

Stebbins-Saint Michael Wind-Diesel Feasibility Analysis



AVEC Photo

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This report was prepared by V3 Energy, LLC under contract to Alaska Village Electric Cooperative, Inc. to assess the technical and economic feasibility of installing wind turbines in the village of Stebbins to serve a combined Stebbins-St. Michael load. This analysis is part of a conceptual design report funded by the Renewable Energy Fund, which is administered by the Alaska Energy Authority.

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Introduction

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

Stebbins and Saint Michael

Stebbins has a population of 585 people while Saint Michael has a population of 401 people (2010 census). Both villages are located on Saint Michael Island in Norton Sound, 125 miles southeast of Nome and 48 miles southwest of Unalakleet. The villages have a subarctic climate with maritime influences during the summer. Summer temperatures average 40° to 60 °F; winters average -4° to 16 °F. Extremes from -55° to 70 °F have been recorded. Annual precipitation averages 12 inches, with 38 inches of snow. Summers are rainy and fog is common. Norton Sound is typically ice free from early June to mid-November.

A fortified trading post called "Redoubt St. Michael" was built by the Russian-American Company at Saint Michael in 1833; it was the northernmost Russian settlement in Alaska. The Native village of "Tachik" stood to the northeast. When the Russians left Alaska in 1867, several of the post's traders remained. "Fort St. Michael," a U.S. military post, was established in 1897. During the gold rush of 1897, it was a major gateway to the interior via the Yukon River. As many as 10,000 persons were said to live in Saint Michael during the gold rush. Saint Michael was also a popular trading post for Eskimos to trade their goods for Western supplies. Centralization of many Yup'iks from the surrounding villages intensified after the measles epidemic of 1900 and the influenza epidemic of 1918. The village remained an important trans-shipment point until the Alaska Railroad was built. The city government was incorporated in 1969.

A federally-recognized tribe is located in Saint Michael, the Native Village of Saint Michael. In Stebbins, the analogous entity is the Stebbins Community Association. Stebbins' and Saint Michael's population is largely Yup'ik Eskimo and many residents are descendants of Russian traders. Seal, beluga whale, moose, caribou, fish, and berries are important staples. The sale and importation of alcohol is banned in both villages.

Stebbins and Saint Michael are accessible only by air and sea but are connected to each other with a 10.5 mile road. Both villages have airports and a seaplane base is available. Regular and charter flights are available from Nome and Unalakleet. Saint Michael is near the Yukon River Delta and has a good natural harbor but no dock. Lighterage service is provided on a frequent basis from Nome. Both villages receive at least one annual shipment of bulk cargo. At present Saint Michael and Stebbins are not connected electrically with a power distribution intertie, but a project to do so is planned for the near future. The electrical intertie will follow the road connecting the two villages.

Note: Information above obtained from Alaska Community Database Community Information Summaries at www.commerce.state.ak.us/dca/commdb/CF_CIS.htm.

Stebbins Wind Resource

A met tower was installed on a plateau area located on Stebbins Native Corporation land near the road that connects Stebbins to the village of Saint Michael to the east. The site is large enough to accommodate several or more wind turbines and in many respects is ideal for wind power development with close proximity to an existing road and planned new electrical distribution connecting Stebbins to Saint Michael. Additionally, geotechnical conditions at the site appear to be highly suitable for turbine foundation construction.

Note that the Stebbins met tower is the second wind site in the Stebbins-Saint Michael area studied. A met tower had been in service from July 2010 to September 2011 on the summit of an old, eroded cinder cone nearer Saint Michael. This met tower was removed in September 2011 and re-located to the Stebbins site where it has been in service since January 2012.

A synopsis of Stebbins met tower data is presented below. The wind project site will be at or very near this location. For reference, a synopsis of the Saint Michael met tower data is also presented below. Both sites exhibit outstanding potential for wind power development.

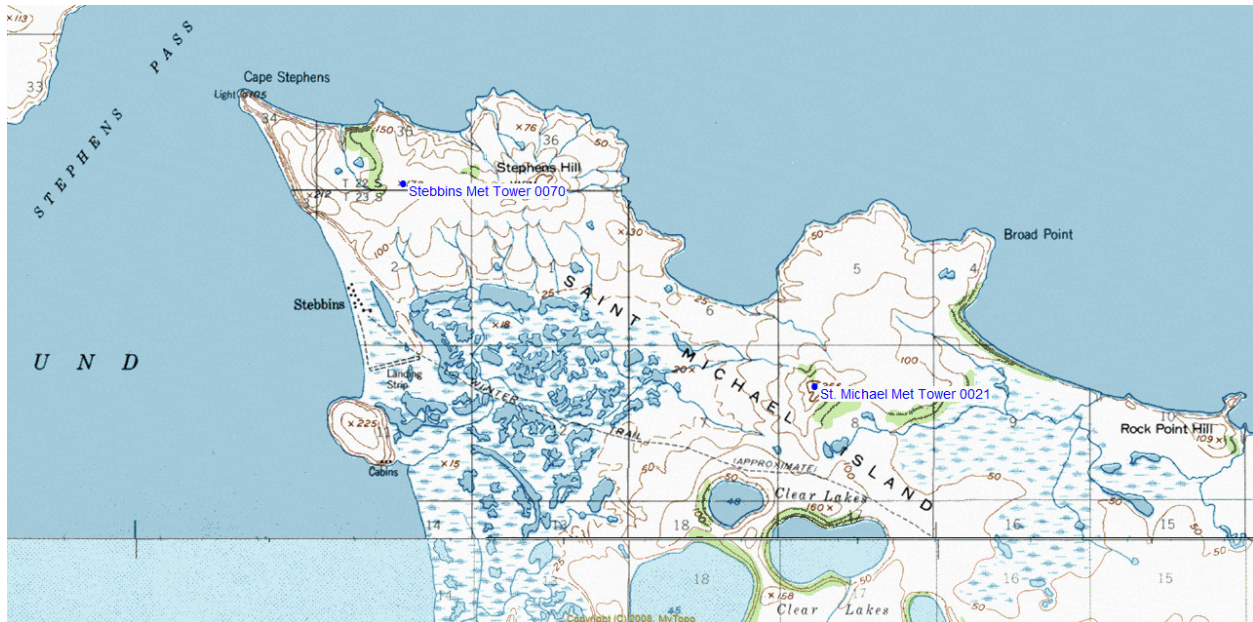
Stebbins (Site 0070) met tower data synopsis

Data dates	1/19/2012 to 8/13/2013(19 months; in service)
Wind power class	Class 6 (outstanding)
Power density mean (MoMM), 30 m	490 W/m ²
Wind speed mean (MoMM), 30 m	7.08 m/s
Max. 10-min wind speed average	25.9 m/s
Maximum wind gust	30.6 m/s (Feb. 2012)
Weibull distribution parameters	k = 1.77, c = 7.55 m/s
Wind shear power law exponent	0.236 (moderate)
Roughness class	3.02 (many trees)
IEC 61400-1, 3 rd ed. classification	Class III-C
Turbulence intensity, mean	0.081 (at 15 m/s)
Calm wind frequency, 30 m	26% (wind speeds <4 m/s)

Saint Michael (Site 0021) met tower data synopsis (for reference)

Data dates	07/21/2010 to 09/19/2011 (14 months)
Wind power class	Class 5 (excellent)
Power density mean (MoMM), 30 m	435 W/m ²
Wind speed mean (MoMM), 30 m	6.73 m/s
Max. 10-min wind speed average	24.7 m/s
Maximum wind gust	29.8 m/s (Feb. 2011)
Weibull distribution parameters	k = 2.03, c = 7.70 m/s
Wind shear power law exponent	0.116 (low)
Roughness class	0.60 (snow surface)
IEC 61400-1, 3 rd ed. classification	Class III-C
Turbulence intensity, mean	0.081 (at 15 m/s)
Calm wind frequency, 30 m	26% (wind speeds <4 m/s)

Topographic map



Google Earth image

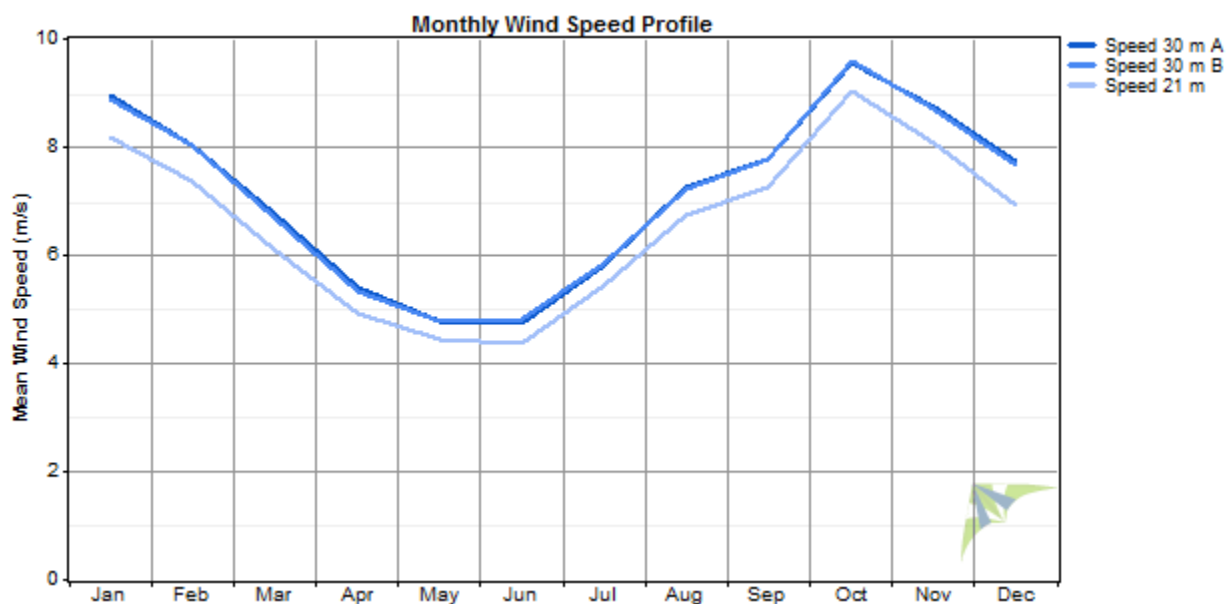


Measured Wind Speeds

Anemometer data collected from the Stebbins met tower, from the perspectives of mean wind speed and mean wind power density, indicates an outstanding wind resource. Note that cold temperatures contributed to a higher wind power density than otherwise might have been expected for the mean wind speeds.

Anemometer data summary

Variable	Speed 30 m A	Speed 30 m B	Speed 21 m
Measurement height (m)	30	30	21
Mean wind speed (m/s)	6.73	6.72	6.19
MoMM wind speed (m/s)	7.08	7.06	6.51
Max 10 min avg wind speed (m/s)	25.9	25.9	25.0
Max gust (m/s)	30.2	30.6	29.8
Weibull k	1.77	1.80	1.79
Weibull c (m/s)	7.55	7.56	6.97
Mean power density (W/m ²)	428	425	343
MoMM power density (W/m ²)	490	487	396
Mean energy content (kWh/m ² /yr)	3,747	3,724	3,005
MoMM energy content (kWh/m ² /yr)	4,291	4,264	3,469
Energy pattern factor	2.16	2.16	2.22
Frequency of calms (%)	27.4	27.7	32.2

Time series graph**Temperature and Density**

The Stebbins met tower site experiences cool summers and cold winters with a resulting air density that is higher than standard for that altitude. Calculated air density during the met tower test period exceeds standard air density at 46 meters elevation (1.220 Kg/m³) by 6.0 percent. The winter of 2012/2013 was colder than average, however, and it's likely that long term average air density at the Stebbins met tower site is slightly less than measured.

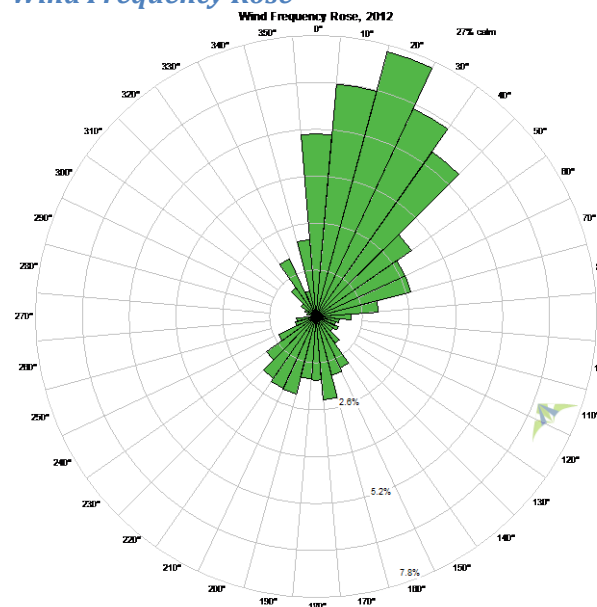
Temperature and density table

Month	Temperature			Density		
	Mean (°C)	Min (°C)	Max (°C)	Mean (kg/m ³)	Min (kg/m ³)	Max (kg/m ³)
Jan	-13.1	-34.1	5.2	1.350	1.219	1.468
Feb	-12.2	-33.3	5.1	1.346	1.261	1.463
Mar	-12.7	-31.0	4.6	1.349	1.264	1.449
Apr	-5.5	-21.2	6.7	1.312	1.254	1.393
May	1.3	-14.3	18.0	1.280	1.206	1.356
Jun	10.2	-0.6	28.6	1.239	1.163	1.288
Jul	13.7	6.4	23.0	1.224	1.185	1.256
Aug	13.8	5.1	21.3	1.223	1.176	1.261
Sep	7.5	-1.6	14.9	1.251	1.218	1.293
Oct	2.4	-4.9	13.1	1.274	1.226	1.308
Nov	-8.1	-18.3	-1.1	1.325	1.290	1.377
Dec	-13.4	-30.6	2.8	1.352	1.272	1.447
	-1.3	-34.1	28.6	1.294	1.163	1.468

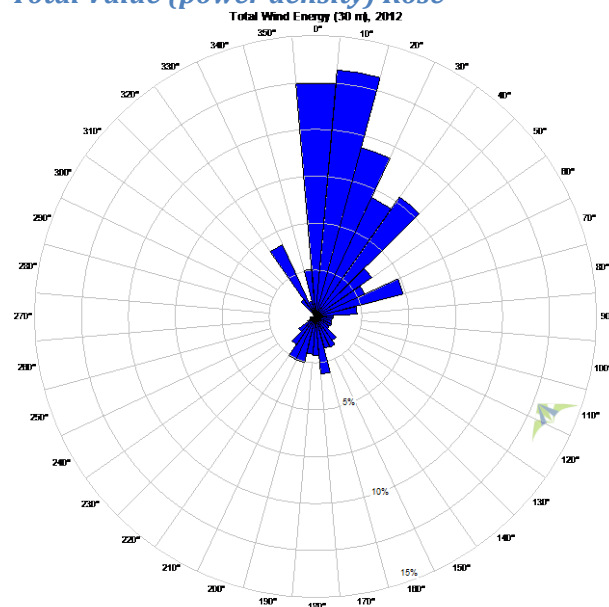
Wind Roses

Wind frequency rose data indicates highly directional northeasterly winds at the project site with a minor occurrence of southwesterly winds. The wind energy rose indicates that for wind turbine operations the majority of power-producing winds will be north-northeast to northeast. Calm frequency (percent of time that winds at the 30 meter level are less than 4 m/s) was 26 percent during the met tower test period.

Wind Frequency Rose



Total Value (power density) Rose



Extreme Winds

The relatively short duration of Stebbins met tower data should be considered minimal for calculation of extreme wind probability, but nevertheless it can be estimated with a Gumbel distribution analysis modified for entry of monthly versus annual data. Analysis indicates that the Stebbins met tower site experiences relatively low extreme wind events and by reference to International Electrotechnical Commission (IEC) 61400-1, 3rd edition (2005), classifies as IEC Class III for extreme wind probability, the lowest defined. All wind turbines are designed to meet this criterion.

Extreme wind speed probability table

	V _{ref}	Gust	IEC 61400-1, 3rd ed.	
Period (years)	(m/s)	(m/s)	Class	V _{ref} , m/s
2	25.8	30.9	I	50.0
10	30.8	36.9	II	42.5
15	32.0	38.4	III	37.5
30	34.2	40.9	S	designer-specified
50	35.8	42.8		
100	37.9	45.4		
average gust factor:	1.20			

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.

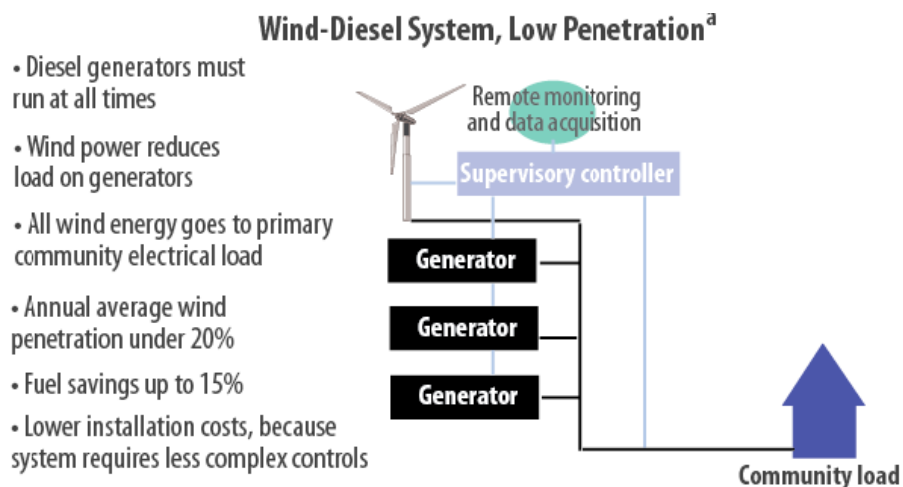
Categories of wind-diesel penetration levels

Penetration	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 minimum loading level. Requires minimal changes to existing diesel control system. All wind energy generated supplies the village electric load; wind turbines function as “negative load” with respect to diesel generator governor response.
Medium	0% to 100+%	20% to 50%	Diesel generator(s) run full time at greater than minimum loading level. Requires control system capable of automatic generator start, stop and paralleling. To control system frequency during periods of high wind power input, system requires fast acting secondary load controller matched to a secondary load such as an electric boiler augmenting a generator heat recovery loop. At high wind power levels, secondary (thermal) loads are dispatched to absorb energy not used by the primary (electric) load. Without secondary loads, wind turbines must be curtailed to control frequency.

Penetration	Penetration Level		Operating characteristics and system requirements
	Instantaneous	Average	
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, secondary (thermal) load, energy storage such as batteries or a flywheel, and possibly additional components such as demand-managed devices.

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.

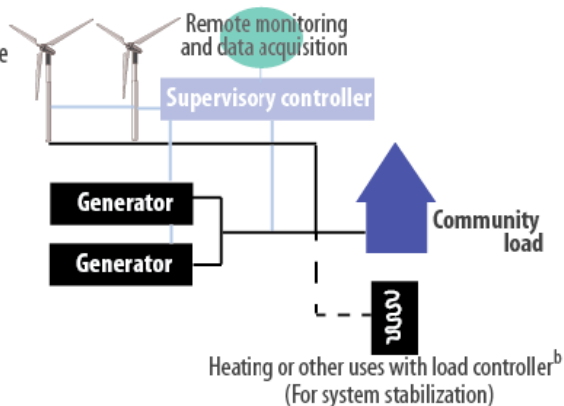


Medium Penetration Configuration

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.

Wind-Diesel System, Medium Penetration^a

- Potential exists for diesel generators to run under lower, less efficient loads; this should be considered during design
- At high wind power production, part of wind energy diverted for space heating, or wind generation is curtailed
- Annual average wind penetration 20% to 50%
- Fuel savings 15% to 50%
- System controls must be more advanced, which increases installation costs

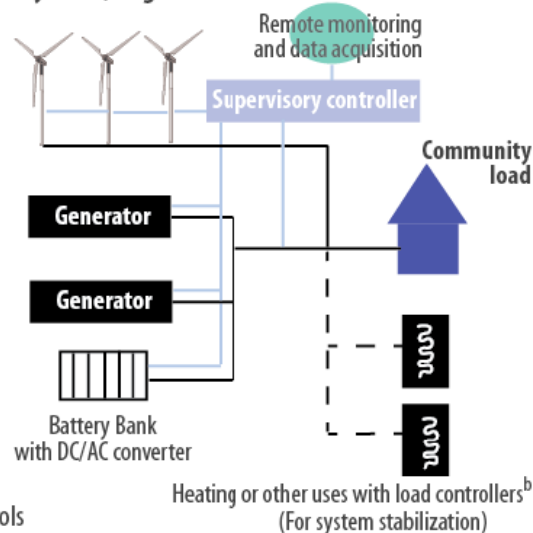


High Penetration Configuration

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, High Penetration^a

- If properly configured, diesel generators may be shut down when wind power exceeds electrical demand
- Auxiliary components regulate voltage and frequency when needed
- Power in excess of what is needed for primary electrical load can be used for space heating or stored in batteries
- Annual average wind penetration 50% to 150%
- Fuel savings 50% to 90%
- Higher installation costs, because system requires sophisticated controls
- Operators must be highly skilled



^aWind penetration is the percentage of electricity supplied by wind.

^bBesides residential or commercial heating, possible other uses include charging electric cars.

Note: These are examples of systems; other configurations exist.



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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. The new Stebbins power plant, designed to serve both Stebbins and Saint Michael, will be equipped with a new, wind-ready supervisory control system (per Brian Gray of Gray Stassel Engineering).

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, inside the new Stebbins power plant building, would need to be able to absorb up to 450 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 planned design.

Flywheels

A flywheel energy system has the capability of short-term energy storage to further smooth out short-term variability of wind power, and has the additional advantage of frequency regulation. However, the flywheel system is designed for much larger load systems and would not be economical for Stebbins.

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 Stebbins/St. Michael. 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 V17, and the Windmatic WM17S.

Northern Power Systems 100 ARCTIC

The Northern Power 100 ARCTIC (NPS100), formerly known as the Northwind 100 (NW100) Arctic, is rated at 100 kW and is equipped with a permanent magnet, synchronous generator, is direct drive (no gearbox), and is equipped with heaters 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 meter or 37 meter monopole tower. The rotor blades are fixed pitch for stall control but the turbine is also and inverter regulated for maximum 100 kW power output. For Stebbins, the NPS100 will be equipped with an arctic package enabling a minimum operating temperature of -40° C. The Northern Power 100 ARCTIC 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 ARCTIC wind turbine is manufactured in Barre, Vermont, USA. More information can be found at <http://www.northernpower.com/>.



Vestas V17

The Vestas V17 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 V17 is a higher output version of the two Vestas V17 wind turbines installed in Kokhanok in 2011. The V17 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



Aeronautica 33-225

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, which 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 fully arctic-climate certified to -40° 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> and in Appendix D of this report.

Aeronautica AW 33-225 wind turbine (29-225 version shown)**Homer Software Wind-Diesel Model**

Homer energy modeling software was used to analyze the new Stebbins powerplant presently under construction, serving a combined Stebbins and Saint Michael load which will be realized when an electrical intertie connecting the two villages is complete. 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.

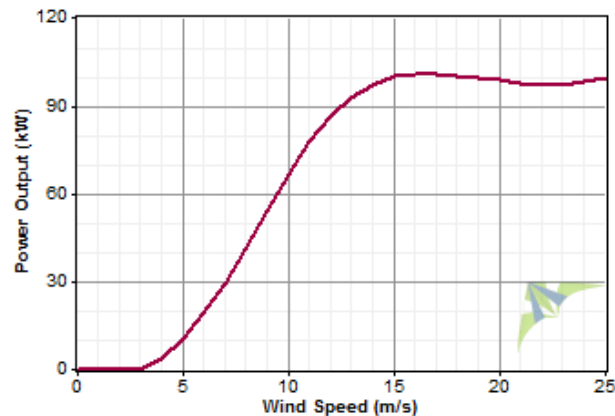
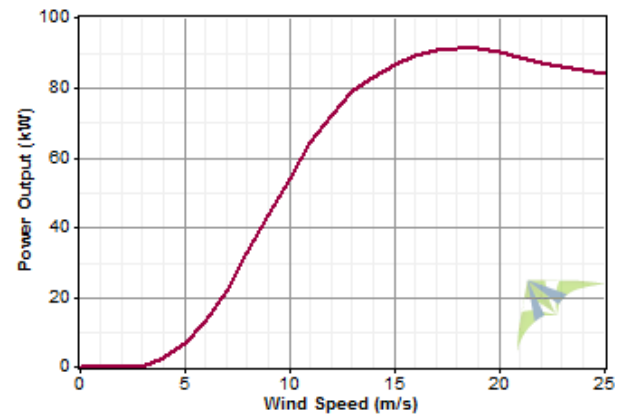
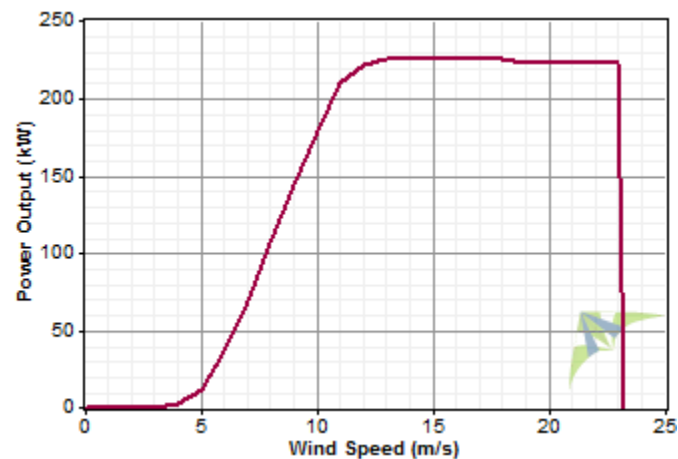
Diesel Power Plant

Electric power (comprised of the diesel power plant and the electric power distribution system) in Stebbins is provided by Alaska Village Electric Cooperative. A new powerplant is presently under construction in Stebbins with four identically configured Caterpillar 3456 diesel generators, rated at 450 kW each maximum electrical power output. The new generators will be equipped with wet turbochargers and after-coolers for a high efficiency co-generation power system.

The new powerplant is considered “wind ready” in that it will be equipped with a new Kohler SCADA that can be readily programmed to accommodate wind turbines. Also, the powerplant heat recovery system was designed for eventual installation of an electric boiler to absorb excess wind energy.

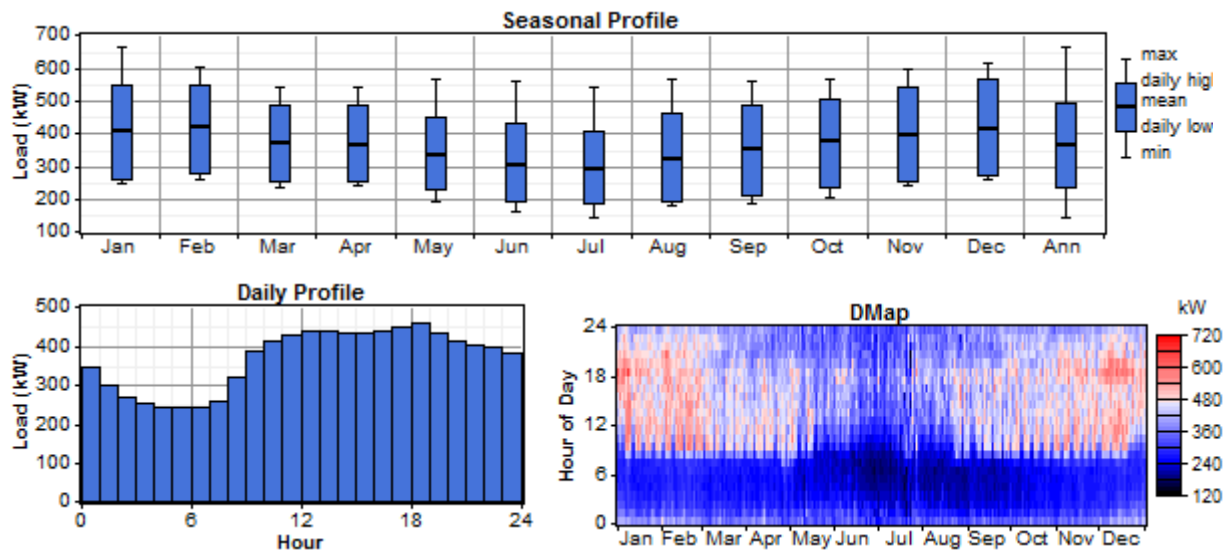
Wind Turbines

This CDR evaluates installation of four new Northern Power Systems Northern Power 100 ARCTIC turbines for 400 kW installed capacity, five remanufactured Vestas V17 turbines for 450 kW installed capacity, or five remanufactured Windmatic WM17S turbines for 450 KW installed capacity. Standard temperature and pressure (STP) power curves are shown below. Note that for the Homer analysis, power curves were adjusted to reflect the measured site mean annual air density of 1.294 kg/m³.

Northern Power 100 ARCTIC power curve*Vestas V17 Power Curve**Aeronautica AW33-225***Electric Load**

Stebbins and Saint Michael load data, collected from December 2010 to December 2011, was received from Mr. Bill 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 GMT to Yukon/Alaska time, multiplying each value by four to translate kWh to kW (similar to processing of the wind turbine data), 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 367 kW with a 662 kW peak load and an average daily load demand of 8,806 kWh.

Electric load



Thermal Load

The new Stebbins power plant will include recovered heat to serve thermal loads which will include the village water plant. The thermal load was described by Brian Gray of Alaska Energy and Engineering, Inc. in the table below and incorporated into the Homer model.

Stebbins thermal load (planned)

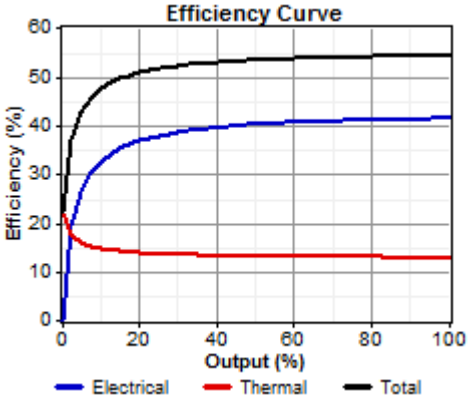
Month	Max Avg Temp, °F	Min Avg Load, kW	Mean Temp, °F	Mean Load, kW	Min Avg Temp, °F	Max Avg Load, kW
Jan	9.9	323	3.1	363	-3.7	403
Feb	10.3	321	2.9	364	-5.1	411
Mar	16.9	282	8.2	333	-0.5	384
Apr	29.3	209	21	258	12.7	307
May	45.8	113	38.1	158	30.4	203
Jun	54.6	61	48	100	41.4	138
Jul	61	23	54.3	63	47.6	102
Aug	59.8	30	52.9	71	46.1	111
Sep	51.2	81	43.9	124	36.7	166
Oct	33	188	26.9	223	20.8	259
Nov	19.1	269	13.2	304	7.3	338
Dec	8.4	332	1.8	370	-4.8	409

Diesel Generators

The HOMER model was constructed with the four new Stebbins generators that will eventually power both Stebbins and Saint Michaels once the intertie connecting the two villages is complete. Diesel

generator information pertinent to the HOMER model is shown below. Cat 3456 fuel curve information from Alaska Energy Authority was used in the Homer model.

Diesel generator HOMER modeling information

Diesel generator	Caterpillar 3456	
Power output (kW)	450	
Intercept coeff. (L/hr/kW rated)	0.007307	
Slope (L/hr/kW output)	0.2382	
Minimum electric load (%)	11.0% (50 kW)	
Heat recovery ratio (percent of waste heat that can serve the thermal load); data point from Brian Gray of Gray Stassel Engineering, Inc.	40%	

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

Slope – the marginal fuel consumption of the generator

Economic Analysis

Installation of four Northern Power Systems NPS100 ARCTIC wind turbines, five remanufactured Vestas V17 wind turbines, or two Aeronautica AW33-225 wind turbines in medium-to-high penetration mode without electrical storage are evaluated to demonstrate the economic benefit of the project options. Note that in the analyses 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. For this CDR, Homer modeling is used to determine system performance and energy balance, but economic valuation is accomplished with use of the Renewable Energy Fund Round 7 economic valuation spreadsheet developed by University of Alaska's Institute for Social and Economic Research (ISER) for use by the Alaska Energy Authority.

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	Project Cost	Installed kW	Cost per kW Capacity	Tower Type	Tower Height (meters)
Northern Power					
NPS100 ARCTIC	\$4,030,650	400	\$10,076	Monopole	37
Vestas V17	\$3,788,750	450	\$8,419	Monopole	26
Aeronautica AW33-225	\$3,946,050	450	\$8,769	Monopole	40

Fuel Cost

A fuel price of \$5.23/gallon (\$1.40/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, 2103 and the *2013_06_R7Prototype_final_07012013* Excel spreadsheet, also written by ISER. The \$5.23/gallon price reflects the average value of all fuel prices between the 2015 (the assumed project start year) fuel price of \$4.34/gallon and the 2034 (20 year project end year) fuel price of \$6.36/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 Stebbins (without social cost of carbon) reported to Regulatory Commission of Alaska for the 2012 PCE report is \$3.86/gallon (\$1.02/Liter), without inclusion of the SCC. Assuming an SCC of \$0.40/gallon (ISER *Prototype* spreadsheet, 2013 value), the 2012 Stebbins fuel price was \$4.26/gallon (\$1.13/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 medium cost projection	2015 (/gal)	2034 (/gal)	Average (/gallon)	Average (/Liter)
Diesel fuel	\$4.34	\$6.29	\$5.23	\$1.38
Heating oil	\$5.39	\$7.34	\$6.28	\$1.66

Modeling Assumptions

As noted previously, HOMER energy modeling software was used to analyze a combined the Stebbins wind-diesel hybrid power plant that will also serve the nearby village of Saint Michael. 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 new Stebbins power plant presently under construction that will be equipped with four identically configured Caterpillar 3456 diesel engines with 450 kW generators. Although the existing Stebbins does not have a heat recovery loop to offset thermal loads in the village, the new powerplant will have this capability.

Note that wind turbines installed in Stebbins will operate in parallel with the diesel generators. Excess energy will serve thermal loads via a secondary load controller and electric boiler. 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 and ISER modeling assumptions

Economic Assumptions	
Project life	20 years (2015 to 2034)
Discount rate	3% (reference: ISER 2013 <i>Prototype</i> spreadsheet)
Operating Reserves	
Load in current time step	10%
Wind power output	100% (Homer setting to 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)	\$5.23/gal (\$1.38/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)	\$6.28/gal (\$1.66/Liter)
Diesel Generators	
Generator capital cost	\$0 (new generators already funded)
O&M cost	\$0.02/kWh (reference: ISER 2013 <i>Prototype</i> spreadsheet)
Minimum load	50 kW; based on AVEC's operational criteria of 50 kW minimum diesel loading with their wind-diesel systems
Schedule	Optimized
Wind Turbines	
Availability	80%
O&M cost	\$0.049/kWh (reference: ISER 2013 <i>Prototype</i> spreadsheet)
Wind speed	7.08 m/s at 30 m, 100% turbine availability 6.22 m/s at 30 m, 80% turbine availability
Density adjustment	1.293 kg/m ³ (mean of monthly means of 19 months of Stebbins met tower data); note that standard air density is 1.225 kg/m ³ ; Homer wind resource elevation set at -590 meters to simulate the Stebbins air density
Energy Loads	
Electric	8.80 MWh/day average combined Stebbins-Saint Michael power plant load
Thermal	5.44 MWh/day average new Stebbins thermal load

Economic Valuation

Homer software was used in this feasibility analysis to model the wind resource, wind turbine energy production, effect on the diesel engines when operated with wind turbines, and excess wind energy that could be used to serve thermal loads. Although Homer software is designed to evaluate economic valuation by ranking alternatives, including a base or “do nothing” alternative by net present cost, AEA

economic valuation methodology differs somewhat in its assumptions of O&M costs, fuel costs each year of the project life, and disposition of excess energy.

In an effort to align economic valuation of project alternatives with Alaska Energy Authority methods, this feasibility analysis uses AEA's economic evaluation methods. Although ISER developed the cost evaluation spreadsheet, AEA determined the assumptions and methods of the model. The model is updated every July in preparation for the next round of Renewable Energy Fund requests for proposals in the form of an explanation report and an Excel spreadsheet. The latest version of the spreadsheet has a file name of *2013_06-R7Prototype_final_07012013* and is available on ISER's website.

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	NPV Benefits	NPV Capital Costs	Diesel #2 Displaced (gal/yr)	B/C Ratio	NPV Net Benefit
NPS100	400	15.2	1,106,920	97,330	1,009,590	\$4,030,650	\$4,447,229	\$3,581,180	68,908	1.24	\$866,049
V17	450	15.2	942,572	86,987	855,585	\$3,788,750	\$3,778,522	\$3,366,255	58,512	1.12	\$412,267
AW33	450	15.2	1,360,237	228,699	1,131,538	\$3,946,050	\$5,241,559	\$3,506,014	80,289	1.50	\$1,735,545

Note: wind energy at 80% availability

Note: NPV benefits and capital costs at 3% discount rate; base year is 2012 (ISER spreadsheet)

Additional Information

Turbine Type	Hub Height (m)	No. Turbines	Wind Energy to Thermal (kWh/yr)	Heating Fuel Equiv. (gal)	Wind Penetration (% electrical)	Wind Penetration (% thermal)	Excess thermal (%)
NPS100	37	4	97,330	2,488	33.0	2.9	0.5
V17	26	5	86,987	2,224	29.0	2.6	0.5
AW33	40	2	228,699	5,846	40.0	6.6	1.9

Note: wind energy at 80% availability

Sensitivity Analysis

In general, the economic valuation (benefit-to-cost ratio) of a project increases when, all other things being equal, project capital cost decreases, fuel price increases, fuel displacement increases, or wind turbine annual energy production (AEP) increases.

Wind energy projects in rural Alaska are expensive compared to Lower 48 or urban Alaska projects for several reasons, principally difficult logistics, isolation of the project villages, relatively high expense of small compared to large wind turbines, and complex powerplant integration requirements. The reality is that project costs are high and opportunities for significant reduction are constrained.

The amount of fuel displaced by wind energy and the value of that fuel significantly impacts the economic valuation of a project. For Stebbins, the wind resource was measured at the proposed turbine site and hence accurate within the confines of the relatively short study timeframe of 19 months. The wind resource dictates, for a given type and number of turbines, the annual energy production of the turbines and this energy displaces fuel that otherwise would be burned by the diesel engines to meet the load demand. Wind turbine energy production cannot of course be higher than 100 percent availability (wind turbines on-line and available to produce power 100 percent of the time), but adoption of a historic turbine availability is problematic as comprehensive data from existing rural Alaska projects is difficult to obtain. For this reason, this feasibility analysis adopts the Alaska Energy Authority's default 80 percent wind turbine availability assumption. If wind turbine availability greater than 80 percent is accomplished, then the economic value of the project will increase.

Conclusion and Recommendations

Three wind turbine project alternatives were presented in this feasibility analysis: four Northern Power Systems NPS100-21 wind turbines, five Vestas V17 wind turbines, or two Aeronautica AW33-225 wind turbines. Modeling shows that over a 20 year project life all three alternatives would have a benefit-to-cost ratio greater than unity. Of the three, however, clearly the Aeronautica AW33-225 alternative presents the superior economic benefit as reflected by a benefit-to-cost ratio of 1.50 and a net present value net benefit over the 20 year project life that exceeds \$1.7 million. The AW33-225 is a solid turbine based on a proven design with a long track record in Europe and North America and should perform well at Stebbins. For this reason, a two turbine Aeronautica AW33-225 configuration is the recommended project alternative for Stebbins and Saint Michaels.