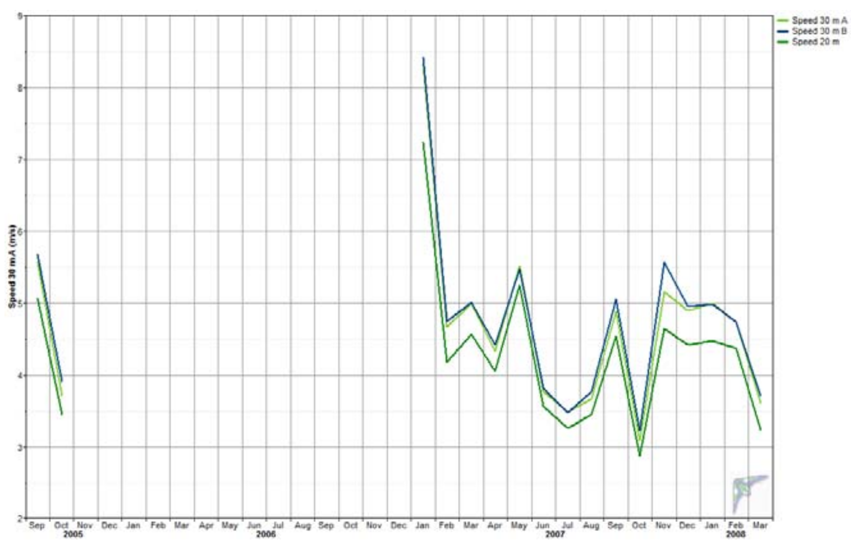
Buckland, Alaska Wind Resource Report

Summary Information

Buckland exhibits a marginal wind resource for wind power development, with an annual average wind speed at 30 meters elevation of 4.6 m/s and Wind Power Class 2 (marginal). This wind resource is generally not adequate for wind power development, other than perhaps for a very small application such as a home-based, off-grid power supply. Given the potential for a significantly better wind resource in the hills west of Buckland, it is strongly suggested that the met tower be moved to a more promising location as soon as possible and a new wind resource study for Buckland initiated.

Meteorological Tower Data Synopsis

The Alaska Energy Authority, assisted by Kotzebue Electric Assn. and village labor support, installed a 30 meter met tower in Buckland in September, 2005 and the wind resource assessment continues to the present. However, a long data gap of fifteen months exists where no data collection occurred, from October 2005 to January 2007. Nevertheless, seventeen months of data have been collected to date, which is sufficient to characterize the site.



Meteorological Tower Information

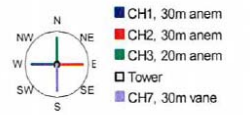
Three anemometers are installed on the Buckland met tower, two at 30 meters and one at 20 meters. In addition, there is a wind vane mounted at 29 meters and a temperature sensor at 2 meters which unfortunately does not appear to have ever worked properly. All temperature data was deleted for this report.

Figure 3. Views Taken from Met Tower Base

Table 1 lists the types of sensors that were used, the channel of the data logger that each sensor was wired into, and where each sensor was mounted on the tower.

Table 1. Summary of Sensors Installed on the Met Tower

Ch #	Sensor Type	Height	Offset	Boom Orientation
1	#40 Anemometer	30 m	NRG Standard	270˚ True
2	#40 Anemometer	30 m	NRG Standard	90˚ True
3	#40 Anemometer	20 m	NRG Standard	360˚ True
7	#200P Wind Vane	29 m	180˚ True	360˚ True
9	#110S Temperature		42˚C	W



Aerial view of equipment on tower

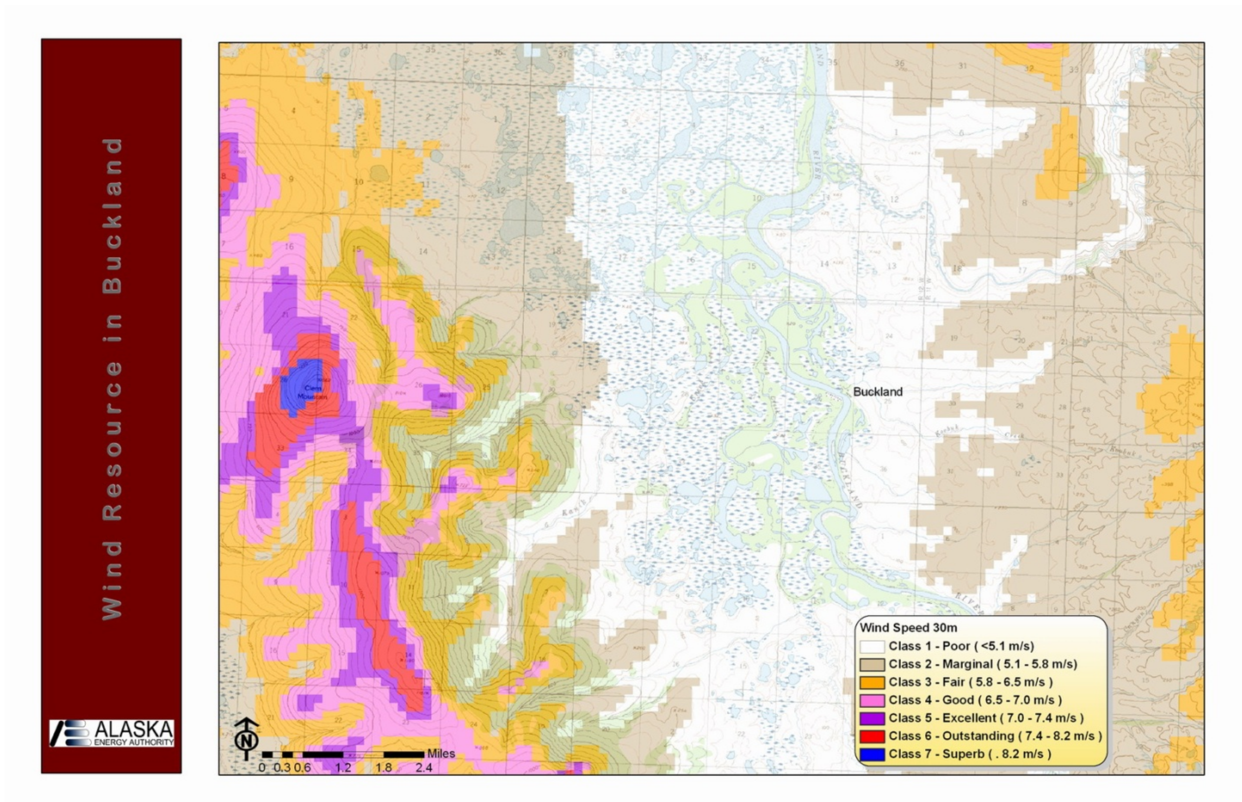
Buckland met tower information from AEA information

Met Tower Location

The Buckland met tower is located near the village at N 65° 58’ 24.2”, W 161° 7’ 50.6”.

Google Earth image of Buckland, rock quarry road, and ridges to the west

Note that the wind resource map below shows significantly higher wind resource potential in the hills and mountains west of Buckland. Conveniently, a road to a rock quarry exists to the very foot of these hills, making it relatively easy to locate a wind power site that has the potential for Class 4 or better winds, yet still close enough to Buckland with existing road infrastructure to be developed.



Wind resource map of Buckland area

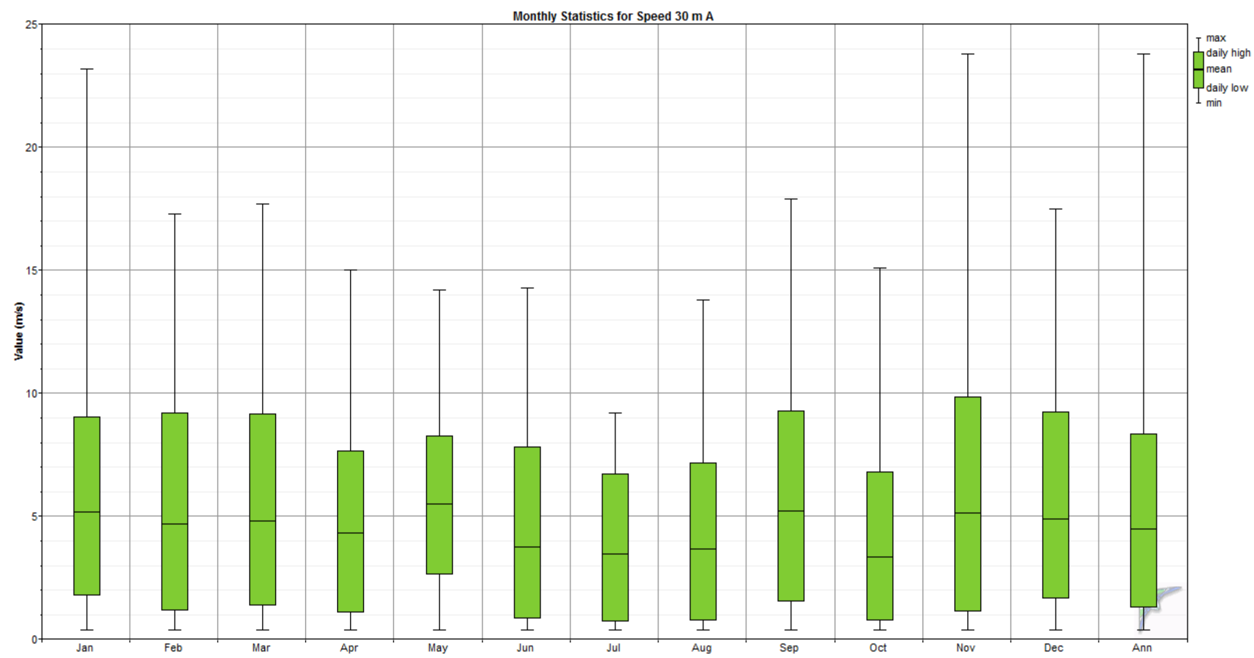
Measured Wind Speeds

The annual average wind speed at the 30 meter level is 4.6 m/s, representative of a Class 2 wind resource.

	Wind Speed, 30 meters					
Month	Mean (m/s)	Max(1) (m/s)	Max(2) m/s	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)
Jan	5.18	23.0	27.5	5.259	0.884	4.871
Feb	4.74	18.0	22.9	3.445	1.305	5.119
Mar	4.86	17.4	22.1	3.266	1.492	5.371
Apr	4.42	14.8	17.6	2.638	1.641	4.911
May	5.48	14.4	17.6	2.161	2.695	6.121
Jun	3.81	12.8	16.8	2.231	1.740	4.273

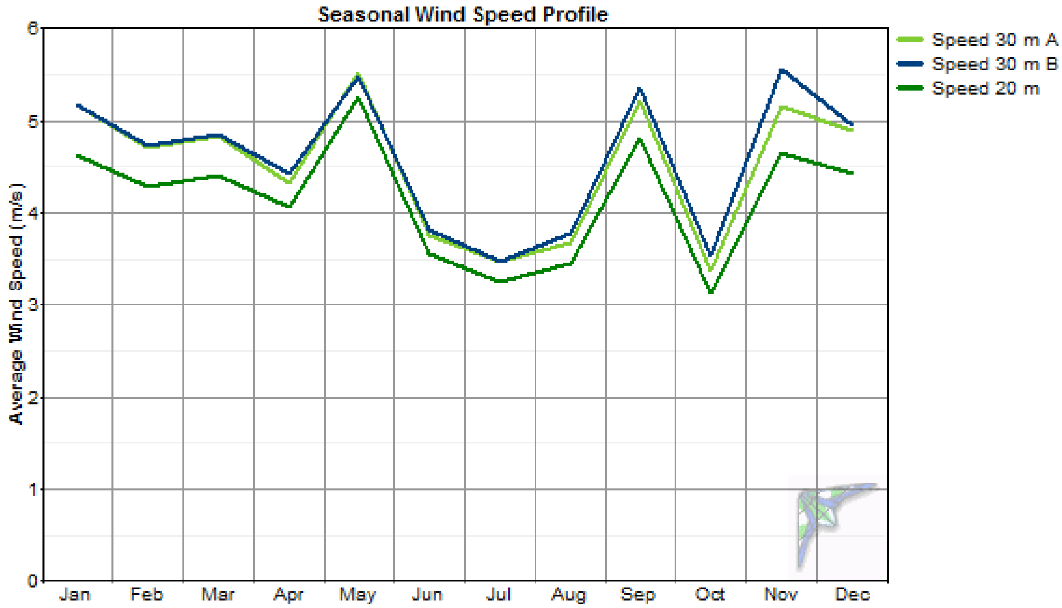
Jul	3.47	9.1	11.8	1.937	1.840	3.903
Aug	3.77	13.6	17.6	2.274	1.710	4.231
Sep	5.37	17.7	25.6	3.216	1.682	5.995
Oct	3.53	14.8	20.2	2.749	1.306	3.831
Nov	5.57	24.7	29.4	4.714	1.210	5.945
Dec	4.96	18.0	22.6	4.246	1.062	5.074
Annual	4.60	24.7	29.4	3.364	1.359	5.001

(1) Ten minute average maximum wind speeds
(2) Max. 2 second gust wind speeds



Time Series of Wind Speed Monthly Averages

As is true in most of Alaska, winter winds in Buckland are generally stronger than summer winds, although some significant variability was measured, for example in October. This variability would likely smooth out with another year of data, but the existing site shows too little promise for wind power development to warrant that decision.

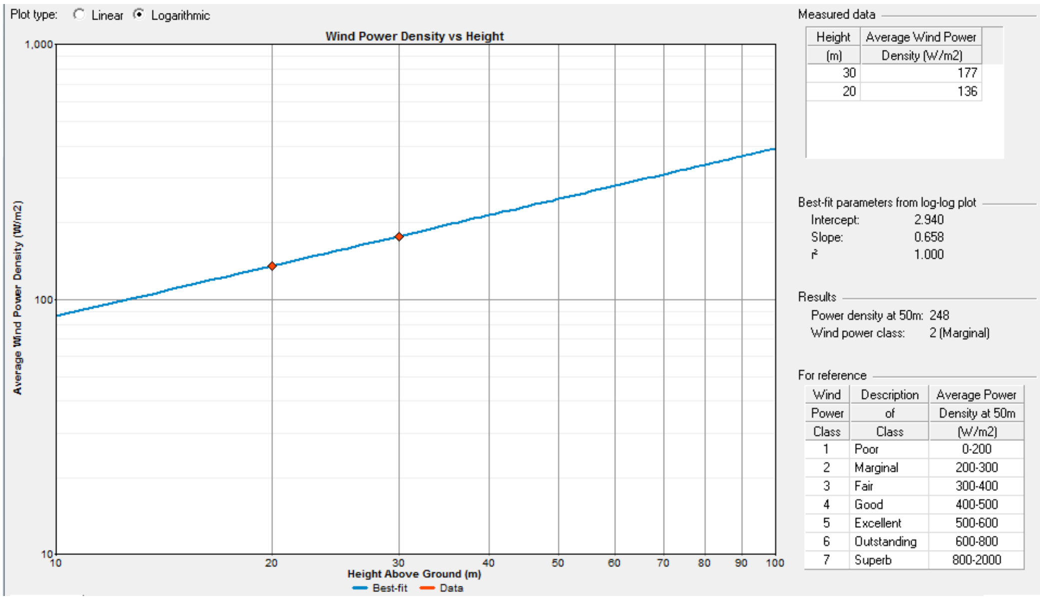


Wind Power Density

The wind power density is defined as the power per unit area of the wind with units of Watts per square meter. It is calculated by multiplying ½ times the air density (ρ) times the wind speed (U) cubed for each time step. The equation is: $P/A = ½*\rho*U^3$. The time step values are averaged to generate an overall wind power density. Note that the temperature data was compromised; hence the air density for the purpose of the calculation is held constant at the standard 1.225 kg/m^3. In reality, given Buckland's very cold temperatures, air density will be considerably higher than standard, perhaps as much as five to seven percent annually, which would result in a higher wind power density than calculated.

The wind power density at 50 meters is a wind industry standard method of comparing and evaluating sites. If the anemometer measurement heights are other than 50 meters, the wind analysis software extrapolates up or down using the power law exponent value calculated for wind shear.

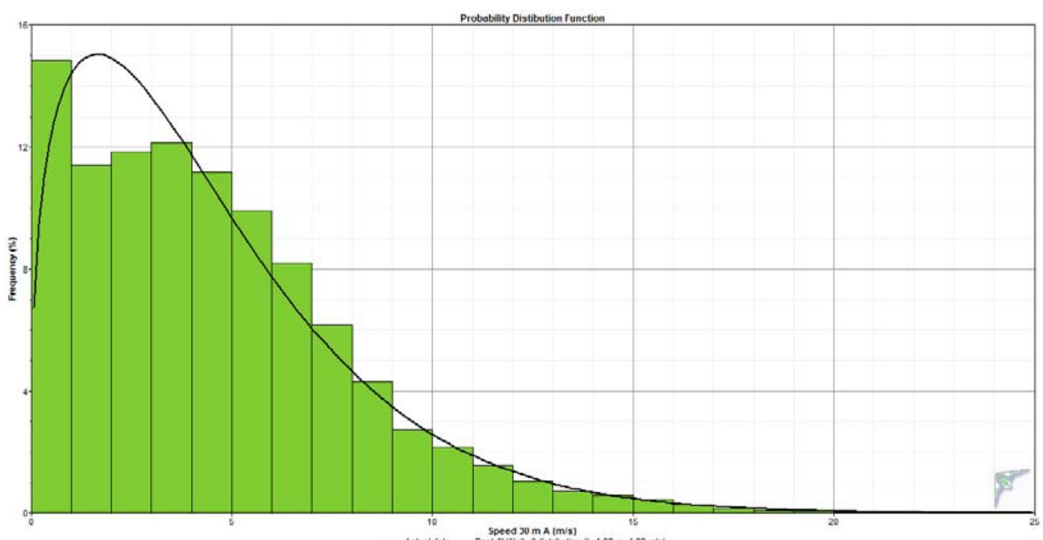
The wind power density in Buckland for the seventeen months of collected data is calculated at 248 W/m^2 at 50 meters, categorizing it as a Class 2 (marginal) wind resource. However, by a different view, looking only at the annual average wind speed of 4.6 m/s at 30 meters, Buckland would categorize as a Class 1 (poor) wind resource.



Probability Distribution Function

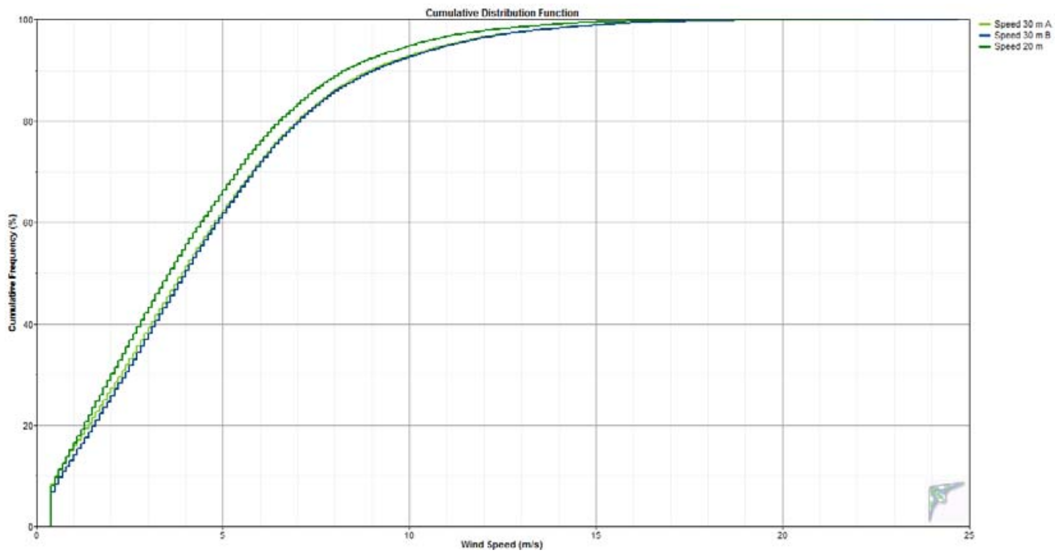
The probability distribution function indicates the probability that a variable will return a value “x”, in the case of wind speed this means the frequency that the speed falls within 1 m/s bins, as shown in the histogram below. Note that most wind turbines do not begin to generate power until the wind speed at hub height reaches 4 m/s, also known as the “cut-in” wind speed. Also note that most turbines have a cutout wind speed of 25 m/s.

The black line in the graph below is the best fit Weibull distribution. Note that the Weibull k is shape factor of the Weibull distribution, indicating the breadth of values. Low k values indicate a broad distribution of wind speeds while high k values indicate a narrow distribution of wind speeds. For Buckland, the k value of 1.32 is within the normal range typical for wind power sites.



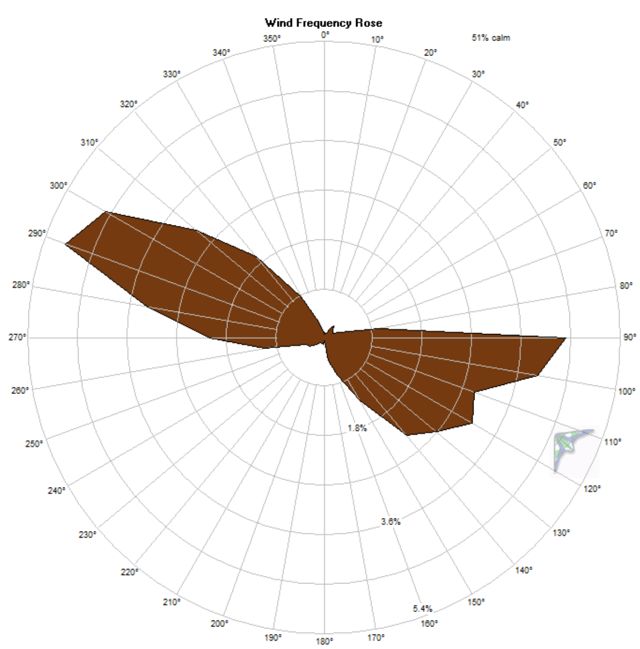
Cumulative Distribution Function

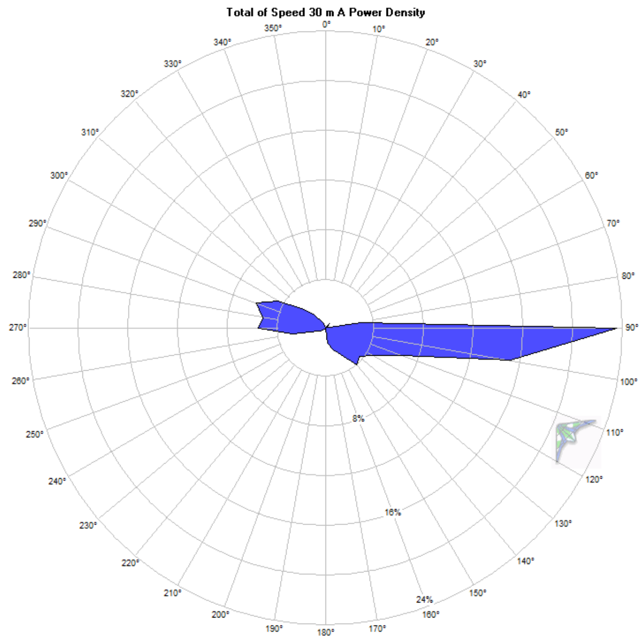
The cumulative distribution function represents another way to understand the probability distribution function. Note that annual data set represented below, about 50% of the winds are less than 4 m/s and 100% of the winds are less than 25 m/s; hence the time frequency of wind speeds suitable for energy production in Buckland is approximately 50 percent.



Wind Roses

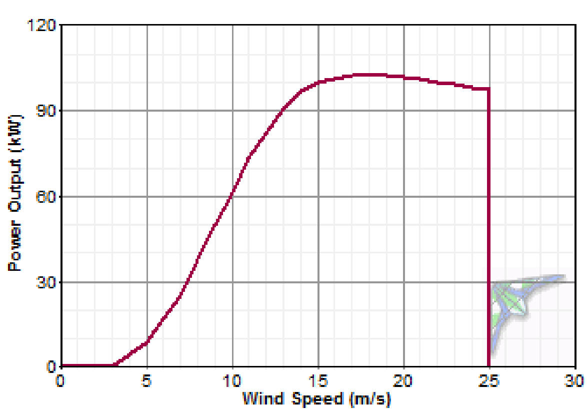
Buckland winds are highly directional east and west as seen in the frequency rose below, although in the power density rose, one can see that the power producing winds are principally easterly.





Sample Turbine Performance

For general information, predicted annual performance of a Distributed Energy Northwind 100/21 (B model) wind turbine is shown below. This turbine was selected due to its reasonably widespread use in Alaska (the A model that is), its proven performance in cold temperatures, and the commitment of the manufacturer to service their turbines in Alaska. The NW 100/21 is just entering production, has a 100 kW rated output, a 21 meter rotor diameter, is stall-controlled, and reportedly will be offered with a 25 meter or 30 meter tower. For this analysis, a 30 meter tower was chosen as it is the highest available and better suited to a lower wind speed environment. Also note that 90 percent turbine availability was assumed which is a reasonable estimate for a remote Bush Alaska community.



NW100B/21, 90% availability, 30 m hub height, annual performance

Month	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Average Net Power Output (kW)	Average Net Energy Output (kWh)	Average Net Capacity Factor (%)
Jan	5.18	48.3	5.9	22.4	16,700	22.4
Feb	4.70	36.9	0.3	15.5	10,427	15.5
Mar	4.83	35.3	0.7	15.1	11,225	15.1
Apr	4.32	35.6	0.0	10.9	7,875	10.9
May	5.52	15.8	0.0	15.8	11,733	15.8
Jun	3.77	42.2	0.0	7.4	5,360	7.4
Jul	3.48	46.3	0.0	5.6	4,161	5.6
Aug	3.67	44.0	0.0	7.3	5,443	7.3
Sep	5.22	29.4	0.4	17.2	12,384	17.2
Oct	3.37	53.7	0.0	7.5	5,586	7.5
Nov	5.16	40.7	5.8	18.1	13,050	18.1
Dec	4.90	44.4	1.8	19.2	14,311	19.2
Annual	4.51	39.4	1.2	13.5	118,255	13.5

Note that in this estimate, 118,215 kWh of electricity are produced per year. If the diesel power plant efficiency is assumed to be 12.5 kWh/gallon of fuel consumed, one turbine would displace approximately 9,450 gallons of fuel per year. If the delivered diesel fuel cost is assumed to be $4.00/gallon, the annual fuel cost savings for one turbine would be $37,800.

Appendix B, Buckland Wind Resource Report (West Hills, Site 5063)

Buckland Wind Resource Report

By: Douglas Vaught, P.E., V3 Energy LLC, Eagle River, Alaska
Date: September 17, 2010

Buckland met tower; D. Vaught photo

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Summary

The wind resource measured at the new Buckland site is good with at mid-wind power Class 3. The met tower site experiences low turbulence conditions but is subject to storm winds that raise the probability of extreme wind events higher than one might otherwise expect from a Class 3 site. Met tower site selection (new site) in Buckland was based on results of a previous met tower study at a site immediately south of the village which showed very quiet Class 1 to 2 winds. The new site is more exposed and at a much higher elevation than the village but distant from the village compared to the previous site.

Met tower data synopsis

Data dates	June 11, 2008 to March 13, 2010 (21 months)
Wind Power Class	Mid Class 3 (fair)
Power density mean, 30 meters	302 W/m^2
Wind sped mean, 30 meters	5.58 m/s
Max. 10-minute wind speed average	39.6 m/s
Maximum wind gust	44.3 m/s (January 2009)
Weibull distribution parameters	K = 1.53, c = 6.22 m/s
Wind shear power law exponent	0.0717
Roughness class	0.00
Turbulence intensity, mean	0.082
IEC 61400-1, 3rd ed. classification	Class II-C

Community profile

Current Population:	432 (2009 DCCED Certified Population)
Incorporation Type:	2nd Class City
Borough Located In:	Northwest Arctic Borough
Taxes:	Sales: 6% (City), Property: None, Special: None
National Flood Insurance Program Participant:	Yes
Coastal Management District:	Northwest Arctic Borough

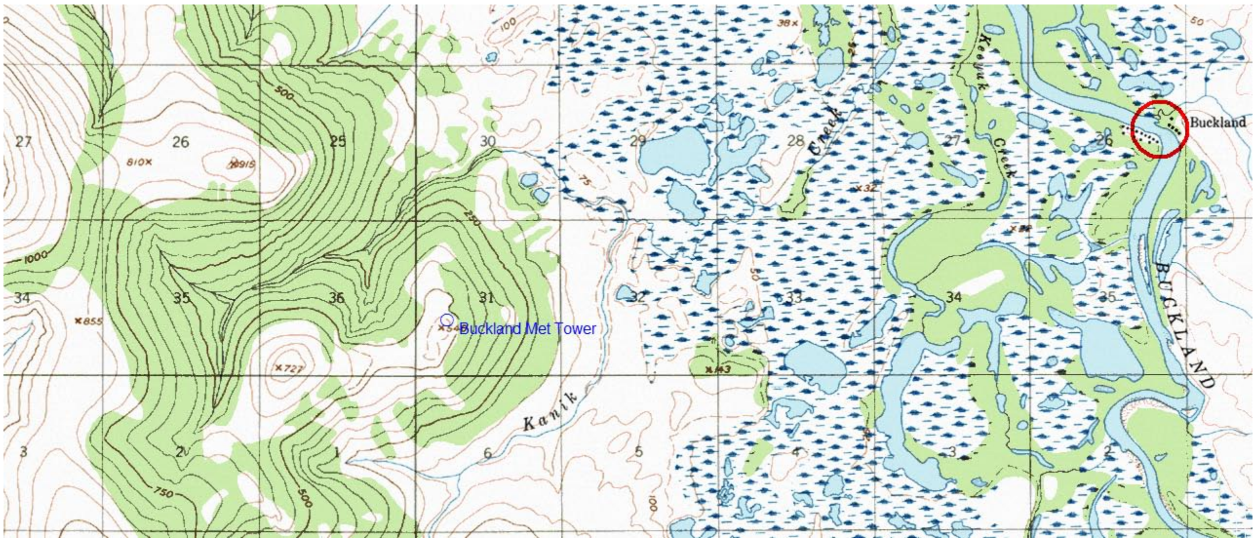
Test Site Location

The met tower was located 7 km (4.5 miles) from the western edge of the village on a plateau of the first significant hill of a north-south trending boundary range of high hills separating the river drainage where Buckland is located from Seward Peninsula to the west. The site is at 143 meters elevation but a higher hill a few kilometers west is 430 meters high. Conveniently, the site is located immediately above a rock quarry constructed to upgrade the village airport and hence an excellent road exists across the marshy bottomland separating the met tower site from the village.

Site information

Site number	5063
Latitude/longitude	N 63° 57.724’, W 161° 17.111’
Site elevation	143 meters
Datalogger type	NRG Symphonie, 10 minute time step
Tower type	NRG 30-meter tall tower, 152 mm (6 inch) diameter
Anchor type	DB88 duckbill

Topographic map image



Google Earth image

Tower sensor information

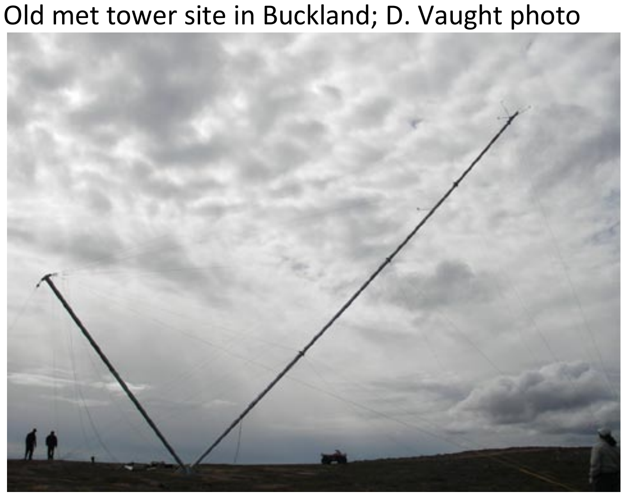
Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	30 m (A)	0.765	0.35	110° T
2	NRG #40 anemometer	30 m (B)	0.765	0.35	305° T
3	NRG #40 anemometer	20 m	0.765	0.35	110° T
7	NRG #200P wind vane	30 m	0.351	220	040° T
9	NRG #110S Temp C	2 m	0.136	-86.383	N

Photographs

Installation crew; D. Vaught photo

Old met tower site in Buckland; D. Vaught photo

Transporting tower parts to site; D. Vaught photo



Raising the met tower; D. Vaught photo

Data Recovery

The quality of data from the (new) Buckland met tower was acceptable to describe the essentials of the wind resource, but unfortunately the temperature sensor never worked properly and data from it was deleted. Temperature data from the airport AWOS was substituted for this report. Also, the 30 meter B anemometer often exhibited odd behavior which necessitated deleted a higher percentage of its data than from the other sensors. For the remaining sensors, the relatively minor data loss was due to apparent winter icing events. Although the met tower site is at an elevation potentially susceptible to rime icing conditions, rime ice does not appear to a factor in the data loss which likely is attributable to freezing rain and sleet conditions.

Data recovery summary table

Label	Units	Height	Possible Records	Valid Records	Recovery Rate (%)
Speed 30 m A	m/s	30 m	92,250	89,623	97.2
Speed 30 m B	m/s	30 m	92,250	83,390	90.4
Speed 20 m	m/s	20 m	92,250	89,919	97.5
Direction 30 m	°	30 m	92,250	87,247	94.6
Temperature	°C		92,250	0	0.0

Anemometer data recovery

			30 m A		30 m B		20 m	
Year	Month	Possible Records	Valid Records	Recovery Rate (%)	Valid Records	Recovery Rate (%)	Valid Records	Recovery Rate (%)
2008	Jun	2,970	2,805	94.4	2,805	94.4	2,805	94.4
2008	Jul	4,464	4,464	100.0	4,464	100.0	4,464	100.0
2008	Aug	4,464	4,464	100.0	4,464	100.0	4,464	100.0
2008	Sep	4,320	4,320	100.0	4,320	100.0	4,320	100.0
2008	Oct	4,464	4,265	95.5	4,315	96.7	4,315	96.7
2008	Nov	4,320	3,463	80.2	3,548	82.1	3,590	83.1
2008	Dec	4,464	4,464	100.0	4,464	100.0	4,464	100.0
2009	Jan	4,464	4,464	100.0	4,464	100.0	4,464	100.0
2009	Feb	4,032	4,032	100.0	3,472	86.1	4,032	100.0
2009	Mar	4,464	4,464	100.0	3,626	81.2	4,464	100.0
2009	Apr	4,320	4,320	100.0	3,948	91.4	4,320	100.0
2009	May	4,464	4,271	95.7	3,848	86.2	4,464	100.0
2009	Jun	4,320	4,320	100.0	4,227	97.9	4,320	100.0
2009	Jul	4,464	4,464	100.0	4,464	100.0	4,464	100.0
2009	Aug	4,464	4,464	100.0	4,230	94.8	4,464	100.0
2009	Sep	4,320	4,320	100.0	4,199	97.2	4,320	100.0
2009	Oct	4,464	4,464	100.0	4,464	100.0	4,464	100.0
2009	Nov	4,320	3,706	85.8	3,644	84.4	3,706	85.8
2009	Dec	4,464	4,418	99.0	3,781	84.7	4,464	100.0
2010	Jan	4,464	4,464	100.0	3,673	82.3	4,464	100.0
2010	Feb	4,032	3,479	86.3	2,604	64.6	3,359	83.3
2010	Mar	1,728	1,728	100.0	366	21.2	1,728	100.0
All data		92,250	89,623	97.2	83,390	90.4	89,919	97.5

Wind Speed

Wind data collected from the met tower, from the perspective of mean wind speed and mean wind power density, indicates a good wind resource for wind power development. Although not considered in the power density calculations because the temperature sensor was inoperative for the duration of the test period, the cold arctic winter temperatures in Buckland would increase wind power density above that reported below. Although not strictly necessary for this analysis, missing anemometer data was synthesized to illustrate a more complete wind profile, especially for the 30 meter B (channel 2) sensor. The synthetic data results in some curve smoothing, but does not significantly change the analysis.

Anemometer data summary

	Original Data			Synthesized data		
Variable	Speed 30 m A	Speed 30 m B	Speed 20 m	Speed 30 m A	Speed 30 m B	Speed 20 m
Measurement height (m)	30	30	20	30	30	20
Mean wind speed (m/s)	5.65	5.27	5.51	5.64	5.64	5.50
Max 10-min avg wind speed (m/s)	39.2	39.6	38.0			
Max gust wind speed (m/s)	43.6	44.3	43.9			
Weibull k	1.53	1.67	1.54	1.53	1.55	1.54
Weibull c (m/s)	6.22	5.85	6.06	6.20	6.19	6.04
Mean power density (W/m²)	302	210	278	300	293	275
Mean energy content (kWh/m²/yr)	2,646	1,842	2,432	2,629	2,567	2,409
Energy pattern factor	2.78	2.41	2.76	2.78	2.72	2.76
1-hr autocorrelation coefficient	0.895	0.867	0.893	0.894	0.892	0.893
Diurnal pattern strength	0.070	0.073	0.075	0.068	0.07	0.076
Hour of peak wind speed	17	17	16	17	17	16

Time Series

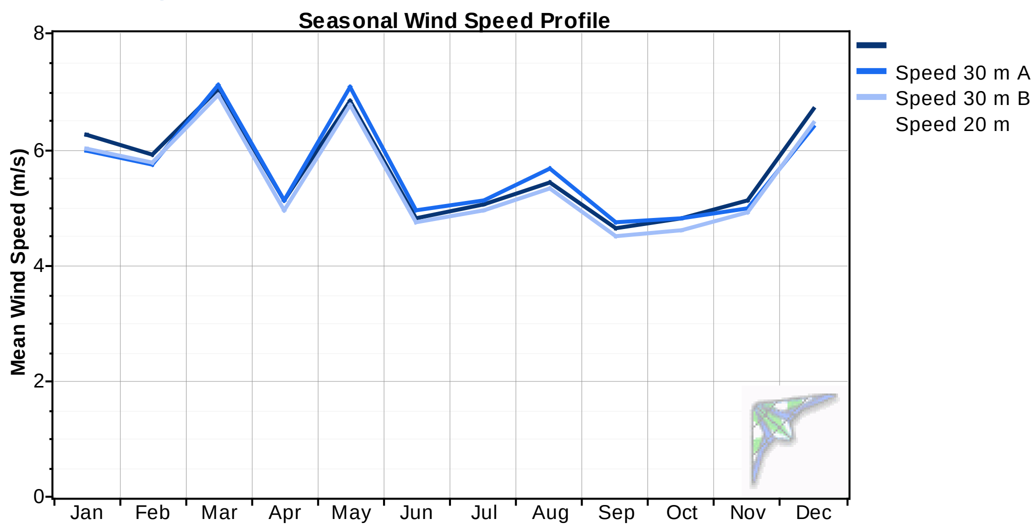
As is the typical rule in Alaska, the Buckland met tower site experiences higher winds in the winter compared to summer. The higher winds of March and May compared to April are likely a measurement artifact that would smooth out with a multi-year data view.

30m A anemometer data summary

		Original 30 m A Data					Synth Data Added	
Year	Month	Mean (m/s)	Max 10-min avg (m/s)	Max gust (m/s)	Weibull k (-)	Weibull c (m/s)	Mean (m/s)	Ratio: synth to original mean spd (-)
2008	Jun	4.98	15.1	16.8	1.79	5.58	4.88	98.1%
2008	Jul	5.62	15.5	18.7	2.02	6.33	5.62	100.0%
2008	Aug	4.88	17.9	21.8	1.74	5.47	4.88	100.0%
2008	Sep	4.72	16.1	17.9	1.77	5.29	4.72	100.0%

2008	Oct	4.73	15.3	18.3	1.70	5.29	4.63	97.9%
2008	Nov	5.49	16.0	19.1	2.19	6.17	5.36	97.7%
2008	Dec	6.53	22.2	26.0	1.93	7.33	6.53	100.0%
2009	Jan	6.45	39.2	43.6	1.19	6.85	6.45	100.0%
2009	Feb	7.93	30.6	35.2	1.35	8.64	7.93	100.0%
2009	Mar	7.27	27.2	30.9	1.64	8.12	7.27	100.0%
2009	Apr	5.11	21.0	28.7	1.29	5.52	5.11	100.0%
2009	May	6.71	19.7	24.0	1.93	7.57	6.83	101.8%
2009	Jun	4.75	17.3	21.4	1.75	5.34	4.75	100.0%
2009	Jul	4.49	18.7	22.1	1.80	5.07	4.49	100.0%
2009	Aug	5.94	26.7	31.3	1.71	6.68	5.94	100.0%
2009	Sep	4.54	20.9	25.2	1.58	5.05	4.54	100.0%
2009	Oct	4.95	14.3	17.6	1.68	5.52	4.95	100.0%
2009	Nov	4.90	17.4	21.4	1.61	5.48	4.85	99.0%
2009	Dec	6.94	22.3	24.4	1.58	7.68	6.89	99.3%
2010	Jan	6.06	21.1	22.6	1.61	6.75	6.06	100.0%
2010	Feb	3.70	16.9	20.6	1.38	4.05	3.86	104.2%
2010	Mar	6.46	22.0	27.1	1.19	6.83	6.46	100.0%
MMM Annual		5.65	39.2	43.6	1.53	6.22	5.64	99.8%

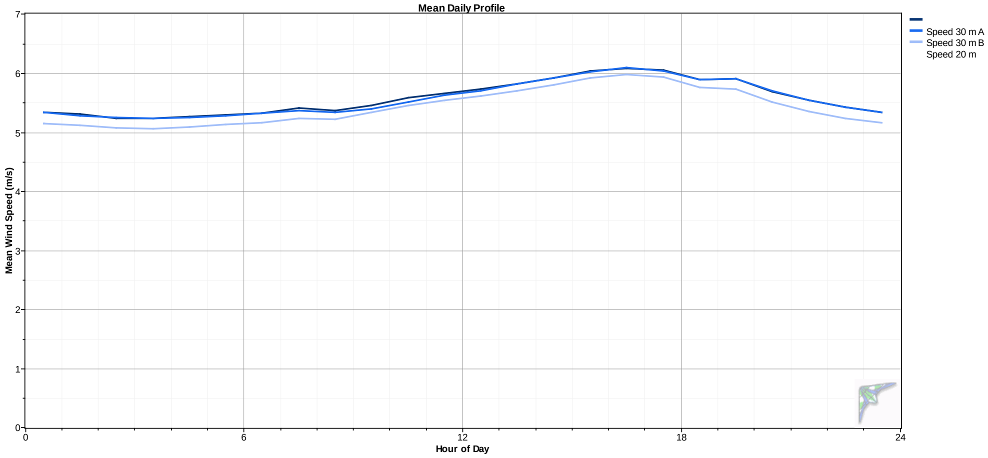
Time series graph (synth. data)



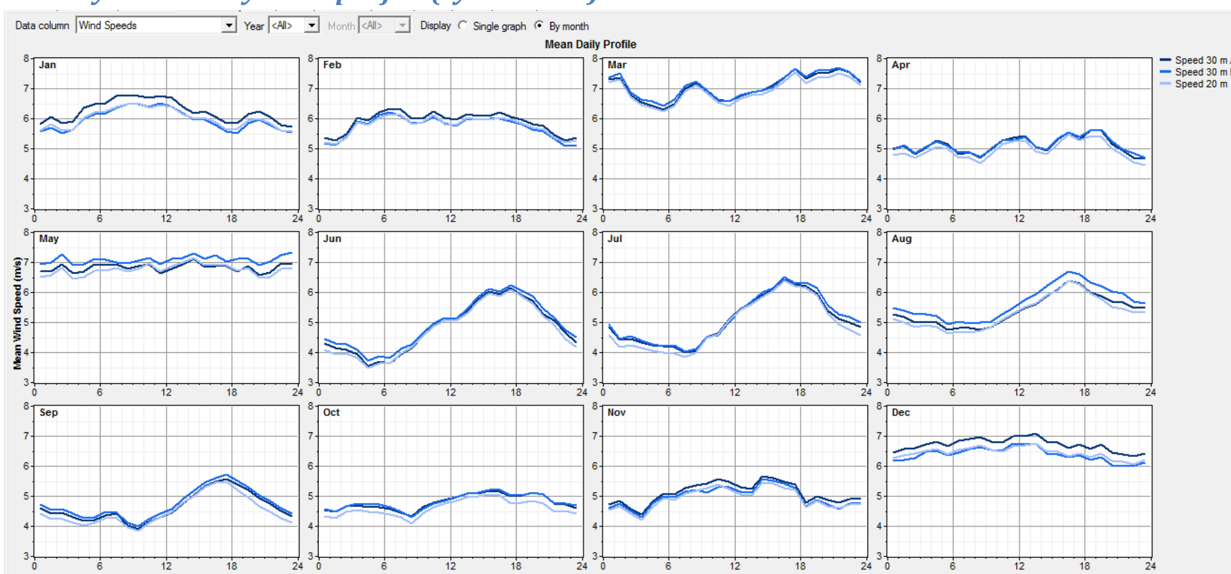
Daily Wind Profile

The average daily wind profile in Buckland indicates somewhat significant diurnal variability of wind speeds throughout the day, with lowest wind speeds in the very early morning hours and highest wind speeds during late afternoon. This coincides nicely of course with typical electrical energy usage patterns.

Annual-basis daily wind profile (synth. data)



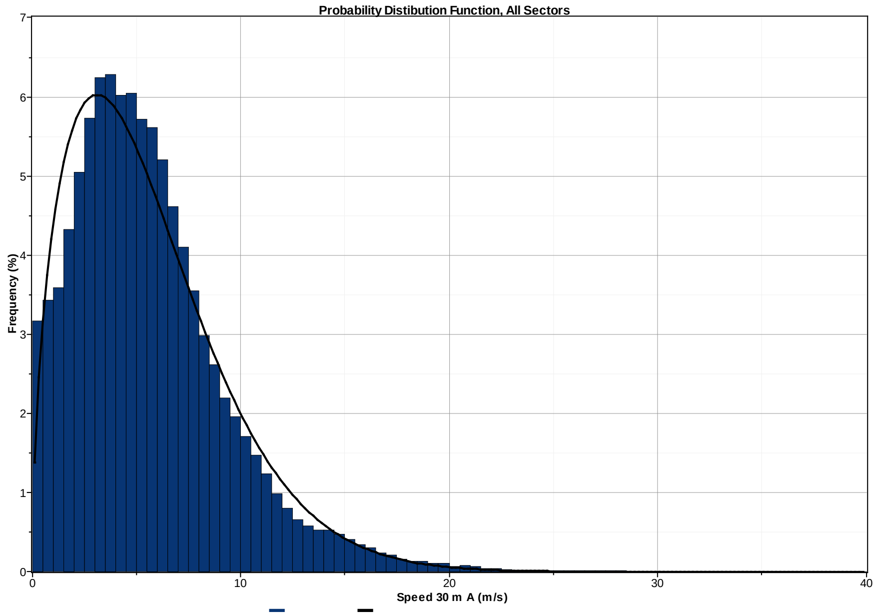
Monthly-basis daily wind profile (synth. data)



Probability Distribution Function

The probability distribution function (PDF), or histogram, of the 30 meter A wind speeds indicates wind speed "bins" oriented toward the lower speeds compared to a normal wind power shape curve of k=2.0, otherwise known as the Raleigh distribution. Note in the cumulative frequency table below that 37.8 percent of the winds are less the 4 m/s, the cut-in wind speed of most wind turbines.

PDF of 30 m A anemometer



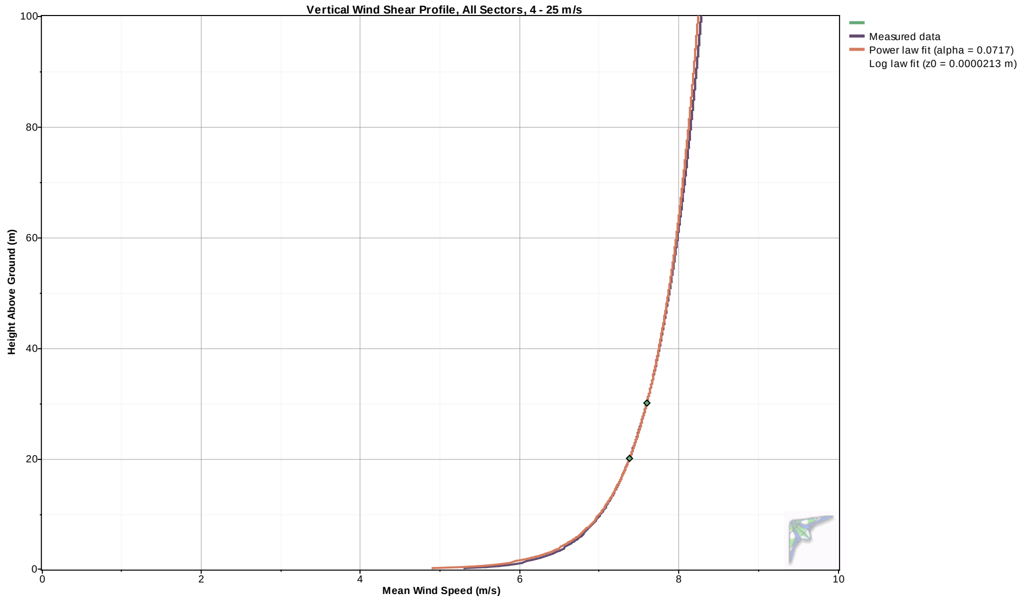
Cumulative frequency table

Bin (m/s) Lower	Bin (m/s) Upper	Occurrences	Freq. (%)	Cum. Freq. (%)	Bin (m/s) Lower	Bin (m/s) Upper	Occurrences	Freq. (%)	Cum. Freq. (%)
0	1	5,911	6.60	6.60	21	22	100	0.11	99.8
1	2	7,092	7.91	14.5	22	23	54	0.06	99.8
2	3	9,654	10.77	25.3	23	24	33	0.04	99.8
3	4	11,219	12.52	37.8	24	25	20	0.02	99.9
4	5	10,815	12.07	49.9	25	26	28	0.03	99.9
5	6	10,152	11.33	61.2	26	27	23	0.03	99.9
6	7	8,801	9.82	71.0	27	28	21	0.02	99.9
7	8	6,848	7.64	78.7	28	29	11	0.01	100.0
8	9	5,013	5.59	84.2	29	30	5	0.01	100.0
9	10	3,725	4.16	88.4	30	31	5	0.01	100.0
10	11	2,855	3.19	91.6	31	32	6	0.01	100.0
11	12	1,983	2.21	93.8	32	33	2	0.00	100.0
12	13	1,306	1.46	95.3	33	34	3	0.00	100.0
13	14	992	1.11	96.4	34	35	5	0.01	100.0
14	15	894	1.00	97.4	35	36	3	0.00	100.0
15	16	665	0.74	98.1	36	37	2	0.00	100.0
16	17	478	0.53	98.6	37	38	1	0.00	100.0
17	18	330	0.37	99.0	38	39	1	0.00	100.0
18	19	238	0.27	99.3	39	40	1	0.00	100.0
19	20	194	0.22	99.5	All		89,623	100.0	100.0
20	21	134	0.15	99.6					

Wind Shear and Roughness

A wind shear power law exponent of 0.0717 indicates very low wind shear at the test site; hence wind turbine construction at a low hub height may be a desirable option. Related to wind shear, a calculated surface roughness of 9.08 EE-6 meters (the height above ground level where wind velocity would be zero) indicates extremely smooth terrain (roughness description: smooth) surrounding the met tower.

Vertical wind shear profile, 4 m/s < wind < 25 m/s



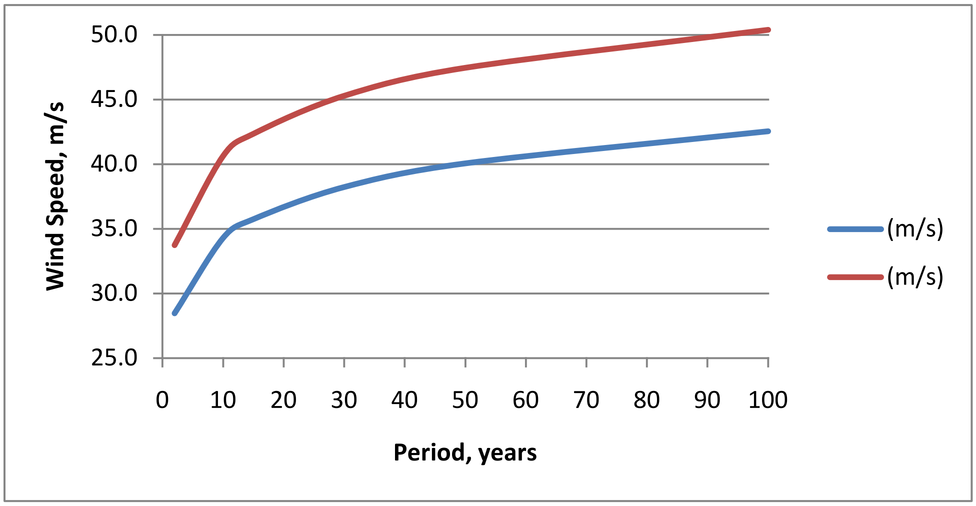
Extreme Winds

The relatively short duration of Buckland met tower data should be considered minimal for calculation of extreme wind probability, but nevertheless it can be estimated with a reasonable level of accuracy. Analysis indicates that Buckland experiences sufficiently robust storm and other high wind events to exceed IEC 61400-1, 3rd edition (2005), Class III criteria and hence classifies as an IEC Class II wind site.

Extreme wind speed probability table

Period (years)	V_{ref} (m/s)	Gust (m/s)	IEC 61400-1, 3rd ed. Class	V_{ref}, m/s
2	28.5	33.7	I	50.0
10	34.3	40.6	II	42.5
15	35.7	42.3	III	37.5
30	38.2	45.3	S	designer-specified
50	40.0	47.5		
100	42.5	50.4		
average gust factor:	1.18			

Extreme wind probability graph



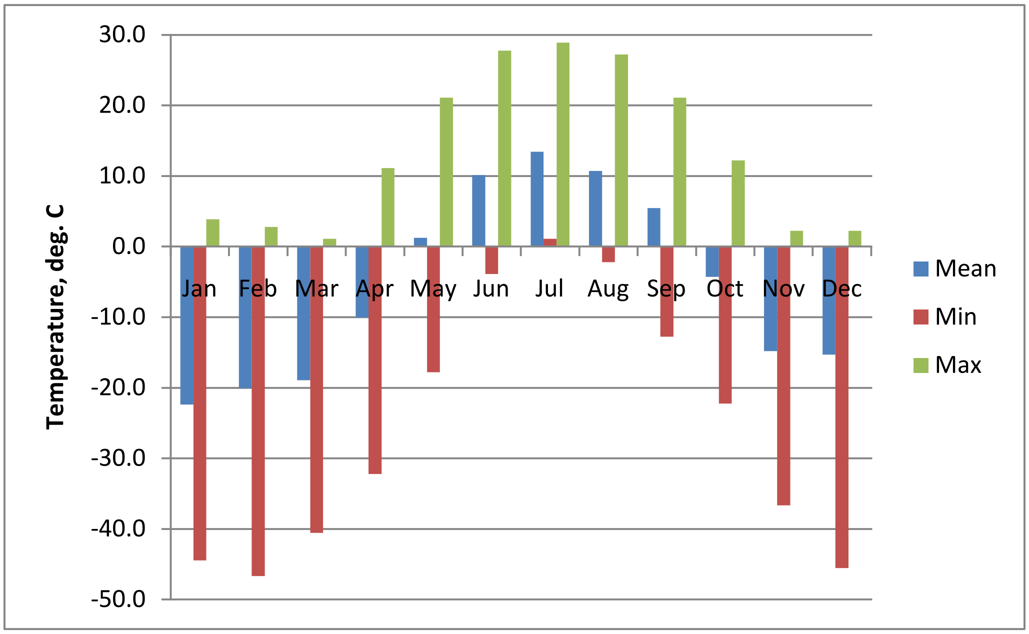
Temperature and Density

The temperature sensor on the met tower, for reasons not understood, did not work properly during the test period. Hence, temperature data from the Buckland airport AWOS are referenced below. This data represents a six year time period – July 2004 to July 2010. Air density was not directly measured, but calculated using standard pressure at eight meters (elevation of the airport) and the ideal gas law. Note that Buckland experiences a typical continental arctic climate with extremely cold winters and cool summers. On many occasions, temperatures colder than -40° C, the minimum operating temperature of arctic-rated wind turbines, were recorded. Of course, it is possible that the airport and village environs, due to inversion effects, experience colder temperatures than the higher elevation met tower site.

Temperature and density table

	Temperature			Air Density		
	Mean (°C)	Min (°C)	Max (°C)	Mean (kg/m^3)	Max (kg/m^3)	Min (kg/m^3)
Jan	-22.4	-44.4	3.9	1.407	1.543	1.273
Feb	-20.1	-46.7	2.8	1.394	1.558	1.278
Mar	-18.9	-40.6	1.1	1.388	1.517	1.286
Apr	-10.0	-32.2	11.1	1.341	1.464	1.241
May	1.2	-17.8	21.1	1.286	1.381	1.199
Jun	10.1	-3.9	27.8	1.245	1.310	1.172
Jul	13.4	1.1	28.9	1.231	1.286	1.168
Aug	10.7	-2.2	27.2	1.243	1.302	1.174
Sep	5.5	-12.8	21.1	1.266	1.355	1.199
Oct	-4.3	-22.2	12.2	1.312	1.406	1.236
Nov	-14.8	-36.7	2.2	1.365	1.492	1.281
Dec	-15.3	-45.6	2.2	1.368	1.550	1.281
Annual	-4.1	-46.7	28.9	1.311	1.558	1.168

Temperature graph



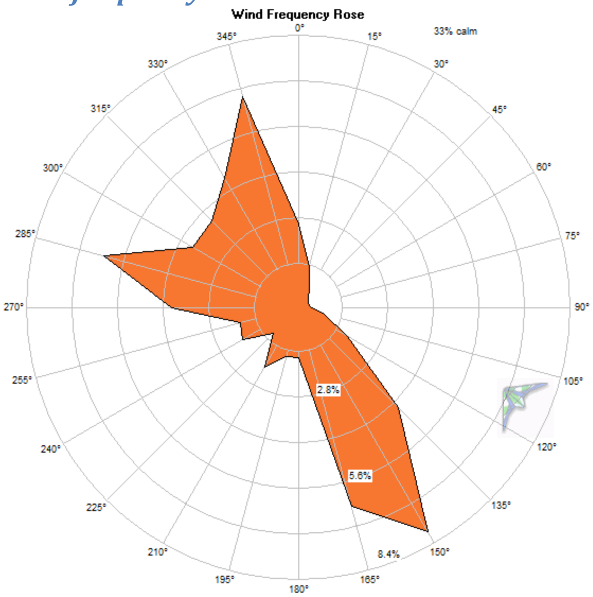
Temperature table, Fahrenheit and Celsius

	Temp (°F)			Temp (°C)		
	Mean	Min	Max	Mean	Min	Max
Jan	-8.3	-48	39	-22.4	-44.4	3.9
Feb	-4.1	-52	37	-20.1	-46.7	2.8
Mar	-2.1	-41	34	-18.9	-40.6	1.1
Apr	13.9	-26	52	-10.0	-32.2	11.1
May	34.2	0	70	1.2	-17.8	21.1
Jun	50.2	25	82	10.1	-3.9	27.8
Jul	56.2	34	84	13.4	1.1	28.9
Aug	51.3	28	81	10.7	-2.2	27.2
Sep	41.8	9	70	5.5	-12.8	21.1
Oct	24.3	-8	54	-4.3	-22.2	12.2
Nov	5.4	-34	36	-14.8	-36.7	2.2
Dec	4.5	-50	36	-15.3	-45.6	2.2
Annual	24.5	-52	84	-4.1	-46.7	28.9

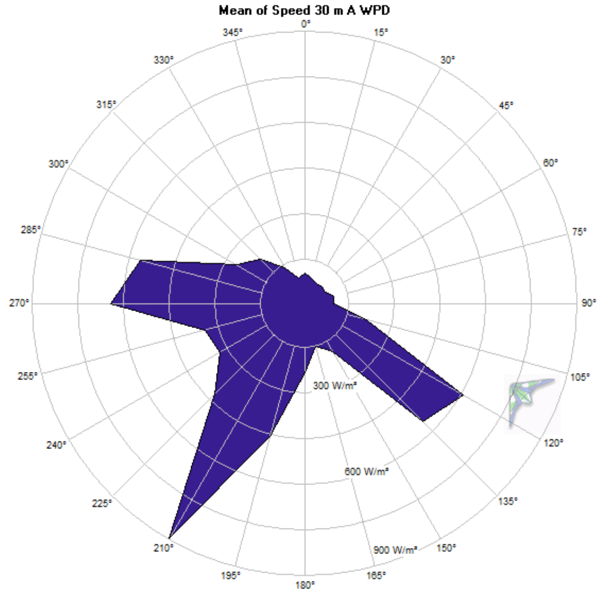
Wind Direction

The wind frequency rose for the Buckland test site indicates predominately southeast and west-northwest to north-northwest winds. Interestingly, though, although a minor frequency component, southwest winds, when present, are exceptionally strong. Integrating the two roses, one can see with the wind energy rose that predominate power winds are southwest and west-northwest with a lesser extent of southwest winds.

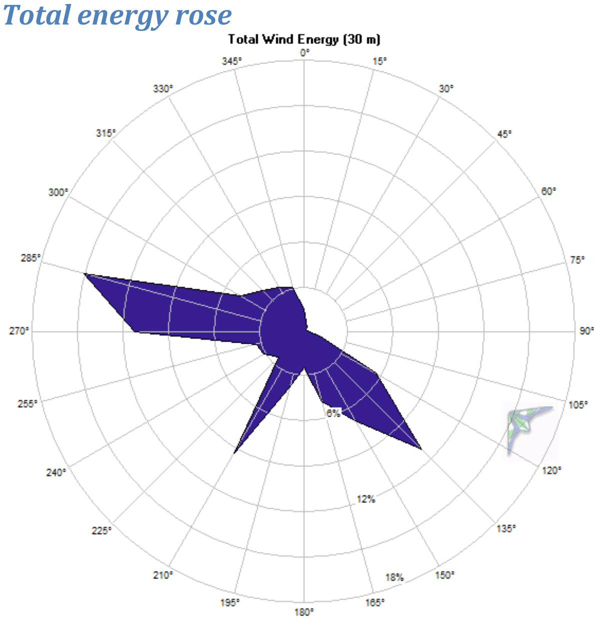
Wind frequency rose



Mean value rose



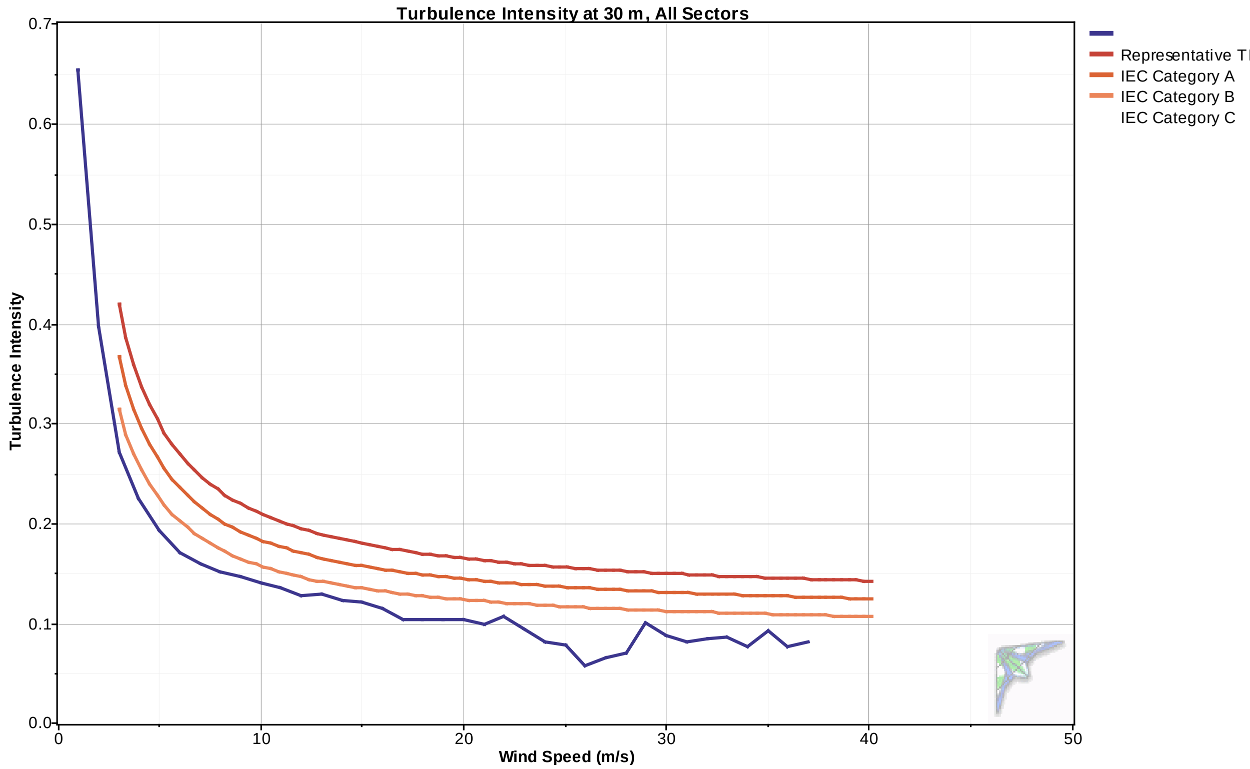
Total energy rose



Turbulence

Turbulence intensity at the Buckland test site is well within acceptable standards for wind power development with an International Electrotechnical Commission (IEC) 61400-1, 3rd edition (2005), classification of turbulence category C, which is the lowest defined. Mean turbulence intensity at 15 m/s is 0.082.

Turbulence intensity, all wind sectors



Turbulence table

Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Upper (m/s)	Records In Bin	Mean TI	Standard Deviation of TI	Representative TI	Peak TI
1	0.5	1.5	6,284	0.436	0.170	0.653	1.286
2	1.5	2.5	8,398	0.238	0.125	0.397	1.063
3	2.5	3.5	10,723	0.162	0.086	0.271	0.840
4	3.5	4.5	11,024	0.135	0.070	0.225	0.821
5	4.5	5.5	10,542	0.119	0.059	0.194	0.851
6	5.5	6.5	9,696	0.107	0.050	0.170	0.500
7	6.5	7.5	7,803	0.102	0.045	0.159	0.412
8	7.5	8.5	5,846	0.099	0.041	0.152	0.407
9	8.5	9.5	4,316	0.096	0.040	0.147	0.441
10	9.5	10.5	3,287	0.093	0.037	0.140	0.379
11	10.5	11.5	2,430	0.090	0.035	0.135	0.342
12	11.5	12.5	1,595	0.087	0.032	0.127	0.244
13	12.5	13.5	1,108	0.088	0.033	0.130	0.228
14	13.5	14.5	940	0.084	0.030	0.122	0.353
15	14.5	15.5	789	0.082	0.030	0.121	0.260
16	15.5	16.5	568	0.078	0.029	0.115	0.261
17	16.5	17.5	398	0.073	0.024	0.103	0.171

18	17.5	18.5	265	0.072	0.024	0.103	0.178
19	18.5	19.5	213	0.071	0.025	0.104	0.229
20	19.5	20.5	159	0.070	0.027	0.104	0.181
21	20.5	21.5	132	0.066	0.025	0.098	0.145
22	21.5	22.5	75	0.071	0.028	0.107	0.207
23	22.5	23.5	36	0.069	0.020	0.095	0.124
24	23.5	24.5	26	0.059	0.018	0.081	0.115
25	24.5	25.5	24	0.056	0.018	0.078	0.102
26	25.5	26.5	27	0.049	0.007	0.058	0.066
27	26.5	27.5	25	0.052	0.011	0.065	0.071
28	27.5	28.5	15	0.058	0.010	0.070	0.074
29	28.5	29.5	7	0.080	0.016	0.100	0.109
30	29.5	30.5	4	0.073	0.012	0.087	0.083
31	30.5	31.5	4	0.072	0.007	0.081	0.081
32	31.5	32.5	4	0.073	0.008	0.084	0.085
33	32.5	33.5	4	0.077	0.007	0.087	0.087
34	33.5	34.5	3	0.071	0.004	0.076	0.076
35	34.5	35.5	3	0.082	0.009	0.093	0.090
36	35.5	36.5	4	0.065	0.008	0.076	0.075
37	36.5	37.5	2	0.069	0.009	0.081	0.075
38	37.5	38.5	0				
39	38.5	39.5	2	0.060	0.001	0.062	0.061
40	39.5	40.5	0				

Airport AWOS Data

Analysis of Buckland airport AWOS wind speed data from July 2004 (date AWOS was installed) to July 2010 indicates that in general, the wind resource at the met tower site is significantly better than at the airport and presumably similar elevations in its vicinity. A trend of the AWOS data (see graph) indicates slightly decreasing average wind speeds from 2004 to 2010, but the time period is too short to be statistically significant enough to scale the met tower data against.

Airport/met tower data comparison

	AWOS, 10 m sensor (m/s)	AWOS data scaled to 30 m (m/s)	Met tower 30 m A (m/s)
Jan	3.20	3.73	6.25
Feb	3.65	4.26	5.89
Mar	4.02	4.69	7.04
Apr	4.39	5.12	5.11
May	4.10	4.78	6.83
Jun	3.42	3.99	4.81

Jul	3.02	3.52	5.05
Aug	2.99	3.49	5.41
Sep	3.05	3.56	4.63
Oct	2.41	2.81	4.79
Nov	2.58	3.01	5.11
Dec	3.43	4.00	6.71
Annual	3.34	3.90	5.64

Buckland Airport AWOS wind speed graph