Life Cycle Cost Analysis and Turbine Review for Mekoryuk Wind Energy Project

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Revision Block

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Executive Summary

The purpose of this report is to provide information about the wind resource and the technology options for a wind-diesel hybrid power system in Mekoryuk, Alaska.

Locally measured wind speed data indicate a Class 6 wind resource in Mekoryuk, providing excellent potential for wind power development. In addition to the wind resource, a number of other factors impact the viability of a wind-diesel project, including the amount and cost of diesel fuel displaced, the cost of installing and operating the wind power equipment, and the ability to service the wind equipment after installation. Computer modeling was performed to compare the economic and technical potential of different wind power options.

The wind turbine models available for a remote Alaska installation are limited. Four wind turbine models were evaluated in this report with respect to different shipping and installation requirements, operation and maintenance requirements, performance in extreme weather conditions, power quality, and cost. Of the wind turbines evaluated in this report, the Distributed Energy Systems NW100/21 contains the most features that allow for operation in cold climates, high reliability, and high power quality in an isolated electric grid.

The life cycle cost analysis shows that most of the wind-diesel hybrid power options have a lower net present value than the diesel-only power system option, assuming a $3.00 per gallon price of diesel fuel and 3% annual fuel escalation rate over the 25-year life of the project. The only wind-diesel option with a greater net present value than the diesel-only system is a high-penetration system consisting of two Distributed Energy Systems NW100/21 wind turbines. This system could displace up to 29,000 gallons per year (41% of current consumption). However, the high installed cost of the wind project relative to the small electric load of the community results in a marginally economic project.

Other non-financial benefits of a wind power system include a reduced amount of diesel fuel that must be transported and stored in the community, a hedge against fuel price volatility, reduced carbon emissions, and an increase in the experience and knowledge base of wind energy technology in Alaska. These intangible benefits may make marginally economic wind-diesel systems more attractive and worthy of the investment. Overall, GEC believes that an investment in wind power in Mekoryuk will have a positive financial and societal impact on the community.

Background and Project Description

Global Energy Concepts, LLC (GEC) has been retained by the Alaska Village Electric Cooperative (AVEC) to perform a life cycle cost analysis for the proposed Mekoryuk wind-diesel hybrid power system. Support that was provided by GEC is summarized in this report and included validation and analysis of on-site wind resource data, energy system modeling, an evaluation of wind turbine options, and a preliminary life-cycle cost analysis of different wind turbine options and wind penetration levels. The community of Mekoryuk is located on Nunivak Island in the Bering Sea along the southwestern coast of Alaska, as indicated in Figure 1.

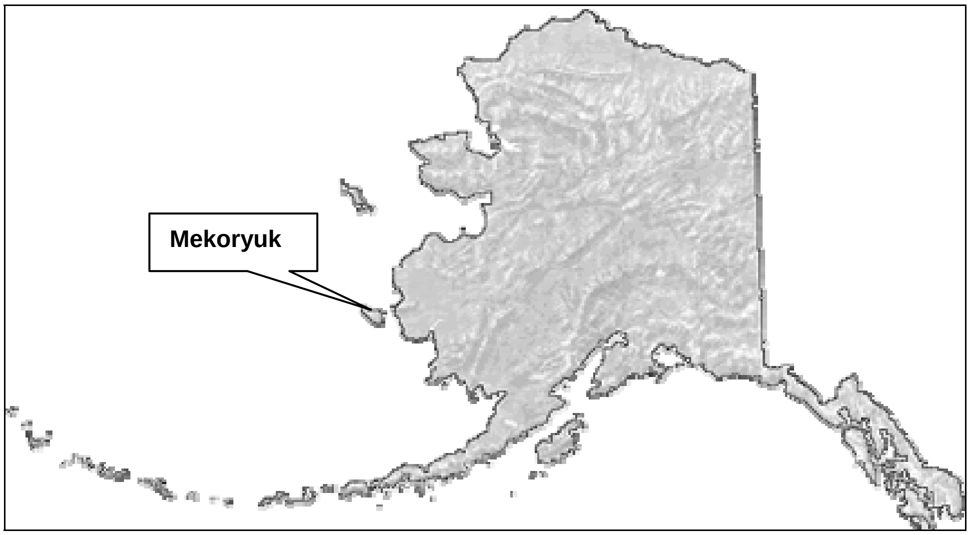


Figure 1. Location of Mekoryuk, Alaska

In June 2005 AVEC installed a 30 m meteorological (met) tower on the western edge of the town site next to the water facilities. This site was originally selected based on its close proximity to power lines and roads and its distance from residential areas. However, the adjacent water lagoon has created a heat sink in the area, thus warming the surrounding tundra and creating an unstable platform for the placement of wind turbines. Preliminary geotechnical investigation of other potential sites has shown six-foot thick waves of lava rock above and below layers of glacial silt. Due to these complex soil conditions, a final wind turbine location has not yet been identified. GEC has not conducted a site visit to determine any influences of the terrain on wind flow between the met tower location and potential wind turbine locations. Figure 2 shows a topographic map of the area, the location of the met tower, and one of the proposed turbine locations.

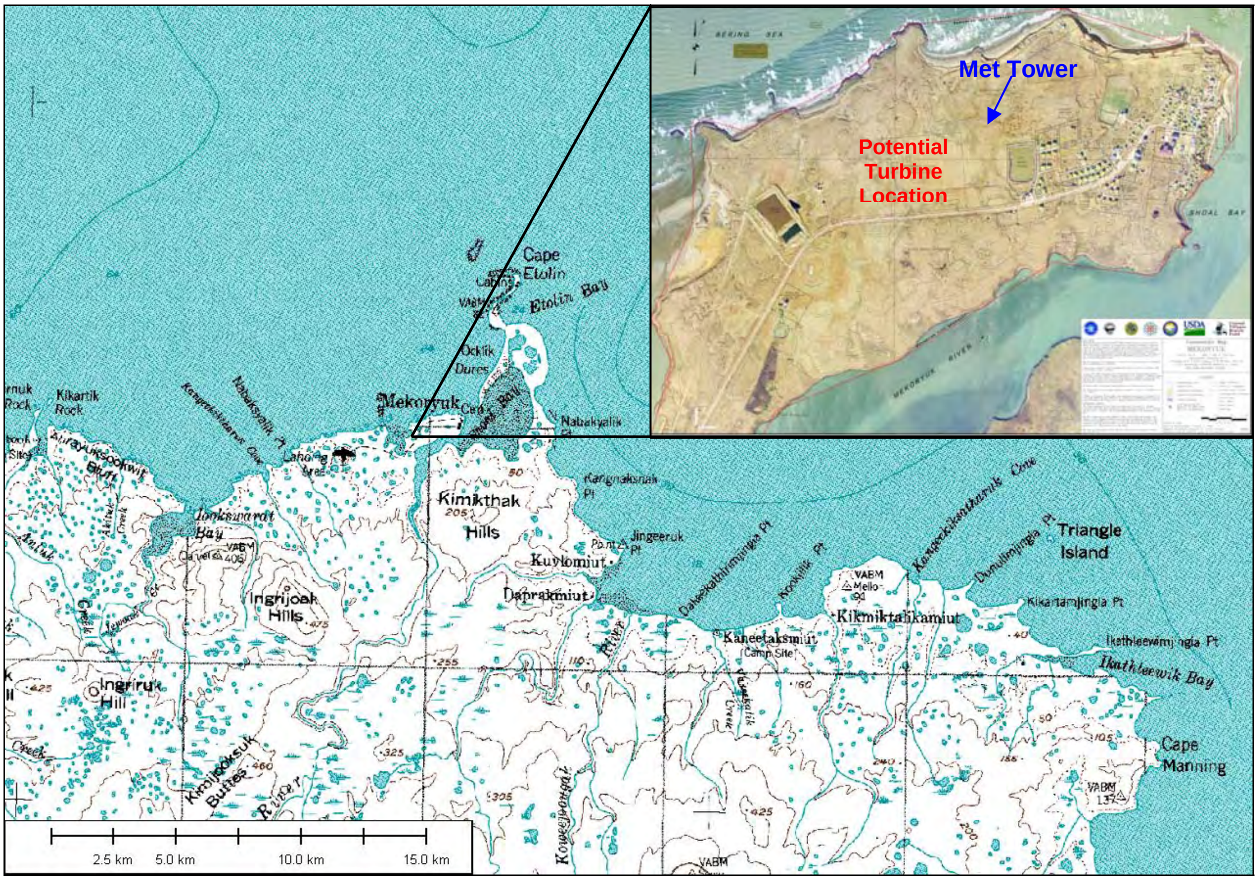


Figure 2. Meteorological Tower and Proposed Wind Turbine Location in Mekoryuk

Wind Resource Evaluation

AVEC installed a 30-m meteorological (met) tower in June 2005 to measure the local wind resource. Wind speed, direction and temperature data were recorded as 10-minute averages. GEC compiled, validated, and incorporated into this analysis on-site tower data from June 11, 2005, through February 19, 2007. GEC checked the data for erroneous measurements and adjusted the data set for local air density and potential turbine hub heights. Since the exact wind turbine location has not yet been determined, GEC could not make any adjustments to account for terrain effects between the met tower and turbine locations. Therefore, it is assumed that the met tower measurements are representative of the turbine locations.

Quality Control

GEC followed a standard validation process to identify and remove erroneous data (e.g., due to icing or tower shadow). Typically, data are considered invalid due to icing if the temperature is below 2°C and the standard deviation of the wind direction equals zero (the wind vane is not moving) for two or more hours. Wind speed data may also be considered invalid if the temperature is less than 2°C and the wind speed recorded by any one anemometer drops substantially below the wind speed recorded by the other anemometers on the tower. The month with the greatest data loss due to icing was January 2006 with only a 70% data recovery rate at 30 m. Data are also typically considered invalid when the sensors are shadowed by the tower (waked data). This occurs when the wind comes from directions that place the tower between the wind and a sensor. Wind speeds collected from an anemometer directly downwind of the tower are shadowed by the tower and consequently invalid. These invalid winds were removed from the data set. When necessary and possible, 20-m wind speed data and on-site wind shear measurements were used to calculate the wind speeds at 30 m. A summary of the sensors and data recovery rates for each are presented in Table 1.

Table 1. Sensor Description and Data Recovery

Sensor Type	Boom Orientation (from true north)	Sensor Height	Data Recovery Rate
#40 NRG anemometer	350º	30 m	85%
#40 NRG anemometer	150º	30 m	74%
#40 NRG anemometer	340º	20 m	86%
#200P NRG vane	80º	25 m	89%
#110S NRG temperature	N/A	2 m	100%

Wind Rose

A wind rose depicts the frequency and energy content of wind by direction. As shown in Figure 2, most energy-producing winds come from the south-southeast and the northwest.

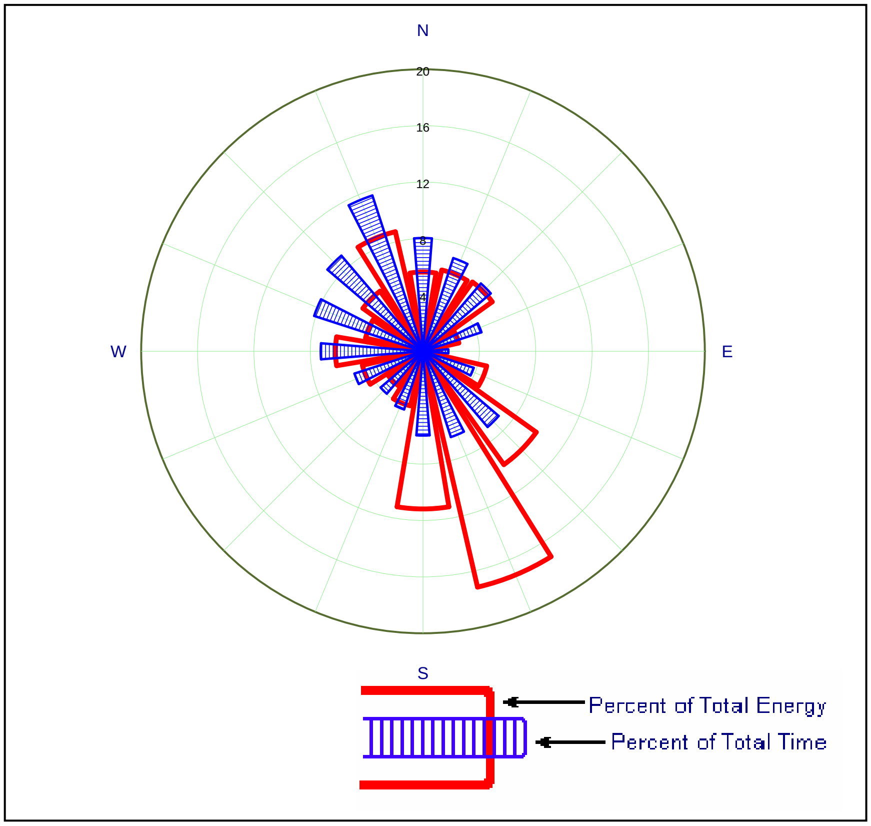


Figure 2. Mekoryuk Wind Rose at 30 m (February 1, 2006, through January 31, 2007)

Long-Term Wind Speeds

The Mekoryuk met tower contained approximately twenty months of data. To adjust the measured wind speeds to represent long-term conditions GEC investigated meteorological data from other sources, including automated surface observation system (ASOS) stations at the Mekoryuk Airport, Cape Romanzoff, Hooper Bay, and Nightmute. For the Mekoryuk Airport ASOS station, the correlation between the airport and met tower wind speed data was good (R^2 = 0.89), however there were substantial periods of missing data that prevented the accurate calculation of long-term adjustment factors. From June 2005 through December 2006, the data recovery rate was only 55% and there were no data available for December 2005 or March 2006. Accurate monthly long-term adjustment factors for the period of interest could not be calculated with such little data. GEC also investigated the possibility of using data from the Cape Romanzoff ASOS station to calculate long-term adjustment factors for the met tower data. However, the correlation between wind speeds at Cape Romanzoff and the met tower was poor (R^2 = 0.45), so the dataset could not be used. Finally, GEC attempted a correlation between the met tower and Rawinsonde data from Bethel. Rawinsonde data are upper air observations collected by instruments on weather balloons. This correlation was also poor (R^2 = 0.44), so the dataset could not be used. Because of the proximity of Cape Romanzoff to Hooper Bay, GEC assumed that the correlation between the met tower and Hooper Bay wind speeds would also be poor and chose not to purchase the long-term data set for correlation. Data for Nightmute was not available for the period of interest.

Figure 3 shows the location of the reference stations in relation to the Mekoryuk met tower. Since a suitable long-term reference station was not available, no adjustments were made to account for long-term trends.

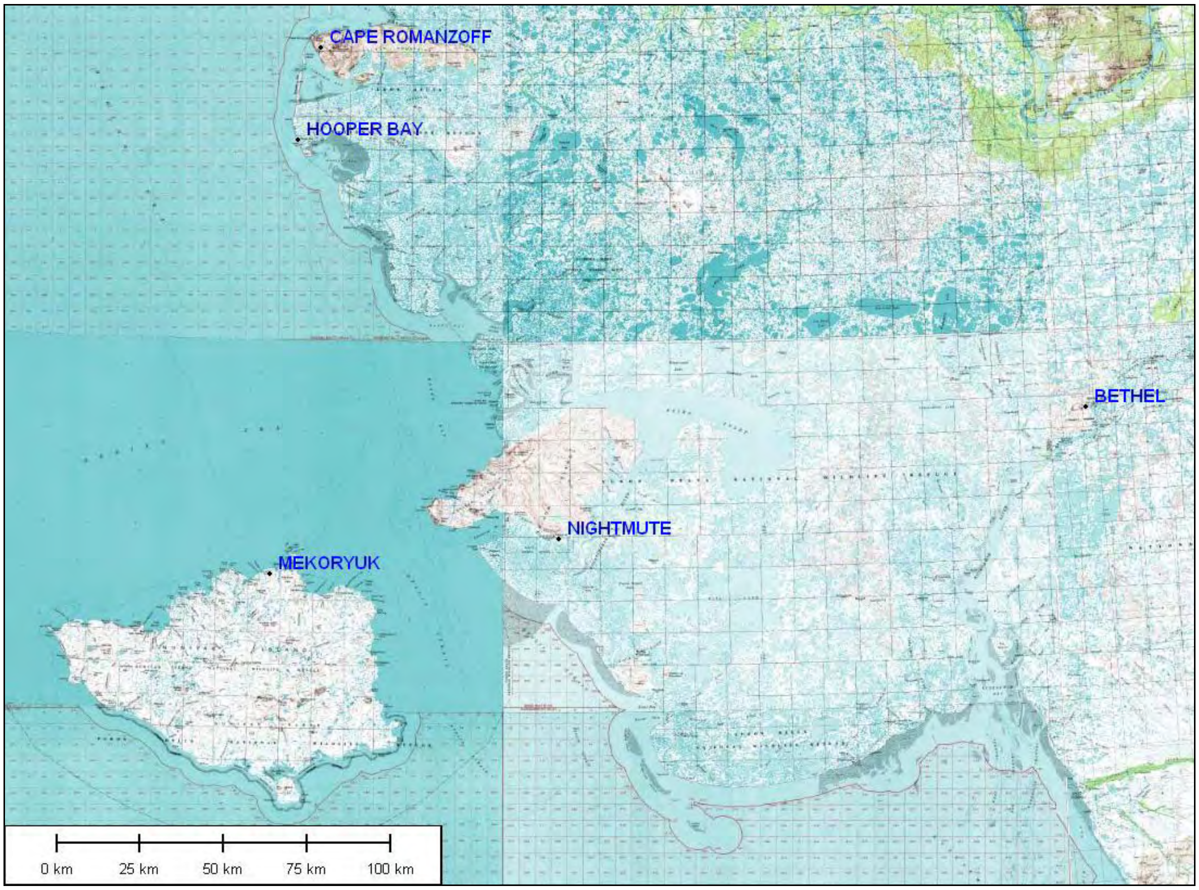


Figure 3. Locations of Long-Term Reference Stations

Wind Shear

The wind shear exponent defines the change in wind speed above ground level of a particular site. GEC calculated the wind shear exponent between the 20 m and 30 m anemometer heights of the Mekoryuk met tower. Only valid wind speeds greater than 4 m/s were included in the calculation. Results are shown in Figure 4.

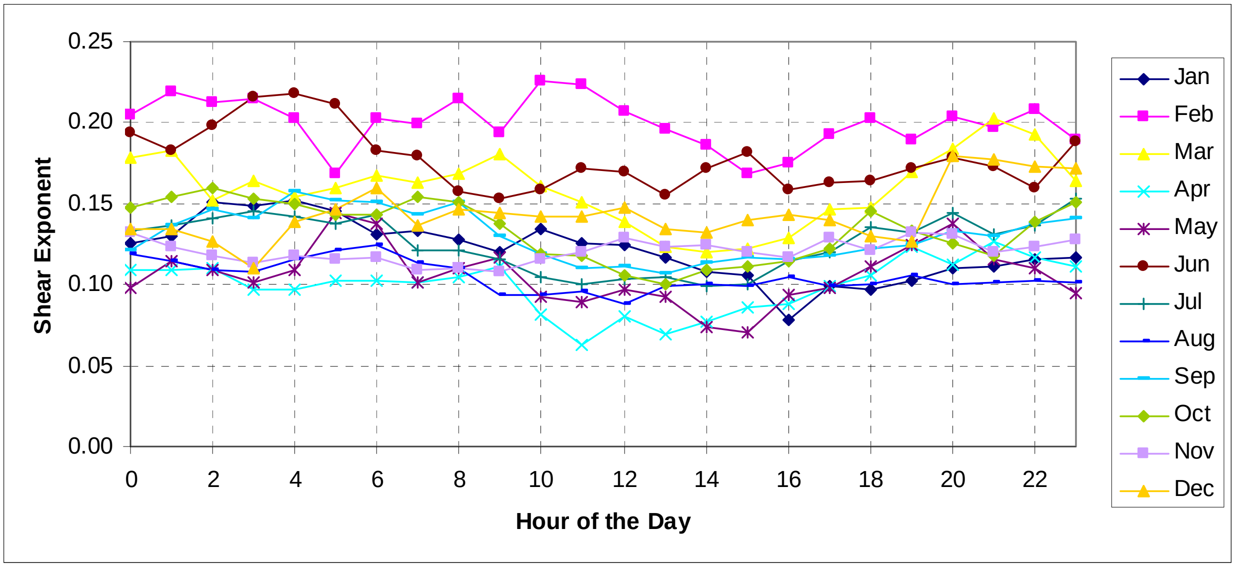


Figure 4. Average Shear Exponent Values by Hour and Month

As shown, the wind shear exponent changes by month, but does not change significantly with time of day. Because wind shear did not vary significantly by hour of day, monthly average wind shear values were used to adjust met tower wind speeds from the measurement height of 30 m to the various potential wind turbine hub heights. The monthly average wind shear values are summarized in Table 2.

Table 2. Monthly Wind Shear

Month	Air Temperature (ºC)
January	0.12
February	0.20
March	0.16
April	0.10
May	0.11
June	0.18
July	0.13
August	0.11
September	0.13
October	0.13
November	0.12
December	0.14
Annual Average	**0.14**

Air Density

The density of the air affects power production from a wind turbine, with denser air leading to greater power production potential. The density of air depends on the air temperature and the elevation of the site. Monthly average air density values were calculated for Mekoryuk based on long-term monthly average air temperatures from the Mekoryuk ASOS station and an elevation of 46 m (site elevation of 16 m plus the approximate hub height of 30 m). The monthly average air temperatures and air density values are summarized in Table 3.

Table 3. Monthly Air Temperature and Density

Month	Air Temperature (ºC)	Air Density (kg/m^3)
January	-12.4	1.35
February	-8.0	1.32
March	-7.6	1.32
April	-4.3	1.31
May	2.2	1.27
June	7.8	1.25
July	10.1	1.24
August	10.8	1.24
September	8.0	1.25
October	2.8	1.27
November	-2.3	1.30
December	-10.4	1.34
Annual Average	**0.3**	**1.29**

Wind turbine power curves are typically provided at a standard air density of 1.225 kg/m^3. To account for the impact of higher air density in Mekoryuk on potential power production, the hourly wind speed values at the met tower were adjusted according to the following formula:

$$V_2 = V_1\left(\frac{\rho_2}{\rho_1}\right)^{\frac{1}{3}}$$

Where V_2 is the adjusted wind speed, V_1 is the original wind speed, ρ_2 is the monthly average site air density, and ρ_1 is the standard air density of 1.225 kg/m^3.

Final Wind Speed Data Set

In summary, the original met tower data were validated to remove any iced or waked data and, to the extent possible, the gaps were filled by shearing up the 20-m wind speed data. The data were adjusted to account for air density but could not be adjusted to long-term conditions or the final wind project location. Figure 5 and Table 4 summarize the monthly average wind speeds for the time period used in this analysis (February 1, 2006, to January 31, 2007).

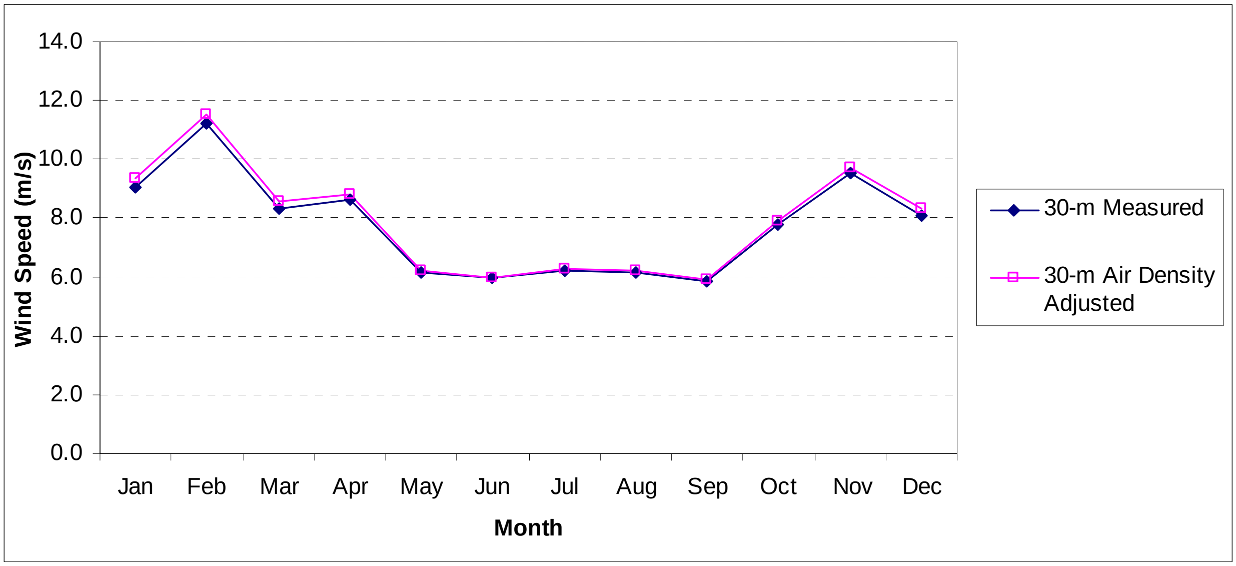


Figure 5. Monthly Average Wind Speeds in Mekoryuk (30 m)

Table 4. Monthly Average Wind Speeds at Various Hub Heights in Mekoryuk (m/s)

Month	Measured (30 m)	Adjusted[1] (30 m)	Adjusted[1] (32 m)	Adjusted[1] (25 m)
January	9.0	9.3	9.4	9.1
February	11.2	11.5	11.7	11.1
March	8.3	8.6	8.6	8.3
April	8.6	8.8	8.9	8.7
May	6.1	6.2	6.3	6.1
June	6.0	6.0	6.1	5.8
July	6.2	6.3	6.3	6.1
August	6.2	6.2	6.2	6.1
September	5.9	5.9	5.9	5.8
October	7.8	7.9	8.0	7.7
November	9.5	9.7	9.8	9.5
December	8.1	8.3	8.4	8.1
Annual Average	**7.7**	**7.9**	**7.9**	**7.7**

[1] Wind speeds have been adjusted for site air density and turbine hub height.

The met tower measurements in Mekoryuk result in an annual average wind speed of 7.7 m/s at a height of 30 m above ground level. The wind resource in Mekoryuk varies seasonally, with higher winds in the winter months than the summer months. Figure 6 illustrates the average diurnal wind speeds by month. The wind speeds typically increase slightly in the afternoon hours, which match an increase in community electric load in the afternoon and evening.

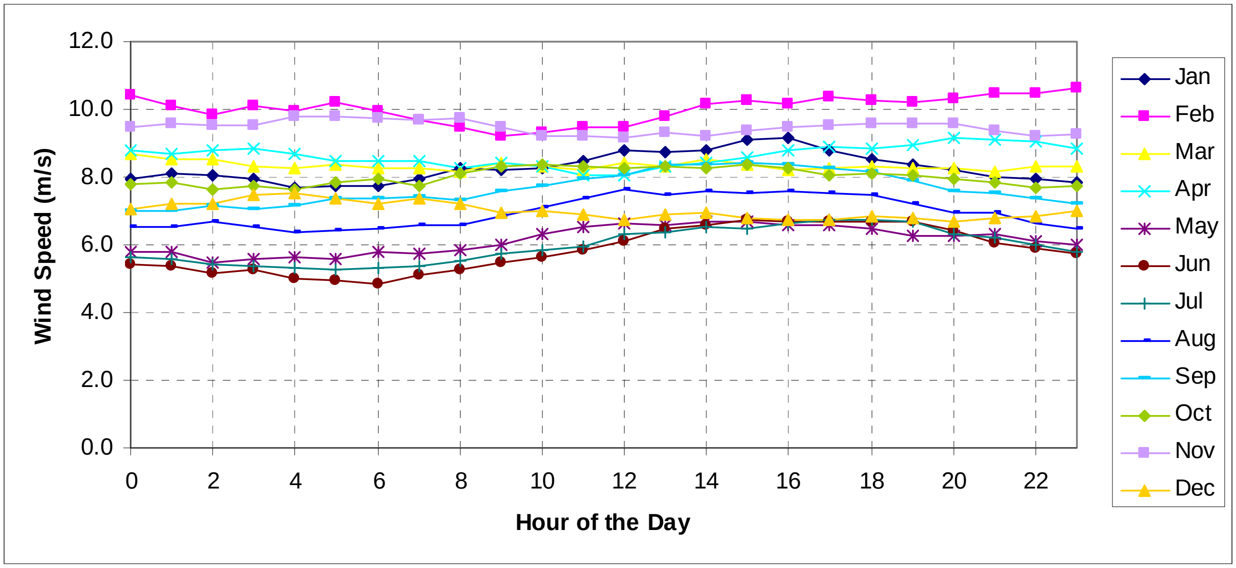


Figure 6. Diurnal Wind Speeds in Mekoryuk (30 m)

Wind Turbine Evaluation

The number of wind turbine options appropriate for Mekoryuk's small electric load, inclement weather conditions and remote location is limited. GEC evaluated the following turbine suppliers for consideration in Mekoryuk: Entegrity Wind Systems (EWS), Distributed Energy Systems (DES), Energie PGE, and suppliers of remanufactured Vestas turbines. Each of these turbine suppliers provides small-scale wind turbines with varying degrees of cold weather features and has expressed some degree of interest in serving the Alaska market. Contact information and a company description for each supplier are provided in Appendix A. Specification sheets for each wind turbine model are provided in Appendix B.

Specifications for the wind turbine models offered by each supplier are summarized in Table 5. Turbines with capacities greater than 100 kW were not included because of their limited availability for small projects and their inappropriate size for this type of application and electrical load. There are currently sixteen Entegrity eW15, six DES NW100, and two remanufactured Vestas wind turbines operating in Alaska. Although there are no Energie PGE wind turbines in Alaska, a small number are currently in operation in Canada.

Table 5. Wind Turbine Options for Mekoryuk

Turbine Supplier	Model & Rating	Hub Height (m)	Rotor Diameter (m)	Features[1]	Operating Temperature Range (ºC)	Operating Wind Speed Range (m/s)
Entegrity Wind Systems	eW15 66 kW	25	15	FP, DW, CS	-40 to 40	4.6 to 22.4
Distributed Energy Systems	NW100/21 100 kW	32	20	FP, UW, DD, SG, VS	-40 to 50	3 to 25
Energie PGE	PGE11/35 35 kW	25	11	DW, VP, CS	-20 to 40	4.8 to 25
Halus Power Systems or Energy Maintenance Service	V15 (or E15) 65 kW	25	15	FP, UW, CS	Not Available	4 to 27

[1] FP = fixed pitch blades, VP = variable pitch blades, DW = down wind, DD = direct drive, SG = Synchronous generator, UW = up wind, CS = constant speed, VS = variable speed

The NW110/21 is the latest version of the Northwind100 series turbines by DES. For comparison purposes, and since a number of the older versions are still available, the NW100/20 with hub extenders are included in the modeling.

Although remanufactured wind turbine models are included in this report, GEC cautions AVEC against their use. Remanufactured turbines generally have operated in a wind farm for roughly 20 years (typically in California or Europe) before being dismantled and remanufactured, which means they are approaching the end of their design life. Although some components are replaced during the remanufacturing process, there is no experience with operating these or any turbines 20 years beyond their design life. Remanufactured turbines have a slightly lower capital cost than new turbines; however, the availability of spare parts for these remanufactured turbines is highly uncertain over the next 20 years. Unless AVEC is confident in the ability of their technicians to troubleshoot and fabricate spare parts with no support from the turbine supplier, GEC believes that the risks and potentially greater repair and replacement costs associated with remanufactured wind turbines are greater than the potential initial cost savings.

Site Climatic Conditions

Most utility-scale wind turbines are designed and certified to operate in "normal" climatic conditions, which include temperatures ranging from -15°C to +40°C and wind speeds up to 25 m/s. The turbines will automatically shut down if the ambient conditions exceed this range and will return to operation when conditions return to "normal." A larger range of air temperatures (-20°C to +50°C) and wind speeds (up to 60 m/s) is usually used for evaluating materials and structural members from a survival (non-operational) perspective.

Entegrity offers an optional cold weather package that includes an oil box heater, StaClean black blades, an electric gearbox heater and alternative lubricants, which lowers the operating temperature of the turbine to -40°C. The remanufactured Vestas V15 comes with a similar optional cold weather package, although the resulting temperature range is unknown. Though not thoroughly tested, at least one installation of the Energie PGE 11/35 turbine has operated at -20°C with no additional cold weather package; however, the manufacturer offers an electric heater for the gearbox oil if needed. The NW100 comes with a standard operating temperature range down to -40°C with no additional modifications to the turbine.

Daily average temperatures in Mekoryuk typically reach a low of -10ºC (14ºF) with record lows of -31ºC (-24ºF) during the winter months (based on 10 years of data from the Mekoryuk ASOS). Based on this information, the standard wind turbine options may be sufficient for Mekoryuk's climate; however, the installation of a cold weather package would likely enhance production during winter months.

Power Quality Considerations

Most wind turbines in the industry (including the Entegrity, Energie PGE, and Vestas machines) use an induction motor that consume reactive power, which must be supplied by the diesel generators or other external equipment. In small, isolated electric grids this demand for reactive power can overwhelm the capacity of the diesel generator and cause voltage instability and a poor power factor. In addition to frequent voltage drops, a poor power factor can result in greater power line losses, reduced electrical distribution capacity, and sluggish motor performance. Possible solutions include the installation of additional equipment that can supply reactive power such as a capacitor bank, synchronous condenser, flywheel, or a wind turbine that utilizes a synchronous generator rather than an induction generator. The NW100 is the only wind turbine model under consideration that utilizes a synchronous generator. The variable speed synchronous generator and integrated power electronics allow the turbine to export high quality AC power and to supply reactive power to the grid if desired.

Of the turbines listed in Table 5, the eW15 and Energie PGE turbines are downwind models. The downwind design eliminates the need for active yaw control; however, downwind turbines can be less responsive to sudden changes in wind direction, causing wide power swings.

Operation and Maintenance Considerations

Modern wind turbines are typically designed for a 20-year operating life; however, the longevity of a wind turbine system is directly related to the operating environment and frequency and quality of routine maintenance. Typically, manufacturers provide a one- to five-year warranty covering the cost of any material, assembly, or design-related defects. The exact composition of warranty agreements will vary between manufacturers and may reflect project-specific structures and/or technical issues.

The frequency of scheduled maintenance activities is determined by the manufacturer and may depend on site wind and environmental conditions. DES and Entegrity offer service contracts and have experience working with Alaska power plant operators to build up a local skill set necessary to perform basic maintenance and repair procedures. Of the possible vendors for the remanufactured Vestas V15 turbine, Energy Maintenance Services (EMS) based in South Dakota has the largest staff of technicians and the most experience operating and maintaining these types of turbines. However, EMS does not have experience working in remote Alaskan villages or with wind-diesel hybrid systems. The service capacity of Energie PGE is unknown but is expected to be limited since it is a relatively new company with a limited number of installations. All of the turbines listed have remote monitoring capability that would allow both the turbine supplier and AVEC to monitor production, troubleshoot faults and take corrective action on some tasks without sending a technician to the site.

Maintenance requirements vary depending on the features of each turbine model. The Entegrity and Vestas V15 have aerodynamic tip brakes, which require maintenance. The Entegrity turbines installed in Kotzebue and Selawik have had problems with inadvertent tip brake deployment, which required much troubleshooting and modification. The tip brakes have been recently redesigned based on experience in Alaska; however, it is unknown whether the problem has been fully resolved. The lack of a gearbox, lack of blade tip brakes, and the permanent magnet generator reduce the overall system complexity and potential maintenance needs of the NW100 turbine compared to others. The NW100 is designed according to the IEC 61400-1 standard for a 30 year life at an IEC WTGS Class I site (10 m/s average hub height wind speed), which results in a more robust design than the other turbine options.

The NW100 turbine is installed on a tubular tower with internal ladder and enclosed nacelle that protects service personnel from the elements and allows tasks to be performed in harsh weather conditions. The Entegrity, Energie, and Vestas turbine options are typically installed on lattice towers that must be climbed or tilted down for service, thus potentially restricting the ability to perform repairs during the winter months.

Shipping and Installation Requirements

The shipping and installation requirements of the different wind turbine models depend in large part on the weight and size of the components. Table 6 summarizes the weight of the nacelle, rotor and tower for each turbine option.

Table 6. Weights of Wind Turbine and Tower Options

Turbine Model	Nacelle & Rotor Weight (kg)	Tower Weight (kg)	Total Weight on Foundation	Tower Type
Entegrity eW15	2,420	3,210	5,630	24-m 3-legged lattice
DES NW100/21	7,747	8,500	16,247	30-m tubular
Energie PGE 11/35	~ 3,500	~ 5,000	~ 8,500	24-m 3-legged tilt-up lattice
Remanufactured V15	5,190	4,320	9,510	24-m 4-legged lattice

According to DES the nacelle, hub, tools, and power converter for either one or two NW100/21 turbines are shipped in one 20-ft long seaworthy ISO Hi-cube container. The container is transported by flat bed semi-truck (5-day delivery) or by train (4-week delivery) from the manufacturing facility in Barre, Vermont, to Seattle, Washington, where it is transferred onto a barge to Anchorage, Alaska. The blades and tower, which are manufactured near Shanghai, China, are shipped by barge to Anchorage. One standard 40-ft ISO container can transport up to nine blades. In Anchorage, the shipping containers and tower sections are placed on a "lighterer" barge that is able to navigate rivers and land on the beach to deliver goods at the village.

For the Energie PGE11/35 turbines, two standard 40-ft shipping containers could transport up to two turbines. The tower and blades would be placed in one container and the nacelle and related wiring and controls would be placed in the other. Similar to the NW100, the containers could be placed on a train or flat-bed truck from the facilities in Saint-Jean-Port-Joli, Quebec, to Seattle or Anchorage. From there the turbine would be barged and/or lighterered to the village. The shipping logistics of the remanufactured Vestas V15 depends on the place of origin. Some units may be shipped from locations in Europe before being remanufactured in either California or South Dakota. After being remanufactured, the turbine would be shipped by ground transport to Seattle, barged to Anchorage, and lighterered to the village.

The Entegrity turbine can be transported in a similar manner as the other turbines using shipping containers; however, due to the small size and light weight of the components, the large container is not necessary and shipping logistics are more flexible. For example, the turbine could be transported by cargo plane from Anchorage to the village if necessary, allowing for a winter delivery when barge access is restricted.

Figure 7 illustrates typical methods for installing each type of wind turbine. The Energie PGE 11/35 and Entegrity eW15 are installed on three-legged lattice towers while the heavier Vestas V15 is installed on a four-legged lattice tower and the NW100 is installed on a tubular tower. The Energie PGE 11/35 is the only model that comes with the tilt-up lattice tower and winch as a standard option. The other turbine options are typically installed with the use of a crane. Designs exist for modifying both the Entegrity and Vestas lattice towers to a tilt-up design; however, the weight of the Vestas V15 turbine will require a significantly larger winch than the Energie or Entegrity turbines. Currently, the only option for installing the NW100 is with a crane.

Figure 7. Installation Methods for PGE11/35, EWS eW15, and DES NW100 Turbines

(sources: Energie PGE website, STG Inc website)

The exact design and installation requirements of the turbine foundation depend on the results of the geotechnical investigation currently underway in Mekoryuk. AVEC's experience from other locations in Alaska indicates that the foundation requirements for the NW100 turbine are the most complex and costly, requiring more steel, concrete, and heavy equipment than the other turbine options. In Toksook Bay and Kasigluk, a custom designed star-shaped steel frame filled with concrete was used to couple the tubular tower of the NW100 to six pilings, which elevated the foundation two feet above ground level. The pilings in Toksook Bay were drilled into the permafrost and anchored to the bedrock below, while the pilings in Kasigluk were installed with helical anchors and thermal siphons that circulate refrigerant solution to maintain the temperature of the permafrost around the piles. The foundation for AVEC's Entegrity eW15 machines in Selawik consist of three steel pilings that anchor each leg of the lattice tower to the ground. The pilings are installed by drilling a hole deep into the ground, placing the pilings, then backfilling the hole with a slurry of soil and water, which then freezes and holds the piles in place. These pilings can also include thermal siphons to ensure the permafrost temperature is maintained. The foundation for the Energie PGE and Vestas V15 turbines are expected to be similar to that of the Entegrity turbine; however, due to the additional weight of the V15, the foundation for that turbine is expected to be more robust and costly. The tilt-up lattice tower design will require additional piles to support the winch anchor and a platform for receiving the lowered tower.

Energy System Modeling

GEC modeled different power system configurations including different numbers and types of wind turbines, diesel generators, energy storage options, and wind penetration levels (ratio of wind capacity to diesel capacity). GEC used the HOMER software program developed by the National Renewable Energy Laboratory, as well as customized analysis spreadsheets. The inputs and results of the modeling are described below.

Wind Resource

The validated hourly wind resource data described in a previous section were input into the model. The wind speeds were adjusted for site air density and turbine hub height but not for long-term trends or the proposed wind project location.

Electric Load

High-resolution electric load measurements have not been recorded at the Mekoryuk powerhouse. For modeling purposes GEC synthesized an hourly electric load data set based on monthly averages from the Power Cost Equalization (PCE) Statistics and an assumed daily profile based upon electric load data obtained from other remote Alaskan communities. Results are shown in Figure 8. Similar to the wind resource, the electric load typically increases in the afternoon and evening hours. This match between the wind resource and the electric load will help to facilitate the efficient use of wind-generated electricity.

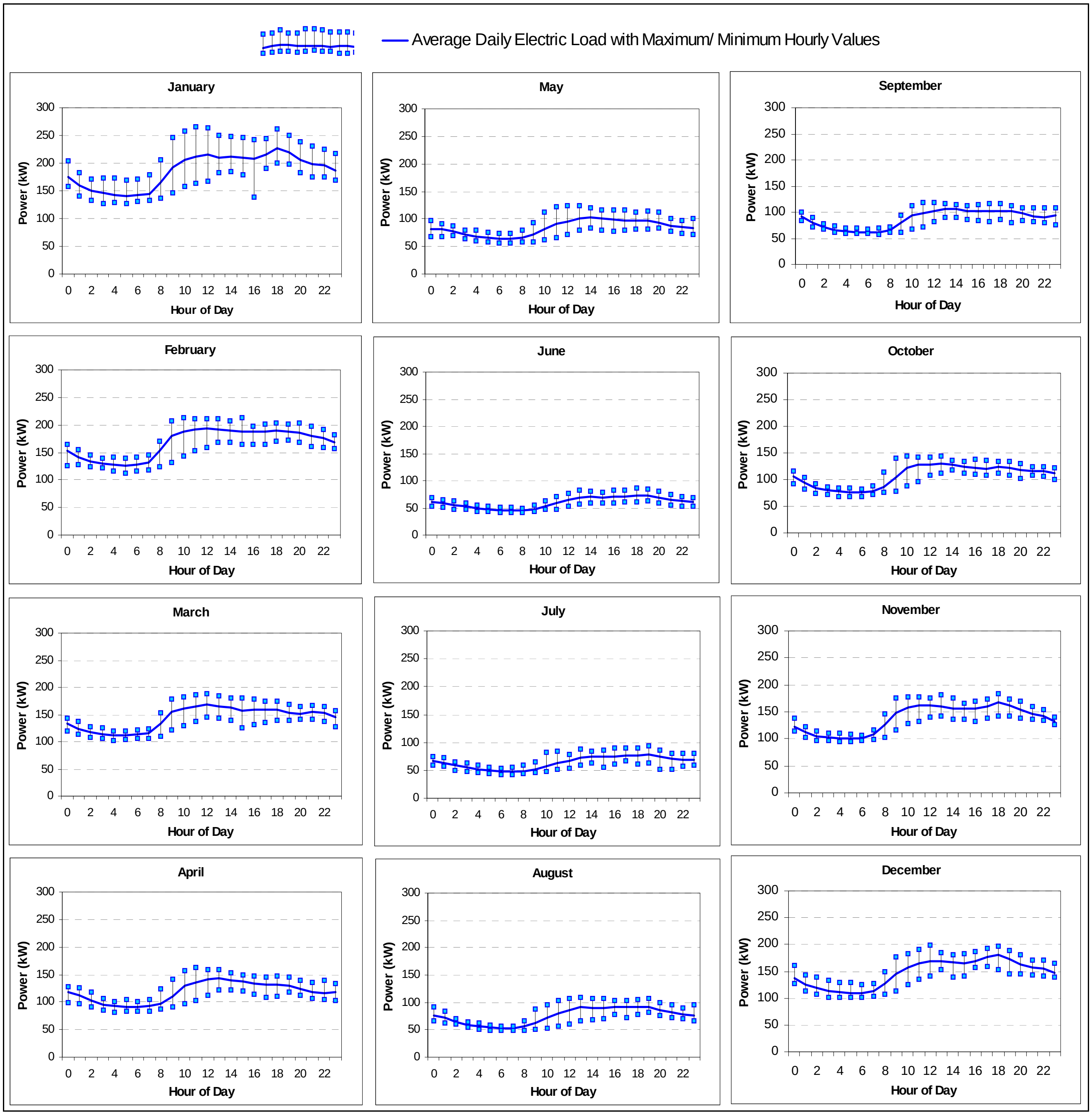


Figure 8. Estimated Electric Load Data in Mekoryuk

The average electric load in Mekoryuk is estimated at 114 kW with a peak of 266 kW. Annual diesel fuel consumption is about 70,700 gallons. According to the PCE data, the electric load in Mekoryuk has been growing at an average rate of 2% per year over the past 10 years. It is assumed in the modeling that this rate of growth will continue over the life of the project.

Diesel Generators and Controls

The diesel generators currently specified for the Mekoryuk power plant are summarized in Table 7 and include two 236 kW units and one 363 kW unit. Fuel efficiency data for different load levels was provided by AVEC. The minimum required loading on the generators is assumed to be 30% of rated output.

Table 7. Specifications for the Diesel Generators in Mekoryuk

Make	Model	Rating	Minimum Load
Detroit Diesel	Series 60 1200 rpm	236 kW	71 kW
Detroit Diesel	Series 60 1200 rpm	236 kW	71 kW
Detroit Diesel	Series 60 1800 rpm	363 kW	109 kW

Low, medium, and high-penetration options were modeled. Due to the low electric load of Mekoryuk, the installation of the smallest available wind turbine (35 kW) resulted in a medium-penetration system; therefore, no low-penetration options are available for Mekoryuk. For the medium-penetration options at least one diesel generator capable of providing adequate spinning reserve will be online at all times. The spinning reserve for all medium-penetration systems is set at 50% of wind power output plus 10% of electric demand. In other words, at any given time the operating diesel generator will be capable of covering a sudden decrease in wind power output of up to 50% and a simultaneous increase in electric demand of up to 10%. For high-penetration options, the diesel generators are allowed to turn off when wind output meets or exceeds demand. During these times, any fluctuations in wind output or electric demand is supplied by an energy storage system.

Heat Recovery and Energy Storage Options

The variations in the wind resource often do not exactly match variations in the electric load. The wind turbines will generate more power than needed at times and will generate less power than needed at other times. In order to maximize use of the renewable resource, electric resistive heaters or energy storage devices may be beneficial, but would increase system cost.

In northern climates, it is common to install an electric boiler consisting of fast-acting electric resistive heaters to absorb excess wind electricity. The heat generated by the excess wind electricity can be incorporated into the diesel generator heat recovery loop, which supplements the heat system of the school, community buildings, powerhouse, or water treatment plant. Modeling of the thermal energy and sizing of the dump load in Mekoryuk is beyond the scope of this report; however, the cost of a moderately-sized dump load is included in the economic analysis for all medium- and high-penetration options evaluated. More analysis is necessary during the final design stage of the project to determine the proper sizing of the dump load.

Typically, energy storage systems only prove economically beneficial in high-penetration systems where the storage device can reduce the operating hours and number of starts of the diesel generators. In these systems, the diesel generators can be shut down when the wind turbines supply more power than is needed by the load. During lulls in wind power generation, the energy storage device supplies any needed power. If the lulls are prolonged and the storage becomes discharged, a diesel generator is started and takes over supplying the load. The primary energy storage devices commercially available include flywheels, ultra-capacitors, and batteries. This equipment can be coupled with a low-load diesel to extend fuel savings.

The sizing and specification of an energy storage system in Mekoryuk is beyond the scope of this report; however, the cost and resulting diesel fuel savings of an energy storage system is included in the economic analysis for all high-penetration system options evaluated. In order to estimate fuel savings without specifying the particular energy storage equipment, the operating reserve in the HOMER model was reduced to zero, which would allow the diesel generators to turn off when the wind power output is sufficient to meet the community load. It is assumed that the energy storage system would be sized to cover any intra-hour fluctuations in the net load and to supply the entire load long enough for a diesel generator to come online if the wind turbines were to fault and suddenly drop off-line. This method of system modeling, although sufficient for the comparative life cycle cost analysis included in this report, is not adequate for final system design. If AVEC decides to move forward with a high-penetration system in Mekoryuk, GEC recommends the performance of a more specific economic and risk analysis of the various energy storage options to evaluate the magnitude of cost savings versus operation risks of the different storage technologies available.

Energy Losses

The gross wind turbine output will be reduced by a number of factors. GEC evaluated each potential area of energy loss in the Mekoryuk wind power system and estimated a correction factor to be applied to the projected diesel-fuel savings calculated by the HOMER model. The estimated system losses are summarized in Table 8 and described below.

Table 8. Estimated System Losses

Description	Loss Correction Factors for NW100 Turbine	Loss Correction Factors for Other Turbine Models
Turbine Availability	90%	85%
Transformer/ Line Losses	98%	
Control System	99%	
Blade Soiling	98%	
Power Curve	98%	
Wake	99%	
Total Correction Factor	**83%**	**78%**

Turbine availability is estimated to be the primary cause of energy loss for the wind system. Factors affecting turbine availability include overall system complexity, downtime due to routine maintenance, faults, minor or major component failures, and balance-of-plant downtime (transformer failures, electrical collection system or communication system problems, or transmission outages). While a “typical” year may have relatively limited downtime associated with component failures, the infrequent events of long duration can result in significant lost energy. Although AVEC technicians have been gaining experience with wind turbines in Alaska, the remote location of Mekoryuk and common inclement weather conditions will limit maintenance capabilities in many cases. Separate turbine availability estimates are presented for the NW100 and all other turbines to account for differences in turbine complexity between the models. Lack of a gearbox and blade pitch system combined with purpose-built considerations for the arctic climate within the NW100 turbine is expected to result in higher mechanical availability than the other models under consideration. Therefore, GEC estimated long-term turbine availability for the NW100 of 90% which corresponds to an average of 876 turbine-hours per year of project downtime while the turbine availability for the other models of 85% corresponds to an average of 1,314 turbine-hours per year of downtime.

Transformer or electrical line losses represent the difference between energy measured at each wind turbine and energy that enters the electric grid. GEC estimates these losses to be 2%. Control system losses include potential reduction in turbine performance due to variable winds creating significant off-yaw operations or high-wind hysteresis. GEC estimates control system losses to be 1%. Surface degradation or build-up of dust, ice, or insects on the blades may cause a reduction in turbine performance. GEC estimates an average 2% energy loss per year due to blade soiling. There is a probability that the turbines will perform at a level different from the reference power curve due to conditions such as high turbulence. GEC estimates a 2% energy loss due to power curve losses. An additional source of energy loss, if more than one turbine is installed, is the wake effects from turbine to turbine. GEC estimates a modest 1% energy loss due to wake effects.

Since each loss category is independent of the other categories, total losses are calculated by multiplying each system loss correction factor to result in total correction factors of 83% for the NW100 and 78% for the other turbines (as shown in Table 8). These correction factors are applied to the projected diesel fuel savings calculated by the HOMER model.

System Performance Results

The wind turbine energy output based on the site wind resource and accounting for estimated system losses described previously is shown in Table 9. The net wind energy output is the amount of electricity available from the wind turbines, including losses, to meet the community demand. The turbine capacity factor is calculated by dividing the estimated actual energy production by the maximum possible energy production throughout the year.

Table 9. Estimated Monthly Wind Energy Output Per Turbine (kWh)

	PGE11/35	eW15	NW100/20	NW100/21	V15
January	11,300	20,300	30,700	35,400	21,100
February	15,700	28,200	42,700	46,900	29,900
March	10,600	19,300	29,100	34,000	19,800
April	10,800	19,900	29,700	35,000	20,000
May	5,300	9,500	14,500	18,400	9,600
June	4,100	7,300	11,200	15,300	7,100
July	5,400	9,700	14,600	18,800	9,700
August	5,300	9,500	14,300	18,800	9,300
September	4,200	7,500	11,300	15,400	7,300
October	8,900	16,200	24,500	28,900	16,600
November	13,200	23,600	35,900	40,300	24,800
December	10,700	19,200	28,900	33,800	19,700
Total Gross Energy Production[1]	105,600	190,100	287,400	340,900	194,800
Gross Turbine Capacity Factor	34%	43%	33%	39%	34%
Total Net Energy Production[2]	87,600	157,800	238,500	282,900	161,700
Net Turbine Capacity Factor	29%	36%	27%	32%	28%

[1] Based on density-adjusted wind speed measured on site for one year and standard turbine power curves.

[2] Includes energy loss factor of 83% for the NW100 and 78% for the other turbine models.

GEC compared the net wind energy production to the community electric demand and the required output of the diesel generators on an hourly basis to determine annual fuel consumption. Table 10 summarizes the performance results of different wind-diesel system options in Mekoryuk.

Table 10. Performance Results of Wind-Diesel System Options for Mekoryuk

System Description	Wind Energy Output[1] (kWh/year)	Diesel Fuel Savings[1] (gal/year)	Average Wind Penetration[2]	% of Year Below 20% Penetration[2]	% of Year Below 50% Penetration[2]	Excess Electricity (kWh/yr)
Low-Penetration Options						
No available options	-	-	-	-	-	-
Medium-Penetration Options						
1 x PGE11/35	87,600	4,200	11%	81%	100%	38,000
2 x PGE11/35	175,200	8,300	21%	59%	89%	74,000
1 x eW15	157,800	5,900	19%	60%	91%	55,000
1 x V15	161,700	7,600	19%	61%	90%	68,000
High-Penetration Options						
3 x PGE11/35	262,800	12,300	32%	49%	74%	106,900
2 x eW15	315,600	11,700	38%	45%	66%	98,000
2 x V15	323,400	15,000	39%	46%	67%	126,000
1 x NW100/20	238,500	12,600	29%	50%	78%	103,900
2 x NW100/20	477,000	24,800	58%	37%	55%	211,800
1 x NW100/21	282,900	14,600	35%	43%	71%	122,000
2 x NW100/21	565,800	28,800	70%	28%	49%	249,000

[1] Includes estimated system energy losses. Estimated diesel fuel savings based on 25-year average, including electric load growth.
[2] Wind penetration is the percentage of the community electric demand that is supplied by wind. In this analysis wind penetration is calculated on an hourly basis.

Due to the low electric demand in Mekoryuk, the installation of a single unit of the smallest available wind turbine results in a medium-penetration system; therefore, no low-penetration system options are listed. The existing diesel-only system in Mekoryuk consumes approximately 70,700 gallons of fuel per year. A high-penetration system consisting of two NW100/21 turbines would result in a 40% reduction in fuel consumption in the community. This system would also generate a significant amount of excess electricity that could be captured in an energy storage system or used to supply a thermal load to further reduce fuel consumption in the community.

All system options show some excess electricity being generated. For the medium-penetration options the excess electricity could be used to supply a thermal load in the community. For the high-penetration systems, a thorough investigation into the sizing of the diesel generators and energy storage system may result in a system with the potential for more efficient energy capture. For example, a low-load diesel generator would have a lower minimum load requirement than the existing generators and would generate less excess electricity during times of high wind output while still providing some spinning reserve. This example is illustrated in more detail below.

Example System Option

To illustrate the impact of a high-penetration system on the electric demand of the power plant, the installation of two NW100/21 wind turbines is used as an example. Based on the energy output of these turbines, Figure 9 shows the resulting net electric load that would need to be met by the diesel generators or energy storage system. The net electric load is defined as the difference between the total community electric demand and the power output from the wind project. As shown, the wind turbines would significantly reduce the loading on the diesel generators. During the summer months the average load would be near zero. Figure 9 does not include the impact of an energy storage system on the net electric load. An energy storage system would help to smooth out any short-term fluctuations in the net load and reduce the spread between the maximum and minimum values shown.

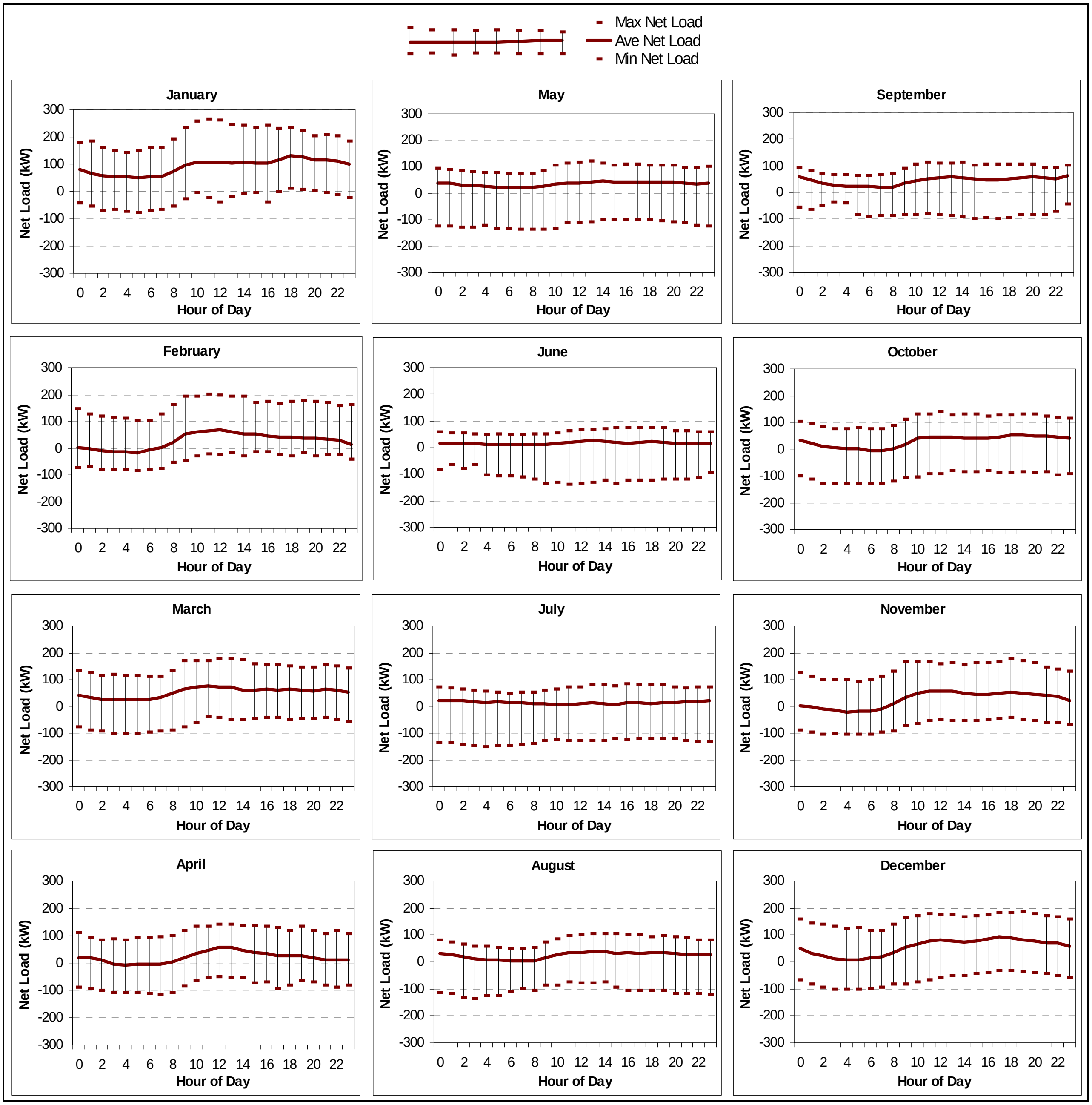


Figure 9. Daily Net Electric Load by Month for High-Penetration Example (2 x NW100/21)

Figure 10 shows a 2-day snapshot of the power output from the different components in the example high-penetration system. It should be noted that these snapshots are based on hourly averages; actual system performance will have more dynamic fluctuations on an instantaneous basis, which is not illustrated in this report. The intent of these snapshots is to provide a general idea of when the electric load will be served by one component of the system over another.

As shown, in the morning hours of January 25, the wind turbines are supplying a portion of the electric load and the 236 kW diesel generator is supplying the remainder. In midday, the wind turbine output increases enough for the diesel generator to turn off. During this time, the energy storage system responds to any short-term fluctuations in the net load. In the evening of January 25, the electric demand increases above the capacity of the wind turbines and energy storage system. The diesel generator is needed to supply up to 25 kW of power for a number of hours; however, since the smallest diesel generator available has a minimum load requirement of 71 kW, excess electricity is generated. If a smaller or low-load diesel were installed, additional fuel savings could be realized.

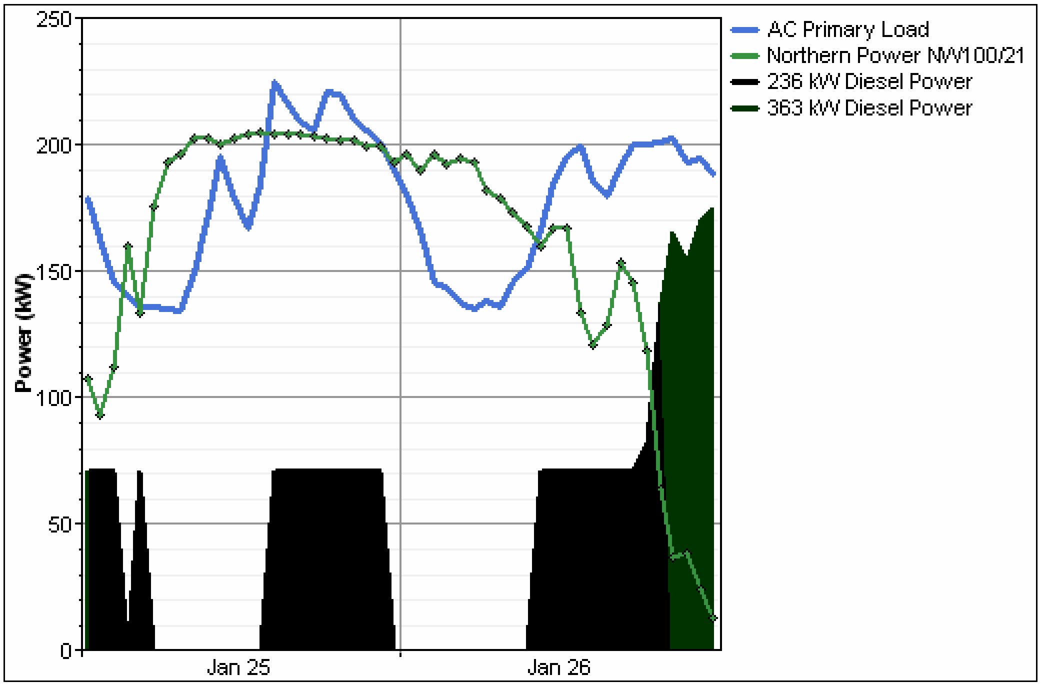


Figure 10. Two-Day Snapshot of Example High-Penetration System Operation (2 x NW100/21)

Although some additional fuel savings may be possible with a revised power system design, the economic analysis in this report assumes the more conservative diesel fuel savings listed in Table 10.

Preliminary Life Cycle Cost Analysis

GEC utilized the results of the HOMER model combined with additional analysis that HOMER is not capable of performing to evaluate the life cycle cost of the different wind-diesel system options. The HOMER analysis includes the installed cost of the wind turbines and related components, annual diesel fuel cost savings, and operation and maintenance costs over the life of the system. Additional analysis includes fuel price escalation rates, electric load growth, and energy system losses. The economic assumptions used for the analysis are presented below.

The baseline wind turbine cost assumptions are summarized in Table 11. The estimated range of installed cost is $6,461 to $10,714 per kW of installed wind capacity, which GEC believes is within the range of other wind projects recently installed in Alaska. For example, AVEC's medium-penetration Toksook Bay wind project cost about $7,000 per kW in 2006.

Table 11. Estimated Wind Turbine Unit Costs

Model	Energie PGE PGE 11/35 35 kW [1]	Entegrity Wind Systems eW15 66 kW [2]	Distributed Energy Systems NW100/21 100 kW [3]	Remanufactured Vestas V15 65 kW [4]
Turbine	$100,000	$132,000	$265,000	$100,000
Tower	$35,000	$5,000	$60,000	$40,000
Shipping	$25,000	$25,000	$40,000	$25,000
Installation	$30,000	$30,000	$60,000	$30,000
Foundation	$130,000	$130,000	$240,000	$150,000
Power Conditioning Equipment	$60,000	$75,000	-	$75,000
Total Installed Cost	$380,000	$397,000	$665,000	$420,000
Cost per kW Capacity	$10,857	$6,015	$6,650	$6,461
Annual O&M Cost	$15,000	$18,000	$10,000	$18,000

[1] Turbine cost based on May 2007 quote from Energie PGE. Tower cost includes tubular tilt-up tower.

[2] Turbine cost based on June 2007 quote from Entegrity and includes 100-ft lattice tower, controls for 60 Hz grid-tie, web monitoring capability, and a cold weather package. Tower cost consists of tilt-up tower modifications. Foundation cost based on May 2007 estimate from STG Inc.

[3] Turbine and tower cost based on June 2007 quote from Distributed Energy Systems for the latest model of the NW100/21. It is assumed that the NW100/20 would have the same installed cost. Foundation cost based on May 2007 estimate from STG Inc.

[4] Turbine cost based on December 2006 estimate from Halus Power Systems and includes cold weather modifications. Tower cost includes lattice tower and tilt-up tower modifications. Foundation cost based on May 2007 estimate from STG Inc.

The costs in Table 12 are based on installation of a single unit. Some economies of scale will apply if multiple units are installed. For example, the cost of mobilizing and demobilizing a crane and construction crew would be spread over the cost of all turbines. Combining the wind project installation with a power plant upgrade or other construction project in the community will further reduce costs. For this analysis, it was assumed that installing two or more of the same turbine would result in a 10% decrease in the total installed cost per turbine. Similarly, the annual O&M cost for a multi-turbine installation was assumed to be 10% less per turbine than for a single turbine installation to account for travel costs distributed over multiple turbines.

The Entegrity, Energie PGE, and Vestas wind turbines are asynchronous machines that require a source of reactive power. The NW100, on the other hand, produces grid-quality AC power at near unity power factor that can supply reactive power to support, rather than burden, a weak grid. To account for the difference in power quality from the different wind turbines the cost of additional power conditioning equipment and the design work for integrating this equipment is included in the cost for the asynchronous generator wind turbines. Power conditioning equipment may include a synchronous condenser for providing reactive power, a soft start motor to minimize impact on the grid when the turbines are energized, and/or other similar equipment.

The annual operation and maintenance (O&M) figures are based on manufacturer estimates of annual service contracts, which typically consist of 6-month inspections. An additional $2,000 is included for materials and minor spare parts that may be required throughout the year. The O&M estimate also includes the annualized cost of occasional major repairs and replacement.

Estimated balance-of-system costs required for different levels of wind penetration are listed in Table 12. Other economic parameters used in the analysis are listed in Table 13.

Table 12. Estimated Balance-of-System Costs

System Type	Low	Medium	High
Power line extension	$150,000	$150,000	$150,000
Electric boiler and controls	-	$50,000	$50,000
Diesel control upgrades	$5,000	$30,000	$50,000
Energy storage	-	-	$400,000
Design and engineering	$20,000	$30,000	$50,000
Total	**$175,000**	**$260,000**	**$700,000**

Table 13. Other Economic Parameters

Parameter	Value
Discount rate	5%
Inflation rate	2%
First year price of diesel fuel	$3.00 per gallon
Fuel price escalation rate	3% per year
236 kW diesel generator O&M cost	$3.00 per hour of operation
363 kW diesel generator O&M cost	$4.00 per hour of operation
Diesel generator minor overhaul	$30,000 per 20,000 hours of operation
Diesel generator major overhaul	$150,000 per 60,000 hours of operation
Project economic lifetime	25 years

Table 14 summarizes the results of the life cycle cost analysis of several wind-diesel system options compared to the diesel-only system. The table shows the installed cost of the wind turbines and related components, the average annual diesel fuel savings, and the net present value of the system. The Net Present Value (NPV) is a common measure for evaluating the financial merit of long-term projects. NPV measures the excess or shortfall of cash flows, in present dollars, that results from an initial capital investment. Positive NPV indicates that the investment in wind energy would add value to AVEC, while negative NPV indicates that the value of the wind-diesel system is less than that of the diesel-only system.

Table 14. Summary of Life Cycle Cost Analysis Results

System Description	Installed Cost	Average Annual Diesel Fuel Savings	Net Present Value
Diesel-only	-	-	-
Low-Penetration Systems			
No available options	-	-	-
Medium-Penetration Systems			
1 x PGE11/35	$640,000	$18,000	-$569,000
2 x PGE 11/35	$944,000	$36,000	-$857,000
1 x eW15	$655,000	$26,000	-$515,000
1 x V15	$680,000	$33,000	-$489,000
High-Penetration Systems			
3 x PGE11/35	$1,726,000	$54,000	-$1,561,000
2 x eW15	$1,411,000	$51,000	-$1,149,000
2 x V15	$1,456,000	$66,000	-$945,000
1 x NW100/20	$1,365,000	$55,000	-$648,000
2 x NW100/20	$1,897,000	$110,000	-$279,000
1 x NW100/21	$1,365,000	$64,000	-$502,000
2 x NW100/21	$1,897,000	$127,000	$1,000

Assuming the baseline economic parameters described above, only one system, the high-penetration option consisting of two NW100/21 wind turbines, offers positive Net Present Value. The negative NPV for the other system options indicates that a wind-diesel system in Mekoryuk may not offer financial benefits over a diesel-only system. Barring changes in the baseline economic assumptions of this analysis, other non-financial benefits would be required to justify investment in these projects.

GEC has conducted additional analysis on the five projects with the highest net present value to determine the impact on NPV of the most significant economic variables. Starting with the baseline assumptions described above, GEC ran sensitivities for each system option to determine the break point at which the respective wind-diesel systems would be equal to the diesel only system in terms of NPV. The results for selected variables are presented below.

Wind Resource and Diesel Fuel Price Sensitivity

The wind resource and the price of diesel fuel have the greatest impact on project economics and are the source of greatest uncertainty. Table 15 illustrates the annual average wind speed and starting diesel fuel price at which the net present cost of the diesel only system and the wind-diesel system are equal. Since the wind resource could not be adjusted for long-term trends, the actual average annual wind speed in Mekoryuk could be higher or lower than what is presented in this report. The baseline wind speed assumption is 7.87 m/s at a 30 m height. Table 15 lists wind speeds from 7 m/s to 8.5 m/s. The baseline assumption for the first year price of diesel fuel is $3.00 per gallon. Table 15 lists the price that would be required at each wind speed level in order for the NPV of the wind-diesel system to be equal to the diesel-only system.

Table 15. First Year Diesel Fuel Price Break Points for Various Site Wind Speeds ($/gallon)

System Option	Annual Average Hub-Height Wind Speed				
	7.00 m/s	7.50 m/s	7.87 m/s	8.25 m/s	8.50 m/s
1 x PGE11/35	$11.20	$9.70	$8.80	$8.15	$7.75
1 x eW15	$8.85	$7.45	$6.70	$6.10	$5.75
1 x V15	$6.80	$5.85	$5.75	$5.30	$5.05
1 x NW100/21	$5.35	$4.80	$4.45	$4.20	$4.00
2 x NW100/21	$3.60	$3.20	$2.95	$2.75	$2.65

As shown, if the long-term average wind speed in Mekoryuk is 7.0 m/s, or 12% less than what the short-term measurements indicated, then the first-year price of diesel fuel would need to be $3.60 in order for the NPV of the wind-diesel system consisting of two NW100/21 turbines to break even with the diesel-only system.

Fuel Price Escalation Sensitivity

GEC ran sensitivities for five select system options to determine the fuel escalation rate break point at which the respective wind-diesel systems would be equal to the diesel only system in terms of NPV. The results are presented in Table 16. The baseline fuel escalation rate is 3%. At this rate, the system consisting of two NW100/21 turbines was the only option with positive NPV. Table 16 shows that if the actual fuel escalation rate is 2.9%, this system would break even with the diesel-only system. Further reducing the fuel escalation rate would result in a negative NPV for this system. For the other wind turbine options, the fuel escalation rate would need to be significantly higher than the baseline assumption in order to break even with the NPV of the diesel-only system.

Table 16. Fuel Escalation Rate Break Points

System Option	Fuel Escalation Rates
1 x PGE11/35	11.3%
1 x eW15	9.3%
1 x V15	8.1%
1 x NW100/21	6.2%
2 x NW100/21	2.9%

Wind Project Installed Cost Sensitivity

GEC ran sensitivities of the installed cost of the wind project for five select system options to determine the break point at which the respective wind-diesel systems would be equal to the diesel-only system in terms of NPV. The results are presented in Table 17. The baseline installed cost of each system option in listed in Table 14. Table 17 lists the increase or decrease in the baseline assumption that would result in the NPV of the wind-diesel system being exactly equal to the NPV of the diesel-only system. The system options consisting of the PGE11/35, eW15, and V15 turbines would require a significant reduction in installed cost in order to break even with the diesel-only system in terms of NPV. On the other hand, the system options consisting of NW100/21 wind turbines are very close to the diesel-only option in terms of NPV. The break points for these system options are well within the margin of error associated with the preliminary cost estimates.

Table 17. Wind Turbine Installed Cost Break Points

System Option	% Difference from Baseline Assumption	$ Difference from Baseline Assumption	Break Point Installed System Cost
1 x PGE11/35	-92%	-$589,000	$51,000
1 x eW15	-81%	-$530,000	$125,000
1 x V15	-74%	-$503,000	$177,000
1 x NW100/21	-1%	-$14,000	$1,351,000
2 x NW100/21	+2%	$30,000	$1,927,000

Operation and Maintenance Cost Sensitivity

GEC ran sensitivities of the annual O&M cost for five select system options to determine the break point at which the respective wind-diesel systems would be equal to the diesel-only system in terms of NPV. The results are presented in Table 18. The baseline O&M costs for each turbine are listed in Table 11. Table 18 lists the increase or decrease in the baseline assumption that would result in the NPV of the wind-diesel system being exactly equal to the NPV of the diesel-only system. The system options consisting of the PGE11/35, eW15, and V15 turbines have a negative NPV even if the annual O&M cost is reduced to zero. The system consisting of two NW100/21 turbines could accommodate a $100 increase in annual O&M expenses and still have an equivalent NPV as the diesel-only option. Any further increase in O&M cost would result in a negative NPV.

Table 18. Operation and Maintenance Cost Break Points

System Option	% Difference from Baseline Assumption	Break Point O&M Cost
1 x PGE11/35	N/A	(Less than $0)
1 x eW15	N/A	(Less than $0)
1 x V15	N/A	(Less than $0)
1 x NW100/21	-7%	$9,300 per year
2 x NW100/21	+10%	$9,900 per year

Conclusions and Recommendations

Short-term wind speed measurements in Mekoryuk indicate an average wind speed of 7.7 m/s at a height of 30 m, offering excellent potential for a wind power project. However, the viability of utilizing this wind resource depends on a number of factors including the installed cost of the wind project, the cost and amount of diesel fuel displaced, and the operation and maintenance costs of the system. GEC performed preliminary technical and economic modeling of these variables for different wind turbine options and different wind penetration levels.

Four wind turbine models were evaluated in this report: Energie PGE11/35, Entegrity e15, remanufactured Vestas V15, and Distributed Energy Systems NW100/21. Differences in installation and foundation requirements, power quality, and repair, operation and maintenance expectations were evaluated to distinguish between the technologies in terms of installed and annual O&M costs. The Energie PGE11/35 turbine is estimated to have the highest installed cost per kW of rated capacity at $10,900/kW. The other turbines range from $6,015/kW to $6,650/kW. Although the NW100/21 has a higher installed cost than the Entegrity and remanufactured Vestas turbines, it is expected to have lower maintenance costs and less downtime. The arctic design, lack of a gearbox, and lack of blade pitch system reduce the overall system complexity and potential maintenance needs of this turbine compared to others. The integrated power electronics will simplify integration into a high-penetration wind-diesel system.

A life cycle cost analysis was performed to compare the cost of different wind turbine options with the potential diesel fuel savings. Assuming a diesel fuel price of $3.00 per gallon, an annual fuel escalation rate of 3%, and an annual average wind speed of 7.8 m/s at a 30 m height, the most economic wind-diesel option is a high-penetration system consisting of two NW100/21 wind turbines and a short-term energy storage system. The system would reduce fuel consumption by roughly 29,000 gallons per year, resulting in long-term fuel savings of approximately $127,000 per year. The system option consisting of one NW100/21 turbine also has a net present value very close to that of the diesel-only system, particularly if a modest reduction in installed cost can be attained.

GEC recommends that AVEC pursue final design for a high-penetration wind-diesel system in Mekoryuk. consisting of either one or two NW100/21 wind turbines and an energy storage system. A detailed analysis of the type, size, and cost of the energy storage system is not included in this report. Therefore, in the final system design process, GEC recommends a more specific economic and technical analysis of the various energy storage options to evaluate the magnitude of cost savings versus operation risks of the different storage technologies available. In addition, the final design process should include the investigation of different sizes of diesel generators, including a low-load diesel option, to determine the optimal configuration that would maximize diesel fuel savings while maintaining an adequate level of system reliability.

Appendix A – Wind Turbine Manufacturer Information

Distributed Energy Systems (formerly Northern Power Systems) 182 Mad River Park Waitsfield, VT 05673 USA Tel.: 802-496-2955 bpingree@distributed-energy.com www.northernpower.com	Distributed Energy Systems (DES) has headquarters and a manufacturing facility in Vermont. DES offers the Northwind NW100, a three-bladed, horizontal-axis, upwind, active-yaw turbine with a direct-drive generator instead of a gearbox. This turbine, released in 1999, is a result of a five-year research and development effort by DES, the Department of Energy, the National Aeronautics and Space Administration, and the National Science Foundation. It was designed for high reliability in harsh environments and is installed on a tubular tower to protect maintenance personnel from harsh weather. According to the manufacturer, the NW100 has operated in temperatures as low as -80°C and is specifically designed as a cold-weather machine. DES is a member of the Alaska Wind Resources Group (AWRG), a consortium of companies that partnered to provide complete wind power systems to Alaskan villages. DES provides the wind technology and expertise while the other companies provide the geotechnical, regulatory, and local logistics and construction expertise.
Entegrity Wind Systems PO Box 832 Charlottetown, PE Canada C1A7L9 Tel.: 902-368-7171 info@entegritywind.com www.entegritywind.com	Entegrity offers the eW15 arctic wind turbine that is rated at 50 kW, but produces power up to 66 kW. The eW15 is a three-bladed, horizontal-axis, downwind, passive-yaw machine. This means the blades are downwind of the tower (opposite today's larger turbines). The optional arctic package allows the machine to operate down to a temperature of -40°C. Although the cut-in wind speed is 4.6 m/s, GEC is aware that the eW15 can have trouble starting at this wind speed. The downwind feature also causes the turbine to be less responsive to changes in wind direction.
Energie PGE Inc 82, rue Giasson Saint-jEan-Port-Joli Quebec GOR 3GO Canada Tel.: 418-598-3338 info@energiepge.com www.energiepge.com	Energie PGE is a relatively new Canadian company based in Quebec. Energie PGE produces a 35 kW downwind turbine designed for low wind speeds, quiet operation, and extreme hot or cold conditions. The turbine includes a passive spring-loaded blade pitch control system, gearbox, PLC based controls, and remote monitoring capabilities. The turbine, tower and controls come with a 2-year warranty. PGE turbines are usually installed on tubular or lattice tilt-up guyed towers. PGE recommends that the tower be tilted down at wind speeds of 45 m/s or more. Tilt-down time is estimated at 30 to 60 minutes.
Energy Maintenance Service, LLC 129 Main Avenue PO Box 158 Gary, SD 57237 Tel.: 606-272-5398 www.energyms.com	Energy Maintenance Service, LLC (EMS) is based in Gary, South Dakota with additional facilities in Howard, South Dakota and Tehachapi, California. EMS is an independent service provider whose customer base includes turbine manufacturers, wind farm developers, owners and operators throughout the world. EMS offers the E15, which is a remanufactured Vestas V15 turbine. The turbine comes with a one-year warranty on parts and labor. In addition to remanufacturing turbines, EMS performs operation and maintenance on many different types of turbines, designs and builds wind farm infrastructure, performs warranty repair, provides technical support and assists with asset management.
Halus Power Systems 25352B Cypress Avenue Hayward, CA 94544 Tel.: 1-510-780-0591 louis@halus.com www.halus.com	Halus Power Systems, based in California since 2000, is a renewable energy products and services company that specializes in remanufacturing used Vestas wind turbines, primarily for the North American market. The remanufacturing process includes updating to microprocessor-based controllers, replacement of all worn components, and rewinding the generator from 50 Hz to 60 Hz if necessary. Turbine sizes range from 65 kW and up and can be installed on a lattice or tubular tower. Turbines include a 2-year warranty and maintenance packages are available, although a company representative has indicated that a number of exclusions would apply to installations in Alaska and that a highly qualified client must take responsibility for owning and operating the machine before a purchase can be made.

Appendix B – Wind Turbine Specification Sheets

EW15 Specifications 50 kW, 50 or 60 Hz

SYSTEM

Type	Grid Connected
Configuration	Horizontal Axis
Rotor Diameter	15 m (49.2 ft)
Centerline Hub Height	25 m (82 ft)

PERFORMANCE PARAMETERS

Rated Electrical Power	50 kW @11.3 m/s (25.3 mph)
Wind Speed Ratings	
cut-in	4.6 m/s (10.2 mph)
shut-down (high wind)	22.4 m/s (50 mph)
design speed	59.5 m/s (133 mph)
Calculated Annual Output	
@ 100 % availability	5.4 m/s (12 mph) 87,000 kWh
	6.7 m/s (15 mph) 153,000 kWh
	8.0 m/s (18 mph) 215,000 kWh

ROTOR

Type of Hub	Fixed Pitch
Rotor Diameter	15 m (49.2 ft)
Swept Area	177 m² (1902 ft²)
Number of Blades	3
Rotor Solidity	0.077
Rotor Speed @ rated wind speed	65 rpm
Location Relative to Tower	Downwind
Cone Angle	6º
Tilt Angle	0º
Rotor Tip Speed	51 m/s (114 mph) @ 60 Hz
Design Tip Speed	6.1

BLADE

Length	7.2 m (23.7 ft)
Material	Epoxy /glass fibre
Blade Weight	150 kg (330 lbs) approximate

GENERATOR

Type	3 phase/4 pole asynchronous
Frequency	(Hz) 60 Hz
Voltage	3 phase @ 60 Hz, 400-600 V
kW @ Rated Wind Speed	50 kW
kW @ Peak Continuous	66 kW
Insulation	Class F
Enclosure	Totally Enclosed Air Over
Options	Arctic low temp. shafting -40°c

TRANSMISSION

Type	Planetary
Housing	Ductile iron
Ratio (rotor to gen. speed)	1 to 28.25 (60 Hz)
Rating, output horse power	88
Lubrication	Synthetic gear oil/non toxic
Heater (option)	Arctic version, electric

YAW SYSTEM

Normal	Free, passive
Optional	Yaw damp
Electrical	Twist Cable

TOWER

Type	Free standing galvanized bolted lattice
Tower Height	24.4 m (80 ft)
Options	30.5 m (100 ft),

Tilt down 24.4 m (80 ft)

FOUNDATION

Type	Concrete pad, pier or special

CONTROL SYSTEM

Type	PLC based
Communications	Serial link to central computer for energy monitor and maintenance dispatch (optional)
Enclosures	NEMA 1, NEMA 4 (optional)
Soft Start	Optional

ROTOR SPEED CONTROL

Running	Passive stall regulation
Start up	Aerodynamic
Shut-down	Aerodynamic tip brake and electrodynamic braking. Parking brake for servicing.

BRAKE SYSTEM CONTROL

Fail-safe aerodynamic, electrodynamic, and parking brakes.

APPROXIMATE SYSTEM DESIGN WEIGHTS

Tower	3,210 kg (7,080 lb)
Rotor & Drive train	2,420 kg (5,340 lb)
Weight on Foundation	5,630 kg (12,420 lb)

DESIGN LIFE: 30 Years
DESIGN STANDARDS: Applicable Standards, AWEA, EIA and IEC
DOCUMENTATION: Installation Guide and Operation & Maintenance Manual
SCHEDULED MAINTENANCE: Semi-annual or after severe events.

NOTE 1: Entegrity Wind Systems Inc. is constantly working to improve their products; therefore, product specifications are subject to change without notice.

NOTE 2: Power curves show typical power available at the controller based on a combination of measured and calculated data. Annual energy is calculated using power curves and a Rayleigh wind speed distribution.
Energy production may be greater or lesser dependent upon actual wind resources and site conditions, and will vary with wind turbine maintenance, altitude, temperature, topography and the proximity to other structures including wind turbines.

NOTE 3: For design options to accommodate severe climates or unusual circumstances please contact the technical and sales office in Prince Edward Island, CANADA.

NOTE 4: For integration into high penetration wind-diesel and village electrification schemes contact the technical & sales office in Prince Edward Island, CANADA for technical support and systems design.

Revised January 2005

NorthWind® 100 Wind Turbine

Distributed
ENERGY SYSTEMS

Extending today's resources...
creating tomorrow's choices

Distributed Energy Systems' NorthWind 100 wind turbine provides cost-effective, highly reliable renewable energy in demanding environments worldwide.

Designed specifically for isolated grid and distributed generation applications, the NorthWind 100 wind turbine is a state-of-the-art, village-scale wind turbine. Distributed Energy Systems has drawn on 30 years of experience to engineer a wind turbine that provides cost-effective, highly reliable renewable energy in a wide variety of applications. The patented design of the NorthWind 100 wind turbine meets the needs of small utilities and independent power producers.

Key Features

Simplicity

High reliability and low maintenance were the focus in developing the NorthWind 100 wind turbine. The design integrates industry proven robust components with innovative design features to maximize wind energy capture in rural, remote and harsh environment locations. The NorthWind 100 wind turbine features a minimum of moving parts and vital subsystems to deliver high system availability. The uncomplicated rotor design allows safe, efficient turbine operation.

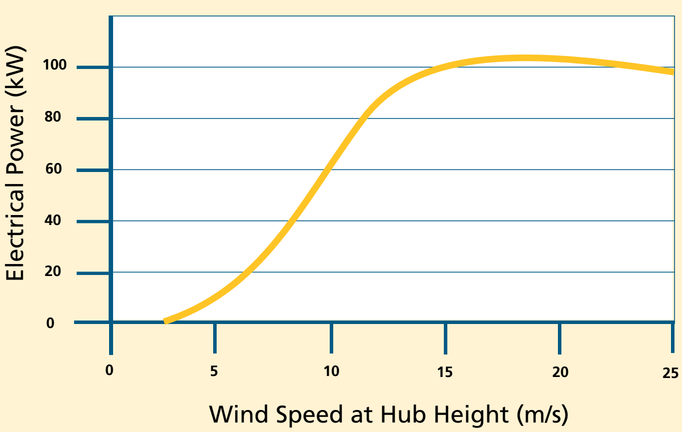
Serviceability

Our sophisticated remote monitoring and control software allows real-time accessibility of the turbine thus minimizing unnecessary service calls. When a site visit is required, all service activities can occur within the tubular tower or heated nacelle housing, providing complete protection from harsh or unpredictable weather conditions. Designated work areas provide ample room to perform service activities.

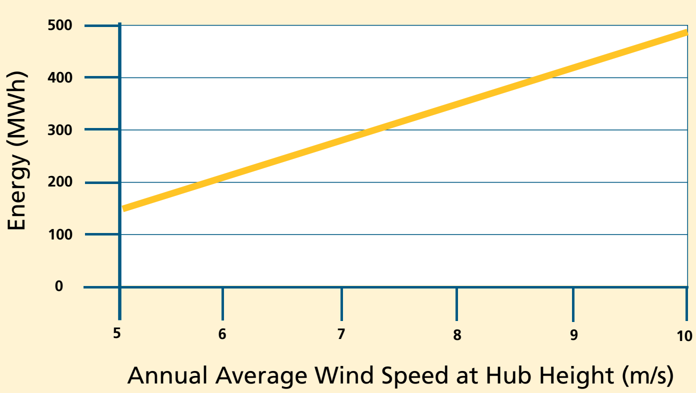
Power Quality

The NorthWind 100 wind turbine provides reliable power in distributed generation and village systems where the power grid is typically "soft and unbalanced." Our synchronous, variable speed, permanent magnet, direct drive generator and integrated power converter increase energy capture while eliminating current inrush during control transitions. This turbine can be connected to large power grids and remote wind-diesel configurations without inducing surges, effectively providing grid support rather than compromising it.

NorthWind 100/21 Wind Turbine Power Curve
Standard Density

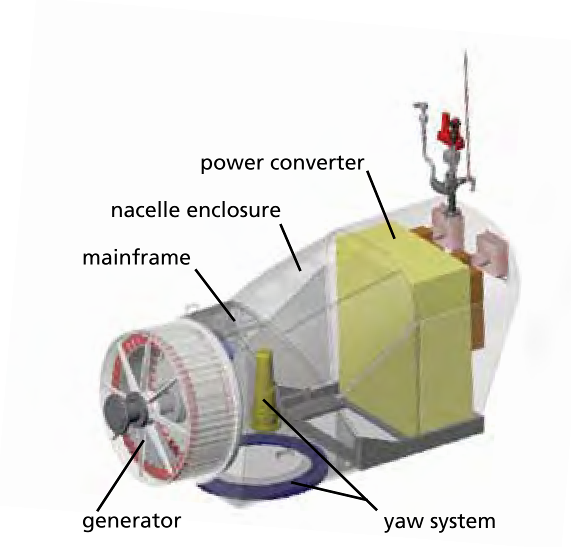


NorthWind 100/21 Wind Turbine Annual Energy Production
Standard Density, Rayleigh Distribution



Patented NorthWind 100 System

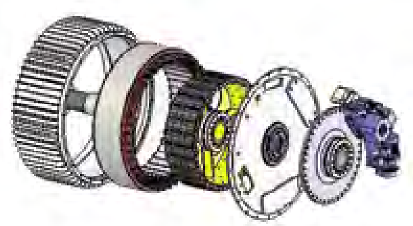
- Three fiberglass reinforced plastic blades bolted to a rigid hub that mounts directly to the generator shaft eliminates the need for rotating blade tips, blade pitch systems and speed increasing gearboxes.
- Variable speed, permanent magnet, direct drive generator/converter system is tuned to operate the rotor at the peak performance coefficient, and also allows stall point rotor control to contend with wide variation in air density found in the target applications.
- Safety system provides both normal shutdown and emergency braking backup functions.
- Advanced power converter features setpoint control of power factor and/or VARs.
- Web-based SmartView® remote monitoring system also available.



Nacelle assembly

NorthWind 100 Wind Turbine Technical Specifications

Turbine Design Class	IEC WTGS Class S
Design Standard	Compliant with IEC 61400-1
Rated Power	100kW
Power Regulation	Variable speed stall
Rotor Diameters	19m, 20m, 21m
Hub Heights	25m, 30m
Yaw System	Active upwind
Turbine Electrical Output	480VAC, 3 phase, 50/60Hz
Grid Tolerance	+10/-15% voltage; +/- 2Hz
Grid Interface	115kVA transformer (spec available)
Operating Temperature	-40 °C to 50 °C
Lightning Protection	Compliant with IEC 61024-1
Icing	to 30mm



Passively-cooled, permanent magnet, direct drive generator eliminates the drivetrain gearbox and maximizes energy capture.

Case Study

Wind-Diesel Systems in Remote Alaska

Distributed Energy Systems successfully installed and commissioned three new NorthWind 100 turbines in the community of Kasigluk, Alaska. As part of a larger wind-diesel energy initiative by Alaska Village Electric Cooperative (AVEC), these turbines will produce approximately 675,000 kWh annually. By displacing 32% of the energy normally generated by diesel fuel, the new systems are expected to generate a potential savings of over $95,000 per year.

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Visit us online at
www.distributed-energy.com

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Distributed ENERGY SYSTEMS

Extending today's resources...
creating tomorrow's choices

THE QUIET POWER

PGE 11/35

www.EnergiePGE.com

Renewable energy ensures a prosperous future for next generations and helps in protecting our environment. We offer the best turbine on the market, designed with the latest technology, the PGE 11/35.

THE QUIET POWER

BENEFITS

- Designed to perform in low wind sites and to be particularly effective in high wind conditions (up to 35kW)
- Noiseless, it can be installed close to tenements
- Rugged and reliable even in severe climates (extreme heat or cold)
- Self-regulating mechanism (patent pending) that guarantees steady RPM even when free wheeling in strong wind
- Optimum performance, thanks to its latest PGE power control system
- Innovative design that blends into any environment

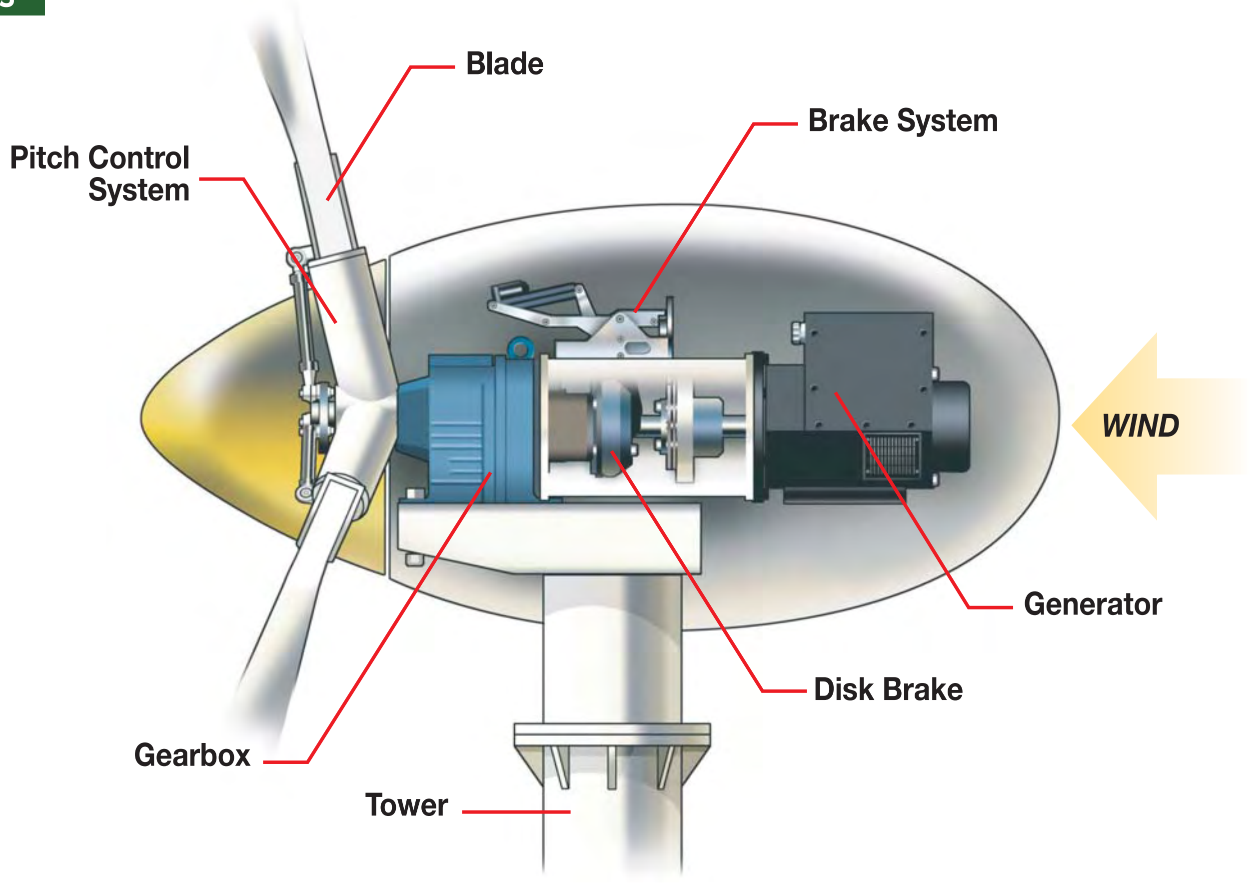
APPLICATIONS

- Commercial/industrial
- Institutional/public
- Residential/resorts
- Agricultural
- Outfitting operations
- Remote communities (in developing countries)
- Power generation

DUAL-ENERGY COMBINATIONS

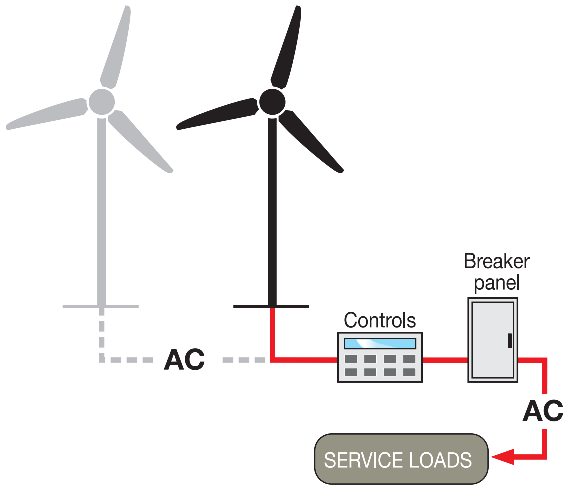
- Solar
- Diesel Generator
- Hydroelectric plants
- Biomass
- Others…

PGE 11/35

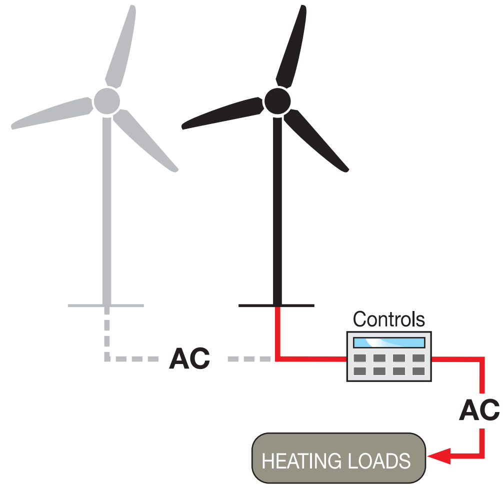


POSSIBLE OPERATING MODES

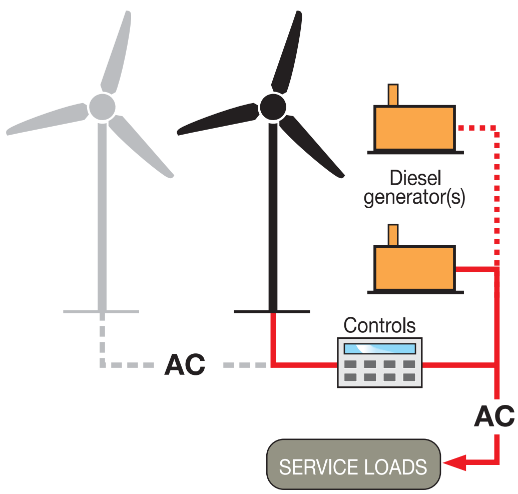
GRID-TIED



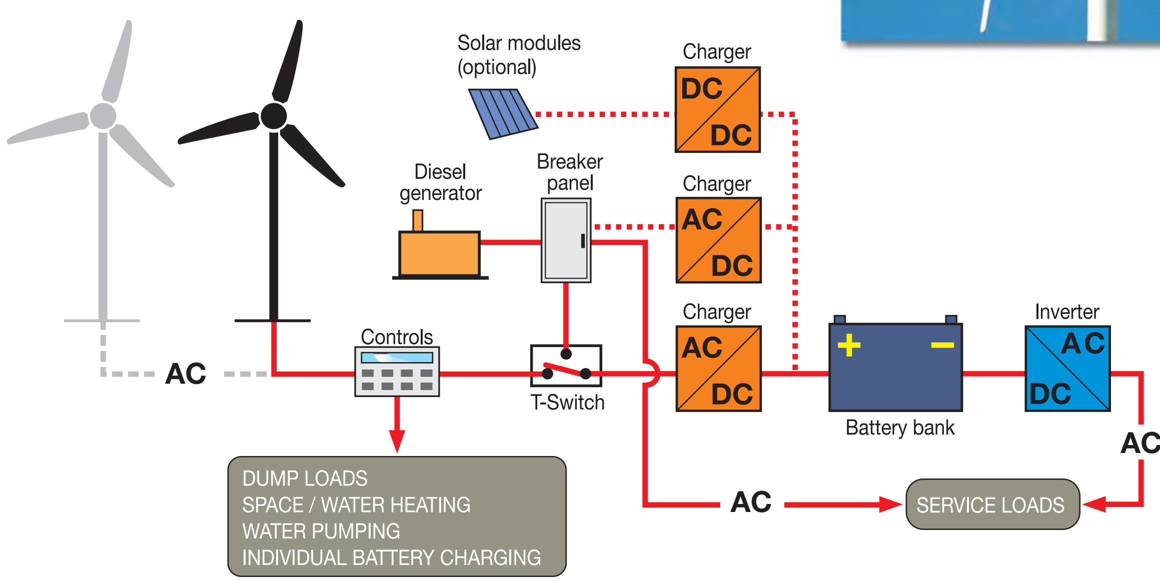
STAND ALONE WITH RESISTIVE LOADS



WIND-DIESEL



STAND ALONE WITH BATTERIES



PGE 11/35 SPECIFICATIONS

TURNINE

Nominal power	35 kW @ 14 m/s	
Type	3 blades, horizontal axis	
Orientation	- Passive, downwind	
Generator	Grid-Tied - Asynchronous - Single & 3 phase	Stand Alone - Synchronous - 3 phase
Frequency	50 / 60 Hz	
Voltage	400, 480, 600 V	
Rotor speed	75 rpm	
Rotor diameter	11 m (36 ft)	
Swept area	95 m² (1023 ft²)	
Blade length	5 m (16,5 ft)	
Blade material	Epoxy / Fiberglass	
Lightning protection	Lightning rod on top of nacelle	
Rotor control	Constant speed regulated by the *PGE Optinergy* controls (stand alone unit only) and the passive, blade pitch system.	
Noise level	Inaudible at 100 m (330 ft) and more.	
Life expectancy	20 years	

GEARBOX

Type	Grinded parallel gears
Maintenance	Oil change every two years (normal use, depending on weather conditions).
Lubricant	Synthetic oil (10 L / 2,64 USG)

CONTROLS

	Grid-Tied	Stand Alone
PLC based control	Standard	Standard
Text Interface	Standard	Standard
Remote control (modem, Internet, satellite)	Optional	Optional
Remote monitoring (modem, Internet, satellite)	Optional	Optional
Remote software update (modem, Internet, satellite)	Optional	Optional
Multi unit centralized control system (SCADA)	Available	Available
Dump loads	N/A	If necessary
Battery accumulation	Available	Available
Connection	Direct	N/A

WARRANTY

Turbine, tower, controls	2 years excluding: batteries, charger(s), inverter(s)

Specifications subjected to change without notice due to continuous development.

OPERATIONNAL DATA

Cut-in wind speed (production)	4.8 m/s
Nominal wind speed	14 m/s
Cut-out wind speed	25 m/s (before automatic brake triggering)
Tilt down wind speed	45 m/s
Blade pitch control system	- Passive synchronised spring loaded mechanism (patent pending)

BRAKE SYSTEM

Type	Two double sided disks
Manual	For maintenance

Automatic	- For over power (above 25 m/s)
	  - electric actuator
	- For excessive vibration
	  - mechanical device
	- For over speed
	  - centrifugal device
	  - electric actuator
	- In multi-unit systems
	  - to match power production with demand

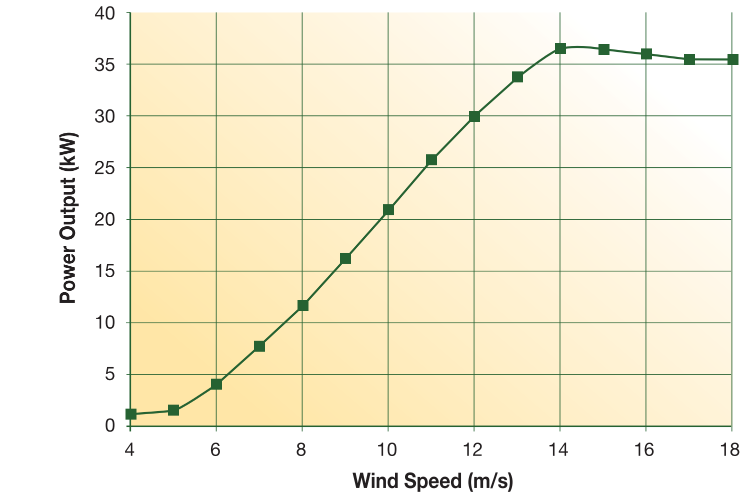
TOWER

Height*	18 m (60 ft) *Other heights available upon request
Hub height	Tower height + 1 m (3 ft)
Type (available for icy conditions)	- Guyed tubular - Lattice
Design	Tilt-up with gin pole and winch
Finish	- Zinc primer / epoxy paint - Galvanized
Foundation	- Concrete - Buried metallic structure
Operating limits	- Should be lowered at 45 m/s and above winds.
Tilting time	30 – 60 minutes
Benefits	Lower installation costs. 1) Only a backhoe loader is required. 2) No concrete necessary, depending on ground conditions.

GET THE MAXIMUM FROM THE WIND

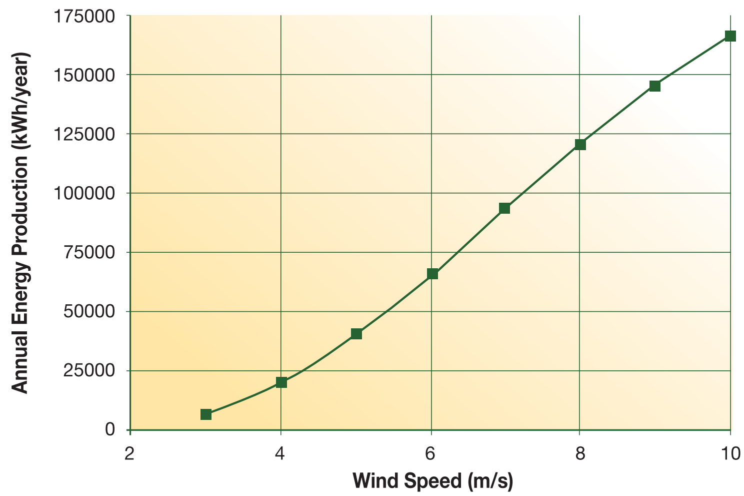
WIND SPEED (M/S)	POWER OUTPUT kW
4	1.2
5	1.6
6	4.1
7	7.8
8	11.7
9	16.3
10	21.0
11	25.8
12	30.0
13	33.8
14	36.5
15	36.5
16	36.0
17	35.5
18	35.5

POWER CURVE



WIND SPEED (M/S)	AEP kWh/YEAR
3	6280
4	19527
5	40173
6	65697
7	93163
8	120111
9	144727
10	165734

ANNUAL ENERGY PRODUCTION

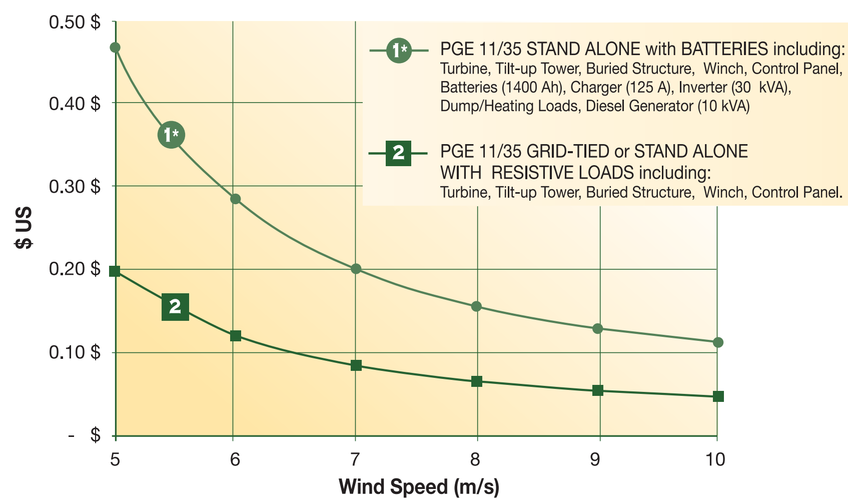


According to: IEC 61400-12 standards
Note: These results must be used as an estimate of the expected turbine performance.

WIND SPEED (M/S)	1*		2	
	10 years	15 years	10 years	15 years
5	0.68 $	0.46 $	0.29 $	0.20 $
6	0.42 $	0.28 $	0.18 $	0.12 $
7	0.29 $	0.20 $	0.13 $	0.08 $
8	0.23 $	0.15 $	0.10 $	0.07 $
9	0.19 $	0.13 $	0.08 $	0.05 $
10	0.17 $	0.11 $	0.07 $	0.05 $

* *kWh cost includes typical system losses (charger & inverter)*

KWH COST ESTIMATE



Based on a 15 years return on investment. Not included: Shipment, installation and maintenance. May 2006 prices, subjected to change without notice. Contact Energie PGE for prices.

CONVERSION TABLE

m/s	4	6	8	10	12	18	25	45
km/h	14	22	29	36	43	65	90	160
mph	9	13	18	22	27	40	56	100

A FEW REALIZATIONS

MISSION

Energie PGE is a Canadian company based in Quebec.
Its mission is to design, manufacture and market innovative products in the small and medium wind turbine industry.
Energie PGE can rely on the strength of its R&D team, committed in developing reliable alternative energy devices as well as competitive and efficient technologies.

ENERGIE PGE

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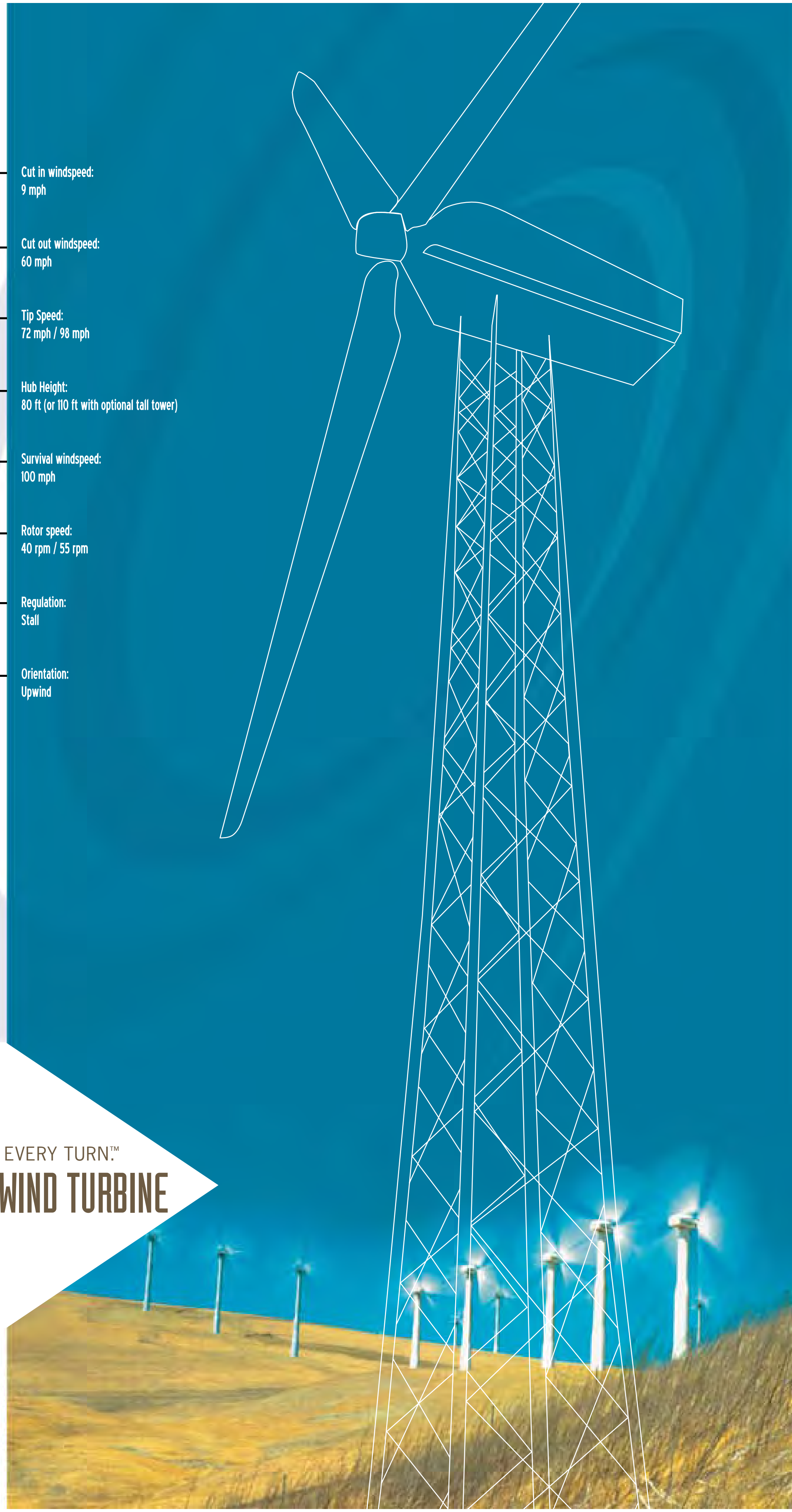
To us, 20 years of solid performance in the most extreme environments is just the beginning.

That's why we've remanufactured the E15 wind turbine generator to give you the most advanced, efficient wind turbine available in its class.

Combine that with an unrivalled system warranty and service structure, and it's easy to understand why EMS is Reliable with Every Turn.™

Operating Characteristics (35/65kW)

- **Cut in windspeed:** 9 mph
- **Cut out windspeed:** 60 mph
- **Tip Speed:** 72 mph / 98 mph
- **Hub Height:** 80 ft (or 110 ft with optional tall tower)
- **Survival windspeed:** 100 mph
- **Rotor speed:** 40 rpm / 55 rpm
- **Regulation:** Stall
- **Orientation:** Upwind



E15

RELIABLE WITH EVERY TURN.™

35/65kW WIND TURBINE

EMS
Energy Maintenance Service, LLC

Weight	Rotor: 2,420 lbs	Nacelle: 9,000 lbs	Tower: 9,500 lbs (80 ft) 18,500 lbs (110 ft)			
Gearbox	Configuration: 3 stage parallel shaft	Gear Ratio: 1:22.4				
Control Panel	Logic: Modular PLC	Enclosure: Type 12	Listing: UL			
Tower	Height: 80 ft or 110 ft	Material: Hot dip galvanized lattice	Ladder: Staggered foot pegs (to access exterior man baskets)	Safety: Safety cable (harness with fall arresting device)	Configuration: 4-legged (80 ft) 3-legged (110 ft)	
Nacelle	Welded plate steel bed plate (galvanized) with reinforced fiberglass hood					
Yaw System	Friction bearings on geared slew ring with electric worm gear drive (control input from nacelle mounted wind vane)					
Rotor	Number of blades: Three	Diameter: 50 ft	Swept Area: 1964 ft	Material: Fiberglass reinforced polyester	Pitch: Fixed	Power regulation: Passive stall
Brake System	Aerodynamic: Centrifugally actuated blade-tip brakes	Mechanical: Fail-safe hydraulic disc brake on low speed shaft				

Standard Warranty
Two years parts

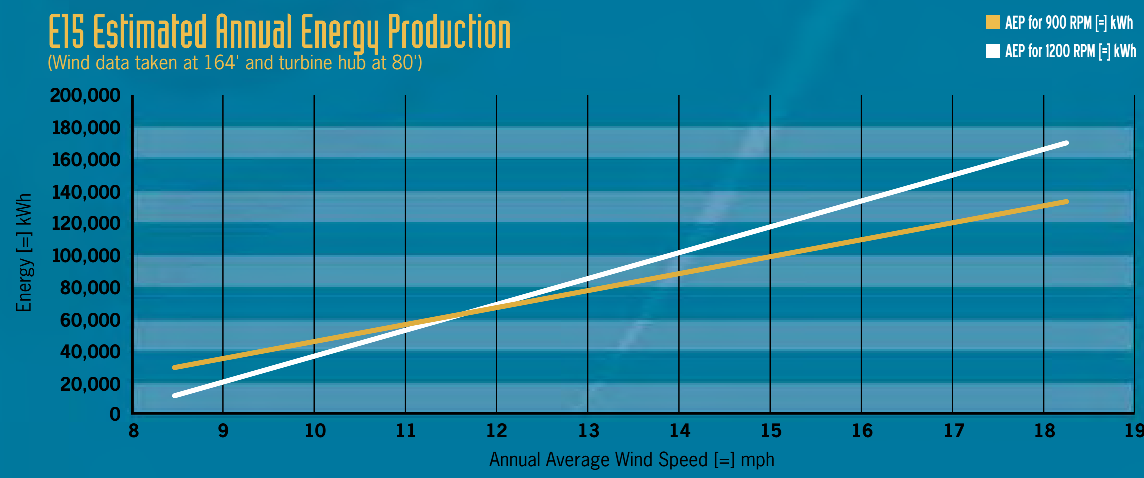
E15 35/65kW WIND TURBINE

Safety Systems

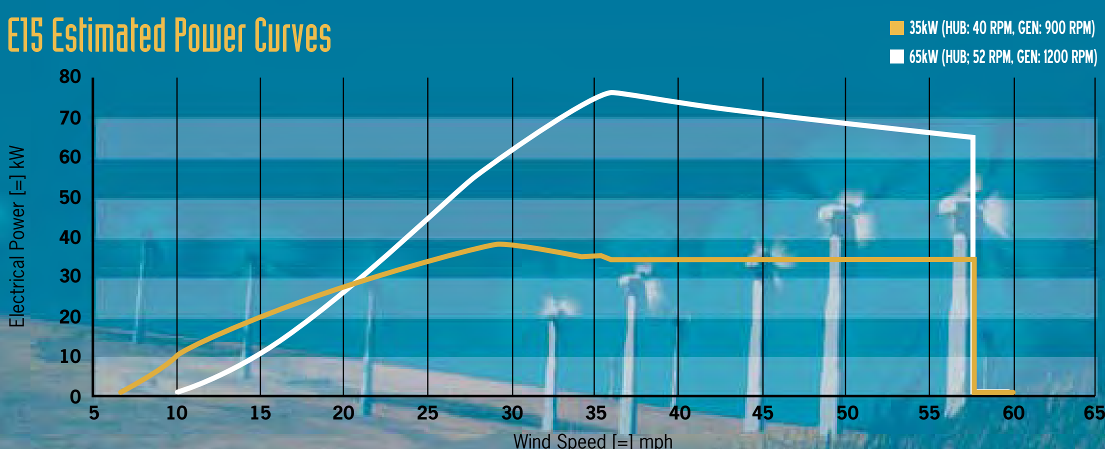
- Induction generator has inherent anti-islanding
- Centrifugally actuated blade-tip brakes
- Fail-safe hydraulic disc brake
- Grid monitoring for fault shutdown inputs: Line Voltage, Line Frequency, Overproduction
- Over-speed monitoring on hub and generator for fault shutdown
- Thermal protection on generator
- Vibration sensor for fault shutdown
- Automatic cable untwist with emergency override for fault shutdown
- Thermal protection for pump and yaw motor circuits
- 90° nacelle yaw on fault events
- High wind speed fault shutdown

E15 Estimated Annual Energy Production

(Wind data taken at 164' and turbine hub at 80')



E15 Estimated Power Curves



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