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Lake and Peninsula Borough
Chignik Lagoon
Wind Resource Assessment
Final Report

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Executive Summary

This report presents a feasibility-level investigation of several alternatives for the construction of a wind power facility at Chignik Lagoon, Alaska, and includes discussions of the site characteristics, wind climate, preliminary cost estimates, and an economic analysis. The report is also based on site visits conducted in September/October 2010 and October 2011, and information from vendors, experience with similar projects, and published information on developed community-size wind power projects.

Construction of a wind power facility at Chignik Lagoon presents many challenges in part due to its remoteness and distance from a major urban center.

The village is located on the Alaska Peninsula approximately 470 miles southwest of Anchorage and is accessible only by boat or by air. The local runway is a 1,800-foot gravel airstrip that is suitable only for small aircraft. Water access is via the Chignik Bay and Lagoon on the Pacific Ocean and is subject to tidal fluctuations, and is only navigable by boats with a shallow draft.

These factors together with the high costs of mobilization, transport of equipment and materials, and of transmission-line construction in remote areas yield a relatively high cost-per-installed-kilowatt (kW) of wind power. No major environmental obstacle is expected at this time. However, several state and federal agencies will need to be involved from the inception of the project, and FAA permitting will be complicated by the presence of the airstrip in the middle of town.

The current average electrical load for the village is about 65 kW, and significant growth in demand is not anticipated in the near future. In addition, there is no readily available market for any excess power that may be produced. Therefore, the concept for this study was to minimize costs by designing a facility that generally meets the current needs of the village, while at the same time utilizing excess wind power for space heating purposes and hot water.

A 34-meter (111.5 foot) meteorological tower instrumented for wind data collection was erected and began collecting data in September 2010. Data was collected for over a year and the wind resource assessment for the local geographical area was primarily based on the measured data at this tower. The data underwent a rigorous quality assurance process to compensate for the tower shadowing effects on the anemometers and wind vanes.

During the site surveys in the fall of 2010 and 2011, data on the electric and thermal loads of the village, the current diesel expenses, and the suitability of a new wind power installation was also gathered. Further, more recent (2011) data was collected on the cost of diesel.

In order to verify the site suitability for wind turbine installations, and to calculate values of capacity factor (CF) and annual energy production (AEP) for various turbine models, a refined wind flow model was produced based on: measured wind data, correlations to long-term Automated Weather Observing System (AWOS) station data from a near-by airport (Chignik Bay), correlations to Chignik Lake met-tower data, high-definition (1 meter [m]) digital elevation models, and surface roughness.

Three turbine models (in their cold-weather package configurations) were considered: Northwind 100B/21 rated at 100 kW; Aeronautica 29-225 rated at 225 kW; and Enercon E33 rated at 330 kW.

The three turbines differ in size and control systems. The Northwind and Enercon turbines do not have a gearbox, which simplifies maintenance. The Northwind 100 and Aeronautica 29-225 are the only turbines in the group which do not have pitch control. Pitch control assures an optimal energy capture at various wind speeds, regulates the rotation speed at the highest wind speeds, and protects the machine by feathering the blades in potentially damaging strong wind events. At the same time, the moving parts are more numerous and the possibility of failures increases. All of the models come with standard monopole towers, which let the operator climb inside a weather-protected environment.

The calculated AEPs, assuming a 10 percent loss (due to turbine availability, electrical losses, soiling, etc.), range between 320 and 1,600 megawatt hours per year (MWh/yr) depending on turbine models and site locations, and are associated with a high wind penetration level. Lower penetration levels are not economically viable at Chignik Lagoon.

The various turbine candidate sites showed large variations in AEP for any given turbine model, while also being characterized by different terrain and access conditions. The economic modeling was based on a common hub-height of 37 m.

An economic analysis using the HOMER© Micropower Optimization Model (U.S. Department of Energy, 2005 [6]) was conducted for the four turbine models for the site that showed the best wind resource among those identified during the site survey.

The HOMER© output includes several economic measures that show the value of the difference between the wind power alternative and the current diesel-only system. The 'present worth' shows how much the alternative system saves over the project lifetime compared to the diesel-only system, and is the primary measure for comparing the economic feasibility of the two systems. Each alternative was compared to the existing diesel system using three assumed prices for diesel fuel: the current price of US$4.40 per gallon (data from Chignik Lagoon Power Utility, at a current oil price of $86.5/bbl), a price of US$5.60 per gallon (based on a crude oil price of US$110/bbl), and a price of US$6.36 per gallon (based on a crude oil price of US$125/bbl).

While a due-diligence of the machines needs to be carried out before arriving at the final solution and selection of the most suitable model, the economic analysis has revealed the main results summarized in Table 1. These results are from analysis at the intermediate (long-term) diesel price of US$5.50 per gallon. The color coding associated with the benefit/cost ratios identifies with: green the 'best economic alternative'; cyan the 'second best'; orange the marginal; and red the unfeasible alternative.

Table 1. Summary of economic results for alternatives at the three potential sites, with diesel price @ US$5.60/gal.

NW - 100 kW	**1**	**2**	**3**
Capital (USD)	1,357,524	1,357,524	1,506,852
*Present Worth (USD)	-365,057	-504,059	-162,713
**Annual Worth (USD)	-24,311	-33,568	-10,836
Internal Rate of Return (ROI) (%)	N/A (4.89)	N/A (4.2)	1.71 (5.96)
Discounted (simple) Payback Period (years)	N/A	N/A	N/A (17)
Levelized Cost of Energy (USD/kWh)	0.82	0.84	0.80
Diesel Only Cost of Energy (USD/kWh)	0.78	0.78	0.78
Benefit/Cost Ratio	0.95	0.94	0.98
Aeronautica- 225 kW	**1**	**2**	**3**
Capital (USD)	1,624,164	1,624,164	1,770,339
*Present Worth (USD)	692,243	385,139	1,258,498
**Annual Worth (USD)	46,100	25,649	83,811
Internal Rate of Return (ROI) (%)	7.05 (9.52)	5.3 (8.26)	9.51 (11.4)
Discounted (simple) Payback Period (years)	12.7 (10.4)	15.4 (12)	10.3 (8.88)
Levelized Cost of Energy (USD/kWh)	0.70	0.73	0.63
Diesel Only Cost of Energy (USD/kWh)	0.78	0.78	0.78
Benefit/Cost Ratio	1.10	1.05	1.20
Enercon - 330 kW	**1**	**2**	**3**
Capital (USD)	2,117,184	2,117,184	2,265,387
*Present Worth (USD)	722,308	458,368	1,180,674
**Annual Worth (USD)	48,103	30,525	78,628
Internal Rate of Return (ROI) (%)	6.28 (8.95)	5.10 (8.12)	7.89 (10.1)
Discounted (simple) Payback Period (years)	13.7 (11.2)	15.7 (12.3)	11.8 (10)
Levelized Cost of Energy (USD/kWh)	0.69	0.72	0.64
Diesel Only Cost of Energy (USD/kWh)	0.78	0.78	0.78
Benefit/Cost Ratio	1.11	1.07	1.19

* Represents the avoided cost over the life of the project when operating the alternative system rather than the diesel system.

** Represents the avoided cost on an annual basis when operating the alternative system rather than the diesel only system.

The Aeronautica 29-225 and the Enercon E33 are the most economically attractive alternatives.

For a long-term diesel price of US$4.40/gal, the lowest-levelized COE is obtained with an Aeronautica 29-225 installed at Site 3, resulting in a projected reduction in COE of about US$0.08/kWh. Site 1 and 2 are also valid alternatives, with easier access and likely loss turbulence.

For a long-term diesel price of US$6.36/gal, the lowest-levelized cost-of-unit-energy (COE) is obtained with an Aeronautica 29-225 installed at Site 3, resulting in a projected reduction in COE of about US$0.20/kWh.

Enercon has a very solid reputation in the international market and has successfully installed turbines throughout the world and in harsh environments in Canada and Antarctica for wind-diesel applications. A patent-dispute prevented Enercon from exporting to the U.S. until 2010.

Aeronautica manufactures the Norwin 29-225 on license in the U.S. The 29-225 machine has been proven all over the world for decades.

The Northwind 100B/21 has shown an impressive reliability, though it has only been in the market and operational for less than a decade. This model is considerably more expensive (50 percent) than the others on a per-installed-kW basis, and only at diesel prices at or above US$6.36/gal is economically promising.

The analysis does not account for emergency maintenance following major unexpected events, but that could be a factor for machines having spare parts difficult to retrieve. For this reason, it is recommended that an inventory of spare parts be acquired at the time of project installation.

Because of the harsh wind regime, it can also be expected that a 50-year wind gust may be encountered during the lifetime of the project, and discussion with the turbine manufacturer is encouraged to verify which components may fail under those circumstances.

The Aeronautica and Enercon machines are class I, and generally suitable for the sites. Northern Power Systems has communicated that the NW100B/21 (class II) may still be deployed if: (1) a manual turbine arrest is performed prior to an expected wind storm of that category; (2) an inspection by a licensed technician is performed after such an event.

If 80 percent of the project's initial capital is guaranteed by a state grant, all the configurations analyzed are economically advantageous to the local community and Borough. Results are given in Section 5.7.

Recommendations for future activities include:

- Investigate whether suitable financing is available to develop a wind power installation at Chignik Lagoon given the illustrated initial capital costs and economic benefits.
- Initiate permitting process, starting with Federal Aviation Administration (FAA) determination of no-hazard to air navigation, while also initiating discussions with state and federal agencies to identify potential environmental and permitting issues.
- Contact Enercon to assess exporting capabilities to the U.S.
- Identify potential parallel projects that could share the costs for heavy construction equipment, transportation of materials, etc.
- Conduct geotechnical investigations at the turbine installation site(s).
- Identify and recruit local potential workers for construction activities, with the double benefit of reducing expenses and involving the local community in the project.
- Identify suitable contractors and engineering/construction management firms.

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Section 1.0 - Introduction

1.1 Background

Knight Piésold and Co. (Knight Piésold) was contracted by Lake and Peninsula Borough (LPB) to carry out a feasibility study for the community of Chignik Lagoon in the Southwest Alaskan Peninsula to verify the economic viability of a wind-diesel electric generation facility.

The hybrid facility could provide lower cost of energy to the local community, which currently relies on diesel generators to provide electricity. Previous studies conducted in the area[1] estimate that the cost of electricity generated by a small wind power facility could be up to US$0.03/kWh below the projected cost of electricity from diesel generators with heat recovery.

This report highlights the main aspects involved in the study at Chignik Lagoon and the results of the economic analysis for four different types of wind turbines. This project (103-240/05) is part of a widespread wind regional assessment being carried out at various communities within the LPB boundaries.

1.2 Scope of Work

The scope of work included both a preliminary and a detailed wind resource assessment (WRA), met-tower installation, site survey to identify suitability of wind turbine installations, and collection of data for input to an economic analysis, namely: village electrical and thermal load data, village fuel expenses, vendors' and contractors' information, and quotations. Also included in the scope of work is a review of the permitting requirements.

Following a site visit and an initial screening process, three sites were selected for a more detailed analysis, including a conceptual project layout, an estimate of power generation, a preliminary cost estimate, and an analysis of the economic feasibility.

1.3 Sources of Information

Information used during the study included GPS data obtained during the site visit; information on wind data, power and fuel consumption from: the power plant maintenance personnel; the Lake and Peninsula Borough; the Chignik Lagoon Power Utility (CLPU); and the City of Chignik Lagoon; information on the design of the existing power plant from CLPU; information on the physical setting collected by Knight Piésold staff during a site visit; geologic maps and reports, topographic and land-usage maps from the

[1] Information Insights, 2008: The Lake and Peninsula Borough Regional Energy Plan, Fairbanks, Alaska.

United States Geological Survey (USGS), MODIS (or Moderate Resolution Imaging Spectroradiometer), the State of Alaska, and the Lake and Peninsula Borough.

1.4 Limitations and Disclaimer

This report titled *Chignik Lagoon Wind Resource Assessment Final Report* has been prepared by Knight Piésold for the exclusive use of LPB. No other party is an intended beneficiary of this report or the information, opinions, and conclusions contained herein. Any use by any party other than LPB of any of the information, opinions, or conclusions is the sole responsibility of said party. The use of this report shall be at the sole risk of the user regardless of any fault or negligence of LPB or Knight Piésold.

The information and analyses contained herein have been completed to a level of detail commensurate with the objectives of the assignment and in light of the information made available to Knight Piésold at the time of preparation. This report and its supporting documentation have been reviewed and/or checked for conformance with industry-accepted norms. Calculations and computer simulations have been checked and verified for reasonableness, and the content of the report has been reviewed for completeness, accuracy, and appropriateness of conclusions. To the best of the information and belief of Knight Piésold, the information presented in this report is accurate to within the limitations specified herein.

This report is Knight Piésold pdf file: *ChignikLagoonWRA_Rev0.pdf*. Any reproductions or modifications of this report are uncontrolled and may not be the most recent revision.

1.5 Contributors and Contacts

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Section 2.0 - General Site Conditions

2.1 Site Location

The village is located on the Alaska Peninsula approximately 470 miles southwest of Anchorage and is accessible only by boat or by air. The local runway is a 1,800-foot gravel airstrip that is suitable only for small aircraft. Water access from the Pacific Ocean is via the Chignik Bay and Lagoon; it is subject to tidal fluctuations, and is only navigable by boats with a shallow draft.

Terrain is very complex in the surrounding of the village, and the mountains slopes reach the lagoon shores with very little beach available. The slopes are heavily forested.

2.2 Climate

The nearest official weather station is at Chignik Bay, about 5 miles northeast of Chignik Lagoon. The average annual precipitation at Chignik Bay is 83 inches, with an average annual snowfall of 46 inches. The climate of Chignik Lagoon is typical of the Alaska Peninsula, with cool, rainy summers and moderately cold winters with precipitation occurring as rain or snow. Seasonal temperature extremes can range from 10 degrees Fahrenheit (°F) in mid-winter to as high as 65°F in the summer. Average January temperatures range from 20°F to 31°F. Average July temperatures range from 46°F to 61°F.

2.3 Geology

The area is characterized by sedimentary bedrock (sandstone, siltstone, conglomerate, shale, and coal), with mixed unconsolidated sedimentary deposits (alluvial, colluvial, glacial, and marine) in some areas. The mountains southwest of Chignik Lagoon are volcanic [2].

2.4 Permitting

At this time, no major permitting obstacles are foreseen, though state and federal agencies will need to be involved from the inception of the project.

In particular, the presence of an important airport for the community will require the FAA to issue a determination of no hazard to air navigation posed by the wind turbine installation (see Section 6).

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Section 3.0 - Preliminary Wind-Flow Modeling and Tower Installation

3.1 Wind Flow Modeling

A numerical simulation was employed to look at wind flow trends around the town of Chignik Lagoon, Alaska. This simulation was necessary to identify candidate sites for the met-tower (and potentially the wind turbine to be deployed in the future) based on terrain and wind characteristics.

The following extensive data was collected: USGS topographical maps, Digital Elevation Maps (DEMs), and satellite imagery. Additionally, surface roughness data was acquired based on satellite MODIS mission and analysis of aerial imageries and maps. Wind data was purchased for the AWOS station at Chignik Bay, Alaska (PAJC) and for a wind monitoring tower (CB tower) installed in proximity of the same town (approximately 5 miles to the east of Chignik Lagoon). The CB tower's data had to be manipulated and correlated to PAJC to correct for some deficiencies in and to validate the data. As a result, a local climatology was calculated, and this was then numerically transferred to the site of interest.

The acquired data was used in a WAsP® calculation to evaluate the wind speed trends over the topography about Chignik Lagoon. The results are shown in Figure 1.

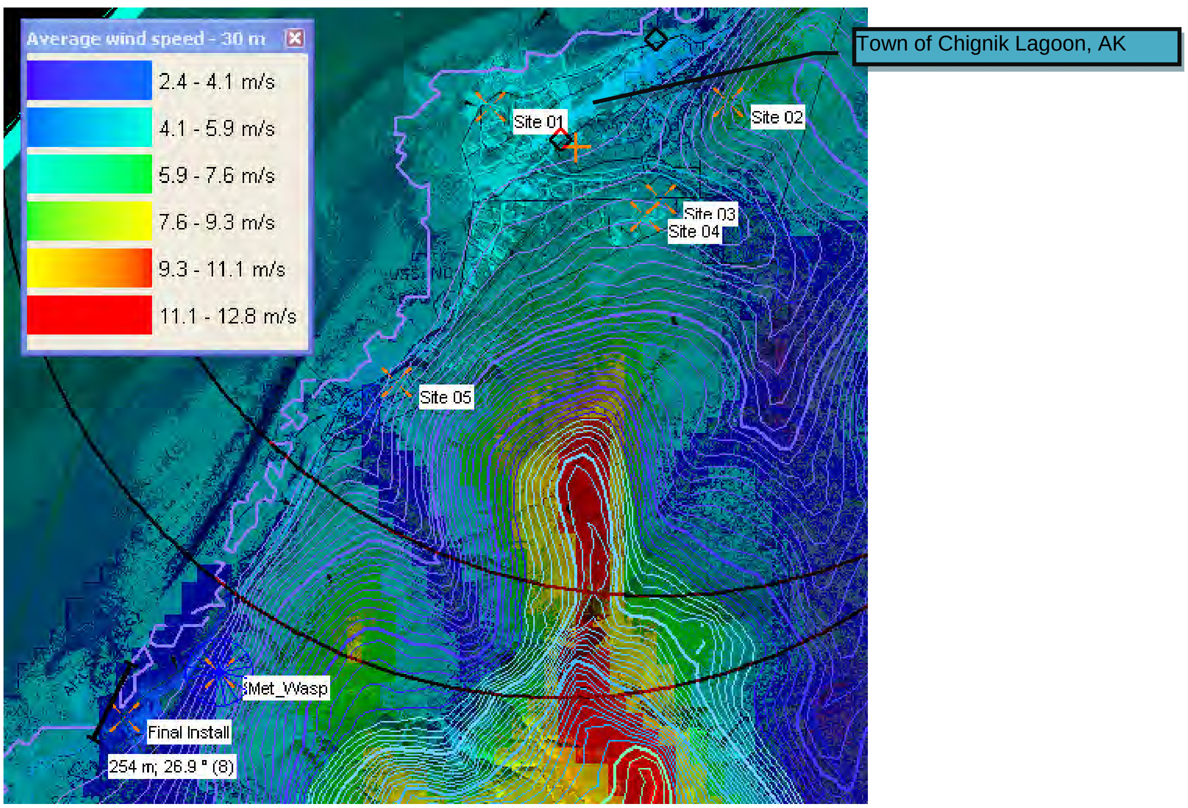

Figure 1. Filled contours of wind speed at 30 m above ground level (agl) as derived from a preliminary numerical model overlaid onto topographical contour lines in the geographical area surrounding Chignik Lagoon. Topo-contour interval is 5 m (lake is at ~2 m mean sea level [msl]). Topography, surface roughness and other factors affect the wind flow. This calculation employs data from nearby Chignik Bay to deduce a first approximation wind flow distribution at Chignik Lagoon.

Note that these wind speed values were used qualitatively only, due to large uncertainties in the numerical calculations using wind data from 5 miles away and with irregular sampling frequency.

The accumulated results led to the identification of (6) six candidate sites for tower installation. They can be seen as ‘x’ marks in Figure 1 - Figure 2.

All of the locations were further analyzed to look at wind direction distributions. In most cases the predominant wind direction appeared to be southwesterly or aligned with the runway at Chignik Lagoon. An example of this wind rose is provided for ‘Site 06’ in Figure 4.

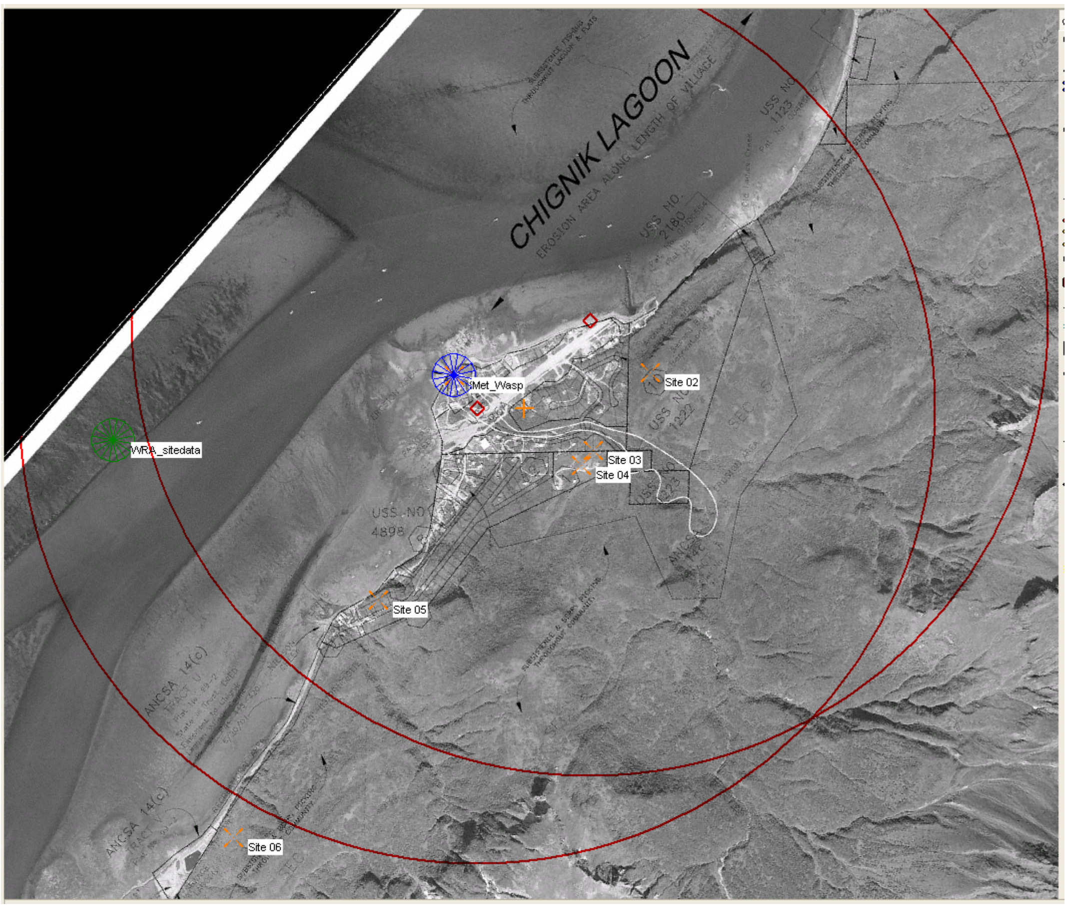

Figure 2. Potential tower sites marked with small blue circles and red ‘x’ marks. Red circles are centered on either end of the airstrip and have a radius of 1.5 kilometer. Background is a LandSat satellite image.

A geological map was also acquired to narrow down the number of potential installation sites based on soil conditions. However, the information in the USGS map was not adequate to discard any of the initially selected sites.

An application was filed with the FAA to assess any potential hazard to air traffic.

Note that the best locations for wind resource appear to be at higher elevations, but access there proved to be prohibitive (see also Figure 3).

Figure 3. Aerial view of the town and surroundings at Chignik Lagoon. Note the airstrip in the middle of the town and the dense vegetation.

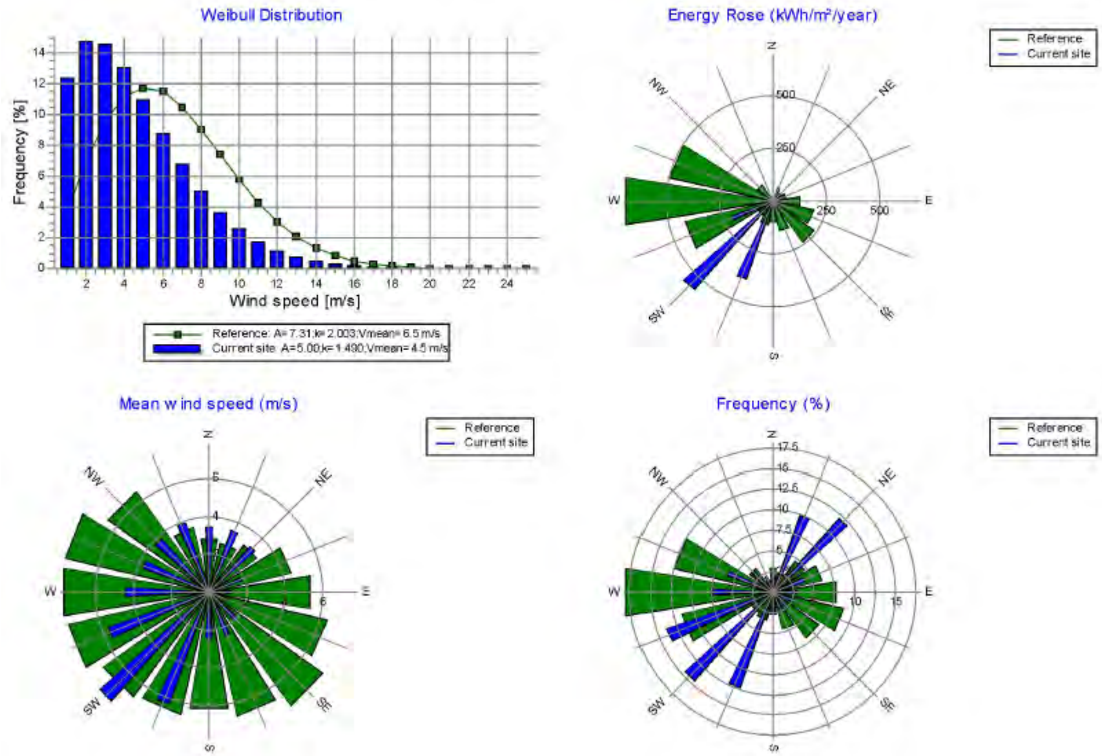

Figure 4. Wind Speed, Energy, and Direction distribution at Tower Site 06 denoted as Current Site (reference is CB Tower).

3.2 Site Survey and Data Acquisition

In Fall 2010, staff members from Knight Piésold traveled to Chignik Lagoon, Alaska, carrying the meteorological instruments. At the same time, a met-tower that was procured in advance was shipped from Anchorage. Some hardware components (such as the anchors) had to be fabricated by Knight Piésold personnel and subcontractors to assure a safe installation. The tower and instrumentation underwent a rigorous inventory check and functionality test; the top portion of the tower was then painted to FAA specs.

A GPS-guided, photographical survey of most of the locations was executed during the first day of the site visit. Select pictures from the survey are shown in Knight Piésold's Met-Tower Installation Report [4] for the tower sites that were examined in greater detail. Some of the candidate sites were inaccessible due to the dense vegetation and absence of roads or trails. This made it impossible with the limited resource and time to erect a tower at those locations. FAA approval further limited site selection to areas around Sites 05 and 06. Access and steep terrain made Site 05 unfeasible, ultimately leaving Site 06 as the only candidate. To satisfy the FAA response to erect the tower on lower elevation we had to move the final erection site to within the landfill fence limits.

Details of the installation are found in reference [4]. A view of the erected tower can be seen in Figure 5. After commissioning of the tower, Knight Piésold staff performed a few routine checks on data quality and tower hardware. Data was inspected for compliance for one entire day after erection, while staff was on site. The instrumentation on the tower is mounted according to the parameters as shown in Table 2.

Official valid data collection started on August 31, 2010 at 9:20 (AM) AST and terminated on October 3, 2011 at 7:40 (AM) AST.

Table 2. Instrumentation Parameters.

Instrument	Channel Name	Height [m AGL]	Orientation
Cup Anemometer	A1	33	293º
Cup Anemometer	A2	33	203º
Cup Anemometer	B	19.3	293º
Wind Vane	A	32	293º (offset=+113º)
Temperature Probe	T	4.6	0º

The cup anemometers' booms were oriented to minimize the tower shadow (aerodynamic effects due to the tower on the measurements), and according to the preliminary study which resulted in the wind direction and energy distribution rose as given in Figure 4. The cup anemometers were therefore oriented at 45º from the expected predominant SW-NE wind direction.

Figure 5. View of the tower fully erected.

Section 4.0 - Refined Wind Resource Assessment

4.1 Refined Wind Resource Map

A refined WRA was conducted with the goal of assessing the wind regime at an altitude between 30 and 50 m AGL at various locations across the site. The model employed high-resolution surface characteristics data, and terrain-elevation data in the immediate proximity of the village. Digital Elevation Maps were kindly provided by Mr. Lamar Cotten (LPB Manager) and Mr. George Plumley (Planner, Dept. of Commerce, State of Alaska).

Wind data from the combined anemometer readings at the installed meteorological tower described above was correlated to the long-term (last 10 years) data set at the Chignik Bay (PAJC) AWOS station, as well as the almost two years' worth of wind data from a similar tower at Chignik Lake (CLK_TOWER, [7]). Wind speed and direction distributions as received from the local met-tower (CLG_TOWER) can be seen in Figure 6 and Figure 7. The correlation coefficient proved to be approximately 0.5, fairly low and likely due to the unfortunate location of the CLG_TOWER and the associated high level of turbulence.

Figure 8 shows the turbulence intensity measured at CLG_TOWER as a function of wind speed. The smooth curves represent the IEC standards for turbulence. The turbulence intensity at the tower location is very large, an indication that the site selected for the met-tower would not be suitable for a wind turbine installation. As mentioned previously, the landfill location was the only one permitted by FAA.

The correlation coefficient between the data from the Chignik Lake tower and the PAJC AWOS is about 0.7, despite the larger distance of CLK_TOWER from the AWOS. These results thus confirm that the local long-term climatology at Chignik Lagoon is well represented by PAJC, and that the local micro-climate at CLG_TOWER may give rise to some spurious results due to presence of significant terrain and turbulence at the landfill site.

In order to augment the reliability of the model, two refined (25 m resolution) wind resource maps (at 37 m (121 feet) AGL) were created: one based on CLG_TOWER correlated to both CLK_TOWER and PAJC; and another one solely based on a correlation between CLK_TOWER and PAJC. It is reassuring to observe that the results are very similar (see Figure 11-Figure 12); therefore, confirming the validity of the wind resource study and accumulated data. The wind resource in Figure 12 was selected as more representative of the wind climatology around Chignik Lagoon.

It may also be expected that turbulence levels would decrease at least to IEC Class A in the area closer to town and along the shore. Figure 9-Figure 10 show turbulence intensity as a function of wind direction as well as terrain profile along the easterly wind direction (largest recorded turbulence levels). From those figures, it can be seen that the turbulence decay with height is significant, and that the presence of terrain in proximity of the CLG_TOWER was likely the largest contributor to the recorded turbulence-intensity levels. A full computational-fluid-dynamic simulation may extend these results to verify the levels of expected turbulence at potential turbine installation sites, but the current results are encouraging.

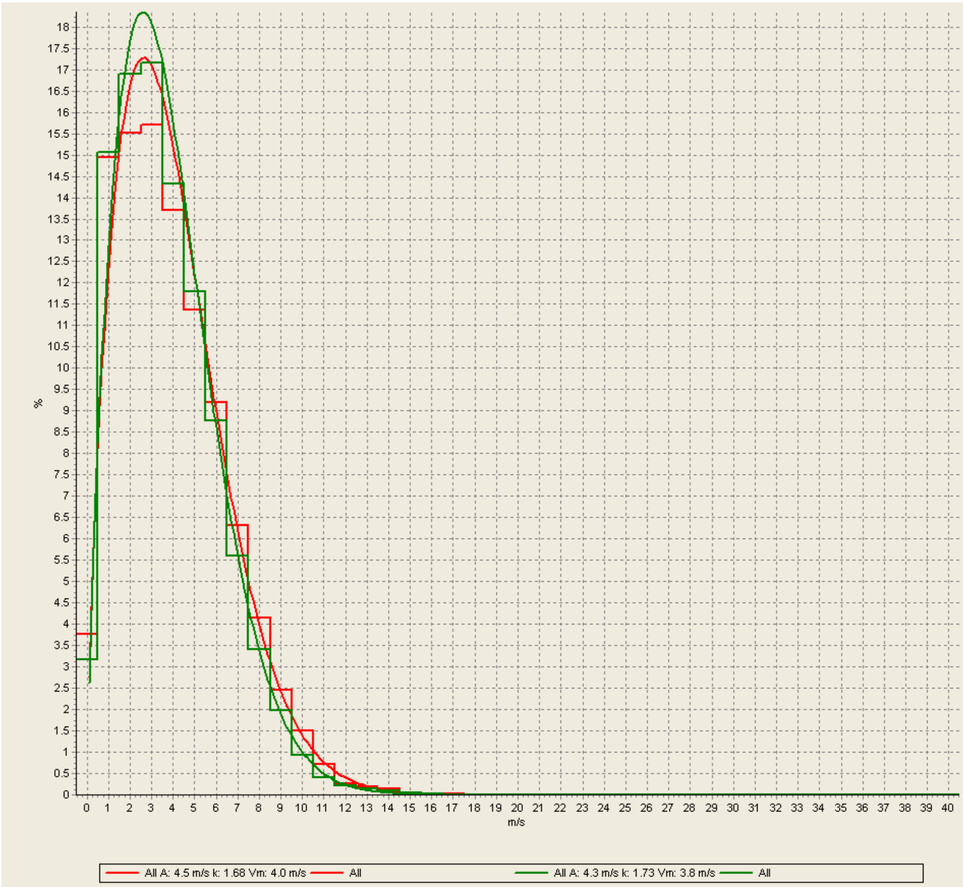

Figure 6. Wind Distribution at the Chignik Lagoon MET-Tower (CLG_TOWER), at 33m (red histograms and Weibull fit curve) and at 19 m AGL (green histograms and Weibull fit curve).

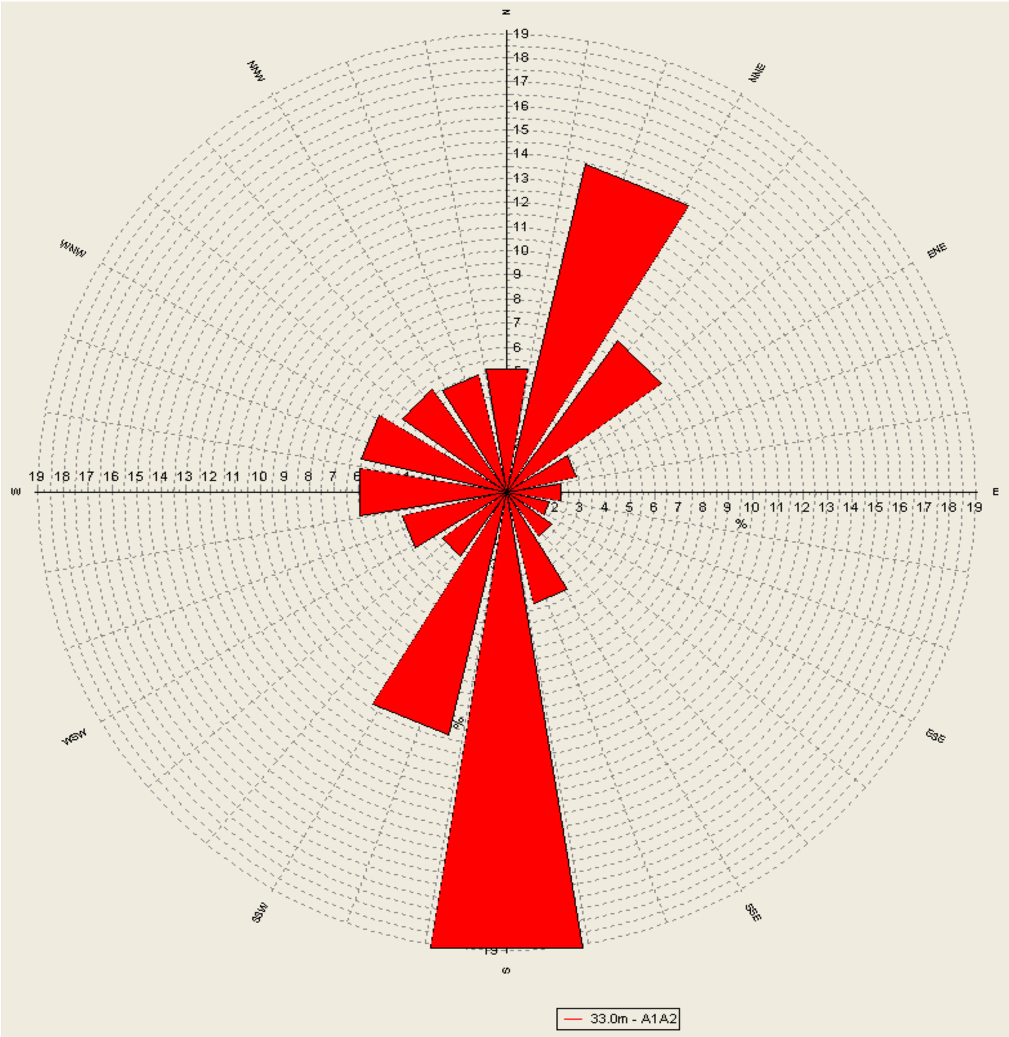

Figure 7. Wind Rose at the Chignik Lagoon MET-Tower (CLG_TOWER).

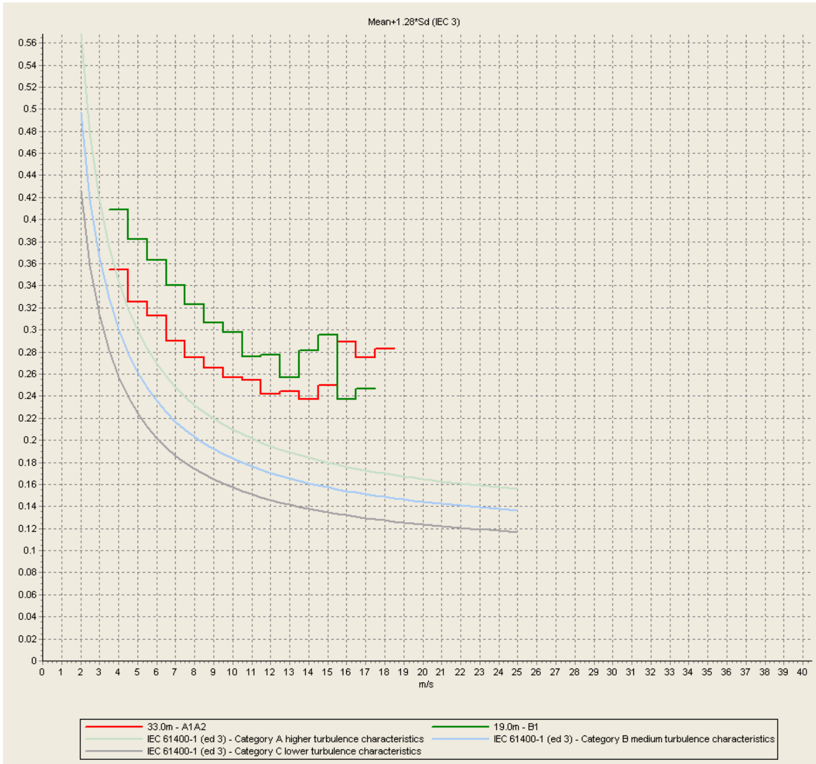

Figure 8. Turbulence as measured at CLG_TOWER compared to IEC standards.

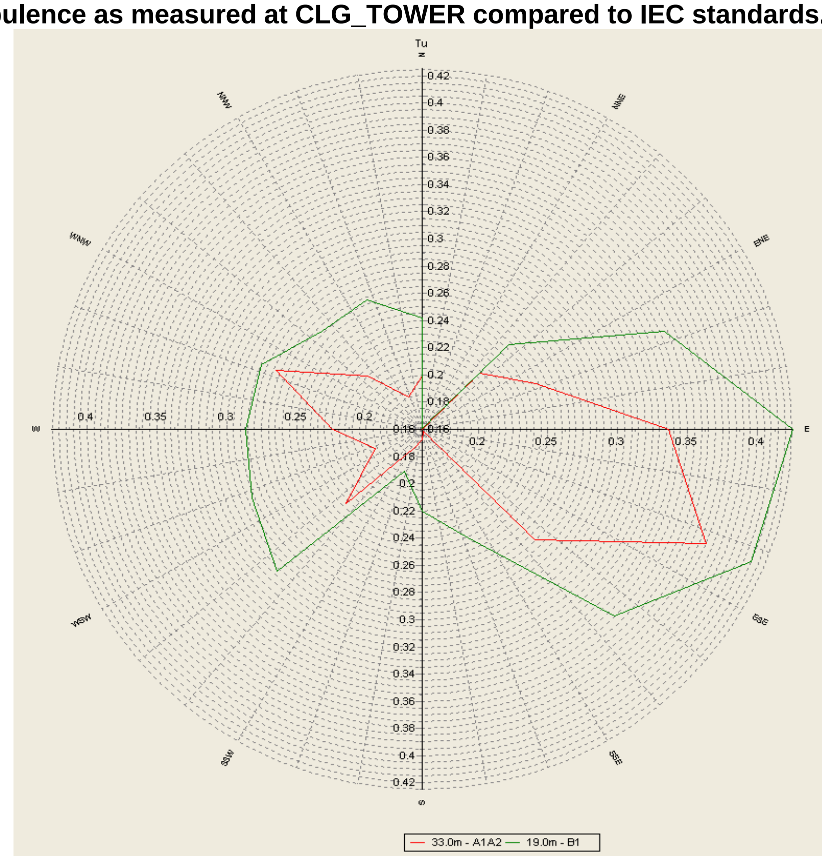

Figure 9. Mean turbulence as a function of wind direction at the CLG_TOWER site.

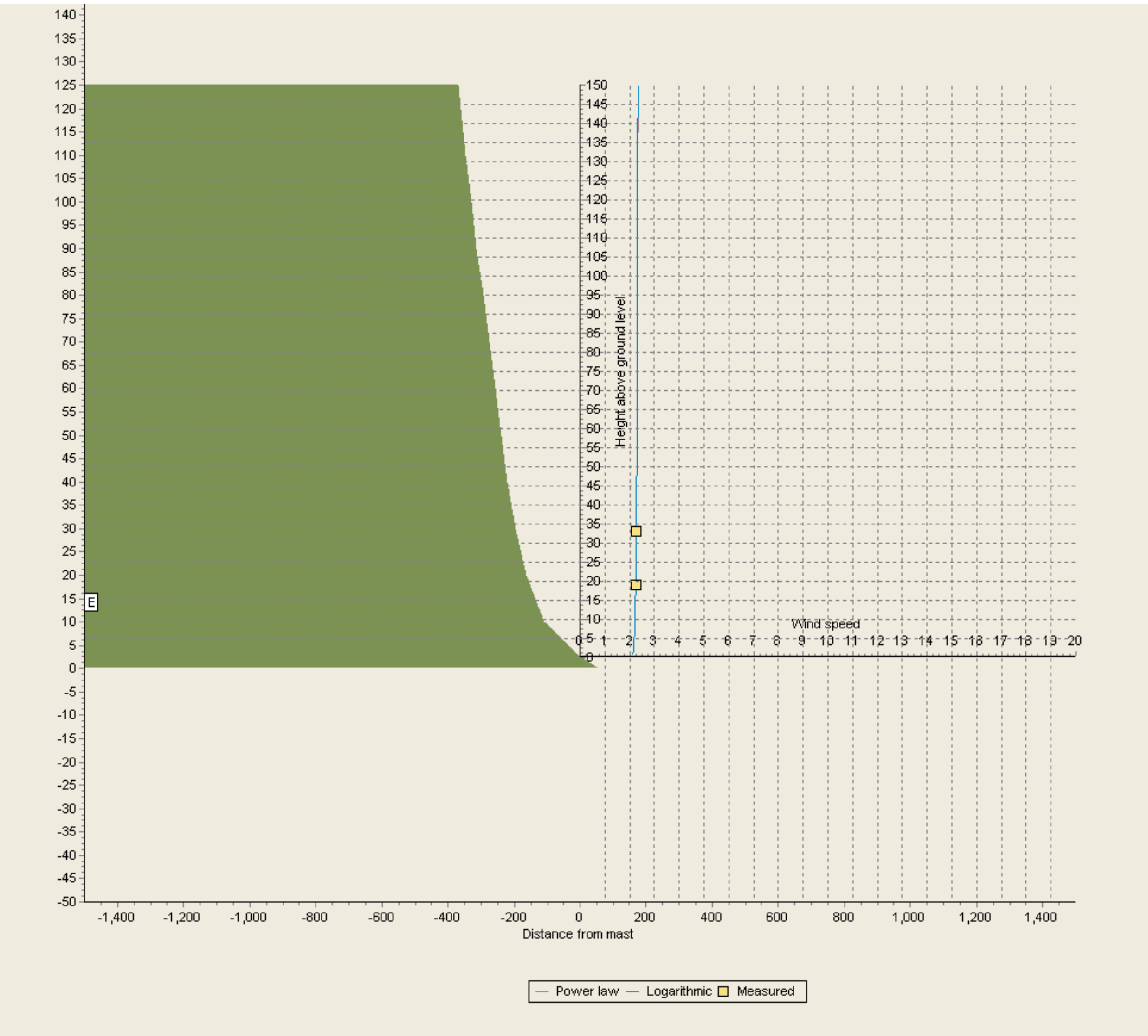

Figure 10. Terrain profile along the easterly approach to CLG_TOWER.

From the high resolution resource map in Figure 13, it can be seen that the local resource ranges from class I (near the landfill and in the ravines) to class 7 (on the ridge north of town and on the highest peaks). The light-blue contours correspond to high class 4; yellow and red regions correspond to the high class 6 and 7 wind speeds and are, in general, the optimal sites for a wind turbine. Three potential sites were chosen for further analysis and are labeled in Figure 13 as WTG1 through WTG3.

WTG1 and WTG3 show better wind resource, but there is potential for larger turbulence intensities as well.

WTG1 and WTG2 (closer to the lagoon) are within the existing electric grid network; WTG3 is located on the ridge north of town, and would require some more significant transmission line connection and access road work. Further, the mean wind speed at location WTG may exceed IEC class 1 standards. This issue could be addressed by more detailed micro-siting and communication with the turbine manufacturer.

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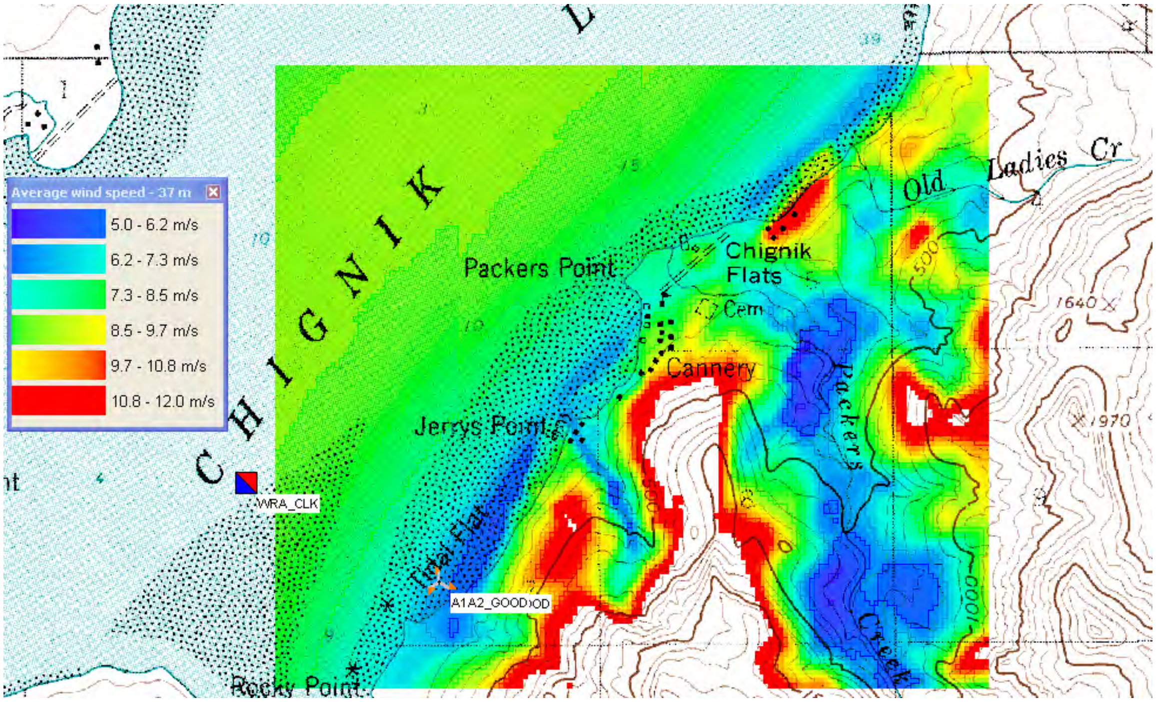

Figure 11. Wind resource map based on data from CLK_TOWER and PAJC.

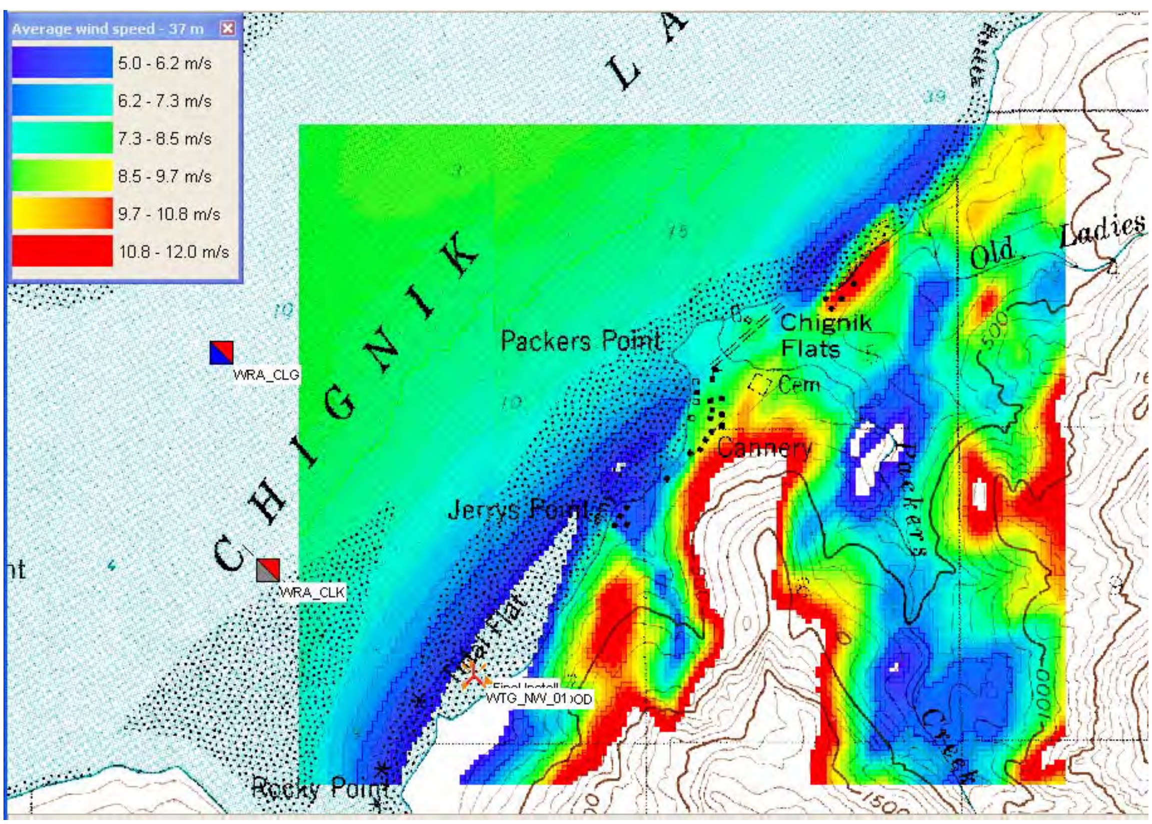

Figure 12. Wind resource map based on data from CLG_TOWER, CLK_TOWER and PAJC.

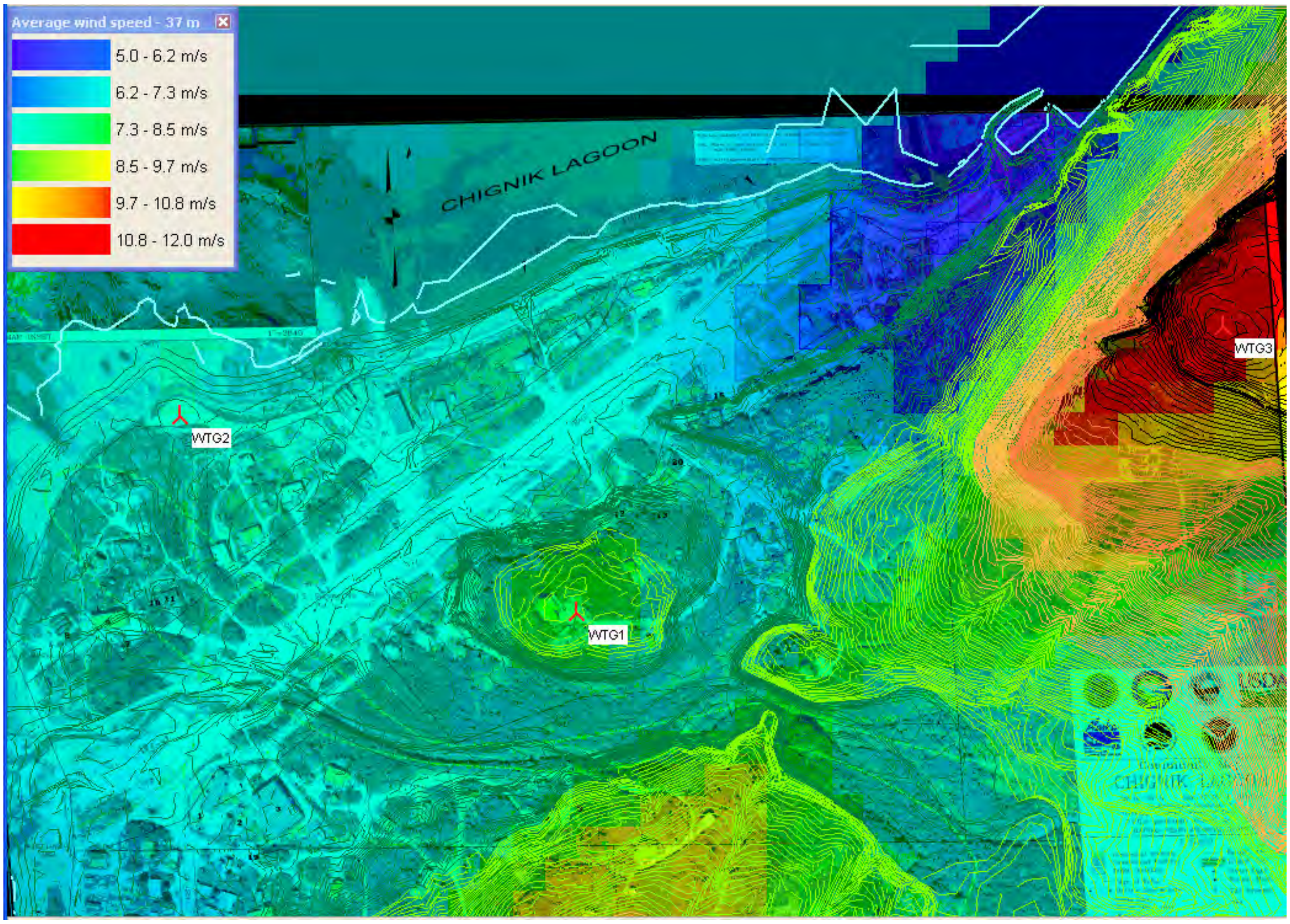

Figure 13. Wind resource map (37 m AGL annual mean wind speeds, 25 m resolution) overlaid on aerial view of Chignik Lagoon and topographical contour lines. Three potential wind turbine sites are shown (labeled WTG1 through WTG3).

4.2 Turbine and System Alternatives

Given the results of the refined WRA, three different turbines were modeled at each of the three proposed locations. The turbines considered in this study are the following:

- Northern Power Systems Northwind NW100B/21 rated at 100 kW
- Aeronautica 29-225 rated at 225 kW
- Enercon E33 rated at 330 kW

Power curves for the three machines are given in Figure 14.

Enercon GmbH (Enercon) has been engaged in a legal battle with General Electric (GE) for patent infringement; there has been extensive evidence that espionage against Enercon enabled the competitor GE to patent turbine components first [5]. Enercon was therefore effectively banned from exporting to the U.S. until 2010. New recent cross-patent agreements and the experience of Enercon technology for wind-diesel applications make that model suitable for this study.

Aeronautica Windpower (Aeronautica) is a U.S. manufacturer that is licensed to produce turbines based on the Danish Norwin design that has been proven for decades around the world.

The three models have been selected as among the most reliable and effective machines for the conditions at Chignik Lagoon. They are either IEC class I or class II, with turbulence category A or B. From previous considerations, it is to be expected that only turbine design category A is adequate for Chignik Lagoon. ASCE 7-05 [1] recommends a 50-year design wind speed of 58 meters per second (m/s) at 10 m AGL, which would translate into 65-66 m/s gusts at hub-heights. These gust levels correspond to IEC class I turbines.

The Enercon E33 and Aeronautica 29-225 are the only class I machines. Other models would likely suffer from some considerable damage in such a strong wind event. For the expected life of the project (20 years), the probability of exposure to such a catastrophic event is on the order of 30 percent. This value is significant enough to warrant more discussion with the manufacturers to verify the expected damage and costs of repair under a 65 m/s (approximately 130 knots) wind gust.

Northern Power Systems has communicated that the NW100B/21 may still be deployed if: (1) a manual turbine arrest is performed prior to an expected wind storm of that category; (2) an inspection by a licensed technician is performed after such an event.

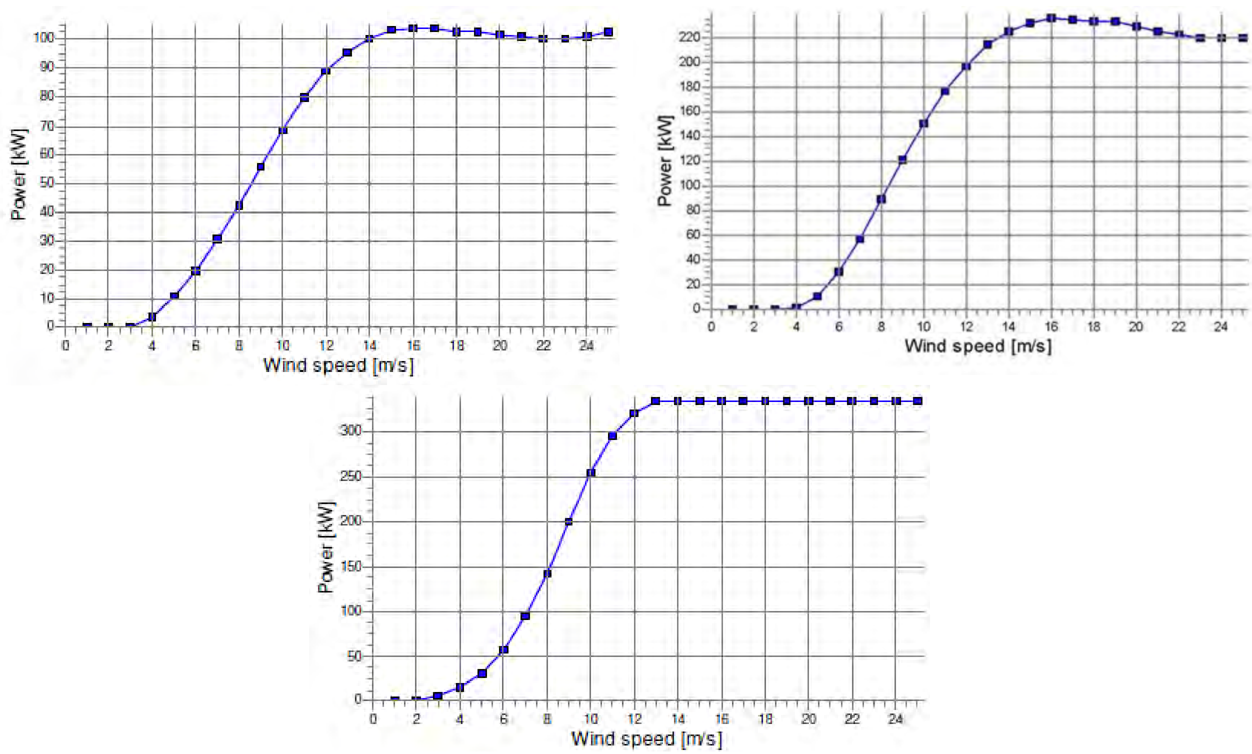

Figure 14. Power curves for the three wind turbine models.
Top row: NW100B/21, Aeronautica 29-225; bottom row: Enercon E33.

The three turbines differ in size and control systems.

The Northwind and Enercon turbines do not have a gearbox, with simplified maintenance.

The Northwind 100 and Aeronautica 29-225 are the only turbines in the group that do not have pitch control. Pitch control assures an optimal energy capture at various wind speeds, regulates the rotor speed at the highest wind speeds, and protects the machine by feathering the blades in potentially damaging strong-wind events. At the same time, with active pitch control the moving parts are more numerous and the cost and likelihood of maintenance increases.

All of the turbine models come with standard monopole towers, which let the operator climb inside a weather-protected environment.

Regardless of the selected model alternative, the turbine generator would produce 3-phase, 60-hertz, 480-volt electricity. The 480-volt electrical output from the generator would be converted to 12.5 kilovolts (kV) by a step-up transformer and then connected to the village electrical grid by a 12.5-kV transmission line.

The wind-power system for Chignik Lagoon should supply (to the extent possible) the thermal load that is currently supplied by diesel furnaces at the school. This would allow the system to reduce even further the cost of unit energy, making it more attractive. Thus, the proposed wind-power system includes an electric hot water boiler, a supervisory control system, and a secondary load controller, which supply the thermal load during those times when wind generated power is in excess of demand.

An installment of one of the larger machines would lead to significant amounts of excess energy generated, even after heating the school. This excess energy can be used in a number of configurations to further reduce the cost of energy.

4.3 Annual Energy Production Estimates

Table 3 summarizes the Annual Energy Production (AEP) and CF (capacity factors) for the various turbines at the various sites including a 10 percent loss due to turbulence, blade soiling, and other miscellaneous items that may cause degraded performance. This table was generated for a machine hub height of 37 meters.

Table 3. Annual Energy Production and Capacity Factor (CF) for all three turbine models at three potential sites. Hub height held constant at 37 m.

Turbine Model	**Site 1**		**Site 2**		**Site 3**	
	AEP (MWh)	CF	AEP (MWh)	CF	AEP (MWh)	CF
Northwind 100B/21	362	0.41	319	0.36	473	0.54
Aeronautica 29-225	769	0.39	667	0.34	1029	0.52
Enercon E33	1253	0.43	1106	0.38	1617	0.56

The Enercon turbine is the best performing machine with the highest CF at all three sites.

Another way to quantify a wind turbine's impact on electricity production is its penetration level. The average annual penetration level is the amount of energy produced by the wind turbine in a year, divided by the energy consumed by the load in a year.

The Northwind 100B/21 is associated with a penetration level between 58 percent and 86 percent, depending on the site. The other models deliver even higher levels. A supervisory controller is then recommended for every model, and every attempt should be made to utilize excess energy into space and water heating at other locations, such as the village council building, village offices, and clinic.

Section 5.0 - Economic Analysis

5.1 Inputs and Assumptions

The economic analysis of a wind power installation at Chignik Lagoon was carried out for all three proposed sites as described above. The AEP used in the economic study is the AEP that corresponds to a specific turbine located at a specific site. These AEPs were calculated by the detailed analysis in WindPRO® as described in Section 4.

The actual discount rate assumed is 2.9 percent, with a nominal interest rate and inflation rate of 5 and 2 percent, respectively. The project lifetime is 20 years.

It is assumed that an electric boiler would be paired with the existing heating system at the school. The electric boiler would be governed by a dedicated secondary load controller to utilize excess wind energy coming from the turbine when the electric load is low, thus allowing a further reduction in fuel costs for heating. Other controllers and boilers may be installed at other public places such as the clinic and the village office buildings.

The interconnection of the turbine will occur either at the powerhouse or at the closest terminal within the existing grid, whichever is closest to the final location of the turbine. The location denoted by WTG3 is the only one that would require a dedicated transmission line, and the costs of an installation at that site reflect this condition.

A separate supervisory controller is needed for high levels of wind penetration. All three turbines give average annual wind penetration levels above 60 percent and would, thus, require this extra controller, whose cost is included in the analysis.

The seasonal electric load at Chignik Lagoon including the monthly maximum, average daily high, monthly mean, average daily low, and monthly minimum values, is given in Figure 15. It is estimated that the average electricity consumption is 1,500 kWh/day with average load of 64 kW and peaks to 150 kW during the winter and summer months.

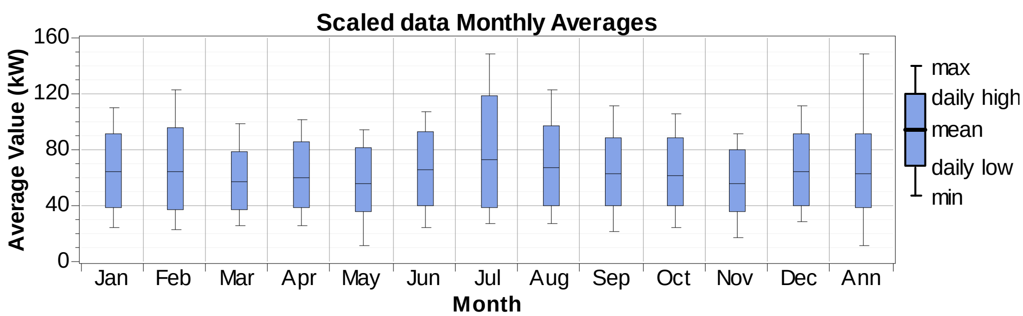

Figure 15. Seasonal electric demand at Chignik Lagoon.

The average daily thermal load data for Chignik Lagoon was estimated using data from Port Heiden, and Chignik Lake, which are communities on the Alaska Peninsula with a population and climate similar to Chignik Lagoon. The average thermal load is estimated to be 1,050 kWh per day. This also translates into the current 3,250 gal/year of diesel consumption at the school boiler (from CLPU). Statistics for the estimated monthly thermal power consumption in kW at Chignik Lagoon, including the monthly maximum, average daily high, daily mean, average daily low, and monthly minimum values are shown in the Figure 16.

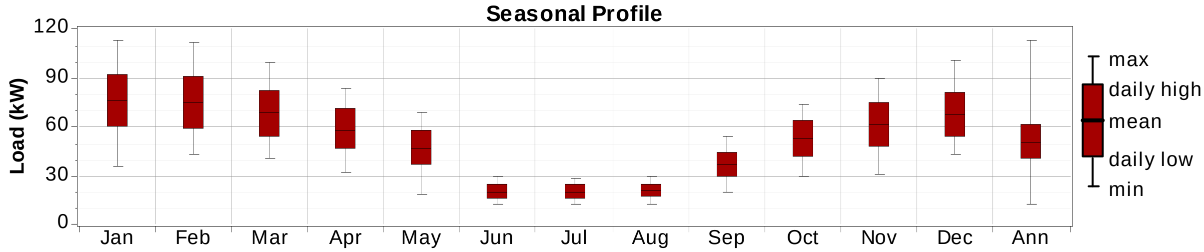

Figure 16. Seasonal thermal demand at Chignik Lagoon School.

5.2 System Alternatives Analyzed

The system alternatives that were analyzed can be seen in Table 4.

Table 4. Wind turbine system alternatives analyzed.

Turbine Model	Hub-Heights (m)	Qty.
NW100B/21	37	1,2,3
Aeronautica 29-225	37	1
Enercon E33	37	1

Higher hub-heights may be more profitable for the larger machines, but foundations and permitting may become more cumbersome and expensive. Transport of the turbines and specifically their towers may also become more challenging and expensive. Thus, it was decided to limit the analysis to the most common configurations as seen above.

5.3 Estimated Capital and Replacement Costs

An opinion of probable project costs for the various alternatives was developed based on October 2011 U.S. dollars. The opinion of probable project costs includes construction, engineering, and contingency. Overall project cost was established by adding engineering, permitting, and legal fees. Engineering costs include preliminary and final design, procurement, construction management, and administration.

Table 5 shows the estimated costs for the installation of the various configurations. Note that a larger cost is associated with construction of a wind turbine at site 3 due to transmission line and access road requirements.

The data were obtained after consulting with the turbine vendors and the following construction and transportation contractors: GeoTek Alaska, Inc., STG, Inc., Sustainable Automation Inc., Northland Services Marine Transportation, and Bellavance Trucking. These cost estimates should be considered accurate to within ±30 percent at the time of project implementation.

Because of the remoteness of Chignik Lagoon, most of the capital costs come from having to transport personnel, materials, components, and special construction equipment to the site. The capital cost would increase or decrease depending on crude oil price fluctuations, as those affects transportation and manufacturing processes. However, there is very little information at this point to provide a solid justification to changes in the current estimates that are provided with a ±25 percent margin.

Table 5. Estimated costs for installation of turbine alternatives, including transmission line (US$). Values in parentheses refer to site 3 costs.

	Aeronautica	Enercon	Northwind
Turbine + Tower	462,050	641,250	360,500
Shipment	63,000	195,000	60,000
Transformer	36,050	41,200	30,900
Supervisory Controller	105,000	105,000	105,000
Secondary Controller	40,000	40,000	40,000
Boiler and misc.	25,000	25,000	25,000
Power line (US$300k/mile)	75,000 (200k)	75,000 (200k)	75,000 (200k)
Geotechnical Investigation and Report	87,800	87,800	87,800
Engineering/Permitting/Construction/Erection	459,570	554,070	347,070
Total	1,353,470 (1,475,280)	1,764,320 (1,887,825)	1,131,270 (1,255,710)
With 20% Contingency	1,624,164 (1,770,340)	2,117,184 (2,265,390)	1,357,524 (1,506,850)
Installed Cost per kW	7,219 (7,885)	6,416 (6,870)	13,575 (15,075)

The total estimated cost of installing more than one Northwind 100 turbine at site 2 (the only one that could host more than 1 turbine) can be seen in Table 6. The replacement cost of a turbine at the end of the project can be seen in Table 7.

Table 6. Total estimated cost of multiple installments of the Northwind 100 turbine (US$).

Configuration	Site 2
2 Northwind 100	$2,082,606
3 Northwind 100	$2,759,718

Table 7. Estimated replacement cost of turbines at the end of the project (US$).

	Aeronautica 29-225	Enercon E33	Northwind 100B/21
Replacement Cost	$200,000	$250,000	$100,000

5.4 Estimated Operation and Maintenance Costs

A fixed system operation and maintenance (O&M) cost of US$135,000 per year was used for both the combined wind power/diesel system and the current system. This is a very large amount for a community in the Alaska Peninsula, and should include a higher than average salary for a maintenance mechanic at the power house. US$4.00 per operational hour is the additional rate assumed for the O&M of diesel generators, for an approximate total yearly fee of US$105,000. The unusually high rates are necessary to justify the current electric rate (pre-PCE, provided by Chignik Lagoon Power Utility) of about US$0.75/kWh at Chignik Lagoon, which is an anomaly throughout the region.

For the wind system, a US$9,940/year O&M cost per installed turbine is assumed; this includes salary amounting to 1 day/month for a local mechanic, plus 2 days every three months for a specialized mechanic from Anchorage and airfares.

If two or three turbines are installed, the O&M is calculated at US$18,280 and US$26,620, respectively.

The overall diesel generator O&M will be less in the combined system due to reduced diesel usage, however the salary of the local mechanic will be higher for the additional maintenance tasks at the wind turbine.

5.5 Estimated Diesel Prices

Three different values for delivered diesel prices were assumed: US$/liter 1.16, 1.48, 1.68 (US$/gal 4.40, 5.60, 6.36). The current value at the time of compiling this report is approximately US$/gal 4.40 (Chignik Lagoon Power Utility). The other long-term estimates are scaled based on projected long-term crude oil price of US$110/bbl and US$125/bbl (see also LPB Energy Report [3]).

5.6 Economic Analysis Results

The software program HOMER© [5] was employed to simulate the economic performance of the various turbines.

In Appendices D-H, complete output reports from the program are provided for the various system alternatives.

The HOMER© analysis produces several economic measures that show the value of the difference between the wind/diesel alternative under consideration and the current diesel-only system, taking into account the 20-year life cycle costs of both systems. Definitions of the economic measures shown in the following sections are as follows:

- The present worth is the difference between the net present cost of the alternative system and the diesel-only system, where the net present cost is the present value of all system costs incurred over the project lifetime (including capital costs, replacement costs, O&M costs, and fuel costs) minus salvage value. Present worth shows how much the alternative system saves over the project lifetime compared to the diesel-only system, and is the primary measure for comparing the economic feasibility of the two systems. The present worth represents the avoided cost over the life of the project when operating the alternative system rather than the current system.
- The discounted payback period is how long it would take to recover the initial investment in the alternative system using the assumed rates for interest (5 percent) and inflation (2 percent).
- The annual worth is the present worth multiplied by the capital recovery factor, which is a ratio used to calculate the present value of a series of equal annual cash flows.
- The Internal Rate of Return is the discount rate that makes the present value of the difference of the two cash flow sequences equal to zero.
- The levelized COE is the average cost per kWh of useful electrical energy produced by the system. This is calculated by dividing the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total annual electric energy production.
- The benefit/cost ratios for each alternative compared to the diesel-only system were calculated by adding the net present cost to the present worth and then dividing by the net present cost.

Table 8 through Table 10 show the economic measures for the select wind/diesel alternatives, assuming the mentioned three different values of diesel prices. The color coding associated with the benefit/cost ratio identifies with: green the ‘best economic alternative’; blue the ‘second best’; orange the marginal; and red the unfeasible alternative.

Table 8. Economic analysis results for four proposed turbines at three proposed; Diesel @ $4.40/gal.

NW - 100 kW	**1**	**2**	**3**
Capital (USD)	1,357,524	1,357,524	1,506,852
*Present Worth (USD)	-599,282	-710,837	-465,849
**Annual Worth (USD)	-39,910	-47,339	-31,024
Internal Rate of Return (ROI) (%)	N/A (3.74)	N/A (3.19)	N/A (4.62)
Discounted (simple) Payback Period (years)	N/A	N/A	N/A
Levelized Cost of Energy (USD/kWh)	0.75	0.76	0.73
Diesel Only Cost of Energy (USD/kWh)	0.68	0.68	0.68
Benefit/Cost Ratio	0.91	0.90	0.93
Aeronautica- 225 kW	**1**	**2**	**3**
Capital (USD)	1,624,164	1,624,164	1,770,339
*Present Worth (USD)	209,833	-38,430	640,190
**Annual Worth (USD)	13,974	-2,559	42,634
Internal Rate of Return (ROI) (%)	4.24 (7.54)	2.65 (6.52)	6.46 (9.09)
Discounted (simple) Payback Period (years)	17.3 (14)	N/A (15.6)	13.5 (11)
Levelized Cost of Energy (USD/kWh)	0.65	0.68	0.60
Diesel Only Cost of Energy (USD/kWh)	0.68	0.68	0.68
Benefit/Cost Ratio	1.03	0.99	1.11
Enercon - 330 kW	**1**	**2**	**3**
Capital (USD)	2,117,184	2,117,184	2,265,387
*Present Worth (USD)	139,008	-74,619	482,772
**Annual Worth (USD)	9,257	-4,696	32,151
Internal Rate of Return (ROI) (%)	3.59 (7.11)	2.52 (6.44)	5.06 (8.09)
Discounted (simple) Payback Period (years)	18.7 (14.1)	N/A (15.8)	15.7 (12.4)
Levelized Cost of Energy (USD/kWh)	0.66	0.69	0.62
Diesel Only Cost of Energy (USD/kWh)	0.68	0.68	0.68
Benefit/Cost Ratio	1.02	0.99	1.08

* Represents the avoided cost over the life of the project when operating the alternative system rather than the diesel system.

** Represents the avoided cost on an annual basis when operating the alternative system rather than the diesel only system.

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Table 9. As in Table 8, Diesel @ US$5.60/gal.

NW - 100 kW	**1**	**2**	**3**
Capital (USD)	1,357,524	1,357,524	1,506,852
*Present Worth (USD)	-365,057	-504,059	-162,713
**Annual Worth (USD)	-24,311	-33,568	-10,836
Internal Rate of Return (ROI) (%)	N/A (4.89)	N/A (4.2)	1.71 (5.96)
Discounted (simple) Payback Period (years)	N/A	N/A	N/A (17)
Levelized Cost of Energy (USD/kWh)	0.82	0.84	0.80
Diesel Only Cost of Energy (USD/kWh)	0.78	0.78	0.78
Benefit/Cost Ratio	0.95	0.94	0.98
Aeronautica- 225 kW	**1**	**2**	**3**
Capital (USD)	1,624,164	1,624,164	1,770,339
*Present Worth (USD)	692,243	385,139	1,258,498
**Annual Worth (USD)	46,100	25,649	83,811
Internal Rate of Return (ROI) (%)	7.05 (9.52)	5.3 (8.26)	9.51 (11.4)
Discounted (simple) Payback Period (years)	12.7 (10.4)	15.4 (12)	10.3 (8.88)
Levelized Cost of Energy (USD/kWh)	0.70	0.73	0.63
Diesel Only Cost of Energy (USD/kWh)	0.78	0.78	0.78
Benefit/Cost Ratio	1.10	1.05	1.20
Enercon - 330 kW	**1**	**2**	**3**
Capital (USD)	2,117,184	2,117,184	2,265,387
*Present Worth (USD)	722,308	458,368	1,180,674
**Annual Worth (USD)	48,103	30,525	78,628
Internal Rate of Return (ROI) (%)	6.28 (8.95)	5.10 (8.12)	7.89 (10.1)
Discounted (simple) Payback Period (years)	13.7 (11.2)	15.7 (12.3)	11.8 (10)
Levelized Cost of Energy (USD/kWh)	0.69	0.72	0.64
Diesel Only Cost of Energy (USD/kWh)	0.78	0.78	0.78
Benefit/Cost Ratio	1.11	1.07	1.19

* Represents the avoided cost over the life of the project when operating the alternative system rather than the diesel system.

** Represents the avoided cost on an annual basis when operating the alternative system rather than the diesel only system.

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Table 10. As in Table 8, Diesel @ US$6.36/gal, in line with crude at US$125/bbl.

NW - 100 kW	**1**	**2**	**3**
Capital (USD)	1,357,524	1,357,524	1,506,852
*Present Worth (USD)	-218,442	-37,4580	26,995
**Annual Worth (USD)	-14,547	-24,945	1,798
Internal Rate of Return (ROI) (%)	1.10 (5.61)	n/A (4.84)	3.09 (6.8)
Discounted (simple) Payback Period (years)	N/A (18)	N/A	19.7 (14.9)
Levelized Cost of Energy (USD/kWh)	0.87	0.89	0.84
Diesel Only Cost of Energy (USD/kWh)	0.84	0.84	0.84
Benefit/Cost Ratio	0.97	0.96	1.00
Aeronautica- 225 kW	**1**	**2**	**3**
Capital (USD)	1,624,164	1,624,164	1,770,339
*Present Worth (USD)	994,003	650,111	1,645,175
**Annual Worth (USD)	66,196	43,295	109,562
Internal Rate of Return (ROI) (%)	8.68 (10.8)	6.82 (9.34)	11.3 (12.9)
Discounted (simple) Payback Period (years)	11 (9.41)	13 (10.7)	9.06 (7.87)
Levelized Cost of Energy (USD/kWh)	0.72	0.76	0.64
Diesel Only Cost of Energy (USD/kWh)	0.84	0.84	0.84
Benefit/Cost Ratio	1.14	1.09	1.26
Enercon - 330 kW	**1**	**2**	**3**
Capital (USD)	2,117,184	2,117,184	2,265,387
*Present Worth (USD)	1,087,107	791,705	1,617,126
**Annual Worth (USD)	72,397	52,724	107,694
Internal Rate of Return (ROI) (%)	7.83 (10.1)	6.58 (9.17)	9.54 (11.4)
Discounted (simple) Payback Period (years)	11.9 (10.0)	13.3 (10.9)	10.4 (8.85)
Levelized Cost of Energy (USD/kWh)	0.71	0.75	0.65
Diesel Only Cost of Energy (USD/kWh)	0.84	0.84	0.84
Benefit/Cost Ratio	1.16	1.11	1.25

* Represents the avoided cost over the life of the project when operating the alternative system rather than the diesel system.

** Represents the avoided cost on an annual basis when operating the alternative system rather than the diesel only system.

Table 11 through Table 13 below show the results for multiple installations of the Northwind turbine at potential site 2 (the only one that could potentially host multiple turbines).

Table 11. Economic analysis results for multiple Northwind 100 turbines at proposed site 2; Diesel @ US$4.40/gal.

Metric	2 NW - 100 kW (200 kW)	3 NW - 100 kW (300 kW)
Capital (USD)	2,082,606	2,759,718
*Present Worth (USD)	-637,516	-1,047,344
**Annual Worth (USD)	-42,456	-69,749
Internal Rate of Return (ROI) (%)	N/A (4.63)	N/A (4.14)
Discounted (simple) Payback Period (years)	N/A	N/A
Levelized Cost of Energy (USD/kWh)	0.76	0.81
Diesel Only Cost of Energy (USD/kWh)	0.68	0.68
Benefit/Cost Ratio	0.91	0.86

* Represents the avoided cost over the life of the project when operating the alternative system rather than the diesel system.

** Represents the avoided cost on an annual basis when operating the alternative system rather than the diesel only system.

Table 12. As in Table 11, Diesel @ US$5.60/gal.

Metric	2 NW - 100 kW (200 kW)	3 NW - 100 kW (300 kW)
Capital (USD)	2,082,606	2,759,718
*Present Worth (USD)	-215,212	-533,328
**Annual Worth (USD)	-14,332	-35,517
Internal Rate of Return (ROI) (%)	1.76 (5.99)	0.712 (5.39)
Discounted (simple) Payback Period (years)	N/A (16.9)	N/A (18.8)
Levelized Cost of Energy (USD/kWh)	0.81	0.84
Diesel Only Cost of Energy (USD/kWh)	0.78	0.78
Benefit/Cost Ratio	0.97	0.93

* Represents the avoided cost over the life of the project when operating the alternative system rather than the diesel system.

** Represents the avoided cost on an annual basis when operating the alternative system rather than the diesel only system.

Table 13. As in Table 11, Diesel @ US$6.36/gal, in line with crude at US$125/bbl.

Metric	2 NW - 100 kW (200 kW)	3 NW - 100 kW (300 kW)
Capital (USD)	2,082,606	2,759,718
*Present Worth (USD)	48,940	-211,837
**Annual Worth (USD)	3,259	-14,107
Internal Rate of Return (ROI) (%)	3.15 (6.83)	2.06 (6.16)
Discounted (simple) Payback Period (years)	19.5 (14.8)	N/A (16.4)
Levelized Cost of Energy (USD/kWh)	0.84	0.87
Diesel Only Cost of Energy (USD/kWh)	0.84	0.84
Benefit/Cost Ratio	1.01	0.97

* Represents the avoided cost over the life of the project when operating the alternative system rather than the diesel system.

** Represents the avoided cost on an annual basis when operating the alternative system rather than the diesel only system.

It is clear from the results of the analysis that either an Aeronautica 29-225 or an Enercon E33 is the most suitable option for Chignik Lagoon.

At a cost of fuel of US$4.40 per gallon, the most economical configuration for a wind turbine installment is an Aeronautica 29-225 turbine located at potential site 3 with a benefit cost ratio of 1.11. An installment of this configuration would lead to a cost of energy of US$0.60 per kWh, an improvement of US$0.08 per kWh over the diesel only system. Trailing the Aeronautica closely, the second most economic configuration is an Enercon E33 system installed at site 3. At this fuel price, site 2 is not economically viable, but site 1 can be a valid alternative with considerable savings.

The Aeronautica turbine installed at site 1 (3) would save approximately US$210,000 (US$640,000), while the Enercon turbine would save approximately US$140,000 (US$483,000) over the life of the project. If the cost of fuel increases to US$6.36 per gallon, the Enercon alternative becomes even closer to the Aeronautica one. Respective savings would be US$1,615,000 and US$1,645,000 over the life of the project. The savings increase rapidly as diesel prices increase.

The installation of a NW100 turbine becomes viable only at site 3 for the largest diesel price considered.

The economic results also indicate that the installment of more than one Northwind 100 turbine is not a feasible alternative except at the highest price of oil, where two NW100 turbines become marginally viable. In general, a single, larger turbine will always be a more economical alternative.

5.7 State Funding Impact

Lake and Peninsula Borough requested additional analyses based on the assumption that the project would be 80 percent funded by a grant from the state of Alaska. This analysis assesses the expense and return on investment incurred by the Borough and the Town of Chignik Lagoon alone.

The following tables summarize the results in the same fashion as Table 8 through Table 13. Under the state funding assumption all the alternatives are economically viable. For this reason, the color coding for benefit/cost ratio has changed to: green for the most economical alternative; blue for the intermediate economic alternatives; orange for the least attractive alternatives.

In the 80 percent state funded case, the Enercon turbine is by far the most economical alternative. Potential Sites 1 through 3 give different results, but all associated with considerable savings.

The analysis further shows that multiple installations of the Northwind turbine become competitive with respect to a single larger turbine, only for diesel prices above $5.50/gal.

At the intermediate diesel price of US$5.60/gal, an Enercon turbine installed at site 3 (2) would represent a savings of approximately US$3,000,000 (US$2,150,000) over the life of the project. The Aeronautica turbine is the second most economical alternative.

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Table 14. Economic analysis results for the proposed turbines at the three proposed sites, with 80 percent state funding; Diesel @ US$4.40/gal.

NW - 100 kW	**1**	**2**	**3**
Capital (USD)	271,505	271,505	301,371
*Present Worth (USD)	486,737	375,182	739,632
**Annual Worth (USD)	32,415	24,986	49,256
Internal Rate of Return (ROI) (%)	17.7 (18.7)	14.7 (15.9)	22.4 (23.1)
Discounted (simple) Payback Period (years)	5.99 (5.42)	7.13 (6.35)	4.77 (4.39)
Levelized Cost of Energy (USD/kWh)	0.62	0.63	0.59
Diesel Only Cost of Energy (USD/kWh)	0.68	0.68	0.68
Benefit/Cost Ratio	1.08	1.06	1.13
Aeronautica- 225 kW	**1**	**2**	**3**
Capital (USD)	324,833	324,833	354,068
*Present Worth (USD)	1,509,164	1,260,901	2,056,461
**Annual Worth (USD)	100,504	83,971	136,952
Internal Rate of Return (ROI) (%)	37.1 (37.7)	32.1 (32.6)	44.8 (45.4)
Discounted (simple) Payback Period (years)	2.85 (2.7)	3.32 (3.12)	2.35 (2.24)
Levelized Cost of Energy (USD/kWh)	0.49	0.52	0.43
Diesel Only Cost of Energy (USD/kWh)	0.68	0.68	0.68
Benefit/Cost Ratio	1.31	1.25	1.48
Enercon - 330 kW	**1**	**2**	**3**
Capital (USD)	423,437	423,437	453,078
*Present Worth (USD)	1,832,755	1,619,129	2,295,082
**Annual Worth (USD)	122,054	107,827	152,843
Internal Rate of Return (ROI) (%)	35 (35.6)	31.7 (32.2)	39.9 (40.5)
Discounted (simple) Payback Period (years)	3.03 (2.86)	3.36 (3.16)	2.65 (2.51)
Levelized Cost of Energy (USD/kWh)	0.46	0.48	0.40
Diesel Only Cost of Energy (USD/kWh)	0.68	0.68	0.68
Benefit/Cost Ratio	1.40	1.34	1.56

* Represents the avoided cost over the life of the project when operating the alternative system rather than the diesel system.

** Represents the avoided cost on an annual basis when operating the alternative system rather than the diesel only system.

Table 15. As in Table 14, Diesel @ US$5.60/gal.

NW - 100 kW	**1**	**2**	**3**
Capital (USD)	271,505	271,505	301,371
*Present Worth (USD)	720,962	581,960	1,042,769
**Annual Worth (USD)	48,013	38,756	69,444.00
Internal Rate of Return (ROI) (%)	23.8 (24.4)	20.2 (21)	29.3 (29.8)
Discounted (simple) Payback Period (years)	4.47 (4.13)	5.25 (4.81)	3.63 (3.39)
Levelized Cost of Energy (USD/kWh)	0.69	0.71	0.65
Diesel Only Cost of Energy (USD/kWh)	0.78	0.78	0.78
Benefit/Cost Ratio	1.11	1.09	1.16
Aeronautica- 225 kW	**1**	**2**	**3**
Capital (USD)	324,833	324,833	354,068
*Present Worth (USD)	1,991,574	1,684,470	2,674,769
**Annual Worth (USD)	132,630	112,179	178,128
Internal Rate of Return (ROI) (%)	47 (47.6)	40.8 (41.3)	56.3 (57.1)
Discounted (simple) Payback Period (years)	2.23 (2.13)	2.59 (2.45)	1.85 (1.78)
Levelized Cost of Energy (USD/kWh)	0.54	0.57	0.45
Diesel Only Cost of Energy (USD/kWh)	0.78	0.78	0.78
Benefit/Cost Ratio	1.37	1.29	1.56
Enercon - 330 kW	**1**	**2**	**3**
Capital (USD)	423,437	423,437	453,078
*Present Worth (USD)	2,416,055	2,152,115	2,992,983
**Annual Worth (USD)	160,899	143,322	199,320
Internal Rate of Return (ROI) (%)	44.2 (44.7)	40.1 (40.6)	50.1 (50.7)
Discounted (simple) Payback Period (years)	2.38 (2.26)	2.63 (2.5)	2.09 (2)
Levelized Cost of Energy (USD/kWh)	0.45	0.52	0.42
Diesel Only Cost of Energy (USD/kWh)	0.78	0.78	0.78
Benefit/Cost Ratio	1.48	1.41	1.68

* Represents the avoided cost over the life of the project when operating the alternative system rather than the diesel system.

** Represents the avoided cost on an annual basis when operating the alternative system rather than the diesel only system.

Table 16. As in Table 14, Diesel @ US$6.36/gal, in line with crude at US$125/bbl

NW - 100 kW	1	2	3
Capital (USD)	271,505	271,505	301,371
*Present Worth (USD)	867,577	711,439	1,232,476
**Annual Worth (USD)	57,777	47,379	82,078
Internal Rate of Return (ROI) (%)	27.5 (28)	23.6 (24.2)	33.5 (34)
Discounted (simple) Payback Period (years)	3.86 (3.6)	4.51 (4.17)	3.15 (2.97)
Levelized Cost of Energy (USD/kWh)	0.74	0.76	0.69
Diesel Only Cost of Energy (USD/kWh)	0.84	0.84	0.84
Benefit/Cost Ratio	1.12	1.10	1.18
Aeronautica- 225 kW	**1**	**2**	**3**
Capital (USD)	324,833	324,833	354,068
*Present Worth (USD)	2,293,334	1,949,442	3,061,446
**Annual Worth (USD)	152,726	129,825	203,879
Internal Rate of Return (ROI) (%)	53.2 (53.8)	46.2 (46.7)	63.6 (64.3)
Discounted (simple) Payback Period (years)	1.96 (1.88)	2.27 (2.17)	1.64 (1.57)
Levelized Cost of Energy (USD/kWh)	0.56	0.61	0.47
Diesel Only Cost of Energy (USD/kWh)	0.84	0.84	0.84
Benefit/Cost Ratio	1.40	1.32	1.61
Enercon - 330 kW	**1**	**2**	**3**
Capital (USD)	423,437	423,437	453,078
*Present Worth (USD)	2,780,854	2,485,452	3,429,435
**Annual Worth (USD)	185,193	165,521	228,386
Internal Rate of Return (ROI) (%)	49.9 (50.5)	45.3 (45.8)	56.5 (57.2)
Discounted (simple) Payback Period (years)	2.10 (2)	2.32 (2.21)	1.85 (1.77)
Levelized Cost of Energy (USD/kWh)	0.50	0.54	0.43
Diesel Only Cost of Energy (USD/kWh)	0.84	0.84	0.84
Benefit/Cost Ratio	1.52	1.44	1.74

* Represents the avoided cost over the life of the project when operating the alternative system rather than the diesel system.

** Represents the avoided cost on an annual basis when operating the alternative system rather than the diesel only system.

Table 17. Economic analysis results for multiple Northwind 100 turbines at site 2, with 80 percent state funding; Diesel @ US$4.40/gal.

Metric	2 NW - 100 kW (200 kW)	3 NW - 100 kW (300 kW)
Capital (USD)	416,521	551,944
*Present Worth (USD)	1,028,569	1,160,431
**Annual Worth (USD)	68,498	77,280
Internal Rate of Return (ROI) (%)	22.5 (23.2)	19.9 (20.7)
Discounted (simple) Payback Period (years)	4.77 (4.39)	5.39 (4.92)
Levelized Cost of Energy (USD/kWh)	0.55	0.54
Diesel Only Cost of Energy (USD/kWh)	0.68	0.68
Benefit/Cost Ratio	1.19	1.22

* Represents the avoided cost over the life of the project when operating the alternative system rather than the diesel system.

** Represents the avoided cost on an annual basis when operating the alternative system rather than the diesel only system.

Table 18. As in Table 17, Diesel @ US$5.60/gal.

Metric	2 NW - 100 kW (200 kW)	3 NW - 100 kW (300 kW)
Capital (USD)	416,521	551,944
*Present Worth (USD)	1,450,873	1,674,446
**Annual Worth (USD)	96,622	111,511
Internal Rate of Return (ROI) (%)	29.4 (29.9)	26.4 (26.9)
Discounted (simple) Payback Period (years)	3.62 (3.39)	4.05 (3.77)
Levelized Cost of Energy (USD/kWh)	0.60	0.58
Diesel Only Cost of Energy (USD/kWh)	0.78	0.78
Benefit/Cost Ratio	1.24	1.29

* Represents the avoided cost over the life of the project when operating the alternative system rather than the diesel system.

** Represents the avoided cost on an annual basis when operating the alternative system rather than the diesel only system.

Table 19. As in Table 17, Diesel @ US$6.36/gal, in line with crude at US$125/bbl.

Metric	2 NW - 100 kW (200 kW)	3 NW - 100 kW (300 kW)
Capital (USD)	416,521	551,944
*Present Worth (USD)	1,715,025	1,995,937
**Annual Worth (USD)	114,213	132,921
Internal Rate of Return (ROI) (%)	33.7 (34.2)	30.3 (30.8)
Discounted (simple) Payback Period (years)	3.14 (2.96)	3.51 (3.29)
Levelized Cost of Energy (USD/kWh)	0.63	0.60
Diesel Only Cost of Energy (USD/kWh)	0.84	0.84
Benefit/Cost Ratio	1.27	1.33

* Represents the avoided cost over the life of the project when operating the alternative system rather than the diesel system.

** Represents the avoided cost on an annual basis when operating the alternative system rather than the diesel only system.

Section 6.0 - Environmental and Construction Permitting

In this section, the necessary steps for the Permitting of the project are described. They include Environmental and Building Permitting.

There are a number of agencies that will have jurisdiction on the project. While the project is on private land belonging to the native corporation at Chignik Lagoon, if federal or state actions such as funding or issuance of permits or licenses are involved, then the appropriate federal and state agencies will need to be consulted to start the regulatory permitting process.

6.1 FAA Permitting

The FAA will need to release a "determination of no hazard to navigation" for the wind turbine at the selected site. This is usually not necessary for small wind turbines, even in proximity of small airports where terrain is relatively flat. Due to the complex terrain at Chignik Lagoon, a FAA Form SF 7460-1 will need to be filed well in advance of other activities, since the FAA has shown extensive delays in their responses in the past.

Due to the runway location, central w.r.t. to town layout, this phase is likely going to need extensive negotiations with the FAA. It is expected that it will be necessary to coordinate with the Anchorage (Alaskan Region) office as well as the Alaska D.O.T. office.

Estimated time for permit is 90-120 days from filing.

6.2 Construction Permitting

A Construction General Permit (CGP) will be needed from the Alaska Department of Environmental Conservation (ADEC) for the construction of the project. In order to get this permit, a Storm Water Pollution Prevention Plan (SWPP) will need to be completed which will include measures to mitigate detrimental effects to the environment during construction. This includes digging and pouring of foundations, tower erection, transformer construction, power line burial and potential power line poles along the road from the site to the interconnection point. Note that the impacted area is foreseen to be larger than one acre (threshold value for this permitting requirement) due to the transmission line corridor from the wind turbine site to the interconnection point.

A Notice of Intent (NOI) must be submitted to the U.S. Environmental Protection Agency (EPA) within this phase.

Additionally, consultations with the U.S. Fish and Wildlife Service (USFWS) and the State Historic Preservation Office will be required, together with the agencies' determinations of "no significant effect to species or historical environment" as per Sections 6.4 and 6.5.

Other building permits and electrical reviews may be needed by the entity in charge of the utility at the village. Generally speaking, the executive mechanical, civil, and electrical drawings will need to be stamped by one or more licensed professional engineers in the State of Alaska.

Note that the assistance of LPB will be required in the determination of these further requirements.

Estimated time for permit is 90 days from filing.

6.3 Alaska Coastal Management Program

Chignik Lagoon is entirely included within the coastal boundaries established by the Alaska Department of Natural Resources (ADNR), Division of Coastal and Ocean Management (DCOM). Consultation with ADNR and Alaska Coastal Management Program (ACMP) will include a Coastal Project Questionnaire (CPQ) to be filled out in order to identify other agencies that may be required to be consulted regarding the project. If at least one state or federal permit is required, a complete ACMP consistency review will be necessary.

Estimated time for permit: 90 days from filing.

6.4 U.S. Fish and Wildlife Service, Alaska Department of Fish and Game: Birds, Bats, Endangered Species Protection, Fish Habitat

The USFWS will need to be contacted in the development of the project. First, a review will be conducted of the draft guidelines that the Alaska Regional Office of USFWS has issued. Knight Piésold will then contact local Fish and Game offices (ADF&G), and village individuals to verify that there are no bird migratory paths affected by the installation of the wind turbine and associated power lines, roosting or nesting habitat of endangered plant or animal species. Site soil preparation may involve some coordination in order to comply with USFWS guidelines.

It is known that sea-gulls and eagles are present in the area; on account of the local inhabitants however, no eagle nest or roosting area is known to be in proximity of the town. The USFWS may require pre- and post-construction observation periods based on these observations and Knight Piésold will contact ADF&G on this regard. With only one wind turbine installation expected, the impact to any bird or mammal species should be insignificant, but the USFWS will need to be made aware of the project to address issues associated with potential wildlife fatalities during operation.

6.5 State Historic Preservation Office and Office of History and Archeology

A letter from State Historic Preservation Office (SHPO) stating that “no historic properties will be adversely affected by the project” will be required. An archeological survey may be required for access and construction footprint. Procedures will be coordinated with a state archeologist.

Estimated time for concurrence is 30 days from filing.

6.6 Land Uses and Rights-of-Way

No federal land is expected to be affected by the project, therefore only a written notice to proceed by the native corporation of Chignik Lagoon is required to allow project implementation. If other private land is involved, further written authorizations will be required.

Note that the assistance of LPB would be required in the determination of Land Status for the areas of interest to the project.

6.7 Wetlands and Other Waters

No further permit with the U.S. Army Corps of Engineers is foreseen, since the project will not involve any construction activities in jurisdictional wetlands.

However, a jurisdictional wetland survey will need to be conducted to determine the existence of any such wetlands within the project area that might be impacted by the project.

6.8 National Environmental Policy Act Review

Although it is not likely that a full-blown environmental impact statement (EIS) will be required under the National Environmental Policy Act (NEPA), the preparation of an environmental assessment (EA) would most likely be required for federal and state agencies permitting requirements. The EA is an abbreviated NEPA process document that is intended to assess the potential environmental impacts of the project, provide for mitigation as required and to confirm minimal impact to the environment. The EA would be used by the regulatory agency(s) to issue a Finding of No Significant Impact (FONSI) to the environment, thereby circumventing the need for an EIS.

Note that LPB would be required to assist in this determination.

6.9 Tentative Cost Estimates associated with Environmental and Construction Permitting

It is not trivial to assess the costs at this stage of the project, especially since there are many unknowns in terms of effective permits required. Per client's request, however, Knight Piésold is offering a best estimate of the costs based on the current knowledge of the factors involved in this project. This estimate (in US$) may change vastly in either direction when the project implementation gets underway.

FAA permitting:	$10,000
Construction Permitting:	$15,000
ACMP Permitting:	$2,000
USFWS-ADF&G Consultation:	$6,500
SHPO-OHA Consultation:	$10,000
Land Uses Rights-of-Way:	$2,500
Wetlands Surveying:	$10,000

Estimated total cost: $56,000

Note that this estimate does not include preparation of an EA as part of the NEPA review process.

Section 7.0 - Conclusions and Recommendations

7.1 Wind Feasibility Study Conclusions

The following conclusions of the present study can be drawn:

- The wind at Chignik Lagoon varies greatly across the area from class 1 to class 7.
- Potential Site 3 is the most attractive site for a wind turbine in both terms of energy production and in terms of economics, but expected turbulence may be higher than at Sites 1 and 2. Site 2 is the most accessible location, and Site 1 the likely most suitable location for a wind turbine at Chignik Lagoon, combining both good wind resource and access. FAA will have to approve any of the sites as they are all in proximity of the runway.
- A high penetration level is the only economically viable option for wind power at Chignik Lagoon, which implies a relatively sophisticated primary and secondary load control system to be implemented in addition to heat storage solutions at the school.
- Initial investments for a wind turbine installation at Chignik Lagoon range between US$1.1M and US$2.2M, or US$3.7M for multiple turbine installations. These cost estimates should be considered accurate to within plus or minus 25 percent.
- The per-installed-kW cost ranges between US$6,400 and US$15,000 depending on the model and quantity of turbines and site location.
- For the lowest US$4.40/gal diesel price analyzed, only sites 1 and 3 are economically attractive and with the larger wind turbine models only.
- The COE can be lowered from 0.02 to 0.20 US$/kWh (diesel prices of US$4.40/gal through US$6.36/gal) with respect to the diesel-only system, depending on the turbine and final installation site.
- At a diesel price of $4.40/gal, the Aeronautica 29-225 is the most suitable option for Chignik Lagoon. Installing it on site 3 (1) would save $640,000 ($210,000) over the life of the project, or $42,600 ($14,000) per year.
- At a diesel price of $5.60/gal, the Aeronautica 29-225 is again the most suitable option for Chignik Lagoon. Installing it on site 3 (2) would save $1,260,000 ($385,000) over the life of the project, or $84,000 ($25,600) per year.
- At a diesel price of $6.36/gal, the Aeronautica 29-225 would save $0.12/kWh if installed at site 1.
- While the NW 100B/21 does not achieve feasibility status in the economic model (except in the 37-m hub-height two-turbine configuration and diesel price equal or greater than US$6.36/gal), it should be emphasized that the manufacturer and support is in the US, and that several installations in Alaska have proven very reliable so far (less than a decade).
- All the configurations become economically viable if the project is awarded 80 percent of the capital cost as an externally provided grant, and the Enercon E33 is by far the most suitable option in that case.
- All the configurations generate some amount of excess electricity, even after heat recovery at the school. If this excess energy could be used to heat other buildings, or in any number of other fashions, the cost of electricity would decrease even further.

7.2 Other Relevant Remarks

- The choice of turbine model should account for accessibility to spare parts. It is reasonable to assume that the NW100B/21 and Aeronautica 29-225 have some advantage there, though difficult to quantify. Due to the remoteness of Chignik Lagoon, an inventory of spare parts should be acquired at the time of project commissioning for any given model.

- The possibility of a catastrophic failure needs to be evaluated with the turbine manufacturers. The harsh wind regime is such that a damaging wind gust may be encountered with a probability of 30 percent throughout the lifetime of the project. The turbine manufacturer will need to provide a risk assessment based on the predicted extreme wind conditions and an evaluation of potential damage and related costs to be expected.
- For any of the alternatives, costs for a wind power project will be high due to the physical setting. Material transport and construction costs will be high, since the contractors capable of performing the work are located in Anchorage.
- Construction materials and equipment for all alternatives will need to be shipped to Chignik Lagoon via sea.
- The small size of the job will not favor a reduction of construction costs under bidding, because only a limited number of contractors are likely to submit bids.
- If multiple wind turbines are to be installed in the region, for example at Port Heiden as well as Chignik Lagoon, further exploration into cost savings may be beneficial. Combining shipment, mobilization, and construction of multiple projects in the area could result in significant cost savings for any individual project.
- While permitting is not seen as a major obstacles, the number of local, state, and federal agencies that need to be involved is large, and if the project is selected, permitting procedures will need to be established early on.

7.3 Recommendations for Future Activities

If LPB decides to continue with the implementation of the wind power project at this site, recommendations include:

- Investigate whether suitable financing is available to develop a wind power project at Chignik Lagoon with the economics as illustrated in this report.

In case of positive outcome of the previous point:

- Initiate permitting procedures, starting with FAA negotiations.
- Initiate contacts with Enercon and other vendors.
- Identify a project manager and a firm to oversee the engineering.
- Initiate geotechnical investigations to assess the requirements for a sound foundation.
- Identify other potential construction projects at Chignik Lagoon and surrounding towns for sharing of costs associated with construction activities, transportation, and logistics.

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Section 8.0 - References

[1] ASCE Standard ASCE/SEI 7-05, Minimum Design Loads for Buildings and Other Structures, ASCE 2005.

[2] Detterman, R.L., T.P. Miller, M.E. Yount, and F.H. Wilson, 1981, *Geologic Map of the Chignik and Sutwik Island Quadrangles, Alaska,* Miscellaneous Investigations Series Map I-1229, U.S. Geological Survey, Fairbanks Alaska.

[3] Information Insights, 2008: The Lake and Peninsula Borough Regional Energy Plan, Fairbanks, Alaska.

[4] Knight Piésold report, *Lake and Peninsula Borough Chignik Lagoon Wind Resource Assessment Met-Tower Installation Report*, dated October 6, 2010.

[5] Report A5-0264/2001 of the European Parliament (English), available at European Parliament website.

[6] U.S. Department of Energy, 2005, *HOMER Version 2.1,* Micropower Optimization Software Model, National Renewable Energy Laboratory, Golden, Colorado.

[7] Knight Piésold report, *Lake and Peninsula Borough Chignik Lake Wind Resource Assessment. Final Report*, dated June 1, 2011.