Deering 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 Deering, Alaska.

Contents

Executive Summary

The purpose of this feasibility study is to assist the Northwest Arctic Borough, the City of Deering, and the Ipnatchiaq Electric Company in evaluating the potential for wind power in Deering, Alaska with goals of reducing the village's near complete reliance on fossil fuel, exploiting a locally sustainable and renewable energy resource, and providing a secure foundation for positive economic advancement over time for residents of the village.

Initial work on this effort began in 2008 with installation of a meteorological test tower to measure the wind. Deering has a mid-range wind resource and though somewhat less windy by comparison to Yukon-Kuskokwim Delta villages, Deering has higher fuel costs which provide a trade-off of resource versus avoided fuel expense. More recent work has included an evaluation of the existing power system and modeling of the power system and village electric and thermal loads in order to evaluate wind turbines in a wind-diesel hybrid system.

This feasibility study includes the evaluation of five scenarios thought suitable for Deering: low penetration wind with no power plant improvements, low penetration wind with power plant improvements, medium penetration wind at a near-village site, medium penetration at more distant site, and high penetration wind (the latter three which require other design features in addition to power plant improvements). All five configuration scenarios or options are technically possible in Deering although naturally the level of complexity increases from Scenario 1 to 5. With HOMER modeling all scenarios and options indicate a benefit to cost ratio of greater than 1.0 with reference to UAA's Institute of Social and Economic Research (ISER)'s 2011 fuel price projection spreadsheet. If fuel prices increase beyond ISER's projections, the benefits of wind power to displace the use of fossil fuel to generate electricity and provide heat would increase and the economic benefits would correspondingly increase.

Although a wind turbine for this project has not yet been chosen, a number of highly suitable wind turbines are identified in this study for low to high penetration wind power generation in Deering. These turbines represent both established and relatively new manufacturing companies, are available from Alaska suppliers, have cold climate certificate or capability, can be installed without need for a crane (for the smaller turbines), and for the Gaia-Wind 11 in particular, are specifically designed for lower wind speed environments.

Based on the modeling results, review meetings, discussions with the project stakeholders, and the desire to balance present utility capability with future potential and possibility for the City of Deering, Scenario 2, low penetration wind with power plant improvements is recommended as the first phase of a wind power development effort that will transition in one to two years to a second phase of medium to high penetration wind (Scenario 3, 4 or 5), which could involve installation of larger turbines than those chosen in Scenario 2 in order to maximize fuel displacement.

Introduction

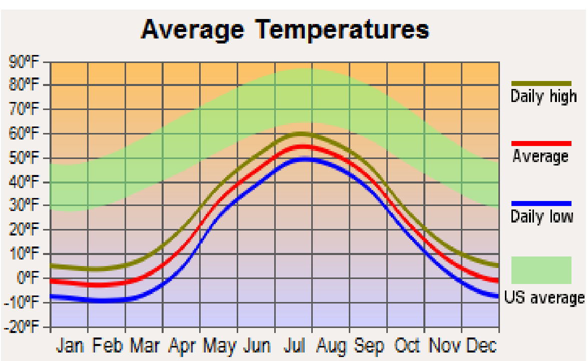
Northwest Alaska is an area with abundant wind energy resources. In 2007, the U.S. Department of Energy's Tribal Energy Program awarded NANA Regional Corporation (NRC) grant #DE-FG36-07GO17076 to fund a Wind Resource Assessment Project (WRAP) for the NANA region. The Deering wind site was identified on a ridge near Cape Deceit, about one mile west of the community. A meteorological ("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.

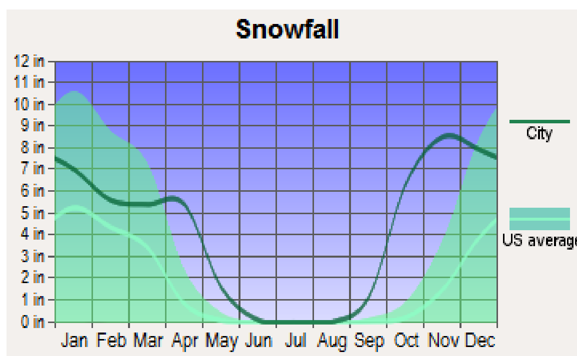
Village of Deering

Deering is located on Kotzebue Sound at the mouth of the Inmachuk River, 57 miles southwest of Kotzebue. It is built on a sand and gravel spit 300 feet wide and a half-mile long. According to Census 2010, there are 61 housing units in the community and 44 are occupied. Its population of 122 people is 87 percent Alaska Native, 9 percent white and 4 percent multi-racial. Deering is located in the transitional climate zone, which is characterized by long, cold winters and cool summers. Annual snowfall averages 36 inches, and total precipitation averages 9 inches per year. Kotzebue Sound is ice-free from early July until mid-October.

Deering temperatures



Deering snowfall



Potential Alternative Energy Resources

At present, all of Deering'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.

Regarding the supply of alternative or renewable energy resources, a 1979 study by the U.S. Department of Energy concluded that there are no potential hydroelectric sites near enough to Deering to develop for village power needs.

Although Deering is located above the Arctic Circle and hence would have a limited wintertime solar energy resource at best, solar power for utility and/or residential application should be considered as a possible future means of reducing diesel fuel consumption.

A low BTU and hence low quality coal resource is located 25 miles southeast of Deering. However several studies have indicated that the resource would be very costly to develop and would not be economically viable at a small scale. No significant coal resource development plans are in place as of this writing.

The only community within reasonable distance for an electrical intertie (connecting power line) is Buckland. The distance between Buckland and Deering is about 50 miles, including several low mountain ridges, making an intertie very expensive and hence would not result in any cost-saving benefits from sharing power generation capacity between the communities.

As of this writing, wind power has been identified as the only viable renewable energy resource available at or near Deering for the purpose of integration with the diesel power plant to create a hybrid power system. Other power supply alternatives and/or efficiency measures, especially on the home or facility level, may be possible and highly advantageous, but these would best be addressed in a comprehensive community energy plan, which this report does not purport to be.

Public Participation

In June 2010 a public forum was held at the Deering City building in Deering to discuss wind energy as a source of power for the community. The wind-diesel hybrid power system project concept as discussed in this feasibility study was presented and explored. Several residents expressed support for wind energy, saying that a reduction in the community's overall diesel fuel consumption and cost of energy is highly desired.

Public forum in Deering, June2010

Deering's Electric Power System

Electric power is provided to Deering by Ipnatchiaq Electric Company (IEC), a subsidiary of the City of Deering. The power plant is co-located with a water treatment plan and washeteria. The combined facilities were constructed in early 2000 to replace and upgrade earlier systems. Five diesel generator units are installed at the power plant: four are primary units to serve the village electrical load and a fifth generator is for station service and water plant power only.

The power plant and water treatment plant and washeteria were co-located to enable use of energy from diesel engine water jacket recovered heat to supplement fuel oil boilers in the water facility.

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 PLC is incorporated into the controls and is designed to automate the operation of the power plant.

The village-wide electrical distribution system consists of three feeders: one to the east of the plant, one to the west, and one dedicated to the treatment plant. Each feeder is three phase.

According to IEC, the power plant burned 53,621 gallons of diesel fuel in FY2010 to generate 673,220 kWh of electricity. This equates to a 77 kW average load and an average fuel efficiency of 12.6 kWh/gallon. IEC's reported cost of fuel for FY2010 was $3.47/gallon ($0.92/liter). The peak recoded electrical load reported by IEC was 180 kW in January 2002.

Ipnatchiaq Electric Company powerplant diesel generators

Generator	Capacity	Diesel Engine Model, Serial #	Generator Model/Serial #
1	100 kW	John Deere 6068T, 825870	Newage UC274E, G990026900
2	138 kW	John Deere 6081AF001, 094749	Newage UC274H, G990022899
3	170 kW	Cummins LTA-10G3, 34985513	Newage HCI636C, 0116853/01
4	170 kW	Cummins LTA-10G3, 34985512	Newage HCI636C, 0116560/01
Emergency	44 kW	John Deere 4045D, 824051	Newage UC224D, G990946715

PLC system generator operation sequence

Load Demand	Level	Generator Running
0 kW – 95 kW	1	1
65 kW – 131 kW	2	2
95 kW – 162 kW	3	3 or 4
130 kW – 226 kW	4	2 and 1
170 kW – 250 kW	5	3 or 4 and 1
225 kW – 315 kW	6	3 or 4 and 2
280 kW – max kW	7	3 or 4, and both 1 and 2

Heat Demand

Heating oil (diesel fuel) is the primary source of energy for space and water heating in Deering. In general, Deering consumes more diesel fuel oil for thermal (space and water heating) needs than for electric power generation. With information from the NANA Region Strategic Energy Plan, rough estimates of Deering annual heating oil consumption are shown below.

Deering annual heating oil consumption

Use	Amount (Gallons)
Residential	35,700
School	15,700
Water treatment plant	9,000
Miscellaneous	3,600
Total (existing)	~ 64,000
Multi-use facility (under construction)	13,000
Total (near future)	~ 77,000

Operational Issues

A number of substantial issues and problems have been identified that impact an efficient operation of the Deering power system in its present form. These include inoperability of the PLC-based automated switchgear, inoperability of the diesel generator water jacket heat recovery system, phase imbalances, and recent non-participation in the power cost equalization (PCE) program.

The first three issues are technical problems that will be addressed during wind turbine installation. With respect to the switchgear, it is not known at present why the power plant is operated in manual mode. This problem must be corrected though in order to accommodate wind turbines on the distribution system. Regarding heat recovery, presumably this involves temperature setpoint issues, but that has not been verified. It is recognized, however, that introducing wind power to Deering works best only when significant efficiency measures such as heat recovery are fully functional and operating efficiently. The phase imbalance problem is a bit complicated and related to seasonable load changes at the school and water plant. This may require a twice yearly load phase rebalancing effort to fully correct. Note that a technician is scheduled to visit Deering in September 2011 to asses and repair if possible problems with the heat recovery system and the PLC-based switchgear.

Deering's lack of participation in PCE as of November 2009 is an administrative issue that does not impact the power system itself, but does point to a need to improve overall utility operations before wind power is introduced to the community. Recent discussions with the City of Deering indicate that the PCE problem is related to reporting requirements of the Regulatory Commission of Alaska. IEC leadership has indicated that the problem will be corrected by the end of August 2011.

Wind Power System Configurations and Equipment

Wind-diesel power systems are categorized based on their average penetration levels, or the overall proportion of wind-generated electricity to the total amount of electric energy supplied to the system. Commonly used categories of wind-diesel penetration levels, are low penetration, medium penetration, and high penetration (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.

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	Penetration Level		Operating characteristics and system requirements
	Instantaneous	Average	
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 a 250 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. A wind-diesel system master controller, also called a supervisory controller, would be installed inside the existing Deering power plant, or in a new module adjacent to it. The supervisory controller would select the optimum system configuration based on village load (demand) and available wind power.

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

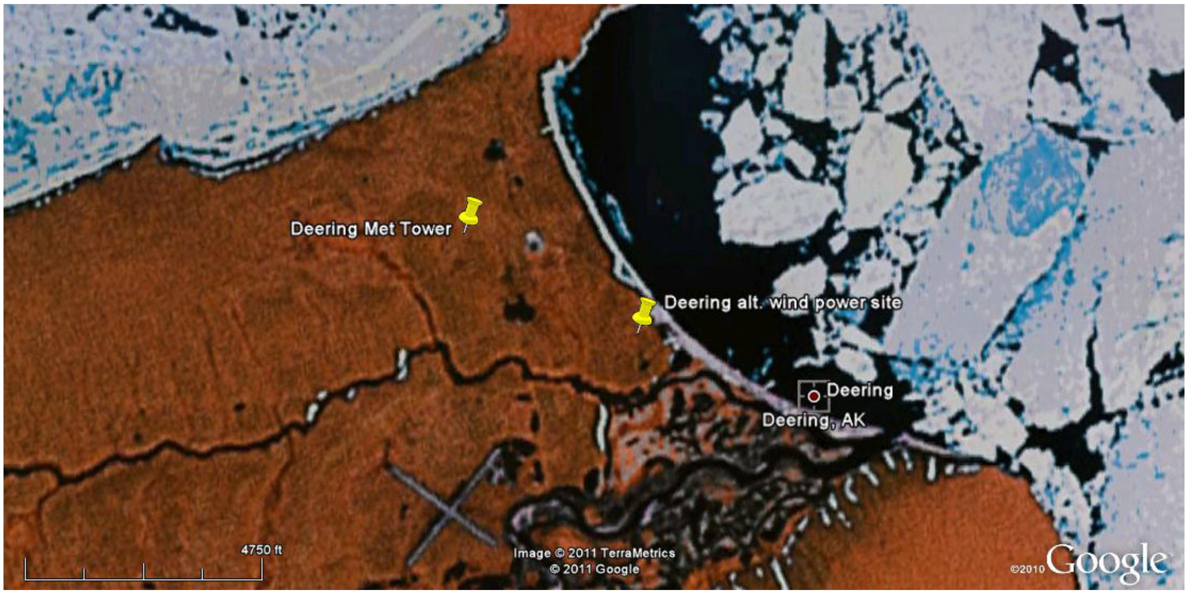
Another possible source of a supervisory control system is Controlled Power, Inc. of Bothell, WA (the original manufacturer of the Deering powerplant switchgear). The switchgear was designed to be "wind-ready" and thus uses a PLC for control of the power system. Discussions have not been held with Controlled Power on the capabilities of the PLC program and switchgear controls.

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.

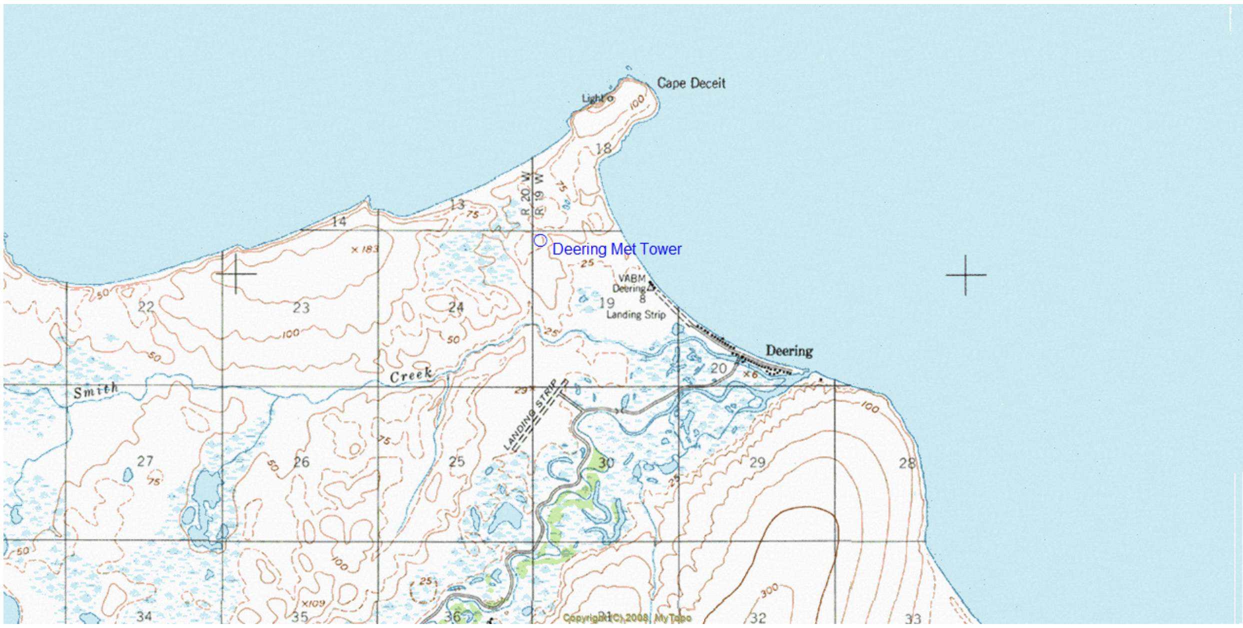
Wind Project Site

The original intent with wind power development in Deering was to install wind turbines at the met tower site located near the crest of a broad hill approximately one mile west of Deering and slightly off a jeep trail that leads to the community cemetery at Cape Deceit. That site was chosen because it has good exposure to both westerly and easterly winds, is owned by NANA Regional Corporation which is highly supportive of wind power development in the region, and its location with respect to the Deering airport runways met the approval of FAA. Recent project planning, however, has raised questions regarding the economic viability of that site for installation of smaller turbines and hence the identification of an alternate project site at the western edge of the village at approximately the point where the power distribution system terminates. The alternate site would be much less costly to develop as a distribution line extension would not be necessary, but it may have a slightly lesser wind resource compared to the met tower site due to some shadowing with westerly winds. Also, FAA considerations regarding the alternate site have not yet been explored.

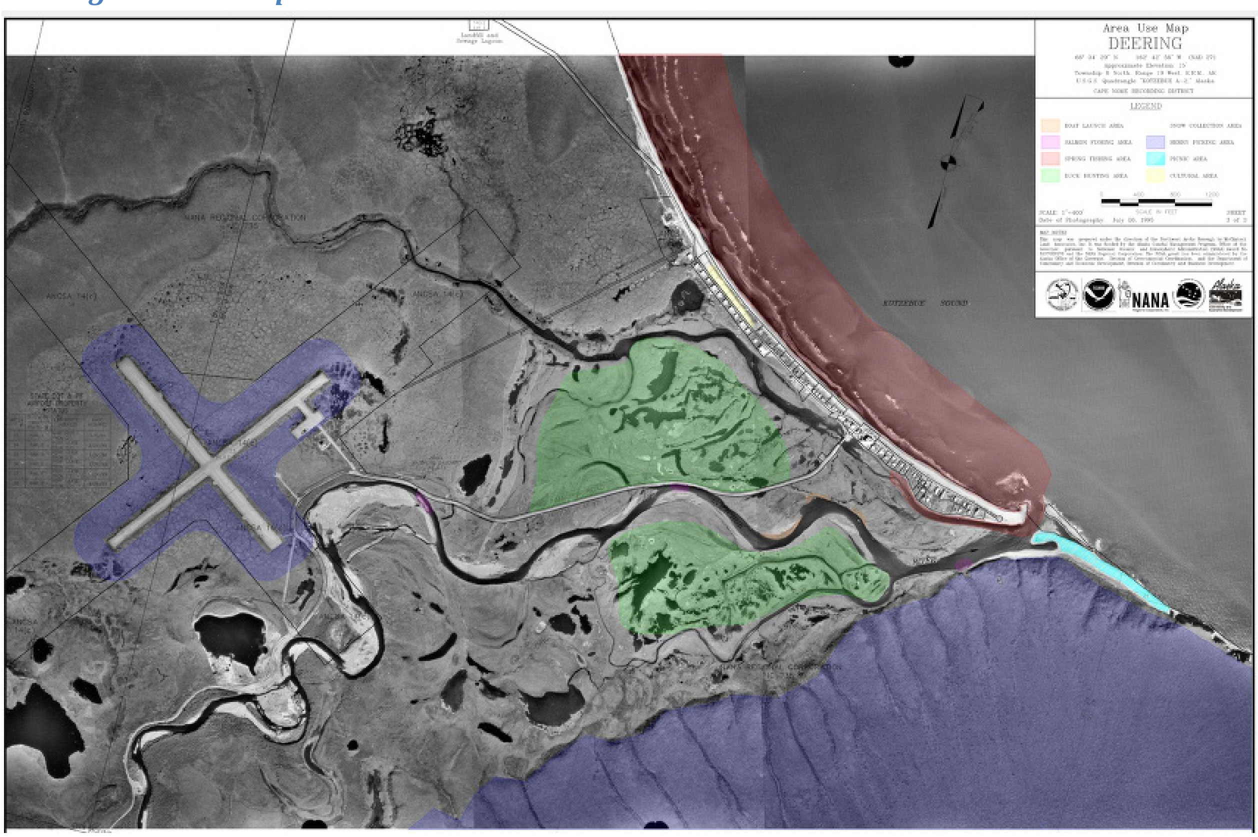
Deering and Met Tower Site



Topographic map of Deering



Deering Area Use Map



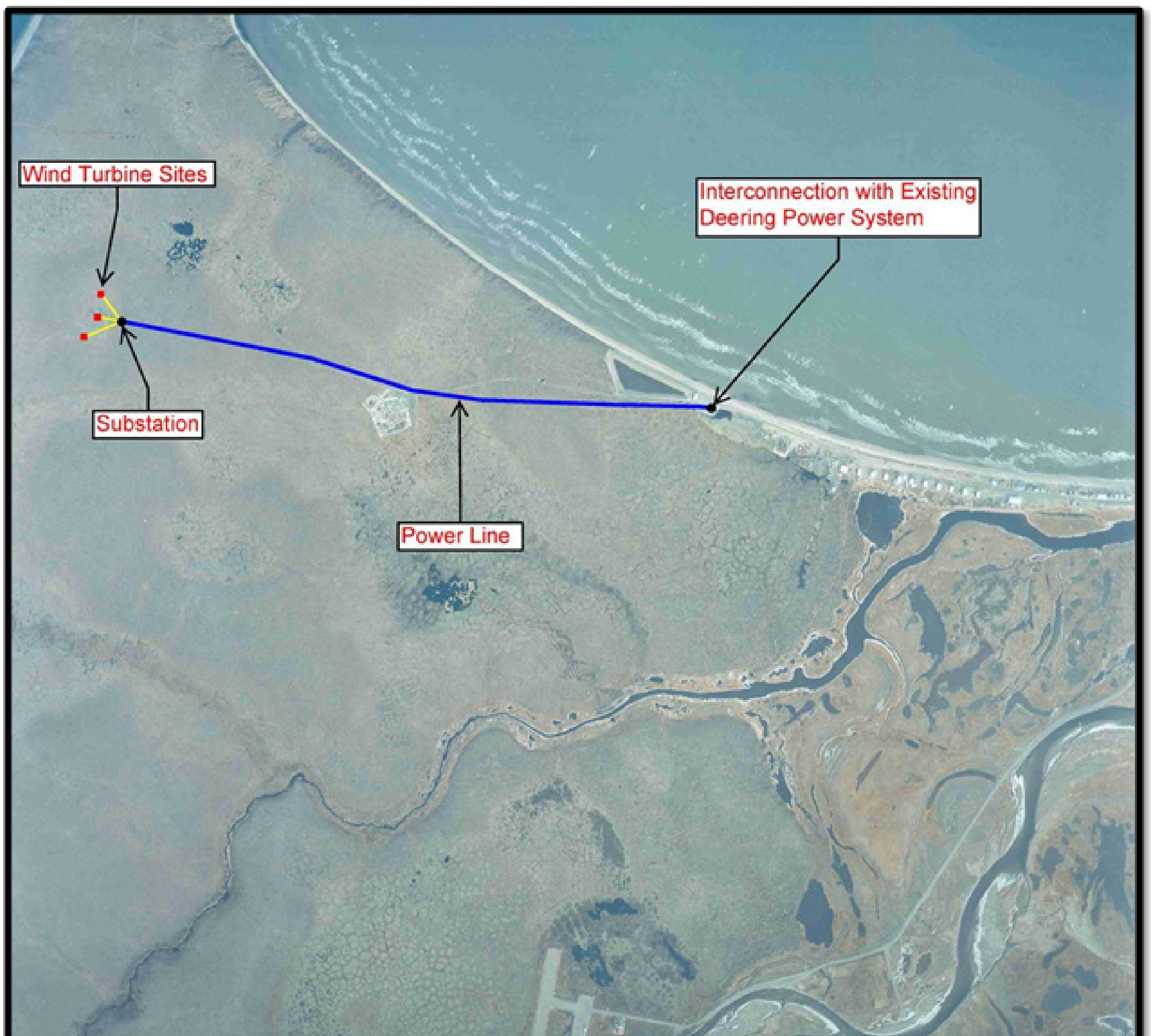
Wind Resource

The wind resource at the Deering met tower site is documented by a V3 Energy LLC report entitled "Deering Wind Resource Report, rev. 1", which is attached in Appendix A. As a brief summary, the site classifies at the high end of wind power class 3 (fair) with a mean annual wind speed of 6.00 m/s and a mean annual wind power density of 316 W/m^2 (at 30 meters elevation). The site experiences very low turbulence conditions and low wind shear conditions. Its IEC classification is III-c.

Development of the Met Tower Site

Installation of wind turbines at the met tower site will require improvements to the existing access road and additional access road (approximately 0.3 miles) and work pads must be constructed. Additionally, a distribution line extension would be required. The preliminary plan would be to construct an overhead, 15 kV extension from the western terminus of the existing distribution system, which is at Deering's vacuum sewer facility on the far western edge of the village. The new distribution extension would route adjacent to the existing jeep path and then along the new access road to the wind turbine site. If an overhead distribution is thought undesirable, a surface level (or utilidor-type) extension might be feasible. One side benefit of extending power to the met tower site is that it would allow the opportunity to provide power and lighting at the village landfill, where at present it is not available.

Distribution Line Route to the Met Tower Site



Preliminary Geotechnical Review

Geotechnical, or sub-surface, conditions in Deering and vicinity vary significantly. In the village itself along Kotzebue Sound, the beach gravel is underlain by discontinuous permafrost. Several different foundations types have been successfully used in Deering including drilled and driven piles and insulated concrete slabs on grade. Sub-surface rock and boulders are also present in Deering. The open terrain to the south and west of Deering is overlain by an intact, insulating cover of tundra vegetation. These tundra areas are expected to be underlain by continuous permafrost.

The met tower site is characterized by open tundra. Significantly continuous permafrost is expected below a shallow active (seasonal thaw) layer. The possible existence of subsurface rocks or boulders is not known at present.

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 and a review of the aggregate supply available in Deering. The analysis will include a survey of known geotechnical conditions in Deering and 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. A NANA-owned gravel source exists approximately seven miles south of Deering.

Development of the Alternate Wind Power Site

Given its proximity to the beach, it is presumed at present that the alternate wind power site at the western edge of Deering is within the area of known discontinuous permafrost; hence it is possible that the site is permafrost-free. A geotechnical investigation of this site would only be initiated after obtaining landowner and FAA approval of wind turbine development, and after assessing the foundation design requirement needs of the smaller and lighter wind turbines that may be constructed at this location.

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 Deering 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 Deering 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. Consultation with the U.S. Fish and Wildlife Service (USFWS) will be initiated and at a minimum, a letter and a map sent to USFWS requesting their opinion regarding level of consultation needed to proceed with construction of the project.

The NWAB and IEC must also be aware of USFWS regulations and guidance under the Migratory Bird Treaty Act, which prohibits the taking of active bird nests, eggs and young. USFWS has developed "bird windows" statewide that prohibit clearing activity. The bird window in the Deering area 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 were sent to the Secretary of the Interior in March 2010 and will be referred to during design and construction of the project.

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 a given 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 turbine(s) is likely to be required.

Alaska Department of Natural Resources

The Alaska Department of Natural Resources (ADNR)-administered Alaska Coastal Management Program (ACMP) evaluates projects within the coastal zone, which includes Deering, 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 Deering is located.

The project design team, on behalf of the NWAB and IEC, 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 Deering are located on wetlands. The project must receive a Section 404 permit from the Alaska District USACE.

Proposed Conceptual Designs of Deering Wind-Diesel Systems

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

- Scenario 1: Low penetration wind (village site), no powerplant work
- Scenario 2: Low penetration wind (village site) with diesel powerplant improvements
- Scenario 3: Medium penetration wind (village site) with diesel powerplant improvements plus installation of a secondary load controller and boiler
- Scenario 4: Medium penetration wind (met tower site) with diesel powerplant improvements plus installation of a secondary load controller and boiler
- Scenario 5: High penetration wind (met tower site) with diesel powerplant improvements, installation of a secondary load controller and boiler, and installation of battery storage with a converter.

Low Wind Penetration, No Changes to Power Plant

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. Despite the lesser avoided fuel usage compared to higher wind penetration options, one very significant advantage of a low wind penetration approach is that it allows IEC to gain experience with wind turbines and wind-diesel operation before potentially expanding the system to higher penetration modes with their concomitant increased complexity.

In this first low wind penetration scenario, wind turbines would be installed but no substantive upgrades or improvements would be made to the existing power plant or power distribution system. In short, status quo of the power plant, distribution system, and related ancillary systems would be maintained.

Configuration Options

In a low penetration scenario, one or more wind turbines in the 2 to 10 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 presuming the diesel generators output is stable and can provide sufficient VAR support. Although a three phase wind turbine connection is most desirable, single or two phase connections are acceptable and may even be somewhat advantageous in Deering in light of the phase imbalance problem; the turbines would be connected to the weakest phases.

A target wind turbine capacity for the low penetration scenario is approximately 25 kW. For Deering, this equates to approximately 50% or less of the minimum projected load. This should mitigate concerns regarding power quality and generator loading.

Comparison Project

A comparative low penetration village wind-diesel system in Alaska is the village of Perryville which has a load profile not too dissimilar from Deering and is presented equipped with ten Skystream 3.7 (2.4 kW rated) wind turbines all directly connected to the AC bus. The Perryville wind-diesel configuration has no secondary (or diversion) load and no energy storage capabilities.

Deering Site for Low Penetration Wind

In a low-penetration wind-diesel scenario for Deering, multiple small wind turbines would be installed and connected to the existing power system at a suitable location in the center or toward the west end of the village. No additional controls or communications would be needed in the Deering powerplant. The wind turbines would operate independently of the powerplant. Power produced by the wind turbines would be seen as reduced load for the diesel generator. A powerline extension would not be necessary for a low penetration installation.

Low Wind Penetration, Diesel Powerplant Improvements

This option is identical to the low penetration scenario discussed above, except that needed repairs and upgrades to the diesel power plant and village power distribution system would be accomplished in tandem with wind turbine installation and commissioning. At this time, the following repairs and upgrades have been identified as necessary to restore the Deering power plant to its original design functionality: diesel recovered heat restoration, diesel generator supervisory control system restoration, and distribution system phase imbalance correction. Specific problems with each include:

- Recovered heat restoration: Engineers who have recently visited the Deering power plant have noted that the diesel generator recovered heat system, connected to the adjacent water plant and washeteria, is secured and hence inoperative. It is not known at present why this system is out of service, nor known is the work required to return it to service. For planning purposes, it is assumed that repairs will cost $25,000.
- Supervisory control system restoration/replacement: Although the Deering power plant is equipped with a reportedly wind-capable supervisory control system, this system is reportedly inoperative at present and the power plant is operated entirely in manual mode with no automatic parallel or switching capability. Although the nature of the fault is not known at present, due to the age of the control system and its PLC-based design, it is assumed to be out-of-date and should be replaced to restore functionality and support possible future medium to high-wind penetration designs. For planning purposes, it is assumed that replacement of the existing supervisory control system with a modern SCADA system will cost $250,000.
- Distribution system phase imbalance correction: Visiting engineers have also noted that a significant power loading phase imbalance in the Deering distribution system. This problem can be corrected by linemen and for planning purposes; it is assumed that these repairs will cost $25,000.

Medium Wind Penetration

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 Deering, appropriate wind turbines or medium wind penetration are ideally in the 10 to 25 kW range, although one could of course simply install more of the smaller turbines to reach a target wind capacity of approximately 50 kW. A possible variation presented in Scenario 4, however, is a medium penetration configuration with larger turbines (90 to 100 kW range).

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 connected to an electric boiler (serving a thermal load) to divert excess wind energy and control bus frequency.

Deering Site for Medium Penetration Wind

In a medium penetration wind-diesel scenario for Deering, multiple smaller or perhaps just one or two larger wind turbines would be installed and connected to the existing power system at the same location as the low penetration scenario: on the west side of the village near the termination of the existing distribution system. Significant power plant upgrades would be required, including a new (or significantly upgraded) SCADA, a secondary load controller and boiler, 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. As noted previously with respect to low penetration with diesel plant upgrades, the estimated cost to upgrade the diesel plant is $300,000.

It is assumed that in addition to the diesel powerplant upgrades, a secondary load controller (SLC) and boiler would be installed to control system frequency and to provide a dump (or secondary) load during periods of excess wind energy generation. For planning purposes, it is assumed that an installed cost for a SLC and boiler is $100,000.

It is possible in the medium penetration scenario that it would be more desirable to locate wind turbines at the met tower site as there is more space for turbine layout, a lesser risk of airport conflict, and likely a slightly better wind resource. This will be discussed in more detail under high wind penetration, but development costs to enable the met tower site to accommodate wind turbines would be necessary.

High Wind Penetration

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 Deering's small load. With high penetration, instantaneous wind penetration will often be 100+% and average wind penetration sufficient high to require energy storage to avoid the need to curtail wind turbines or dump excess energy, hence the need for battery storage.

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.

Deering Site for High Penetration Wind

In a high penetration wind-diesel scenario for Deering, two or more larger wind turbines would be installed and connected to the existing power system at the met tower site about one mile (1.6 km) west of the village. Significant power plant upgrades would be required, including a new (or significantly upgraded) 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 met tower site, a distribution line extension would be necessary to connect to existing distribution on the west side of the village. For planning purposes, $300,000 to develop the met tower site and $125,000 for batteries and converter are assumed.

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 Deering were restricted to rated outputs of 2 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 Deering power system. The primary criteria for wind turbines suitable for Deering 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 monopole
- 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

2 to 9 kW Range Turbines

Using the criteria listed above, the following turbines have been identified as potentially suitable for a low (and possibly medium as well) penetration wind-diesel project in Deering.

Eoltec Scirocco

The Eoltec Scirocco is a French-made upwind turbine, rated at 6 kW power output, has a direct-drive permanent magnet generator with a 240 volt, 3-phase output, and unusual for a small turbine, it is equipped with pitch controlled blades. This enables very good power output at both low and high wind speeds. In Alaska, the Eoltec Scirocco is available through Alaska Wind Industries (AWI). An estimated cost to install one Eoltec Scirocco in Deering at an 18 meter hub height is $65,000; multiple turbines in the HOMER model are valued at 95 percent of the single turbine cost. More information can be found at http://www.eoltec.com/English/Main_en.htm.

MC Energy 17/5

The MC Energy 17/5 is manufactured by MC Energy, an American company based in Washington State. The turbine is rated at 5 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 17/5 is available through AWI. An estimated cost to install one MC Energy 17/5 turbine in Deering at a 24 meter hub height is $69,500; 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/.

Proven 11

The Proven 11 is manufactured by Proven Energy in Scotland and rated at 6 kW. The turbine is downwind, stall-regulated and capable of continued operation in high winds with no cut-out wind speed. The generator is direct-drive, permanent magnet, three-phase AC. Several hinged tilt-up towers are available as well as higher lattice towers requiring crane construction. In Alaska, the Proven 11 is available through AWI. The Proven 11 was not modeled for this report, but it is a suitable wind turbine for Deering in a low penetration operating mode. More information can be found at http://www.provenenergy.co.uk/.

Skystream 3.7

The Skystream 3.7 is manufactured by Southwest Windpower, an American company based in Arizona, and is in wide use nationally. This downwind stall-regulated turbine is rated at 2.4 kW, has a direct-drive permanent magnet generator with a 120/240 volt, single or three-phase output, and is available in a number of tower configurations. In Alaska, the Skystream 3.7 is available through Susitna Energy Systems. An estimated cost to install one Skystream 3.7 turbine in Deering at a 24 meter hub height is $25,000; multiple turbines in the HOMER model are valued at 95 percent of the single turbine cost. More information can be found at http://www.windenergy.com/.

10 to 49 kW Range Turbines

With reference to previously listed criteria, the following turbines have been identified as potentially suitable for a low (if 10 to 15 kW), but mostly likely medium-penetration wind-diesel project in Deering.

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 Deering 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 Deering 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 Deering 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/.

Proven 35-2

The Proven 35-2 is manufactured by Proven Energy in Scotland and rated at 12 kW. It is a successor model of an earlier 15 kW rated turbine. As with the Proven 11, this turbine is downwind, stall-regulated with no cut-out speed. According to AWI, the Alaska distributor of Proven turbines, the 35-2 is best suited for sites with high average wind speeds or robust gust conditions. The generator is direct-drive, permanent magnet, three-phase AC. Two relatively low height hinged tilt-up monopole towers are available as well as higher lattice towers requiring crane construction. The Proven 35-2 was not modeled for this report, but potentially it is a suitable wind turbine for Deering in a medium penetration operating mode. More information can be found at http://www.provenenergy.co.uk/.

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 Deering at a 30 meter hub height is $225,000; multiple turbines presumably would cost less per turbine to install but are not modeled as such in this report. More information can be found at http://www.renewegy.com/index.html.

50 to 100 kW Range Turbines

With regard to Deering's relatively low electric load, larger turbines in the 50 to 100 kW size range are most likely suitable only in a high penetration scenario with battery storage, but possibly just one turbine could be employed in a medium penetration scenario provided a sufficiently 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.

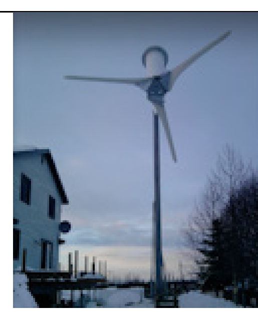
Northern Power Systems Northwind 100

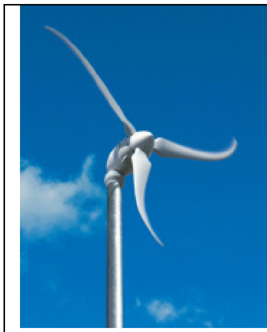
The Northwind 100 (NW100) is manufactured by Northern Power Systems, an American manufacturer based in Vermont. This turbine is stall-regulated, has a direct-drive permanent magnet synchronous generator, active yaw control and is rated at 100 kW. The turbine is fully arctic-climate certified and is the 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 $1,000,000 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 Deering'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 $600,000 is likely approximate; multiple turbines in the HOMER model are valued at 95 percent of the single turbine cost.

Wind turbine photos

		
Eoltec Scirocco (6 kW)	MC Energy 17/5 (5 kW)	Proven 11 (6 kW)

		
Skystream 3.7 (2.4 kW)	Bergey Excel (10 kW)	Gaia-Wind 133-11 (11 kW)
		
MC Energy 31/15 (15 kW)	Proven 35-2 (12 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 Deering's wind resource is relatively low, 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 29 meters, which was the upper anemometer sensor level of the Deering met tower. Turbine performance in the Deering 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 must be curtailed during higher wind conditions. The best performing turbine from a maximum capacity factor perspective is highlighted in green for each size category of turbines. As one can see, the Eoltec Scirocco, the Gaia 11 and the NW100 have the highest capacity factors in the 2-9 kW, 10-49 kW, and 49-100 kW categories respectively with the Gaia 11 superior and the Eoltec Scirocco second best.

Turbine capacity factor comparison

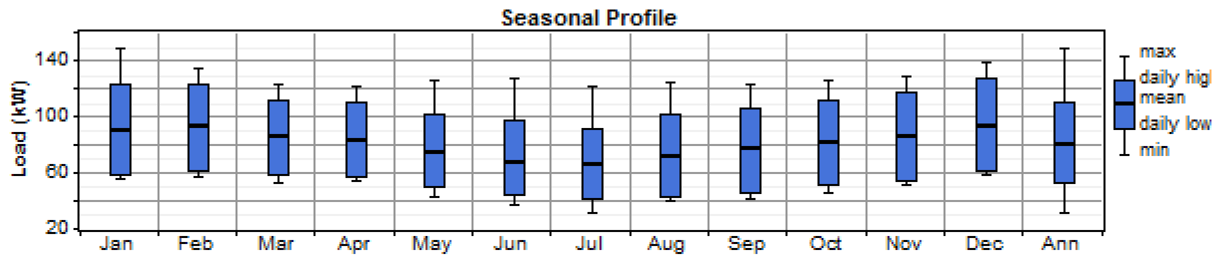
				100% avail.				80% avail.	
Output Range	Manufacturer	Turbine	Rated Turbine Output (kW)	CF of rated power (%)	Max. Turbine Output (kW)	CF of max. power (%)	Annual Energy (KWh)	CF of max. power (%)	Annual Energy (KWh)
2-9 kW	Eoltec	Scirocco	6	29.5	6	29.5	15,489	23.6	12,391
	Proven	11	6	28.8	6	28.8	15,121	23.0	12,097
	MC Energy	17/5	5	29.8	5.7	26.3	13,062	21.1	10,450
	Southwest	Sky 2.4	2.4	27.1	2.5	25.6	5,688	20.5	4,550
10-49 kW	Bergey	Excel	10	27.0	12.6	21.5	23,685	17.2	18,948
	Gaia-Wind	Gaia 11	11	37.6	10.9	38.0	36,268	30.4	29,014
	MC Energy	31/15	15	31.0	17	27.3	40,724	21.9	32,579
	Proven	35-2	12						
	Renewegy	VP-20	20	21.7	20	21.7	38,018	17.4	30,414
49-100 kW	Northern Pwr	NW100	100	26.1	100	26.1	228,211	20.8	182,569
	Vestas	V17	90	23.2	91	22.9	182,569	18.3	146,055
All turbines compared at common 29 meter hub height									

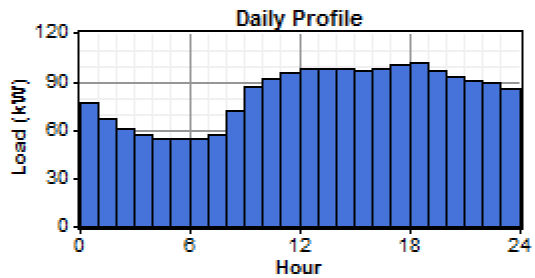
HOMER Modeling

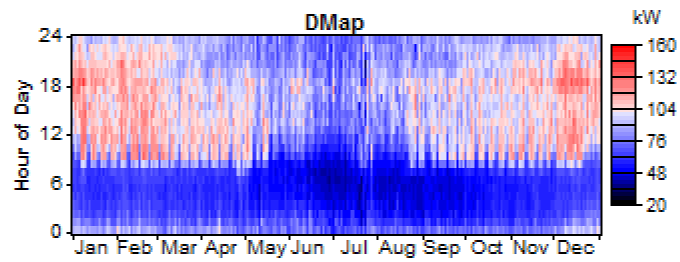
Wind turbine and system performance modeling of wind-diesel configurations in Deering was accomplished with HOMER software. This software enables static modeling of a power system to demonstrate energy balances and fuel displacement with introduction of wind power. A limitation of the software is that 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 $115,000 (from 2009 PCE data), and 100 percent wind turbine availability.

Electric Load

The Deering 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 82 kW average load with a 149 kW peak load, approximate 30 kW minimum load and with a calculated 6.3% day-to-day and 8.9% time step-to-time step random variability. Graphical representations of the electric load are shown below.

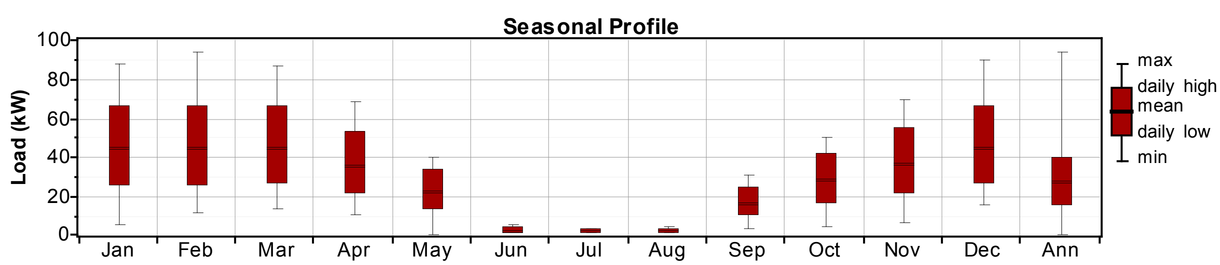


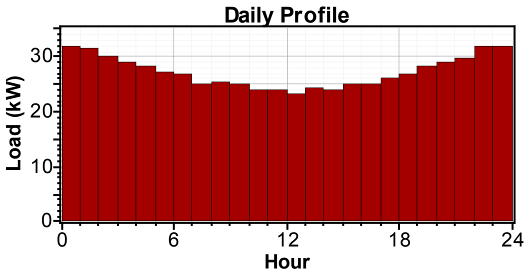


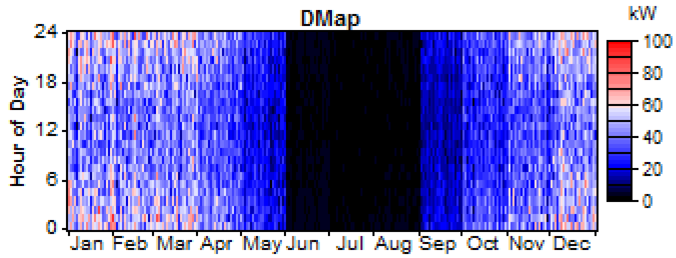


Thermal Load

The thermal load available to the diesel generator heat recovery system (when working) is not well documented in Deering beyond a report that 9,000 gallons of heating oil are burned annually in the water plant boilers. For HOMER modeling, a synthesized hourly thermal load was created with reasonably accurate thermal load data provided by AEA for the nearby village of Buckland. This data was scaled down until a base case modeling scenario (no wind turbines) yielded 9,000 gallon annual heating oil usage without use of heat recovery from the diesel generators (as previously discussed heat recovery is inoperative at present). For modeling purposes 18% diesel generator energy is assumed to be available for thermal loads via heat recovery when operational (this data point provided by D. Lockard at AEA). Graphical representations of the thermal load are shown below. Note that during the conceptual design phase of the project, heat demand of the entire village will be evaluated to determine if additional thermal loads can be added to the heat recovery system. If possible, thermal load available to the heat recovery system will be increased in order to enhance the utility of wind turbines in medium and high penetration configuration scenarios.

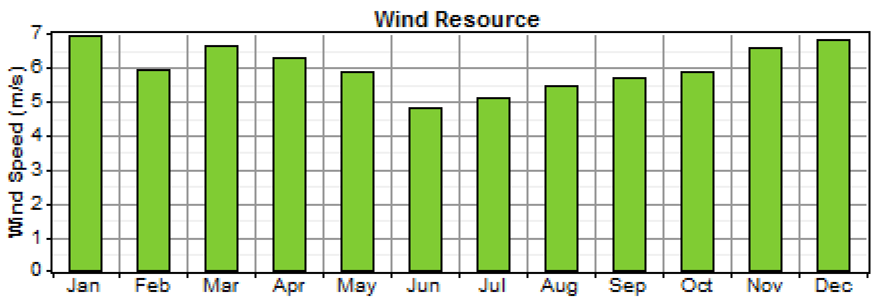






Wind Resource

The wind resource in Deering was measured with a 30 meter met tower as documented in Appendix A. The site is high wind class 3 (description: fair) with a 6.06 m/s mean annual wind speed at 30 meters, a Weibull k of 1.78, and is dominated by westerly winds with occasional easterly and southeasterly winds. A monthly site wind speed histogram is shown below.



Diesel Generators

The HOMER model was constructed with three of Deering's four generators: a 100 kW John Deere 6068T, a 138 KW John Deere 6081AF001 and a 170 kW Cummins LTA-10G3. The Deering power plant is equipped with a second Cummins LTA-10G3, but it is redundant capacity and not necessary to include in the modeling exercise. For planning purposes, AEA assumes a generator O&M cost of $0.02/kWh. Based on Deering's average load of 82 kW, this was converted to $1.64/operating hour for use in HOMER software.

Finding and applying accurate fuel curves for each generator is a desirable endeavor with HOMER modeling, but this was somewhat problematic for Deering due to the age and uncertain condition of the diesel generators and the manual mode status of the power plant supervisory control system. IEC states that the power plant is operated as efficiently as possible with available generators. At times, generators may not be available due to needed repairs that have not been accomplished. IEC states that this highlights a need for additional operator training to accomplish planned maintenance and other maintenance related to O&M activities.

It was possible with 2009 PCE and utility self-reported 2010 data to calculate an aggregate power plant fuel efficiency of 12.9 kWh/gal. With that, the default diesel generator fuel efficiency curves in the HOMER software were adjusted slightly so that overall energy generated and fuel burned matched that reported in the PCE report in Scenario 1 and the base option (existing condition) of Scenarios 2, 3 and 4.

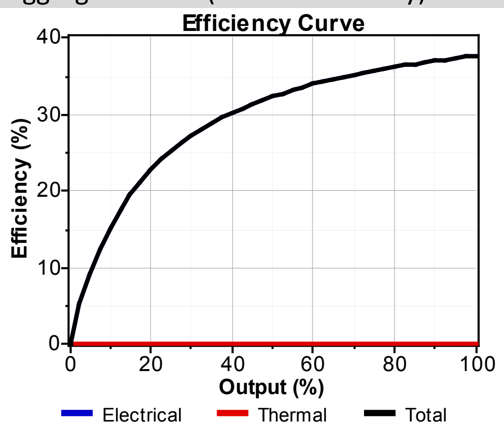
For Scenarios 2, 3 and 4, manufacturer-provided fuel curves for each diesel generator were used in the HOMER models and the modeling runs set to use the most efficient diesel generator at any given time. For Scenarios 3 and 4, this assumes of course repair and upgrade of the SCADA which would allow the Deering powerplant to once again operate in automatic mode.

Diesel generator HOMER modeling information

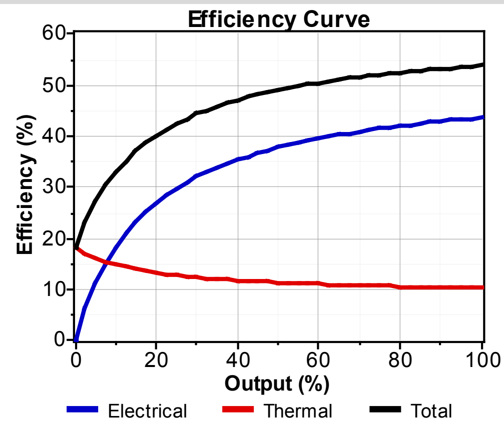
Scenario(s)	1, base option of 2, 3, 4 and 5	2, 3, 4 and 5	2, 3, 4 and 5	2, 3, 4 and 5
Diesel generator	Aggregate (no heat recovery)	John Deere 6068T	John Deere 6081AF001	Cummins LTA-10G3
HOMER model identification	All	Gen 1	Gen 2	Gen 3
Power output (kW)	N/A	100	138	170
Intercept coeff. (L/hr/kW rated)	0.0450	0.0368	0.0036	0.0156
Slope (L/hr/kW output)	0.2300	0.2007	0.2563	0.2145
Heat recovery ratio (%)	0	18	18	18

Diesel generator fuel efficiency curves

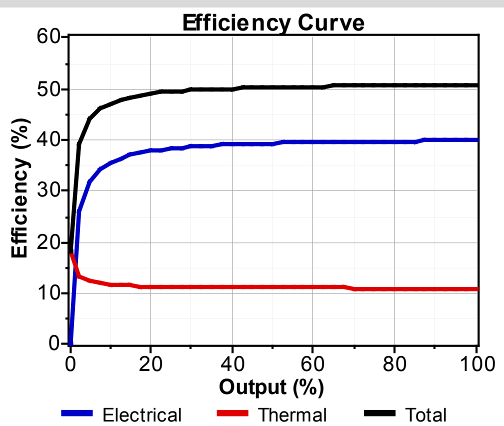
Aggregate curve (no heat recovery)



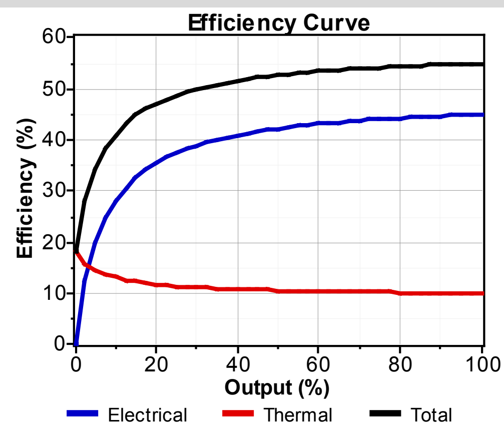
John Deere 6068T



John Deere 6081AF001



Cummins LTA-10G3



Technical and Economic Analysis

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

- Scenario 1: Low penetration wind (at village site), no powerplant work
- Scenario 2: Low penetration wind (at village site) with diesel powerplant improvements (includes restoration of the recovered heat system, replacement and upgrade of the SCADA system, and correction of load phase imbalance)
- Scenario 3: Medium penetration wind (at village site) with diesel powerplant improvements plus installation of a secondary load controller and boiler
- Scenario 4: Medium penetration wind (at met tower site) with diesel powerplant improvements plus installation of a secondary load controller and boiler
- Scenario 5: High penetration wind (at met tower site) with diesel powerplant improvements, installation of a secondary load controller and boiler, and installation of battery storage with a converter.

A Deering wind-diesel hybrid village model was initially developed for the simpler low penetration Scenario 1 and then adjusted in steps to the more complex Scenarios 2, 3, 4 and 5. A fuel price of $6.15/gallon ($1.63/Liter) was selected 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 $6.15/gallon price reflects the median value of the 2013 (assumed project start year) price of $5.17/gallon and 2032 (20 year project end year) of $7.14/gallon, using the medium projection 3-year moving average (MA3) fuel price estimate worksheet.

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 suitable for the low and medium wind penetration scenarios typically experience very high availability, so the 100 percent availability assumption is not unrealistic. 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	$115,000/year
Operating Reserves	
Load in current time step	10%
Wind power output	50%
Fuel Price	
Diesel arctic (generators)	$6.15/gal ($1.63/Liter)
Heating oil (thermal boilers)	$6.15/gal ($1.63/Liter)

Fuel Properties (both types)	
Heating value	42.5 MJ/kg
Density	820 kg/m^3
Diesel Generators	
O&M cost	$3.90/hour
Operating life	unlimited
Minimum load ratio	30%
Schedule	Optimized
Wind Turbines	
Availability	100%
O&M cost	$0.0469/kWh (translated to $/year for use by HOMER with site average turbine CF's)
• Eoltec Scirocco	• $500/year/turbine
• MC Energy 17/5	• $400/year/turbine
• Skystream 3.7	• $200/year/turbine
• Bergey Excel	• $825/year/turbine
• Gaia-Wind 11 kW	• $900/year/turbine
• MC Energy 31/15	• $1,200/year/turbine
• Renewegy VP-20	• $1,650/year/turbine
• Northern NW100	• $8,200/year/turbine
• Vestas V-17	• $7,400/year/turbine

Scenario-specific Cost Assumptions

In Scenario 1 a system fixed capital cost of $0 is assumed as no power plant repairs and/or upgrades would be accomplished; only wind turbine installation and connection in low penetration mode. Four different small wind turbines 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 turbines may suitable for use in Deering as well.

In Scenario 2 all assumptions of Scenario 1 are maintained but a total cost of $300,000 is added step-wise for repair and upgrade of the recovered heat system, SCADA system, and the load distribution system to correct phase imbalances.

In Scenario 3 all assumptions of Scenarios 1 and 2 are maintained, but an additional $100,000 is assumed for installation of a secondary load controller and boiler to augment Deering's thermal load. Note that for modeling purposes turbines were assumed to be located at the west side of the village and hence development costs of the met tower site are not included in the cost model.

In Scenario 4 all assumptions of previous scenarios are maintained but wind turbines would be located at the met tower site, hence an additional $300,000 is assumed for road improvements and extension of the distribution line from the west side of Deering. Although a reasonably passable jeep trail exists near the site, some surface hardening to allow movement of heavy construction equipment plus a short road extension is required to access turbine site(s).

In Scenario 5 all assumptions of Scenario 4 are maintained but, variable turbine costs aside, it is assumed that batteries and a converter (inverter/rectifier) to enable diesels-off operation in high penetration wind mode will cost $125,000.

Synopsis of scenario-specific cost assumptions

Scenario	Cost Assumptions
1	• Capital cost: $0 • Additional turbines at 95% of first turbine
2	• Recovered heat, SCADA, phase imbalance correction: $300,000 • Additional turbines at 95% of first turbine
3	• Recovered heat, SCADA, phase imbalance correction: $300,000 • SLC and boiler: $100,000 • Additional turbines at 95% of first turbine
4	• Recovered heat, SCADA, phase imbalance correction: $300,000 • SLC and boiler: $100,000 • Road improvement/distribution line extension: $300,000 • Additional turbines at 95% of first turbine
5	• Recovered heat, SCADA, phase imbalance correction: $300,000 • SLC and boiler: $100,000 • Road improvement/distribution line extension: $300,000 • Batteries and converter: $125,000 • Additional turbines at 95% of first turbine

Scenario 1, Low Penetration Wind, No Powerplant Upgrade

Bergey Excel, 24 meter hub height

No. Excel	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
2	$190,000	510,947	$7,791,606	0.653	0.05	199,532	33,555	233,087	61,663	2,890	0.0	0.0	1.006
1	$100,000	519,028	$7,821,832	0.656	0.02	204,996	33,554	238,550	63,108	1,445	0.0	0.0	1.003
0	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0.0	0.0	1.000

Eoltec Scirocco, 18 meter hub height

No. Eoltec	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
4	$240,500	507,139	$7,785,446	0.653	0.08	196,980	33,555	230,535	60,988	3,565	0.0	0.0	1.007
3	$182,000	512,041	$7,799,874	0.654	0.06	200,295	33,555	233,850	61,865	2,688	0.0	0.0	1.005
2	$123,500	517,072	$7,816,222	0.656	0.04	203,688	33,554	237,242	62,762	1,791	0.0	0.0	1.003
1	$65,000	522,121	$7,832,847	0.657	0.02	207,093	33,554	240,647	63,663	890	0.0	0.0	1.001
0	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0.0	0.0	1.000

MC Energy 17/5, 24 meter hub height

No. 17/5	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
4	$257,150	508,089	$7,816,226	0.656	0.08	197,809	33,555	231,364	61,207	3,346	0.0	0.0	1.003
3	$194,600	512,779	$7,823,457	0.656	0.06	200,932	33,555	234,487	62,034	2,520	0.0	0.0	1.002
2	$132,050	517,576	$7,832,267	0.657	0.04	204,120	33,554	237,674	62,877	1,677	0.0	0.0	1.001
1	$69,500	522,366	$7,840,981	0.658	0.02	207,304	33,554	240,858	63,719	834	0.0	0.0	1.000
0	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0.0	0.0	1.000

Skystream 3.7, 24 meter hub height

No. S3.7	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
10	$227,500	506,717	$7,766,164	0.651	0.07	196,721	33,555	230,276	60,920	3,634	0.0	0.0	1.010
8	$182,500	510,713	$7,780,622	0.652	0.06	199,419	33,555	232,974	61,633	2,920	0.0	0.0	1.008
6	$137,500	514,793	$7,796,315	0.654	0.04	202,167	33,554	235,721	62,360	2,193	0.0	0.0	1.006
4	$92,500	518,923	$7,812,763	0.655	0.03	204,947	33,554	238,501	63,096	1,458	0.0	0.0	1.004
2	$47,500	523,023	$7,828,758	0.657	0.01	207,708	33,554	241,262	63,826	728	0.0	0.0	1.002
1	$25,000	525,079	$7,836,844	0.657	0.01	209,092	33,554	242,646	64,192	361	0.0	0.0	1.001
0	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0.0	0.0	1.000

Scenario 2, Powerplant Improvements Only

Restore Recovered Heat System, $25,000 cost

Restore Rec. Heat	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Benefit/ Cost Ratio
yes	$25,000	487,644	$7,279,910	0.605	0.00	210,458	9,344	219,802	58,149	6,405	1.077
no	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	1.000

Replace SCADA (without restoration of recovered heat), $250,000 cost

new SCADA system	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Benefit/ Cost Ratio
yes	$250,000	472,319	$7,276,913	0.605	0.00	176,842	33,554	210,396	55,660	8,893	1.078
no	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	1.000

Replace SCADA and Restore Recovered Heat, $275,000 cost

SCADA, rec. heat	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Benefit/ Cost Ratio
yes	$275,000	440,525	$6,828,900	0.563	0.00	176,842	14,053	190,895	50,501	14,052	1.148
no	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	1.000

Replace SCADA, Restore Recovered Heat, Correct Phase Imbalance, $300,000 cost

SCADA, recov. heat, phase	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Benefit/ Cost Ratio
yes	$300,000	440,525	$6,853,901	0.565	0.00	176,842	14,053	190,895	50,501	14,052	1.144
no	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	1.000

Scenario 2, Low Penetration Wind and $300K Powerplant Improvements

Bergey Excel, 24 meter hub height

No. Excel	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
2	$490,000	428,060	$6,858,448	0.566	0.06	167,297	14,938	182,235	48,210	16,343	0.0	16.3	1.143
1	$400,000	434,183	$6,859,547	0.566	0.03	172,000	14,497	186,497	49,338	15,216	0.0	16.7	1.143
0	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0.0	0.0	1.000

Note: Base option of 0 turbines assumes no powerplant upgrade (as-is); turbine options include plant upgrades
Excess thermal principally due to repair of recovered heat system.

Eoltec Scirocco, 18 meter hub height

No. Eoltec	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
1	$365,000	436,580	$6,860,213	0.566	0.02	173,847	14,321	188,168	49,780	14,774	0.0	16.9	1.143
2	$423,500	432,674	$6,860,600	0.566	0.04	170,871	14,594	185,465	49,065	15,489	0.0	16.6	1.143
3	$482,000	428,834	$6,861,966	0.566	0.06	167,933	14,869	182,802	48,360	16,193	0.0	16.3	1.143
4	$540,500	425,143	$6,865,547	0.567	0.08	165,103	15,128	180,231	47,680	16,873	0.1	16.0	1.142
	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0.0	0.0	1.000

Note: Base option of 0 turbines assumes no powerplant upgrade (as-is); turbine options include plant upgrades
Excess thermal principally due to repair of recovered heat system.

MC Energy 17/5, 24 meter hub height

No. 17/5	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
1	$369,500	436,758	$6,867,353	0.567	0.02	174,035	14,303	188,338	49,825	14,729	0.0	16.9	1.142
2	$432,050	433,024	$6,874,349	0.567	0.04	171,244	14,558	185,802	49,154	15,399	0.0	16.6	1.141
3	$494,600	429,342	$6,882,120	0.568	0.06	168,483	14,815	183,298	48,492	16,062	0.0	16.3	1.139
4	$557,150	425,790	$6,891,830	0.569	0.07	165,814	15,059	180,873	47,850	16,703	0.1	16.1	1.138
	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0.0	0.0	1.000

Note: Base option of 0 turbines assumes no powerplant upgrade (as-is); turbine options include plant upgrades
Excess thermal principally due to repair of recovered heat system.

Renewegy VP-20, 30 meter hub height

No. VP-20	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
1	$525,000	430,060	$6,923,213	0.572	0.05	168,664	14,799	183,463	48,535	16,018	0.1	16.4	1.133
2	$727,500	420,396	$6,981,927	0.577	0.10	161,024	15,497	176,521	46,699	17,855	0.3	15.6	1.123
3	$930,000	412,066	$7,060,497	0.585	0.15	154,278	16,120	170,398	45,079	19,475	1.0	15.0	1.111
	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0	0	1.000

Note: Base option of 0 turbines assumes no powerplant upgrade (as-is); turbine options include plant upgrades
Excess thermal principally due to repair of recovered heat system.

Skystream 3.7, 24 meter hub height

No. S3.7	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
8	$482,500	427,824	$6,847,434	0.565	0.06	167,178	14,943	182,121	48,180	16,373	0.1	16.2	1.145
10	$527,500	424,843	$6,848,096	0.565	0.07	164,896	15,151	180,047	47,631	16,922	0.1	16.0	1.145
6	$437,500	430,925	$6,848,577	0.565	0.04	169,547	14,722	184,269	48,748	15,805	0.0	16.5	1.145
4	$392,500	434,093	$6,850,702	0.565	0.03	171,962	14,496	186,458	49,328	15,226	0.0	16.7	1.145
2	$347,500	437,296	$6,853,354	0.565	0.01	174,395	14,273	188,668	49,912	14,641	0.0	17.0	1.144
1	$325,000	438,911	$6,854,881	0.566	0.01	175,620	14,162	189,782	50,207	14,347	0.0	17.1	1.144
0	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0.0	0.0	1.000

Note: Base option of 0 turbines assumes no powerplant upgrade (as-is); turbine options include plant upgrades
Excess thermal principally due to repair of recovered heat system.

Scenario 3, Medium Penetration Wind, $400K Powerplant Improvements/SLC Installation

Bergey Excel, 24 meter hub height

No. Excel	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
2	$590,000	427,934	$6,956,578	0.575	0.06	167,354	14,805	182,159	48,190	16,363	0.2	16.4	1.127
3	$680,000	422,049	$6,959,017	0.575	0.09	163,183	14,859	178,042	47,101	17,452	0.6	16.2	1.127
1	$500,000	434,168	$6,959,318	0.575	0.03	172,005	14,483	186,488	49,335	15,218	0.0	16.8	1.127
4	$770,000	416,524	$6,966,832	0.576	0.12	159,343	14,803	174,146	46,070	18,483	1.2	16.5	1.126
5	$860,000	411,464	$6,981,538	0.577	0.15	155,886	14,649	170,535	45,115	19,438	2.0	17.3	1.123
6	$950,000	406,946	$7,004,333	0.580	0.18	152,860	14,398	167,258	44,248	20,305	3.0	18.7	1.120
0	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0.0	0.0	1.000

Note: Base option of 0 turbines assumes no powerplant upgrade (as-is); turbine options include plant upgrades
Excess thermal principally due to repair of recovered heat system.

Gaia-Wind 11 kW, 18 meter hub height

No. Gaia 11 kW	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
2	$683,100	421,305	$6,951,052	0.575	0.09	162,838	15,161	177,999	47,090	17,464	0.2	15.9	1.128
3	$817,200	412,343	$6,951,825	0.575	0.14	156,693	15,256	171,949	45,489	19,064	0.9	15.8	1.128
1	$549,000	430,807	$6,958,316	0.575	0.05	169,712	14,669	184,381	48,778	15,775	0.0	16.5	1.127
4	$951,300	403,990	$6,961,654	0.576	0.18	151,172	15,100	166,272	43,987	20,566	1.8	16.3	1.126
5	$1,085,400	396,290	$6,981,193	0.577	0.23	146,140	14,856	160,996	42,592	21,962	3.1	17.6	1.123
0	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0.0	0.0	1.000

Note: Base option of 0 turbines assumes no powerplant upgrade (as-is); turbine options include plant upgrades
Excess thermal principally due to repair of recovered heat 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 Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
4	$881,000	400,803	$6,843,935	0.565	0.21	149,093	14,488	163,581	43,275	21,278	3.5	19.1	1.146
3	$764,000	409,110	$6,850,528	0.565	0.16	154,544	14,869	169,413	44,818	19,735	1.8	16.8	1.145
2	$647,000	418,711	$6,876,367	0.568	0.11	161,041	14,998	176,039	46,571	17,982	0.2	16.1	1.140
1	$530,000	429,291	$6,916,768	0.571	0.05	168,496	14,771	183,267	48,483	16,070	0.0	16.4	1.134
0	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0.0	0.0	1.000

Note: Base option of 0 turbines assumes no powerplant upgrade (as-is); turbine options include plant upgrades
Excess thermal principally due to repair of recovered heat system.

Renewegy VP-20, 30 meter hub height

No. VP-20	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
1	$625,000	430,012	$7,022,489	0.581	0.05	168,681	14,752	183,433	48,527	16,026	0.1	16.5	1.117
2	$827,500	419,997	$7,075,989	0.586	0.11	161,232	15,044	176,276	46,634	17,920	0.6	16.0	1.108
3	$1,030,000	410,848	$7,142,385	0.592	0.16	154,676	14,975	169,651	44,881	19,672	1.5	16.4	1.098
4	$1,232,500	402,828	$7,225,569	0.600	0.21	149,067	14,652	163,719	43,312	21,242	3.1	18.1	1.085
5	$1,435,000	396,053	$7,327,261	0.610	0.25	144,433	14,118	158,551	41,945	22,609	5.1	21.5	1.070
0	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0	0	1.000

Note: Base option of 0 turbines assumes no powerplant upgrade (as-is); turbine options include plant upgrades
Excess thermal principally due to repair of recovered heat system.

Scenario 4, Medium Penetration Wind at Met Tower Site, $400K Powerplant Improvements/SLC Installation, $300K Site Development

Vestas V17, 26 meter hub height

No. Vestas V17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
1	$1,300,000	399,175	$7,238,723	0.601	0.25	146,994	13,993	160,987	42,589	21,964	4.8	21.4	1.083
2	$1,840,000	377,439	$7,455,346	0.622	0.50	132,072	11,341	143,413	37,940	26,613	16.8	53.5	1.052
	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0.0	0.0	1.000

Note: Base option of 0 turbines assumes no powerplant upgrade (as-is) e; turbine options include plant upgrade/SLC installation plus met tower site improvement

NW100/21, 37 meter hub height

No. NW	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
1	$1,700,000	386,593	$7,451,526	0.621	0.33	139,681	13,097	152,778	40,417	24,136	8.2	27.6	1.052
	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0.0	0.0	1.000
2	$2,600,000	359,071	$7,942,064	0.667	0.66	121,543	9,956	131,499	34,788	29,765	23.8	78.7	0.987

Note: Base option of 0 turbines assumes no powerplant upgrade (as-is) e; turbine options include plant upgrade/SLC installation plus met tower site improvement

Renewegy VP-20, 30 meter hub height

No. VP-20	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
1	$925,000	430,012	$7,322,490	0.609	0.05	168,681	14,752	183,433	48,527	16,026	0.1	16.4	1.071
2	$1,127,500	419,997	$7,375,990	0.614	0.10	161,232	15,044	176,276	46,634	17,919	0.3	15.6	1.063
3	$1,330,000	410,848	$7,442,385	0.621	0.15	154,676	14,975	169,651	44,881	19,672	1.0	15.0	1.054
4	$1,532,500	402,828	$7,525,570	0.628	0.20	149,067	14,652	163,719	43,312	21,241	3.1	18.1	1.042
5	$1,735,000	396,053	$7,627,261	0.638	0.25	144,433	14,118	158,551	41,945	22,608	5.1	21.5	1.028
	$0	527,105	$7,841,990	0.658	0	210,458	33,554	244,012	64,553	0	0	0	1.000

Note: Base option of 0 turbines assumes no powerplant upgrade (as-is) e; turbine options include plant upgrade/SLC installation plus met tower site improvement

Scenario 5, High Penetration Wind, $625K Powerplant/SLC/Battery Storage, $300K Site Development

Vestas V17, 26 meter hub height

No. Vestas V17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
2	1,965,000	$347,566	$7,135,909	0.592	0.50	107,348	19,219	126,567	33,483	31,070	5.1	21.0	1.099
1	1,425,000	$392,128	$7,258,868	0.603	0.25	138,993	17,788	156,781	41,476	23,077	0.0	13.8	1.080
0	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0.0	0.0	1.000

Note: Base option of 0 turbines assumes no powerplant upgrade (as-is); turbine options include plant upgrade/SLC/battery/converter installation plus met tower site improvement

NW100/21, 37 meter hub height

No. NW	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind Fraction of Load	Diesel arctic (L)	Heating oil arctic (L)	Total fuel (L)	Total fuel (gal)	Fuel Displ. (gal)	Excess Electricity (%)	Excess Thermal (%)	Benefit/ Cost Ratio
1	$1,825,000	371,794	$7,356,354	0.612	0.33	125,135	19,230	144,365	38,192	26,362	0.0	12.5	1.066
2	$2,725,000	318,976	$7,470,552	0.623	0.66	89,987	19,016	109,003	28,837	35,717	11.0	35.1	1.050
0	$0	527,105	$7,841,990	0.658	0.00	210,458	33,554	244,012	64,553	0	0.0	0.0	1.000

Note: Base option of 0 turbines assumes no powerplant upgrade (as-is); turbine options include plant upgrade/SLC/battery/converter installation plus met tower site improvement

Discussion and Recommendations

In the previous revision of this feasibility study, it was recommended that a high penetration wind-diesel system be constructed in Deering. This recommendation has been reconsidered in light of a number of issues, principal among them a collective recognition by Alaska Energy Authority, Northwest Arctic Borough and the City of Deering that Ipnatchiaq Electric Company (IEC) is perhaps not fully prepared at present to accept the demands of operating and maintaining a wind-diesel hybrid system of a highly complex nature. It is collectively felt that IEC should first address several power plant technical issues in Deering such as repair the recovered heat and SCADA systems, correct load phase imbalances, improve powerplant operator training, and address administrative issues such as PCE program management. Also noted from collective experience is that unless starting from scratch, construction of a high penetration wind-diesel power system is most likely to succeed in a community with a highly functional power system, both technically and administratively.

It is a reasonable conclusion that wind power development in Deering would best proceed iteratively where IEC has time to gain experience with wind power on a smaller scale before transitioning to higher penetration modes with more complex designs. This approach would also allow IEC some time to consider utility management support arrangements, if deemed necessary or desirable, such as joining a coop, contracting a management firm, etc.

The recommended plan is to proceed with a phased approach to wind power development in Deering where a low penetration wind scenario is constructed and operated for a short period of time (one or two years) before medium to high penetration elements are constructed. Because the medium to high penetration wind scenarios require that the power plant operate as efficiently as possible, Scenario 2 (low penetration wind with diesel powerplant improvements) is recommended for the first phase of effort, with subsequent transition to Scenarios 3, 4 or 5 (medium or high penetration) in the second phase. Scenario 2 allows the City of Deering to gain experience with an initial wind power project while simultaneously addressing problems in the power plant and upgrading features necessary to achieve maximally efficient power generation, with or without wind turbines, and to provide the foundation necessary to increase wind power input in the future to higher penetration levels.

In the technical and cost analyses all configuration options indicate a benefit to cost (B/C) ratio greater than 1.0 compared to the present or "base" situation. If fuel prices were to increase beyond the 2011 ISER medium future fuel price projection, B/C ratios would increase and, naturally, if fuel prices decrease then B/C ratios for all scenarios would also decrease. Regarding the consideration of fuel price and project scenario B/C ratios, note that wind power is the only viable renewable energy option for Deering. It is locally sustainable and contributes to a lessened dependence on fossil fuel in rural Alaska, which is a stated goal of the legislature.

Several wind turbines were evaluated in the five scenarios as the intent of this feasibility study was to identify viable wind power options for consideration with respect to both configuration and actual equipment selection. All turbines model somewhat similarly in cost and performance with the exception of the Gaia-Wind 11 which with respect to performance models with a significantly higher capacity factor than the other turbines. It is recommended that the Gaia turbine in particular be investigated further as its potential value in relatively low wind power regimes such as Deering may be very high.

Upon AEA approval of system configuration and project approach, a targeted and intensive effort in the conceptual design phase to identify the most suitable turbine will commence. This will require some additional investigation to determine Deering power system stability, maximum allowable turbine height due to airport considerations (presuming that turbines are located on the western edge of the village), documented turbine suitability in an extremely cold climate, level of manufacturer and supplier support, ease of construction, and ease of turbine operation and maintenance. It is possible that a wind turbine not identified in this report may be ultimately be chosen for Deering, but it is felt that the turbines evaluated in this report are well suited for Deering and for operation in an arctic climate.

Appendix A, Deering Wind Resource Report, rev. 1

Deering Wind Resource Report

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

Date: September 17, 2010 (revision1)

Village of Deering; D. Vaught photo

Contents

Summary

The wind resource measured in Deering is good at high 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 might otherwise be expected for a Class 3 site. Met tower placement was based on observations of wind patterns in Deering, the relatively high elevation of the site, and proximity to existing roads. The site is thought to have the best developable wind regime near Deering. Other locations near Deering, such as the summit plateau of the high, broad hill east of the village, are likely windier but development costs there would be very high.

Met tower data synopsis

Data dates	August 9, 2008 to August 6, 2010 (24 months)
Wind Power Class	High Class 3 (fair)
Power density mean, 30 m	316 W/m^2
Wind speed mean, 30 m	6.00 m/s
Max. 10-min wind speed average	25.9 m/s
Maximum wind gust	30.9 m/s (January 2009)
Weibull distribution parameters	k = 1.78, c = 6.72 m/s
Wind shear power law exponent	0.0951
Roughness class	0.0 (smooth)
Turbulence intensity, mean	0.075 (at 15 m/s)
IEC 61400-1, 3rd ed. classification	Class III-C

Community profile

Current Population:	118 (2009 DCCED Certified Population)
Incorporation Type:	2nd Class City
Borough Located In:	Northwest Arctic Borough
Taxes:	Sales: None, Property: None, Special: None
National Flood Insurance Program Participant:	Yes
Coastal Management District:	Northwest Arctic Borough

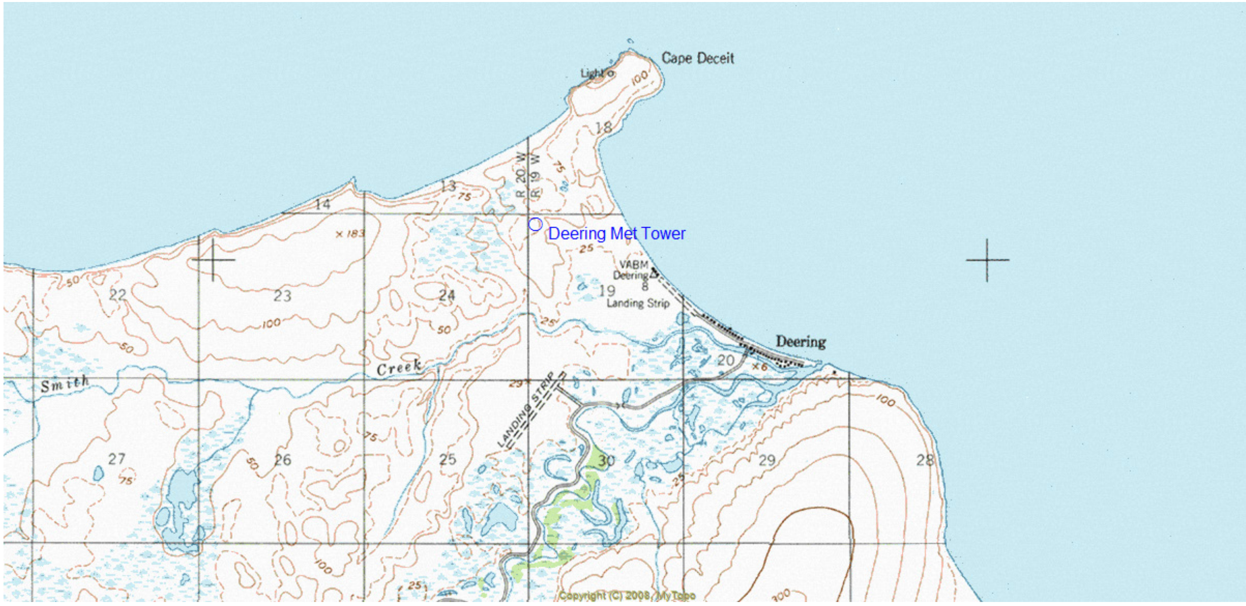
Test Site Location

The met tower is located 1.5 km (0.9 miles ft) from the western edge of the village. The site is south of Cape Deceit on a broad sloping hill overlooking Kotzebue Sound with good exposure to winds from all directions.

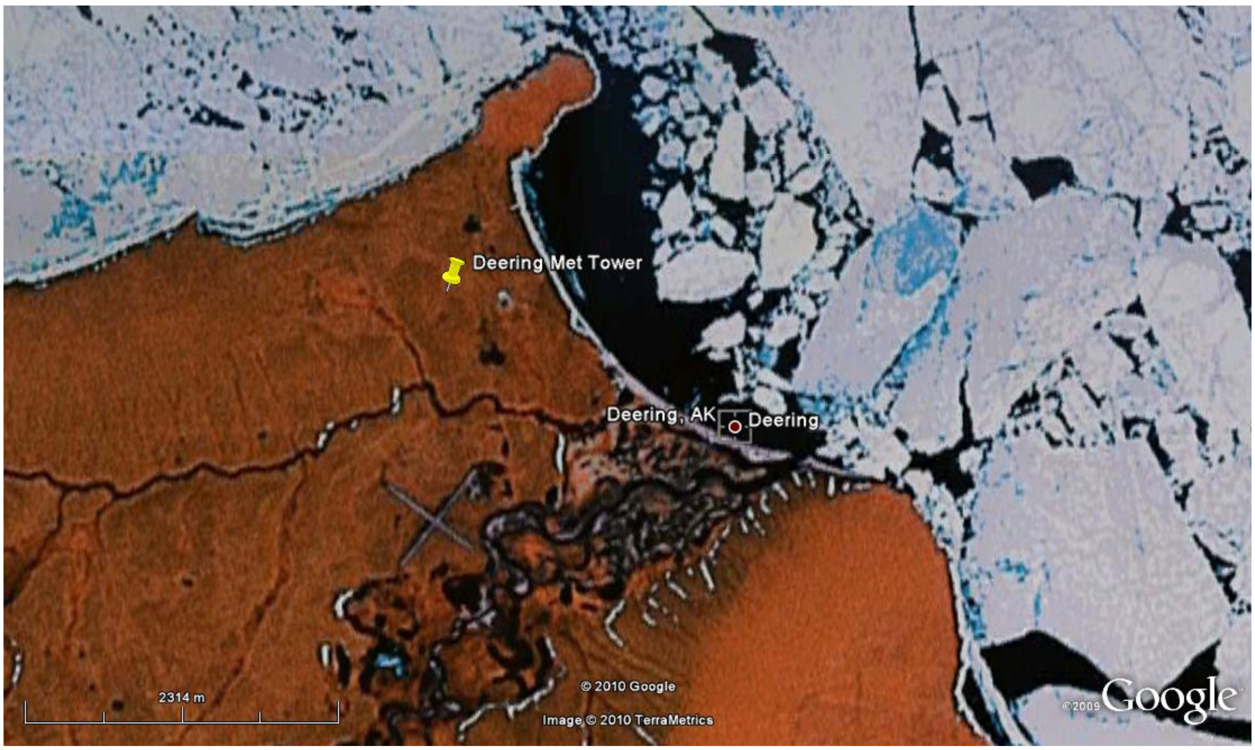
Site information

Site number	7312
Latitude/longitude	N 66° 5.1’, W 162° 45.8’ (WGS 84)
Site elevation	15 meters
Datalogger type	NRG Symphonie, 10 minute time step
Tower type	NRG 30-meter tall tower, 152 mm diameter
Anchor type	Buried plate (configured with plywood and screw-in anchor)

Topographic map image



Google Earth image



Tower sensor information

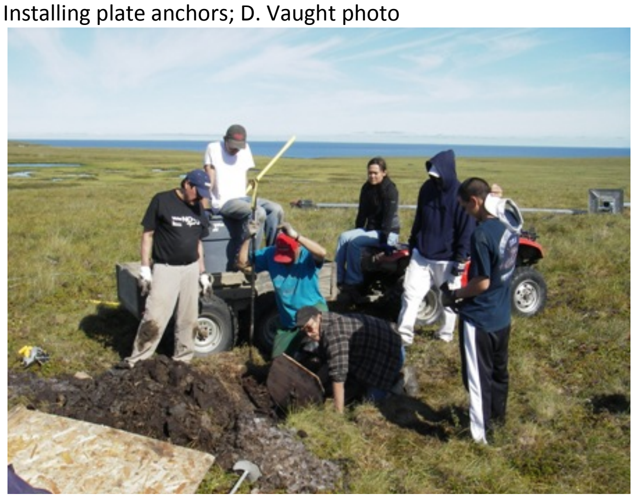
Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	29 m (A)	0.765	0.35	WNW
2	NRG #40 anemometer	29 m (B)	0.765	0.35	ENE
3	NRG #40 anemometer	20 m	0.765	0.35	NNW
7	NRG #200P wind vane	29 m	0.351	000	359° T
9	NRG #110S Temp C	3 m	0.136	-86.383	N

Photographs


Deering crew; D. Vaught photo


Installing plate anchors; D. Vaught photo


Deering met tower; D. Vaught photo


Deering crew; D. Vaught photo

Data Recovery

The quality of data from the Deering met tower was acceptable to describe the essentials of the wind resource, but unfortunately there were a number of problems including inoperability of the temperature sensor for the first three months after tower installation (after which the sensor was replaced but data has been suspect) and complete failure of the wind vane that resulted in no recorded wind data. Fortunately, the nearby Deering airport has been equipped with an Automated Surface

Observing System (ASOS) weather station since 1984 and hence wind direction from it is a suitable substitute for the met tower site. Other data problems with the met tower include two long episodes of missing data: 6/30/09 to 8/31/09 and 11/14/09 to 2/3/10. Reportedly, one episode was due to a lost or misplaced data card and the other to failure of the datalogger.

Apparent icing events, characterized by relatively long periods of zero sensor output, non-variant sensor standard deviation, and temperatures near or below freezing, were removed from the data set for quality control purposes. It is apparent from the data that icing events (likely freezing rain/sleet but also possibly hoarfrost conditions) certainly occur frequently during the winter months, but the site is not of sufficient elevation for the highly problematic rime icing conditions.

Data recovery summary table

Label	Units	Height	Possible Records	Valid Records	Recovery Rate (%)
Speed 29 m A	m/s	29 m	104,717	79,341	75.8
Speed 29 m B	m/s	29 m	104,717	79,229	75.7
Speed 20 m	m/s	20 m	104,717	76,768	73.3
Direction 24 m	°	24 m	104,717	0	0.0
Temperature	°C		104,717	67,853	64.8

Anemometer data recovery

			29 m A		29 m B		20 m	
Year	Month	Possible Records	Valid Records	Recovery Rate (%)	Valid Records	Recovery Rate (%)	Valid Records	Recovery Rate (%)
2008	Aug	3,227	3,227	100.0	3,227	100.0	3,227	100.0
2008	Sep	4,320	4,320	100.0	4,320	100.0	4,320	100.0
2008	Oct	4,464	4,443	99.5	4,439	99.4	4,455	99.8
2008	Nov	4,320	2,365	54.8	2,348	54.4	2,368	54.8
2008	Dec	4,464	4,290	96.1	4,276	95.8	4,331	97.0
2009	Jan	4,464	3,539	79.3	3,511	78.7	3,192	71.5
2009	Feb	4,032	3,615	89.7	3,614	89.6	2,325	57.7
2009	Mar	4,464	4,464	100.0	4,464	100.0	4,464	100.0
2009	Apr	4,320	4,320	100.0	4,320	100.0	4,320	100.0
2009	May	4,464	4,464	100.0	4,464	100.0	4,464	100.0
2009	Jun	4,320	3,906	90.4	3,906	90.4	3,906	90.4
2009	Jul	4,464	0	0.0	0	0.0	0	0.0
2009	Aug	4,464	54	1.2	54	1.2	54	1.2
2009	Sep	4,320	4,320	100.0	4,320	100.0	4,320	100.0
2009	Oct	4,464	4,464	100.0	4,464	100.0	4,464	100.0
2009	Nov	4,320	1,578	36.5	1,578	36.5	1,578	36.5
2009	Dec	4,464	0	0.0	0	0.0	0	0.0
2010	Jan	4,464	0	0.0	0	0.0	0	0.0

2010	Feb	4,032	3,106	77.0	3,245	80.5	2,114	52.4
2010	Mar	4,464	4,464	100.0	4,464	100.0	4,464	100.0
2010	Apr	4,320	4,320	100.0	4,320	100.0	4,320	100.0
2010	May	4,464	4,464	100.0	4,277	95.8	4,464	100.0
2010	Jun	4,320	4,320	100.0	4,320	100.0	4,320	100.0
2010	Jul	4,464	4,464	100.0	4,464	100.0	4,464	100.0
2010	Aug	834	834	100.0	834	100.0	834	100.0
All data		104,717	79,341	75.8	79,229	75.7	76,768	73.3

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. The cold arctic temperatures of Deering contributed to the high power density. It is problematic, however, analyzing wind data with significant concentrated data loss, such as occurred in Deering during the two data loss episodes. Fortunately, however, with met tower data collection encompassing a two year time period, missing months of data in 2009 and 2010 were duplicated by data collected in 2008 and 2009. Nevertheless, to correct the anemometer data loss problem, synthetic data was inserted in the data gaps to create a more complete wind speed profile. To be sure, long segments of synthetic data introduce uncertainty to the data set, but missing data does as well. With synthetic data inserted to fill in the data gaps, the mean wind annual wind speed and power density decrease slightly from the original data.

Anemometer data summary

	Original Data			Synthesized data		
Variable	Speed 29 m A	Speed 29 m B	Speed 20 m	Speed 29 m A	Speed 29 m B	Speed 20 m
Measurement height (m)	29	29	20	29	29	20
Mean wind speed (m/s)	6.00	6.06	5.96	5.94	6.00	5.82
Max 10-min avg wind speed (m/s)	25.9	25.2	24.4			
Max gust wind speed (m/s)	30.9	29.8	29.8			
Weibull k	1.71	1.74	1.77	1.67	1.69	1.72
Weibull c (m/s)	6.62	6.72	6.55	6.64	6.72	6.52
Mean power density (W/m²)	312	322	301	309	316	285
Mean energy content (kWh/m²/yr)	2,737	2,820	2,635	2,703	2,768	2,493
Energy pattern factor	2.244	2.236	2.183	2.311	2.299	2.268
1-hr autocorrelation coefficient	0.913	0.914	0.915	0.908	0.909	0.91
Diurnal pattern strength	0.013	0.018	0.014	0.025	0.028	0.028
Hour of peak wind speed	15	15	13	13	13	12

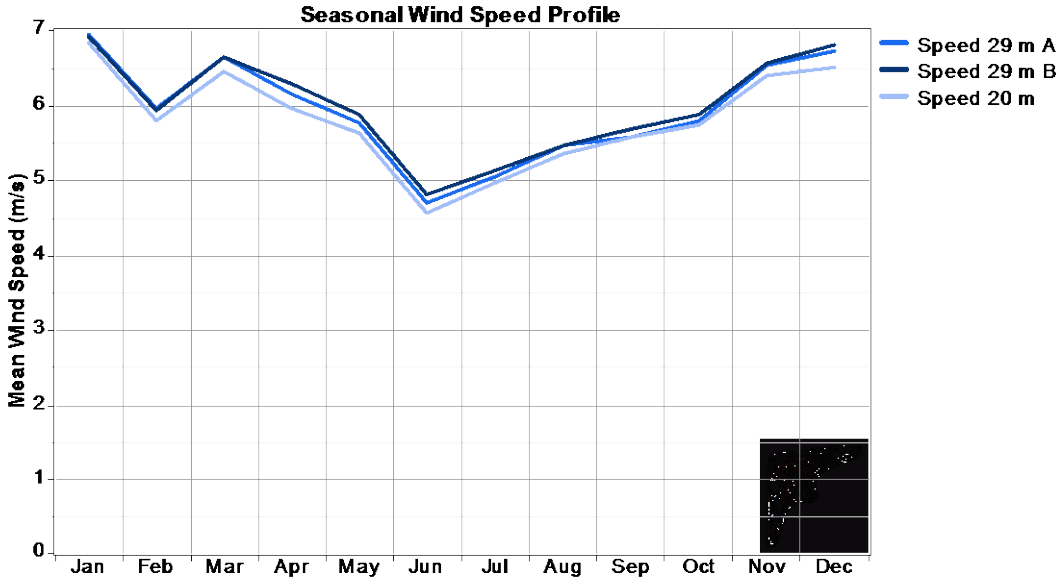
Time Series

Time series calculations indicate moderately wind speed averages during the autumn, winter and spring months, but winds die down during summer. Fortunately, however, seasonal wind speeds correlate to a typical village electric load profile of high winter loads and light summer loads.

29m B anemometer data summary

		Original 29m B 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 speed (-)
2008	Aug	5.52	15.3	17.6	2.198	6.24	5.52	100.0%
2008	Sep	5.94	13.3	15.3	2.15	6.693	5.94	100.0%
2008	Oct	5.59	15.4	18.7	1.958	6.305	5.57	99.6%
2008	Nov	6.38	13.4	16.1	2.484	7.174	6.01	94.2%
2008	Dec	7.05	20.5	24	1.945	7.913	6.92	98.1%
2009	Jan	7.14	25.1	29.8	1.536	7.963	6.69	93.8%
2009	Feb	7.55	22	25.6	1.586	8.375	6.98	92.3%
2009	Mar	6.76	24.7	27.9	1.609	7.538	6.76	100.0%
2009	Apr	5.50	25.2	29.8	1.593	6.128	5.50	100.0%
2009	May	6.30	19.6	24.8	2.175	7.118	6.30	100.0%
2009	Jun	4.91	15.9	19.5	2.042	5.543	4.91	100.1%
2009	Jul						4.96	
2009	Aug	12.07	16.2	19.9	6.252	12.969	5.68	47.1%
2009	Sep	5.42	14.1	17.2	1.947	6.116	5.42	100.0%
2009	Oct	6.21	16.5	19.5	1.72	6.943	6.21	100.0%
2009	Nov	7.38	20.5	23.7	1.533	8.166	7.10	96.3%
2009	Dec						6.67	
2010	Jan						7.14	
2010	Feb	4.37	12.9	14.1	1.942	4.892	4.89	112.1%
2010	Mar	6.52	15.6	19.5	1.695	7.236	6.52	100.0%
2010	Apr	7.05	20.2	22.6	1.66	7.828	7.05	100.0%
2010	May	5.32	15.6	18.7	1.753	5.936	5.47	102.8%
2010	Jun	4.72	17.8	20.6	1.994	5.329	4.72	100.0%
2010	Jul	5.29	16.4	19.1	1.809	5.95	5.29	100.0%
2010	Aug	4.12	10.1	13.3	2.095	4.648	4.12	100.0%
MMM Annual		6.06	25.2	29.8	1.738	6.716	6.00	98.9%

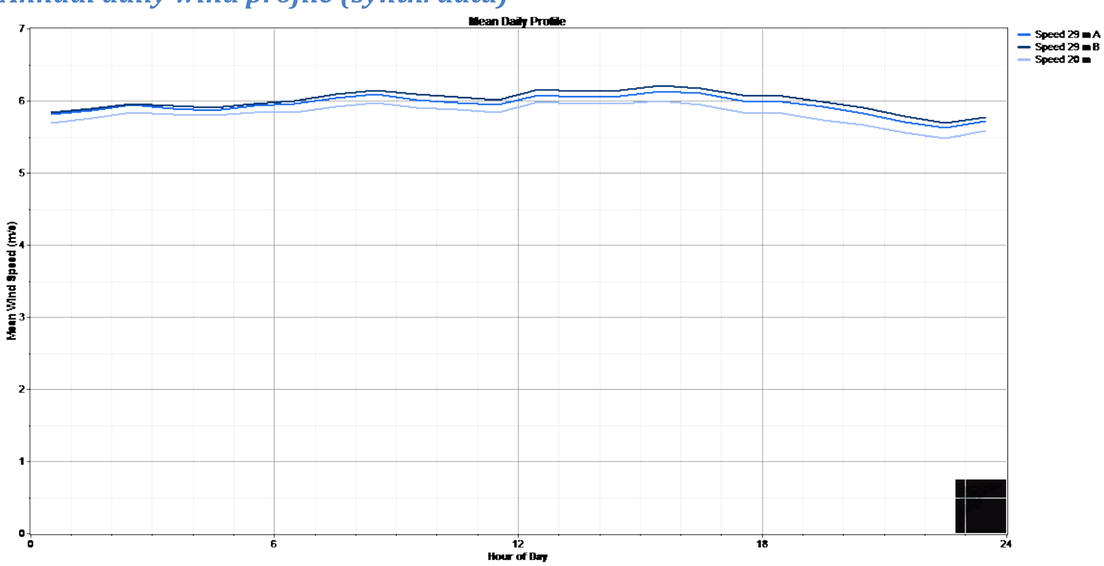
Time series graph (synth. data)



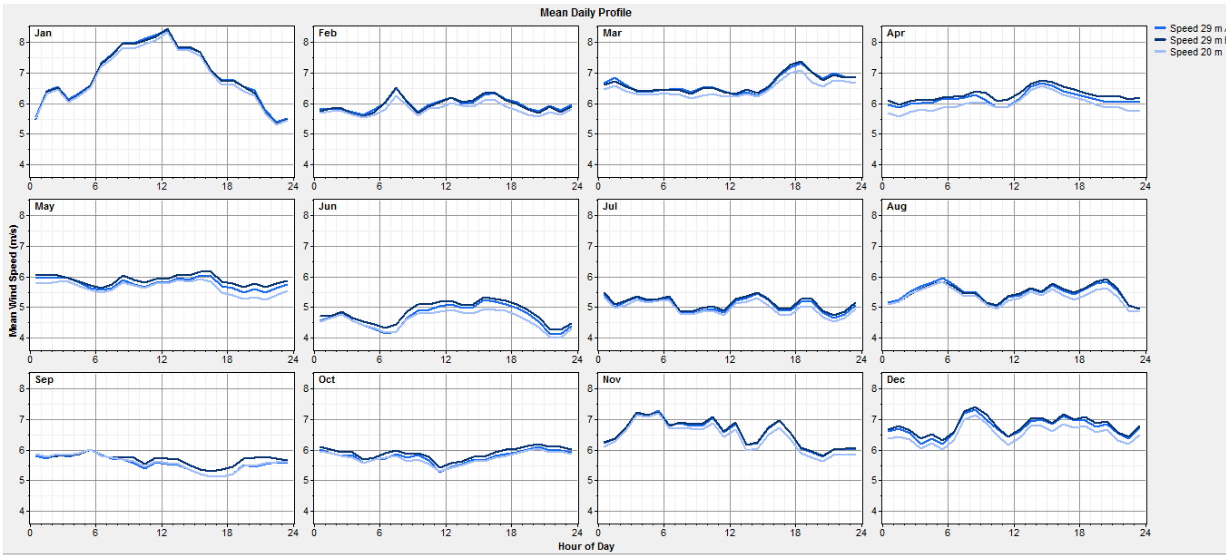
Daily Wind Profile

The average annual daily wind profile in Deering indicates a minor variation of wind speeds throughout the day, with lowest wind speeds during the late night and early morning hours and highest winds during mid to late afternoon. This perspective changes somewhat when considering monthly views of daily profiles as much more variation is observed.

Annual daily wind profile (synth. data)



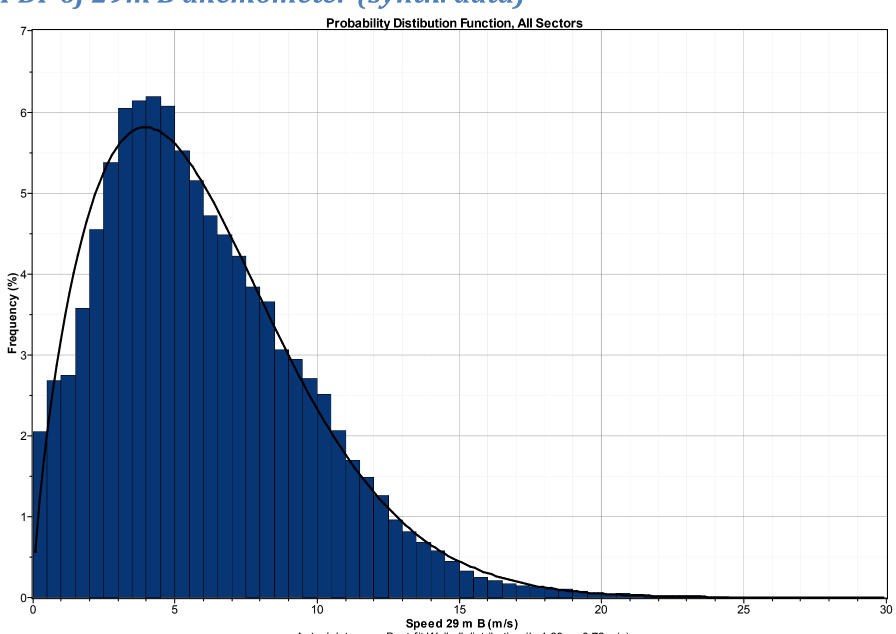
Monthly daily wind profiles (synth. data)



Probability Distribution Function

The probability distribution function (PDF), or histogram, of wind speed indicates wind speed "bins" oriented somewhat 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 cumulate frequency table below that 33 percent of the winds are less than 4 m/s, the cut-in wind speed of most wind turbines.

PDF of 29m B anemometer (synth. data)



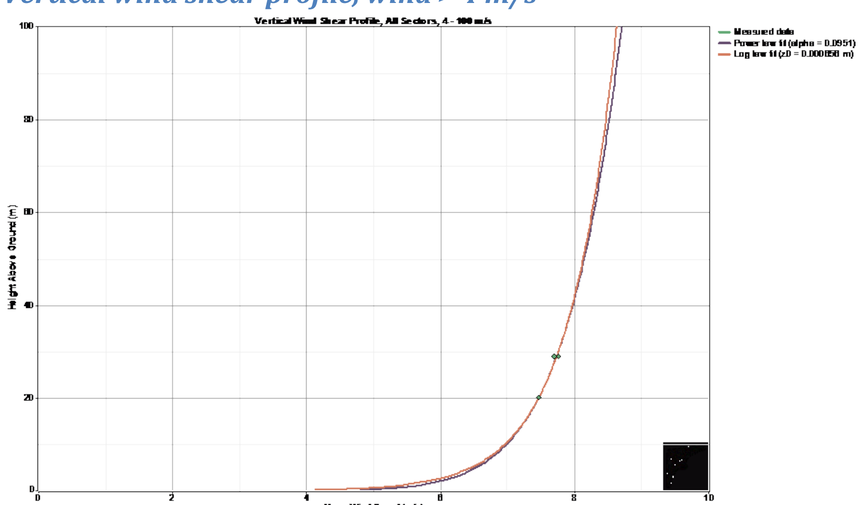
Cumulative frequency table

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	4,952	4.73	4.7	15	16	606	0.58	98.7
1	2	6,616	6.32	11.0	16	17	402	0.38	99.1
2	3	10,382	9.91	21.0	17	18	290	0.28	99.4
3	4	12,747	12.17	33.1	18	19	219	0.21	99.6
4	5	12,827	12.25	45.4	19	20	140	0.13	99.7
5	6	11,167	10.66	56.0	20	21	97	0.09	99.8
6	7	9,635	9.20	65.2	21	22	70	0.07	99.9
7	8	8,429	8.05	73.3	22	23	58	0.06	99.9
8	9	7,030	6.71	80.0	23	24	37	0.04	100.0
9	10	5,918	5.65	85.7	24	25	19	0.02	100.0
10	11	4,773	4.56	90.2	25	26	5	0.01	100.0
11	12	3,331	3.18	93.4	26	27	4	0.00	100.0
12	13	2,317	2.21	95.6	27	28	1	0.00	100.0
13	14	1,572	1.50	97.1	28	29	0	0.00	100.0
14	15	1,073	1.03	98.1	29	30	0	0	100.0
					All		104,717	100.00	

Wind Shear and Roughness

A wind shear power law exponent of 0.0951 indicates very low wind shear at the site; hence wind turbine construction at a low hub height may be a desirable option. Related to wind shear, a calculated surface roughness of 0.00002 meters (the height above ground level where wind velocity would be zero) indicates very smooth terrain (roughness description: smooth) surrounding the met tower.

Vertical wind shear profile, wind > 4 m/s



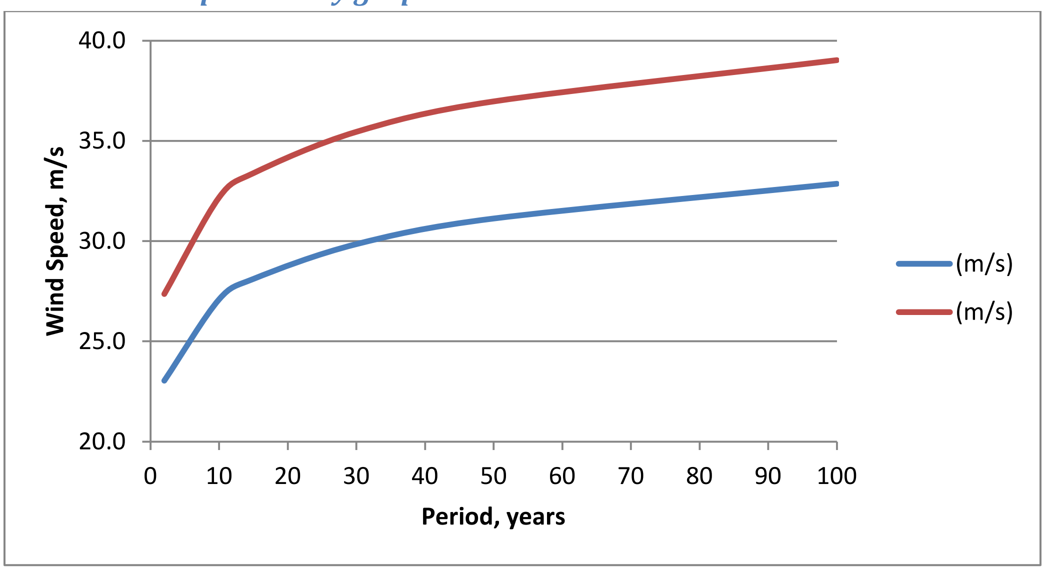
Extreme Winds

The relatively short duration of Deering met tower should be considered minimal for calculation of extreme wind probability, but nevertheless it can be estimated with a reasonable level of accuracy. During the test period, Deering experienced only moderate storm wind events and hence classifies as an IEC 61400-1, 3rd edition (2005), Class III wind site, the lowest defined.

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	23.0	27.4	I	50.0
10	27.1	32.2	II	42.5
15	28.1	33.4	III	37.5
30	29.9	35.5	S	designer-specified
50	31.1	37.0		
100	32.9	39.0		
average gust factor:	1.19			

Extreme winds probability graph



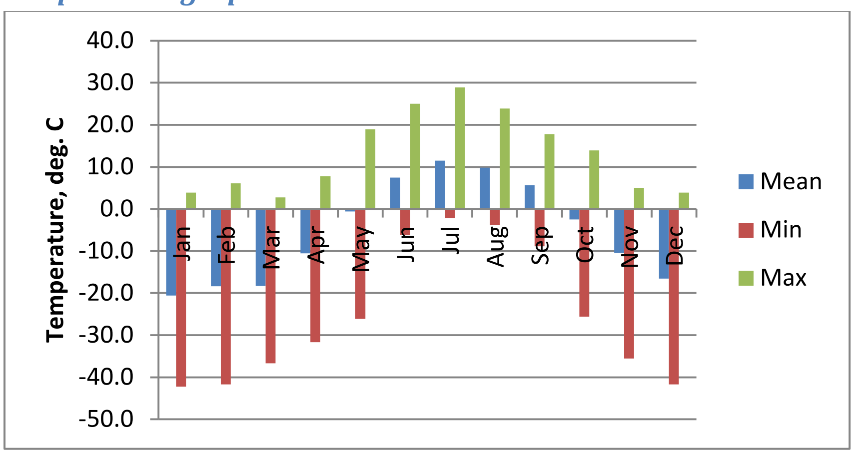
Temperature and Density

In addition to the data loss noted in the Data Recovery section of this report, by examination the met tower temperature data appears faulty. Hence, instead of reporting met tower temperature data, temperature data from the airport ASOS are referenced below. This data represents a restively long time period: 1984 to the present but note that data from years 1986 to 1997 are missing. Density was not directly measured, but calculated using standard pressure at 15 meters elevation and the ideal gas law. Note that in general Deering is a cool maritime climate characterized by severely cold winters.

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	-20.6	-42.2	3.9	1.395	1.526	1.272
Feb	-18.3	-41.7	6.1	1.383	1.523	1.262
Mar	-18.3	-36.7	2.8	1.383	1.490	1.277
Apr	-10.5	-31.7	7.8	1.342	1.460	1.255
May	-0.6	-26.1	18.9	1.293	1.427	1.207
Jun	7.5	-6.1	25.0	1.256	1.320	1.182
Jul	11.5	-2.2	28.9	1.238	1.301	1.167
Aug	9.8	-3.9	23.9	1.246	1.309	1.186
Sep	5.6	-8.9	17.8	1.264	1.334	1.211
Oct	-2.5	-25.6	13.9	1.302	1.423	1.228
Nov	-10.4	-35.6	5.0	1.342	1.483	1.267
Dec	-16.5	-41.7	3.9	1.374	1.523	1.272
Annual	-4.4	-42.2	28.9	1.318	1.526	1.167

Temperature graph



Temperature table, Fahrenheit and Celsius

	Mean (°C)	Min (°C)	Max (°C)	Mean (°F)	Min (°F)	Max (°F)
Jan	-20.6	-42.2	3.9	-5.0	-44.0	39.0
Feb	-18.3	-41.7	6.1	-1.0	-43.0	43.0
Mar	-18.3	-36.7	2.8	-0.9	-34.0	37.0
Apr	-10.5	-31.7	7.8	13.1	-25.0	46.0
May	-0.6	-26.1	18.9	31.0	-15.0	66.0
Jun	7.5	-6.1	25.0	45.5	21.0	77.0
Jul	11.5	-2.2	28.9	52.7	28.0	84.0
Aug	9.8	-3.9	23.9	49.6	25.0	75.0

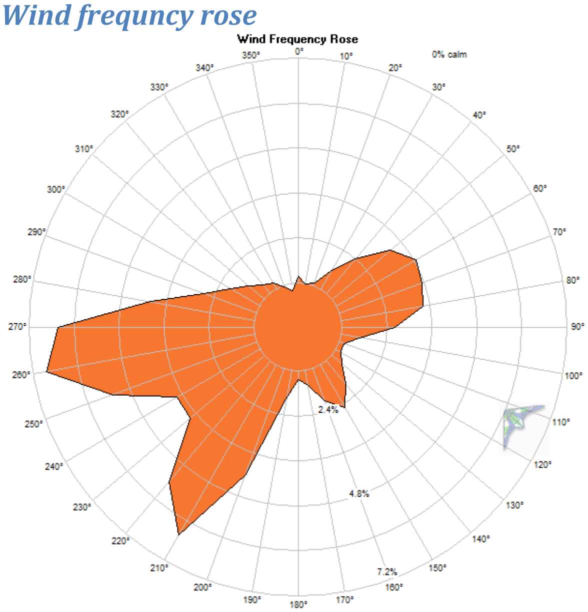
Sep	5.6	-8.9	17.8	42.1	16.0	64.0
Oct	-2.5	-25.6	13.9	27.5	-14.0	57.0
Nov	-10.4	-35.6	5.0	13.2	-32.0	41.0
Dec	-16.5	-41.7	3.9	2.2	-43.0	39.0
Annual	-4.4	-42.2	28.9	24.2	-44.0	84.0

Wind Direction

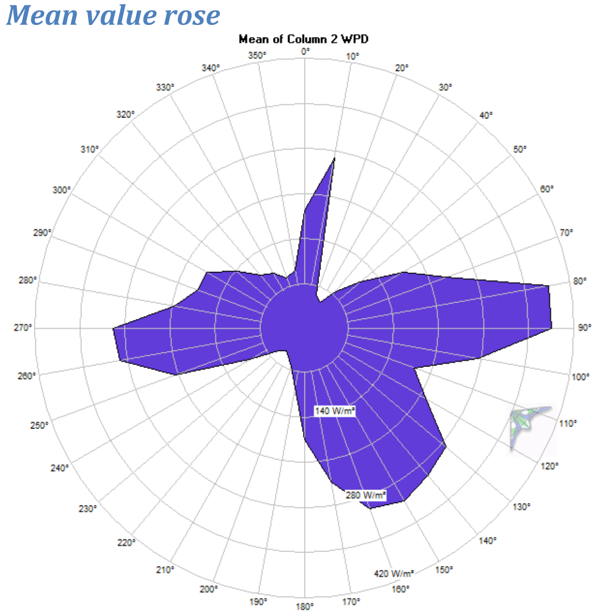
The met tower wind vane was inoperative during the entire measurement period, with no data return. However, nearby airport ASOS data (1984 to present) is usable for wind direction analysis and presented below.

The wind frequency rose for Deering indicates predominately southwesterly to westerly winds with a lesser component of east-northeasterly winds and some southeasterly winds. The mean value rose indicates that when the easterly and southeasterly winds do occur, they tend to be very powerful. Combining the frequency and mean value rose into the total energy rose results in the observation that the power-producing winds are chiefly westerly. Not critically important, but note that the resolution of the ASOS wind direction data is ten degrees, not one degree as with met tower wind vane sensors.

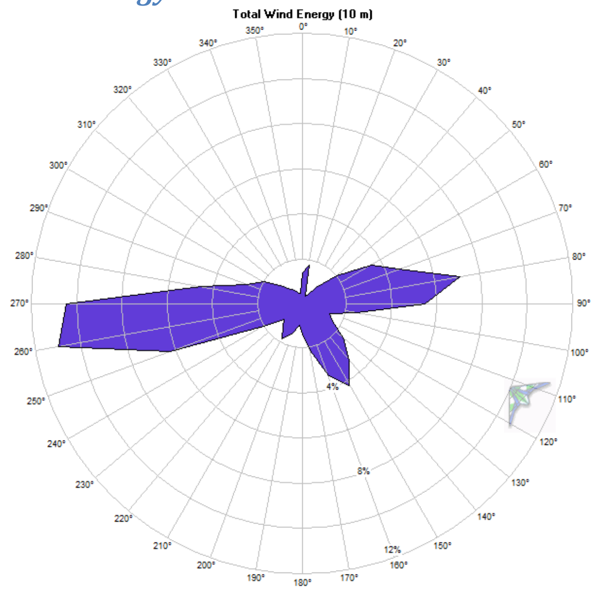
Wind frequncy rose



Mean value rose



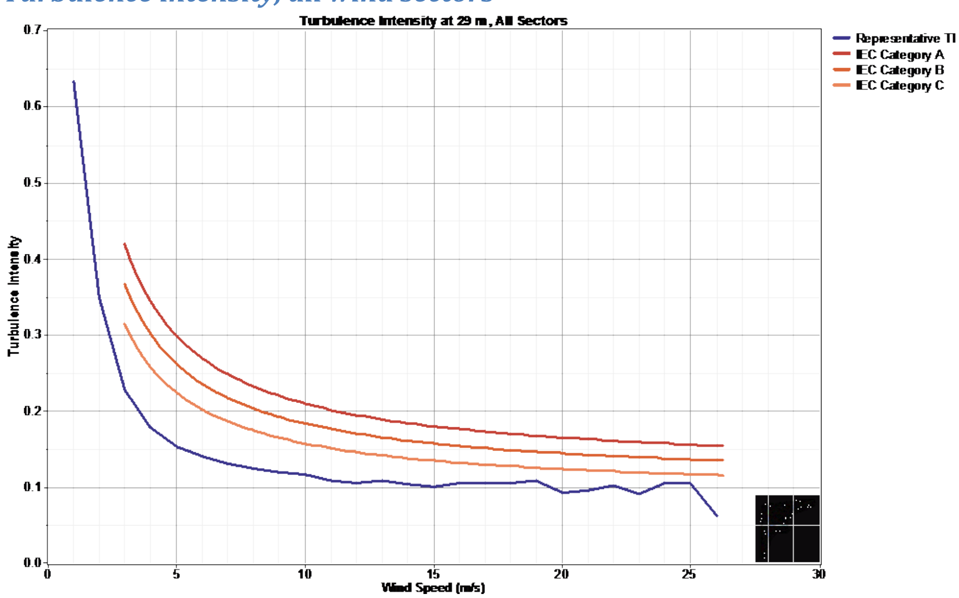
Total energy rose



Turbulence

Turbulence intensity at the Deering 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 0.075.

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	3,858	0.416	0.170	0.634	1.333
2	1.5	2.5	6,218	0.208	0.110	0.349	0.941
3	2.5	3.5	8,963	0.138	0.070	0.228	0.769
4	3.5	4.5	10,044	0.109	0.054	0.178	0.683
5	4.5	5.5	9,206	0.095	0.045	0.153	0.660
6	5.5	6.5	7,891	0.089	0.040	0.140	0.532
7	6.5	7.5	7,298	0.084	0.036	0.131	0.354
8	7.5	8.5	5,994	0.082	0.034	0.125	0.519
9	8.5	9.5	4,751	0.080	0.031	0.119	0.326
10	9.5	10.5	4,028	0.079	0.029	0.116	0.308
11	10.5	11.5	2,995	0.077	0.024	0.108	0.255
12	11.5	12.5	2,103	0.076	0.023	0.105	0.218
13	12.5	13.5	1,359	0.077	0.025	0.109	0.235
14	13.5	14.5	885	0.075	0.022	0.103	0.200
15	14.5	15.5	539	0.075	0.020	0.101	0.158
16	15.5	16.5	317	0.077	0.021	0.105	0.178
17	16.5	17.5	228	0.078	0.021	0.105	0.164
18	17.5	18.5	151	0.078	0.021	0.105	0.152
19	18.5	19.5	99	0.078	0.024	0.109	0.195
20	19.5	20.5	64	0.071	0.018	0.093	0.128
21	20.5	21.5	38	0.070	0.019	0.095	0.125
22	21.5	22.5	43	0.076	0.020	0.102	0.129
23	22.5	23.5	15	0.071	0.015	0.090	0.099
24	23.5	24.5	17	0.075	0.023	0.105	0.119
25	24.5	25.5	8	0.080	0.020	0.106	0.102
26	25.5	26.5	1	0.062	0.000	0.062	0.062

Airport ASOS Data

Analysis of airport ASOS wind speed data since 1984 confirms the met tower data results. Airport data is collected at an elevation of 10 meters. Shown below, the data was scaled to 29 meters with a power law algorithm using an α (power law exponent) value of 0.095 (measured by the met tower) and 0.14 (typical of tundra terrain). In both cases, average wind speeds measured by the met tower exceed airport wind speeds. This likely is due to the more exposed location of the met tower on higher terrain. In 2005, Alaska Energy Authority analyzed the Deering airport data and predicted a Class 3 wind resource from it. Deering met tower data confirms that classification but adjusted to the high end of the Class 3 range.

Airport/met tower data comparison

	Deering Airport			Met Tower, 29 m B	
	AWOS, 10 m sensor (m/s)	Data adj. to 29 m, α=0.095 (m/s)	Data adj. to 29 m, α=0.14 (m/s)	Collected Data (m/s)	Synth. Data (m/s)
Jan	5.16	5.71	5.99	7.14	6.91
Feb	5.90	6.52	6.84	6.05	5.93
Mar	5.19	5.75	6.03	6.64	6.64
Apr	5.10	5.64	5.92	6.27	6.27
May	4.34	4.80	5.03	5.82	5.88
Jun	3.95	4.37	4.59	4.81	4.82
Jul	4.18	4.63	4.86	5.29	5.12
Aug	4.46	4.93	5.18	5.32	5.47
Sep	4.54	5.02	5.27	5.68	5.68
Oct	4.44	4.91	5.15	5.90	5.89
Nov	4.55	5.03	5.28	6.78	6.56
Dec	5.20	5.76	6.04	7.05	6.80
Annual	4.71	5.21	5.47	6.06	6.00

Deering Airport AWOS wind speed graph