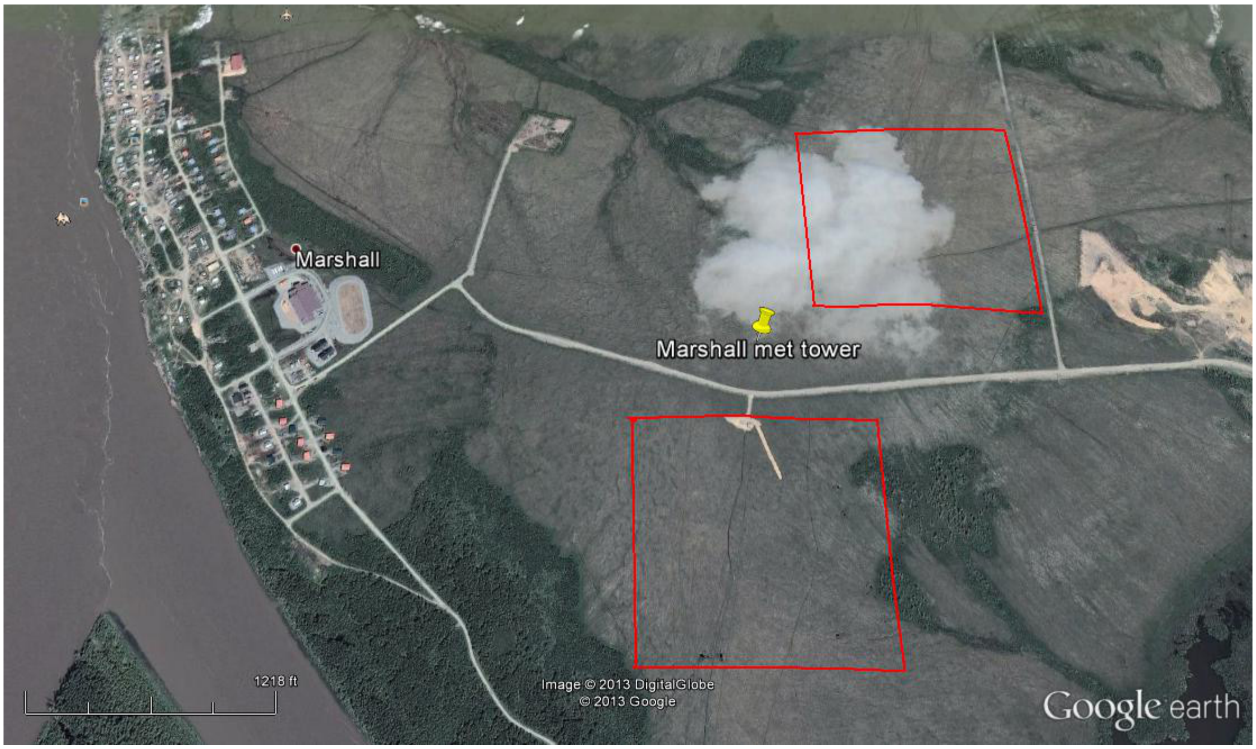
Marshall Wind-Diesel Feasibility Analysis



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This report was prepared by V3 Energy, LLC under contract to Alaska Village Electric Cooperative to assess the technical and economic feasibility of installing wind turbines in Marshall. This analysis is part of a conceptual design project funded in Round IV of the Renewable Energy Fund administered by the Alaska Energy Authority.

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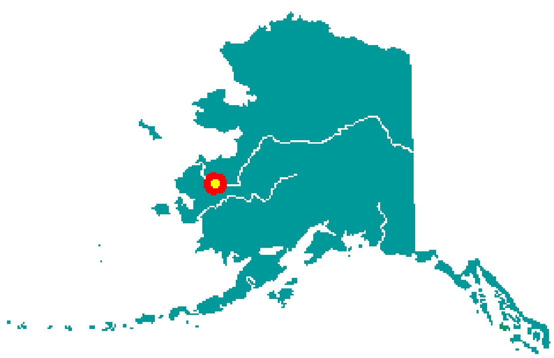
Introduction

Alaska Village Electric Cooperative (AVEC) is the electric utility for the City of Marshall. AVEC was awarded a grant from the Alaska Energy Authority (AEA) to complete feasibility work for installation of wind turbines, with planned construction in 2015.

Village of Marshall

Marshall is located on the north bank of Polte Slough, north of Arbor Island, on the east bank of the Yukon River in the Yukon-Kuskokwim Delta. It lies on the northeastern boundary of the Yukon Delta National Wildlife Refuge. The climate of Marshall is maritime with temperatures ranging between -54 and 86 °F. Average annual rainfall measures 16 inches. Heavy winds in the fall and winter often limit air accessibility. The Lower Yukon is ice-free from mid-June through October.



An expedition came upon an Eskimo village called "Uglovaia" at this site in 1880. Gold was discovered on nearby Wilson Creek in 1913. "Fortuna Ledge" became a placer mining camp, named after the first child born at the camp, Fortuna Hunter. Its location on a channel of the Yukon River was convenient for riverboat landings. A post office was established in 1915, and the population grew to over 1,000. Later, the village was named for Thomas Riley Marshall, Vice President of the United States under Woodrow Wilson from 1913-21. The community became known as "Marshall's Landing." When the village incorporated as a second-class city in 1970, it was named Fortuna Ledge but was commonly referred to as Marshall. The name was officially changed to Marshall in 1984.

A federally-recognized tribe is located in the community -- the Native Village of Marshall. Marshall is a traditional Yup'ik Eskimo village. Subsistence and fishing-related activities support most residents. Members of the Village of Ohogamiut also live in Marshall. The sale, importation, and possession of alcohol are banned in the village.

According to Census 2010, there were 108 housing units in the community and 100 were occupied. Its population was 94.7 percent American Indian or Alaska Native; 2.7 percent white; 0.2 percent Asian; 2.4 percent of the local residents had multi-racial backgrounds. Additionally, 0.2 percent of the population was of Hispanic descent.

Water is derived from five wells. Approximately 70% of the city (60 homes) is served by a piped circulating water and sewer system and has full plumbing. The remainder of the city must haul water and use honey buckets. An unpermitted landfill is available, and the city has a refuse collection service. Electricity is provided by Alaska Village Electric Cooperative. There is one school located in the community, attended by 133 students. Local hospitals or health clinics include Agnes Boliver Health Clinic (Marshall). Emergency Services have river and air access. Emergency service is provided by a health aide.

Marshall has a seasonal economy with most activity during the summer. Fishing, fish processing, and BLM firefighting positions are available seasonally. In 2010, 39 residents held commercial fishing permits. Subsistence activities supplement income. Salmon, moose, bear, and waterfowl are harvested. Trapping provides some income.

No roads connect Marshall to other communities, so access to Marshall is primarily by air or water. The city has a State-owned 3,201' long by 100' wide gravel airstrip. The community is also serviced by barge. Many residents have boats and in winter they rely on snow machines and dog teams for travel.

Wind Resource

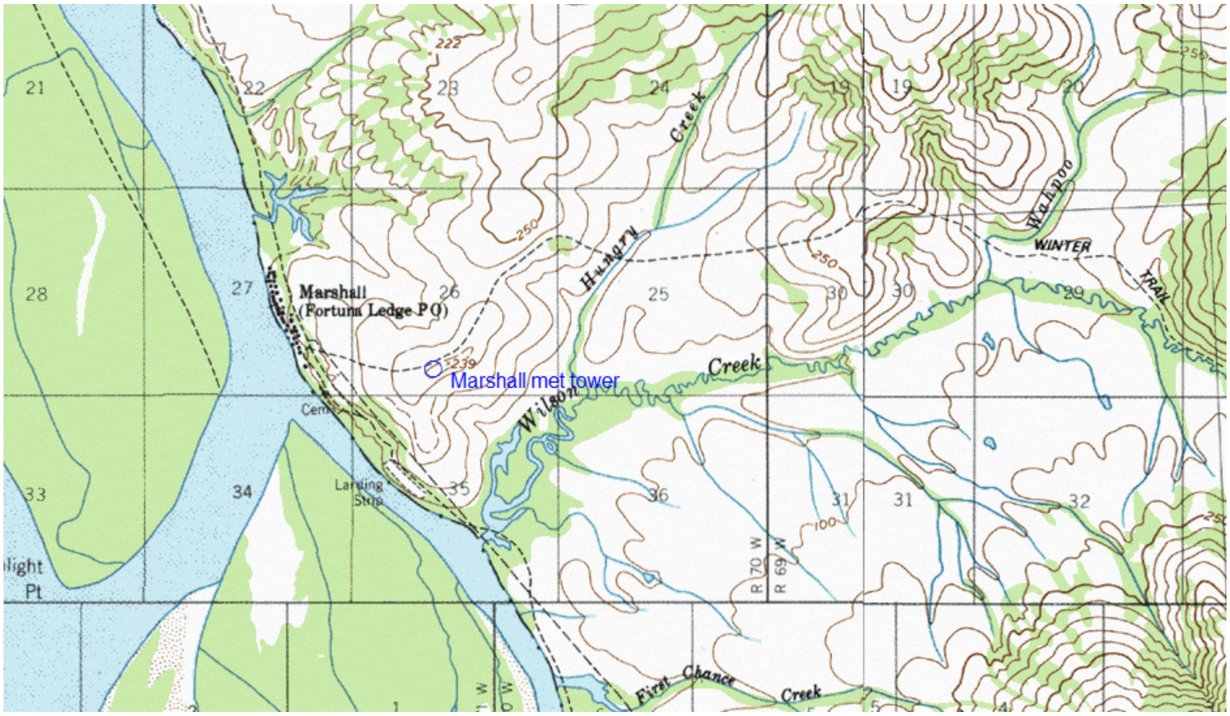
A met tower was installed at the proposed wind turbine site in Marshall on December 18, 2008 and was in continuous operation until October 10, 2009 when an anchor failed during a wind storm and the tower collapsed. The met tower was replaced in September 2012 and is presently operational. With the data through September 2013, a mean annual wind speed of 6.27 m/s was measured, with a mean annual wind power density of 396 W/m^2. This indicates a Class 4 (good) wind resource.

Other aspects of the wind resource also are promising for wind power development. By IEC 61400-1, 3rd edition classification, Marshall is category II to III-C, indicating low turbulence (mean TI at 15 m/s = 0.090) and a moderate probability of extreme wind events. The latter measure is somewhat difficult to quantify with only 24 months of data, but the site clearly is not energetic enough to be IEC Class I. All three wind turbines profiled in this report are certified for IEC Class II conditions.

Marshall met tower data synopsis

Data start date	December 18, 2008
Data end date	Operational (data gap from Oct. 2009 to Sept. 2012); data thru September 26, 2013 for analysis
Wind power class (by WPD)	Class 4 (good)
Wind speed average (30 meters)	6.27 m/s measured
IEC 61400-1 3rd ed. extreme winds	Class II/III (note: 23 months data)
Wind power density (30 meters)	396 W/m^2
Weibull distribution parameters	k = 1.60, c = 6.8 m/s
Roughness Class	0.77 (rough pasture)
Power law exponent	0.133 (low wind shear)
Frequency of calms (4.0 m/s threshold)	34%
Mean Turbulence Intensity	0.090 (IEC 61400-1 3rd ed. turbulence category C)

Topographic map



Google Earth image

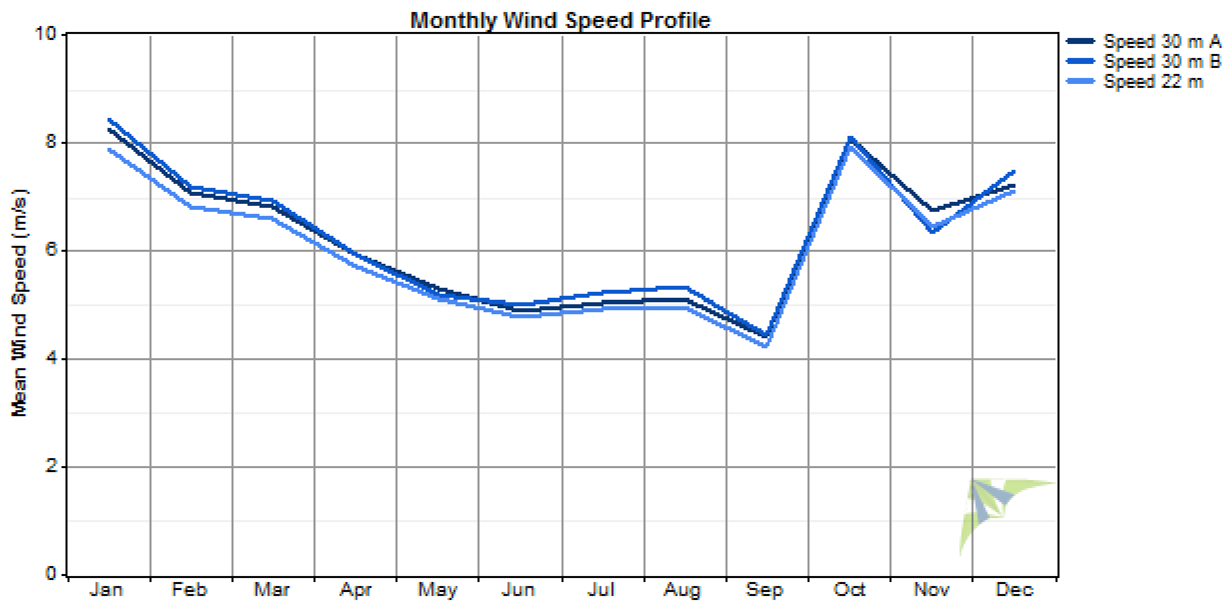
Measured Wind Speeds

Measured wind speeds in Marshall are excellent for an inland site and very promising for wind power development.

Wind Speed Sensor Summary

Variable	Speed 30 m A	Speed 30 m B	Speed 22 m
Measurement height (m)	30	30	22
Mean wind speed (m/s)	6.11	6.15	5.90
MoMM wind speed (m/s)	6.23	6.27	6.01
Max 10-min wind speed (m/s)	26.7	30.8	26.6
Weibull k	1.61	1.57	1.57
Weibull c (m/s)	6.81	6.82	6.55
Mean power density (W/m²)	359	378	331
MoMM power density (W/m²)	376	396	345
Mean energy content (kWh/m²/yr)	3,146	3,311	2,896
MoMM energy content (kWh/m²/yr)	3,296	3,471	3,025
Energy pattern factor	2.41	2.51	2.47
Frequency of calms (%)	35.1	35.9	37.3

Marshall Wind speed graph

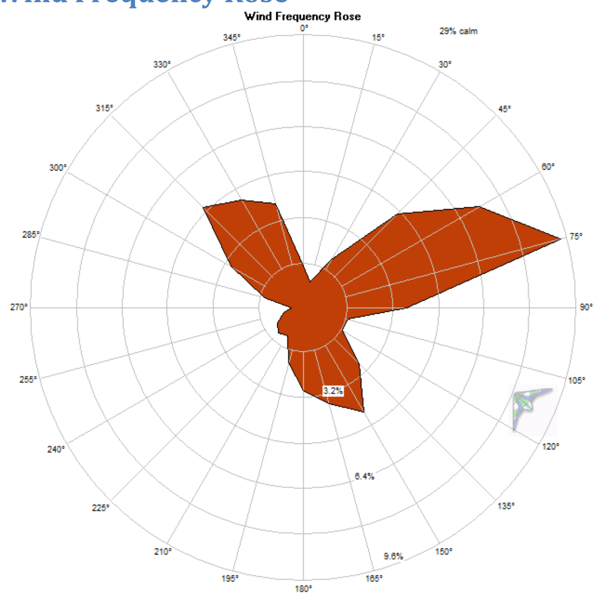


Wind Roses

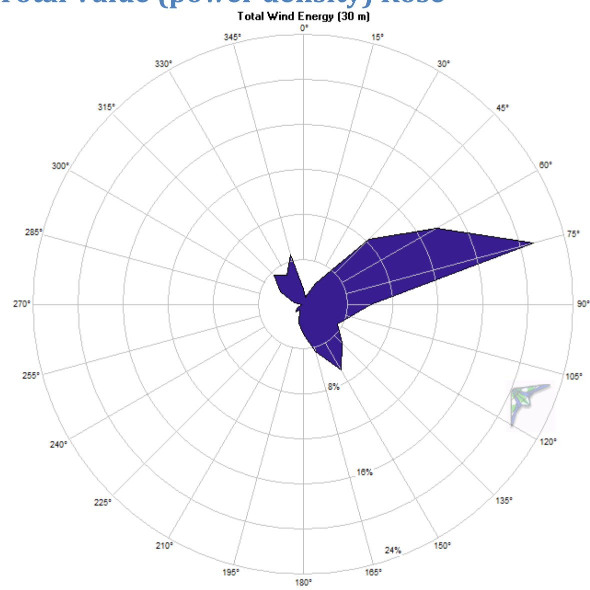
Winds at the Marshall met tower test site are primarily east-northeast, north-northwest with occasional winds from south-southeast (wind frequency rose), with the strongest winds east-northeast (mean value rose). The power density rose indicates that the power producing winds at the site are predominately east-northeast. Multiple wind turbines should oriented an axis north-northeast to south-southwest to provide good exposure to ENE and SSE winds and avoid tower shadowing.

Note that a wind threshold of 4.0 m/s was selected for the definition of calm winds. With this threshold, the Marshall met tower site experienced 34 percent calm conditions during the test period.

Wind Frequency Rose



Total Value (power density) Rose



Wind-Diesel Hybrid System Overview

Wind-diesel power systems are categorized based on their average penetration levels, or the overall proportion of wind-generated electricity compared to the total amount of electrical energy generated. Commonly used categories of wind-diesel penetration levels are low penetration, medium penetration, and high penetration. The wind penetration level is roughly equivalent to the amount of diesel fuel displaced by wind power. Note however that the higher the level of wind penetration, the more complex and expensive a control system and demand-management strategy is required.

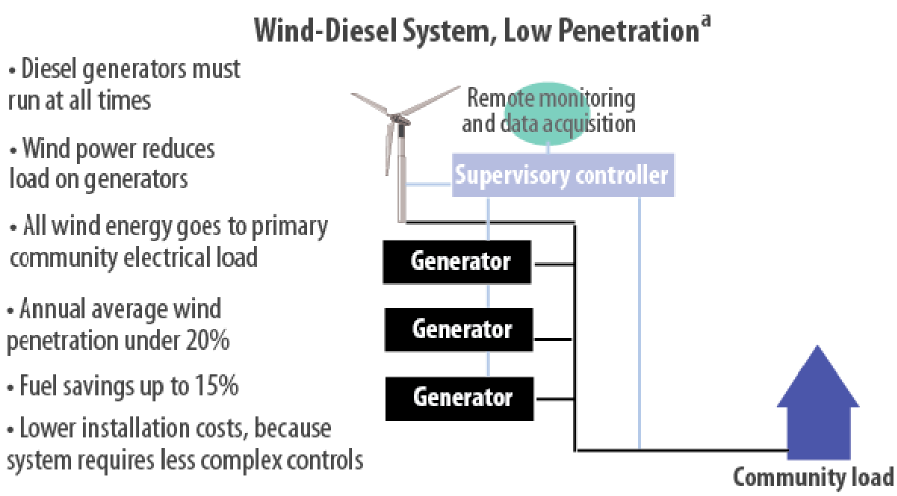
Categories of wind-diesel penetration levels

Penetration Category	Wind Penetration Level		Operating Characteristics and System Requirements
	Instantaneous	Average	
Very Low	<60%	<8%	• Diesel generator(s) runs full time • Wind power reduces net load on diesel • All wind energy serves primary load • No supervisory control system
Low	60 to 120%	8 to 20%	• Diesel generator(s) runs full time • At high wind power levels, secondary loads are dispatched to insure sufficient diesel loading, or wind generation is curtailed • Relatively simple control system
Medium	120 to 300%	20 to 50%	• Diesel generator(s) runs full time • At medium to high wind power levels, secondary loads are dispatched to insure sufficient diesel loading • At high wind power levels, complex secondary load

Penetration Category	Wind Penetration Level		Operating Characteristics and System Requirements
	Instantaneous	Average	
			control system is needed to ensure heat loads do not become saturated • Sophisticated control system
High (Diesels-off Capable)	300+%	50 to 150%	• At high wind power levels, diesel generator(s) may be shut down for diesels-off capability • Auxiliary components required to regulate voltage and frequency • Sophisticated control system

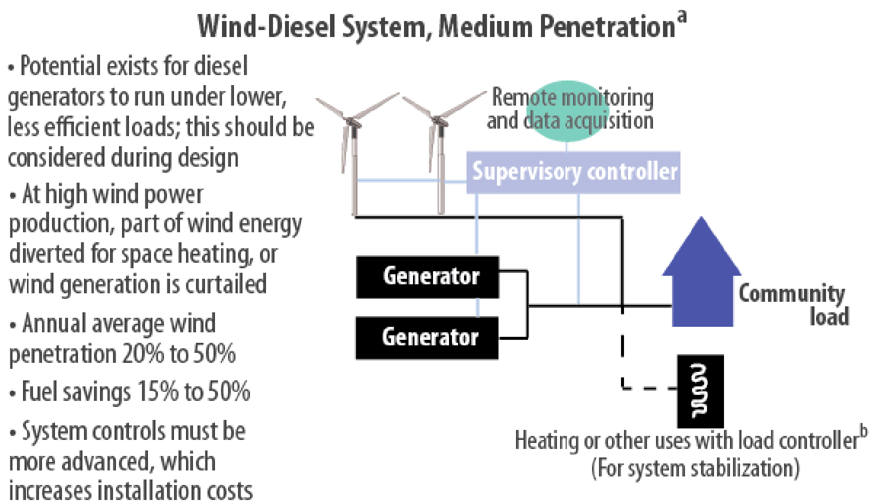
Low Penetration Configuration

Low-penetration wind-diesel systems require the fewest modifications to a new or existing power system in that maximum wind penetration is never sufficient to present potential electrical stability problems. But, low penetration wind systems tend to be less economical than higher penetration systems due to the limited annual fuel savings compared to a relatively high total wind system installation costs. This latter point is because all of the fixed costs of a wind power project – equipment mobilization and demobilization, distribution connection, new road access, permitting, land acquisition, etc. – are spread across fewer turbines, resulting in relatively high per kW installed costs.



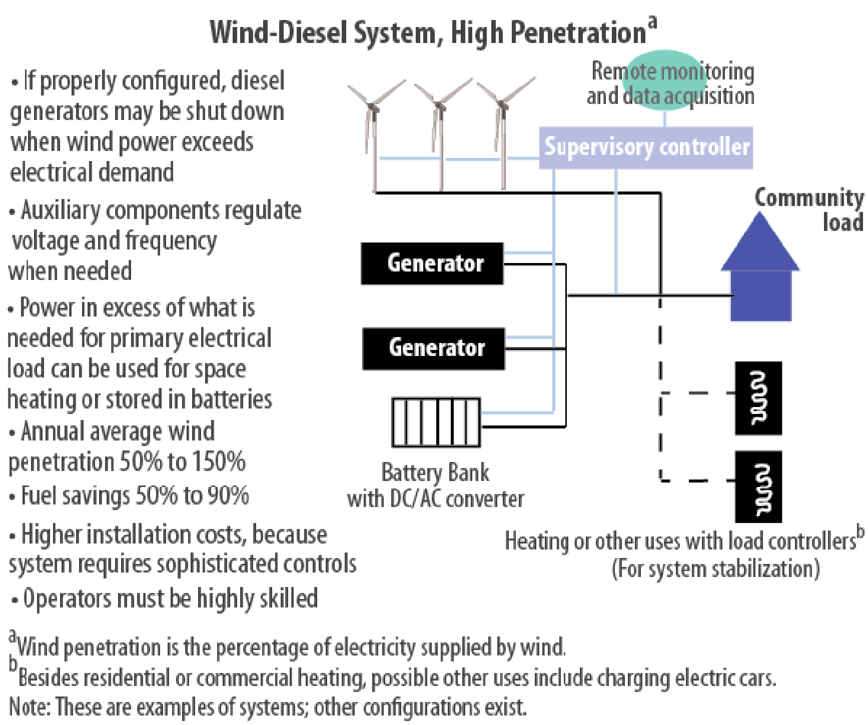
Medium Penetration Configuration

Medium penetration mode is very similar to high penetration mode except that no electrical storage is employed in the system and wind capacity is designed for a moderate and usable amount of excess wind energy that must be diverted to thermal loads. All of AVEC's modern wind power systems are designed as medium penetration systems.



High Penetration Configuration

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



Wind-Diesel System Components

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

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

Wind Turbine(s)

Village-scale wind turbines are generally considered as 50 kW to 250 kW rated output. This turbine size once dominated with worldwide wind power industry but has been left behind in favor of much larger 1,000 kW plus capacity turbines for utility grid-connected projects. Conversely, many turbines are manufactured for home or farm application, but generally these are 10 kW or smaller. Consequently, few new manufacture village size-class turbines are on the market, although a large supply of used and/or remanufactured turbines are available. The latter typically result from the repower of older wind farms in the Continental United States and Europe with new, larger wind turbines.

Supervisory Control System

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

Synchronous Condenser

A synchronous condenser, sometimes called a synchronous compensator, is a specialized synchronous electric motor with an output shaft that spins freely. Its excitation field is controlled by a voltage regulator to either generate or absorb reactive power as needed to support the grid voltage or to maintain the grid power factor at a specified level. This is necessary for diesels-off wind turbine operations, but generally not required for wind systems that maintain a relatively large output diesel generator online at all times.

Synchronous condenser in Kokhanok

Secondary Load

To avoid curtailing wind turbines during periods of high wind/low load demand, a secondary or “dump” load is installed to absorb excess system (principally wind) power beyond that required to meet the electrical load. The secondary load converts excess wind energy into heat via an electric boiler typically installed in the diesel generator heat recovery loop. This heat can be for use in space and water heating through the extremely rapid (sub-cycle) switching of heating elements, such as an electric boiler imbedded in the diesel generator jacket water heat recovery loop. As seen in Figure 16, a secondary load controller serves to stabilize system frequency by providing a fast responding load when gusting wind creates system instability.

An electric boiler is a common secondary load device used in wind-diesel power systems. An electric boiler (or boilers), coupled with a boiler grid interface control system, in a new module outside the Marshall power plant building, would be sized to absorb up to 200 kW of instantaneous energy (full output of the wind turbines). The grid interface monitors and maintains the temperature of the electric hot water tank and establishes a power setpoint. The wind-diesel system master controller assigns the setpoint based on the amount of unused wind power available in the system. Frequency stabilization is another advantage that can be controlled with an electric boiler load. The boiler grid interface will automatically adjust the amount of power it is drawing to maintain system frequency within acceptable limits.

Deferrable Load

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

Interruptible Load

Electric heating either in the form of electric space heaters or electric water boilers should be explored as a means of displacing stove oil with wind-generated electricity. It must be emphasized that electric heating is only economically viable with excess electricity generated by a renewable energy source such as wind and not from diesel-generated power. It is typically assumed that 41 kWh of electric heat is equivalent to one gallon of heating fuel oil.

Storage Options

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

Batteries

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

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

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

Wind Turbine Options

Several village-scale wind turbines are considered suitable for Marshall. The guiding criteria are turbine output rating in relation to electric load, simplicity of design, AVEC Operations department preferences, redundancy, and cost considerations. The turbines chose for review in this CDR are the Northern Power Systems NPS 100, the Vestas V20, and the Aeronautica 33-225.

Northern Power Systems NPS100-21 ARCTIC

The Northern Power 100-21 ARCTIC (NPS100-21), formerly known as the Northwind 100 (NW100), is rated at 100 kW and is equipped with a permanent magnet, synchronous generator, is direct drive (no gearbox), can be equipped with heaters and insulation, and has been tested to ensure operation in extreme cold climates. The turbine has a 21 meter diameter rotor and is available with a 30 or 37 meter monopole towers, or a 48 meter lattice tower. The rotor blades are fixed pitch for stall control but the turbine is also inverter regulated for maximum 100 kW power output. For Marshall, the NPS100-21 will be equipped with a cold climate package enabling a minimum operating temperature of -40° C. The Northern Power 100 is the most widely represented village-scale wind turbine in Alaska with a significant number of installations in the Yukon-Kuskokwim Delta and on St. Lawrence Island. The Northern Power 100-21 wind turbine is manufactured in Barre, Vermont, USA. More information may be found at http://www.northernpower.com/.

Northern Power NPS100 wind turbine

Vestas V20

The Vestas V20 was originally manufactured by Vestas Wind Systems A/S in Denmark and is no longer in production. It is, however, available as a remanufactured unit from Halus Power Systems in California (represented in Alaska by Marsh Creek, LLC) and from Talk, Inc. in Minnesota. The V20 is rated at 120 kW and is a higher output version of the two Vestas V17 wind turbines installed in Kokhanok in 2011. The V20 has a fixed-pitch, stall-regulated rotor coupled to an asynchronous (induction) generator via a gearbox drive. The original turbine design included low speed and high speed generators in order to optimize performance at low and high wind speeds. The two generators are connected to the gearbox with belt drives and a clutch mechanism. In some installations though – especially sites with a high mean wind speeds – the low speed generator is removed to eliminate a potential failure point.

Vestas V17 wind turbines in Kokhanok (similar to the V20)

Aeronautica AW33-225

The Aeronautica AW33-225 wind turbine is manufactured new by Aeronautica in Durham, New Hampshire. This turbine was originally designed by the Danish-manufacturer Norwin in the 1980's with a 29 meter rotor diameter and had a long and successful history in the wind industry before being replaced by larger capacity turbines for utility-scale grid-connect installations. The original 29 meter rotor diameter design is available as the AW29-225 for IEC Class IA wind regimes. The AW33-225 is a new variant designed for IEC Class II and III winds. The AW225 turbine is stall-regulated, has a synchronous (induction) generator, active yaw control, is rated at 225 kW power output, and is available with 30, 40, or 50 meter tubular steel towers. The AW33-225 is cold climate certified to -30° C and is new to the Alaska market with no in-state installations at present. While the AW29-225 has a typical cut-out wind speed of 25 m/s, the larger rotor diameter AW33-225 is designed for a cut-out speed of 22 m/s. More information can be found at http://aeronauticawind.com/aw/index.html.

Aeronautica AW 33-225 wind turbine (29-225 version shown)

Homer Software Wind-Diesel Model

Homer energy modeling software was used to analyze the existing Marshall power plant. Homer software was designed to analyze hybrid power systems that contain a mix of conventional and renewable energy sources, such as diesel generators, wind turbines, solar panels, batteries, etc. and is widely used to aid development of Alaska village wind power projects. It is a static energy balance model, however, and is not designed to model the dynamic stability of a wind-diesel power system, although it will provide a warning that renewable energy input is potential sufficient to result in system instability.

Diesel Power Plant

Electric power (comprised of the diesel power plant and the electric power distribution system) in Marshall is provided by AVEC with the following diesel configuration.

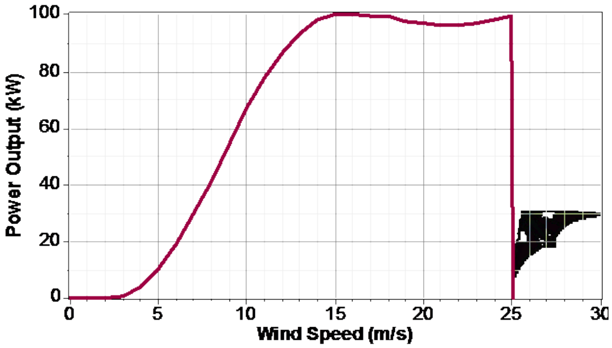
Marshall powerplant diesel generators

Generator	Electrical Capacity	Diesel Engine Model	Generator
1	500 kW	Caterpillar 3456	Cat LC6
2	363 kW	Detroit Series 60 DDEC4	Kato 6P4-1450
3	236 kW	Detroit Series 60 DDEC4	Kato 6P4-1450

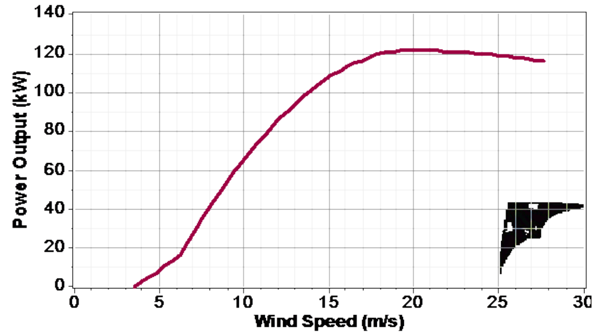
Wind Turbines

This CDR evaluates installation of three new Northern Power Systems NPS100-21 turbines for 300 kW installed capacity, three remanufactured Vestas V20 turbines for 360 kW installed capacity, or one new Aeronautica AW33-225 turbines for 225 KW installed capacity. Standard temperature and pressure (STP) power curves are shown below. Note that for the Homer analysis, site elevation was adjusted to reflect the measured mean annual air density of 1.294 kg/m^3.

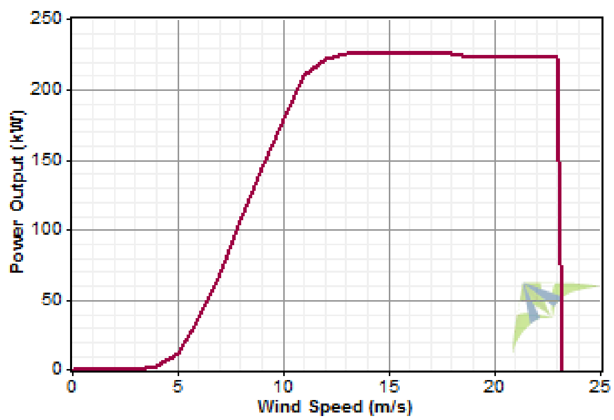
Northern Power 100-24 Arctic



Vestas V20



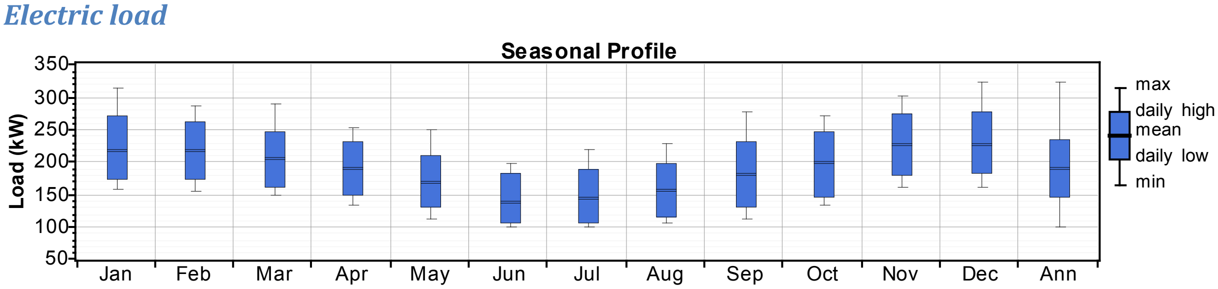
Aeronautica AW33-225

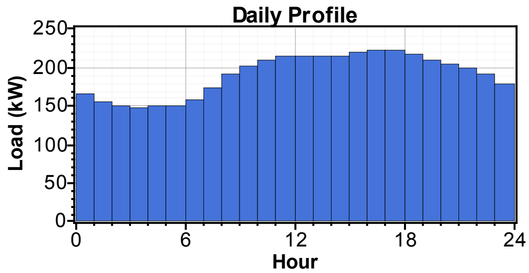


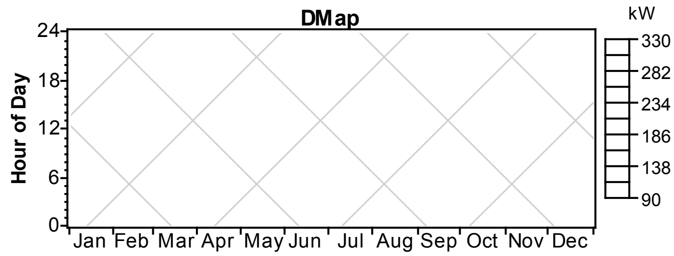
Electric Load

Marshall electric load data, collected from March 2012 to September 2013, was received from William Thompson of AVEC. These data are in 15 minute increments and represent total electric load demand during each time step. The data were processed by adjusting the date/time stamps nine hours from UTC to Yukon/Alaska time, converting the data from kWh to kW, and creating a January 1 to December 31 hourly list for export to HOMER software. The resulting load is shown graphically below. Average load is 190 kW with a 323 kW peak load and an average daily load demand of 4,561 kWh. This compares to a 185 kW average load reported to the RCA for the 2012 PCE report.

Electric load







Thermal Load

Powerplant heat recovery in Marshall is non-functional at present with fairly long distances to relatively large heat loads. Homer modeling indicates that excess wind energy from the wind turbine combinations considered would be large enough to warrant construction of a recovered heat system or remote placement of a secondary load controller/electric boiler in a building with high thermal demand, such as the new school or the water plant. Due to the relatively modest amount of predicted excess energy from wind turbine operation, it is assumed that the school and/or water plant can use this excess energy to displace heating oil usage.

Diesel Generators

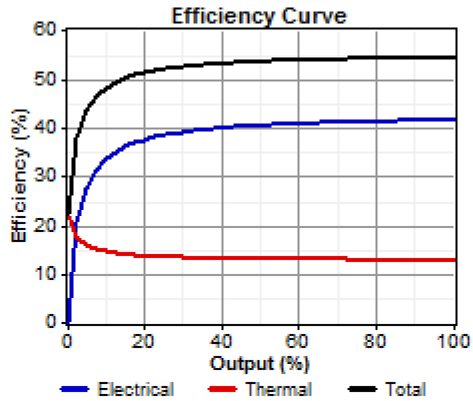
The HOMER model was constructed with all three Marshall diesel generators. For cost modeling purposes, AEA assumes a generator O&M cost of $0.020/kWh. Other diesel generator information pertinent to the HOMER model is shown below. Individual generator fuel curve information is available but Homer modeling with generator-specific fuel curves indicated fuel efficiency of 15.3 kWh/gal in the base case (no wind turbines). This is higher than AVEC's reported fuel efficiency of 12.98 kWh/gal to Regulatory Commission of Alaska for the 2012 Power Cost Equalization Report, and the 14.44 kWh/gal efficiency for Marshall documented in AVEC's 2011 annual generation report.

Diesel generator HOMER modeling information

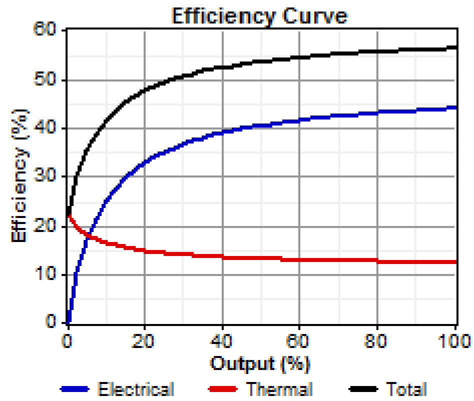
Diesel generator	Caterpillar 3456	Detroit Series 60 DDEC4	Detroit Series 60 DDEC4
Power output (kW)	500	363	236
Intercept coeff. (L/hr/kW rated)	0.00651	0.0195	0.0146
Slope (L/hr/kW output)	0.2382	0.2122	0.2384
Minimum electric load (%)	5.0% (25 kW)	6.9% (25 kW)	10.6% (25 kW)
Heat recovery ratio (% of waste heat that can serve the thermal load)	22	22	22

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

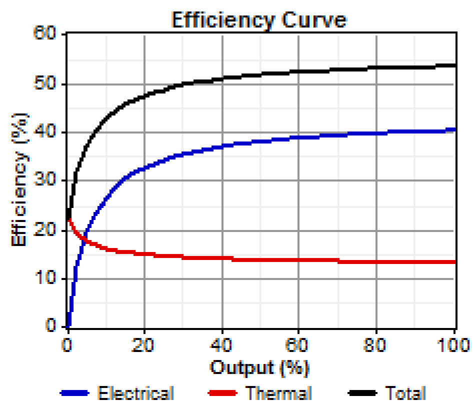
Cat 3456 fuel efficiency curve



DD60 DDEC4 Gen 2



DD60 DDEC4 Gen 3



Economic Analysis

Installation of wind turbines in medium penetration mode is evaluated in this report to demonstrate the economic impact of these turbines with the following configuration: turbines are connected to the electrical distribution system with first priority to serve the electrical load, and second priority to serve the thermal load via a secondary load controller and electric boiler.

Wind Turbine Costs

Project capital and construction costs for the three evaluated wind turbines were obtained from HDL, Inc. and are presented below. Detailed information regarding HDL's cost estimates is available in their portion of this conceptual design report.

Project cost estimates

Turbine	No. Turbines	HDL Estimated Project Cost	Installed kW	Cost per kW Capacity	Tower Type	Tower Height (meters)
Northern Power NPS100-21 Arctic	3	$3,441,275	285	$12,074	Monopole	37
Vestas V20	3	$3,102,175	360	$8,617	Lattice	32
Aeronautica AW33-225	1	$2,808,025	225	$12,480	Monopole	50

Fuel Cost

A fuel price of $4.99/gallon ($1.32/Liter) was chosen for the initial HOMER analysis by reference to *Alaska Fuel Price Projections 2013-2035*, prepared for Alaska Energy Authority by the Institute for Social and Economic Research (ISER), dated June 30, 2013 and the *2013_06_R7Prototype_final_07012013* Excel spreadsheet, also written by ISER. The $4.99/gallon price reflects the average value of all fuel prices between the 2015 (the assumed project start year) fuel price of $4.17/gallon and the 2034 (20 year project end year) fuel price of $5.98/gallon using the medium price projection analysis with an average social cost of carbon (SCC) of $0.61/gallon included.

By comparison, the fuel price for Marshall (without social cost of carbon) reported to Regulatory Commission of Alaska for the 2012 PCE report is $3.32/gallon ($0.88/Liter), without inclusion of the SCC. Assuming an SCC of $0.40/gallon (ISER *Prototype* spreadsheet, 2013 value), the Marshall's 2012 diesel fuel price was $3.72/gallon ($0.98/Liter).

Heating fuel displacement by excess energy diverted to thermal loads is valued at $6.32/gallon ($1.67/Liter) as an average price for the 20 year project period. This price was determined by reference to the *2013_06_R7Prototype_final_07012013* Excel spreadsheet where heating oil is valued at the cost of diesel fuel (with SCC) plus $1.05/gallon, assuming heating oil displacement between 1,000 and 25,000 gallons per year.

Fuel cost table (SCC included)

ISER med. projection	2015 (/gal)	2034 (/gal)	Average (/gallon)	Average (/Liter)
Diesel Fuel	$4.17	$5.98	$4.99	$1.32
Heating Oil	$5.22	$7.03	$6.04	$1.60

Modeling Assumptions

As noted previously, HOMER energy modeling software was used to analyze a wind-diesel hybrid power plant to serve Marshall. HOMER is designed to analyze hybrid power systems that contain a mix of conventional and renewable energy sources, such as diesel generators, wind turbines, solar panels, batteries, etc. and is widely used to aid development of Alaska village wind power projects.

Modeling assumptions are detailed in the table below. Assumptions such as project life, discount rate, operations and maintenance (O&M) costs, etc. are AEA default values and contained in the ISER spreadsheet model. Other assumptions, such as diesel overhaul cost and time between overhaul are based on general rural Alaska power generation experience.

The base or comparison scenario is the existing power plant with no functional heat recovery loop. Note that wind turbines installed in Marshall will operate in parallel with the diesel generators. Excess energy will serve thermal loads via a secondary load controller and electric boiler (to be installed). Installation cost of wind turbines assumes construction of three phase power distribution to the selected site, plus civil, permitting, integration and other related project costs.

Homer modeling assumptions

Economic Assumptions	
Project life	20 years (2015 to 2034)
Discount rate	3%
Operating Reserves	
Load in current time step	10%
Wind power output	100% (Homer setting to always force diesels on)
Fuel Properties (no. 2 diesel for powerplant)	
Heating value	46.8 MJ/kg (140,000 BTU/gal)
Density	830 kg/m^3 (6.93 lb./gal)
Price (20 year average; ISER 2013, medium projection plus social cost of carbon)	$4.99/gal ($1.32/Liter)
Fuel Properties (no. 1 diesel to serve thermal loads)	
Heating value	44.8 MJ/kg (134,000 BTU/gal)
Density	830 kg/m^3 (6.93 lb./gal)
Price (20 year average; ISER 2013, medium projection plus social cost of carbon)	$6.04/gal ($1.60/Liter)
Diesel Generators	
Generator capital cost	$0 (new generators already funded)
O&M cost	$0.02/kWh (reference: ISER 2013 *Prototype* spreadsheet)
Diesel generator efficiency (Homer)	15.2 kWh/gal (from diesel fuel curves)
Diesel generator efficiency (ISER)	13.0 kWh/gal (from 2012 PCE report)
Minimum load	25 kW; based on AVEC's operational criteria of 25 kW minimum diesel loading with their wind-diesel systems
Schedule	Optimized
Wind Turbines	
Availability	80%
O&M cost	$0.049/kWh (reference: ISER 2013 *Prototype* spreadsheet)
Wind speed	6.27 m/s at 30 m, 100% turbine availability 5.57 m/s at 30 m, 80% turbine availability
Density adjustment	1.242 kg/m^3 (mean of monthly means of 18 months of Marshall met tower data; Homer wind resource elevation set at -150 meters to simulate the Marshall air density
Power law exponent	0.133 (met tower data)
Hub height/tower type	NPS100-21 Arctic: 37 meter monopole V20: 32 meter lattice AW33-225: 50 meter monopole
Energy Loads	
Electric	4.56 MWh/day average Marshall power plant load
Thermal	Undefined at present; assumed large enough to absorb excess wind energy

Project Economic Valuation

	Homer Model Input					ISER Model Results							
Turbine Type	Wind Capacity (kW)	Diesel Efficiency (kWh/gal)	Wind Energy (kWh/yr)	Excess Electricity (kWh/yr	Net Wind Energy (kWh/yr)	Project Capital Cost	Diesel Efficiency (kWh/gal)	NPV Benefits	NPV Capital Costs	Diesel #2 Displaced (gal/yr)	B/C Ratio	NPV Net Benefit
NPS100	300	15.2	623,300	99,593	523,707	$3,174,175	13.0	$2,690,261	$2,820,213	42,893	0.95	($129,952)
V20	360	15.2	575,191	103,670	471,521	$2,890,575	13.0	$2,451,169	$2,568,238	38,977	0.95	($117,069)
AW33	225	15.2	522,926	55,037	467,889	$2,660,400	13.0	$2,333,259	$2,363,731	37,454	0.99	($30,472)

Notes:

80% wind turbine availability

Diesel efficiency for ISER model per 2012 PCE Report

Excess energy serves thermal loads not connected to a powerplant heat recovery loop

Additional Information

Turbine Type	Hub Height (m)	No. Turbines	Wind Energy to Thermal (kWh/yr)	Heating Fuel Equiv. (gal)	Wind Penetration (% electrical)	Excess Energy (%)
NPS100	37	3	99,593	2,546	37.4	6.0
V17	32	3	103,670	2,650	34.6	6.2
AW33	50	1	55,037	1,407	31.4	3.3

Conclusion and Recommendations

Marshall has a very good wind resource for wind power development, especially considering its distance from the Bering Sea coast. Wind behavior is desirable with low turbulence, low wind shear, moderate extreme wind probability, and little evidence of severe icing conditions.

The analysis in this report considered configurations of three Northern Power 100 wind turbines, three remanufactured Vestas V20 wind turbines, or one Aeronautica AW225 wind turbine, all in a medium penetration configuration with no electrical storage and a wind-heat node at the school or the water plant.

It is recommended that this project proceed to the design phase. Further analysis and discussion may better highlight advantages and disadvantages of each option considered, but at present all three options present nearly equivalent economic valuation, hence turbine choice is largely a matter of preference for the utility.