Eek, Alaska Wind-Diesel Analysis

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Contents

Introduction

Alaska Village Electric Cooperative (AVEC) is the electric utility for the City of Eek, Alaska. AVEC was awarded a grant from the Alaska Energy Authority (AEA) to complete conceptual design work for installation of wind turbines with planned construction in 2017.

Village of Eek

Eek lies on the south bank of the Eek River, 12 miles east of the mouth of the Kuskokwim River. It is 35 air miles south of Bethel and 420 miles west of Anchorage. Eek falls within the western transitional climate zone, characterized by tundra interspersed with boreal forests, and weather patterns of long, cold winters and shorter, warm summers.

The village was originally located on the Apokok River. It moved to its present location in the 1930s when constant flooding and erosion forced a relocation. A BIA school and a Moravian church were constructed at the new site. A post office was established in 1949. The city was incorporated in 1970.

Eek is a traditional Yup'ik Eskimo village with a subsistence lifestyle and salmon is a dominant food source. All five Pacific salmon species spawn in the Eek River.

Wind Resource

A 30 meter met tower was installed on the north end of the old runway in Eek on December 20, 2012 by STG, Inc. The met tower was operational through November 20, 2013 when problems were encountered with the data logger. After a few failed attempts, the data logger was repaired on October 2, 2014 and the met tower was operational again through January 19, 2015 when modem stopped communicated. Status of the met tower is not presently known, but sufficient wind data has been collected to assess the site for purposes of a conceptual design report.

With 14.5 months of collected data, a mean annual wind speed (at 30 meter level) of 6.49 m/s has been measured, with a mean annual wind power density of 372 W/m^2. This indicates a Class 4 (good) wind resource.

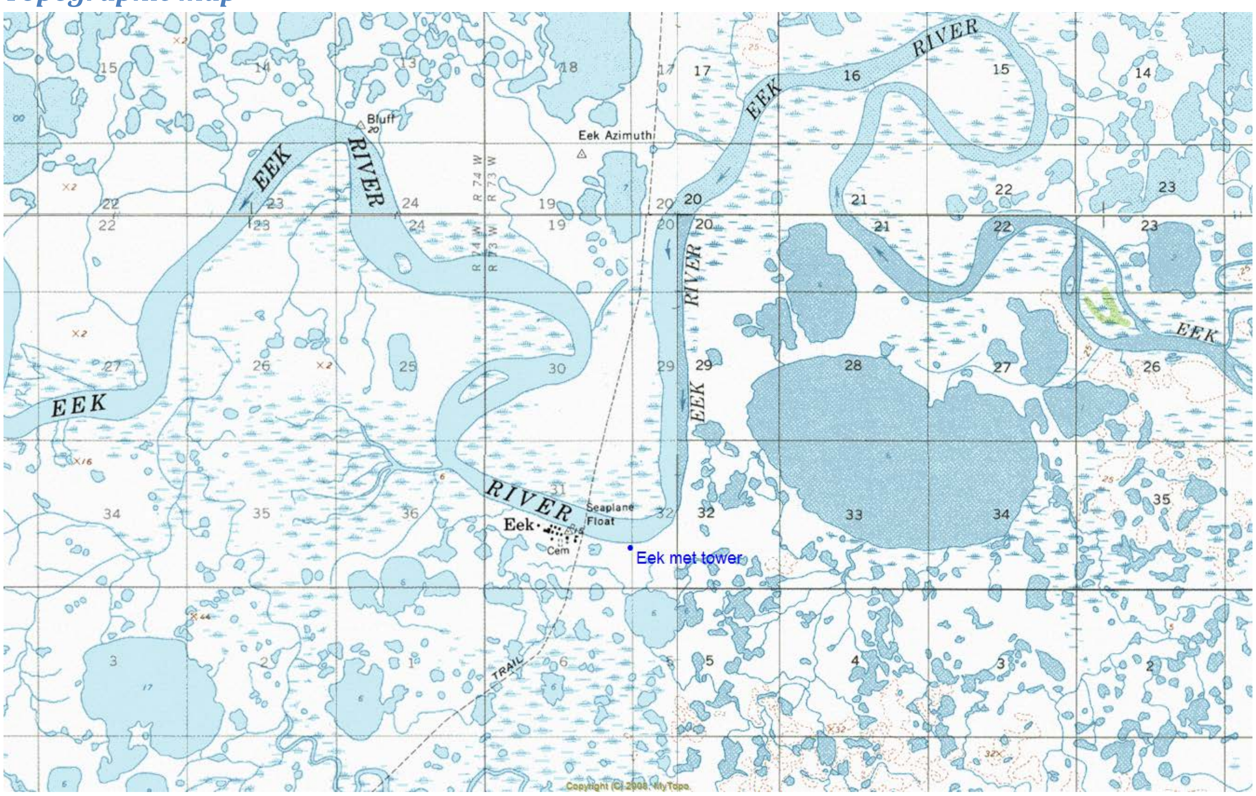
Other aspects of the wind resource also are promising for wind power development. By IEC 61400-1, 3rd edition classification, Eek is category III-C, indicating low turbulence (mean TI at 15 m/s = 0.087) and a low probability of extreme wind events. The latter measure, however, is difficult to quantify with only

14 months of data, but the site clearly is not energetic enough to be IEC Class I and apparently not IEC Class ii either. Both wind turbines profiled in this report are certified for IEC Class III-C conditions.

Eek met tower data synopsis

Data start date	12/20/2012
Data end date	Possibly still operational (data gap from 11/20/2013 to 10/2/2014); data thru 1/19/2015 for analysis
Wind power class (by WPD)	Class 4 (good)
Wind speed average (30 meters)	6.49 m/s measured
IEC 61400-1 3rd ed. extreme winds	Class III (note: 14 months data)
Wind power density (30 meters)	372 W/m^2
Weibull distribution parameters	k = 2.36, c = 7.6 m/s
Roughness Class	0.52 (snow surface)
Power law exponent	0.12 (low wind shear)
Frequency of calms (4.0 m/s threshold)	19%
Mean Turbulence Intensity	0.087 (IEC 61400-1 3rd ed. turbulence category C)

Topographic map



Google Earth image

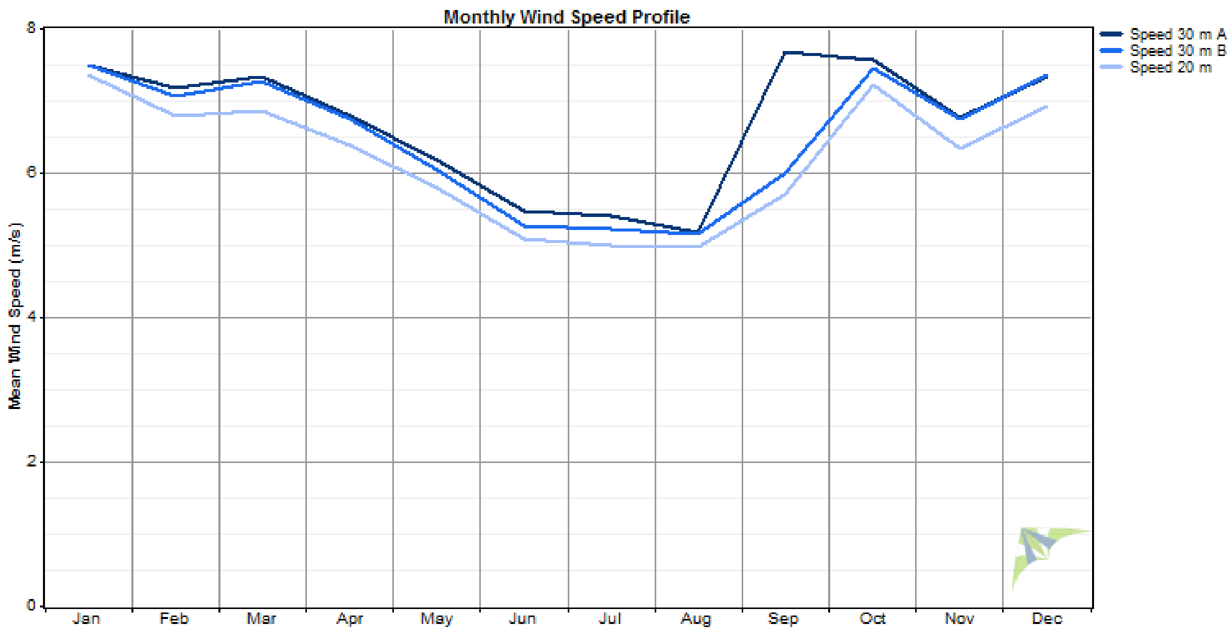
Measured Wind Speeds

Measured wind speeds in Eek are excellent and very promising for wind power development.

Wind Speed Sensor Summary

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

Eek Wind speed graph

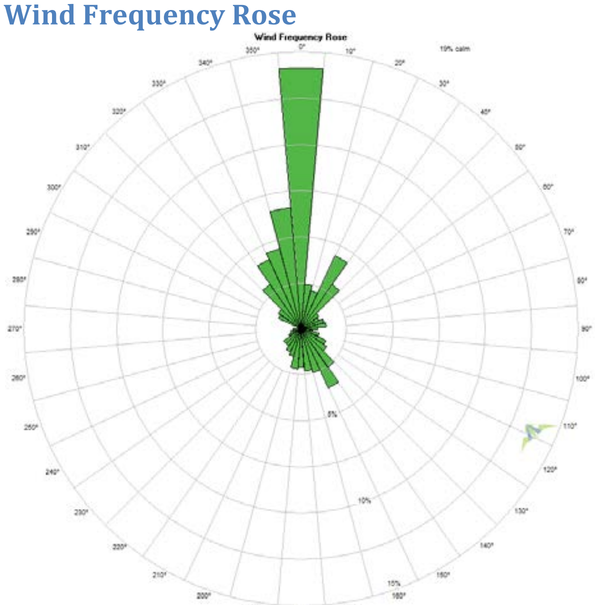


Wind Roses

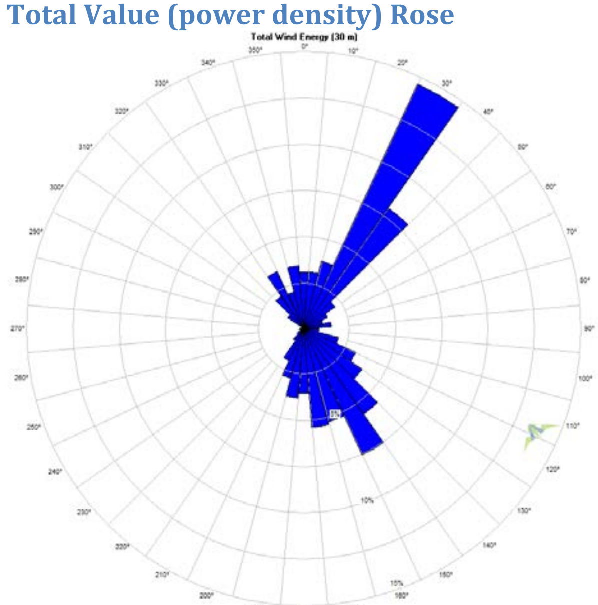
Winds at the Eek met tower test site are primarily northerly with occasional southerly winds. The power density rose indicates, however, that power producing winds at the site are predominately north-northeast and to a lesser extent south-southeast. Ideally, multiple wind turbines should oriented on an east-west axis to avoid turbine shadowing.

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

Wind Frequency Rose



Total Value (power density) Rose



Wind-Diesel Hybrid System Overview

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

Because Eek is a single phase power system with antiquated diesel engines, switchgear and other control system components, only very low wind penetration is possible without expensive control upgrades. AVEC has indicated that this is not an option at present.

Categories of wind-diesel penetration levels

Penetration Category	Wind Penetration Level		Operating Characteristics and System Requirements
	Instantaneous	Average	
Very Low	<60%	<8%	• Diesel generator(s) runs full time • Wind power reduces net load on diesel • All wind energy serves primary load • No supervisory control system
Low	60 to 120%	8 to 20%	• Diesel generator(s) runs full time • At high wind power levels, secondary loads are dispatched to insure sufficient diesel loading, or wind generation is curtailed • Relatively simple control system
Medium	120 to 300%	20 to 50%	• Diesel generator(s) runs full time • At medium to high wind power levels, secondary loads are dispatched to insure sufficient diesel loading • At high wind power levels, complex secondary load control system is needed to ensure heat loads do not become saturated • Sophisticated control system
High (Diesels-off Capable)	300+%	50 to 150%	• At high wind power levels, diesel generator(s) may be shut down for diesels-off capability • Auxiliary components required to regulate voltage and frequency • Sophisticated control system

Wind Turbine Options

Due to the single phase nature of the Eek power system, only two village-scale wind turbines are considered suitable. The guiding criteria for selection were turbine output rating in relation to electric load, single phase design, market availability, AVEC Operations department preferences and cost considerations. The turbines chose for review in this CDR are the Bergey Excel-S and the Eocycle 25.

Bergey Excel-S

Bergey Windpower is the oldest and most experienced manufacturer of residential-sized wind turbines in the world. Thirty years ago Bergey pioneered the radically-simple "Bergey design" that has proven to provide the best reliability, performance, service life, and value of all of the hundreds of competitive products that have come and gone in that time. With only three moving parts and no scheduled maintenance necessary, the Bergey 10 kW has compiled a service record that no other wind turbine can match.

Specifications:

- Reference Rated Power: 10 kW
- AWEA Rated Power: 8.9 kW at 25 mph
- AWEA Rated Annual Energy: 13,800 kWh at 11 mph average
- AWEA Rated Sound Level: 42.9 dBA Cut-in Wind Speed: 5 mph
- Cut-out Wind Speed: none Peak Power: 12.6 kW at 28 mph Max. Design Wind Speed: 134 mph
- Design Operating Life: 30-50 years.
- Turbine Rotor Diameter: 23 ft

Tower options include guyed lattice, tilt-up guyed tubular, self-supporting lattice, tilt-up guyed lattice, and monopole. Available hub heights are 18 to 49 meters. Bergey towers use American-made steel and are assembled in the United States.

Eocycle 25

The Eocycle 25 direct-drive wind turbine represents the next-generation wind turbine for the distributed wind energy (DWE) industry, bringing the most recent technology advancements of utility-scale wind within reach of small wind customers.

The Eocycle 25 has been designed and tested according to the most stringent standards and to be the safest and most durable small wind turbine available on the market. Its robust construction allows it to be installed in higher wind regimes and to withstand gusts of up to 59.5 m/s (133 mph). Safety and durability characteristics of the Eocycle 25 include:

- Redundant rotor overspeed protection and fail-safe emergency disc brake
- Integrated protection against lightning
- 20-year design life in accordance with the IEC 61400-2, Wind Class II standard

- Marine-grade corrosion protection on all components
- Independently-tested carbon and glass fibre / epoxy resin composite blades that will last and procure stable performance under repetitive cyclic loading
- Standard safety devices on nacelle, tower climbing system and work platform and all electrical cabinets
- Design and construction similar to most advanced utility-scale wind turbines
- Certification to AWEA and BWEA standards (in progress, testing to be completed in November 2013)
- Conforms with all applicable European Community directives (CE marking)
- Power inverter certified to UL and CSA standards
- Best-in-class components exclusively manufactured in North America and Europe

Tower options include free-standing and tilt monopole and free-standing lattice. Available hub heights are 18, 24, 30, 36, and 42 meters. Eocycle notes that all tower are hot-dip galvanized and are supplied with work platform, climbing step bolts ad safety cable. Standard warranty is two years; extended warranty is five years. The turbine can be equipped for arctic temperatures.

Homer Software Wind-Diesel Model

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

Diesel Power Plant

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

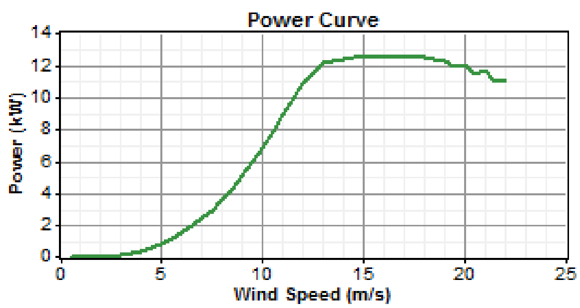
Eek powerplant diesel generators

Generator	Electrical	Diesel Engine Model	Generator
1	168 kW	Cummins LTA10 1200 rpm	Kato 6P4-1025
2	236 kW	Detroit Diesel S60K4 1200 rpm	Kato 6P4-1450
3	175 kW	Caterpillar D342	Kato 6P4-1025

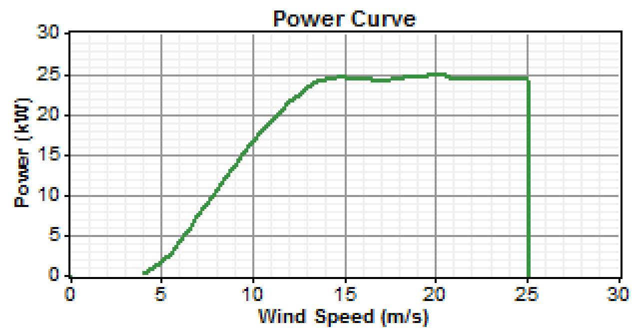
Wind Turbines

This CDR evaluates installation of two new Bergey Excel-S wind turbines for 20 kW installed capacity or one new Eocycle 25 wind turbine for 25 kW installed capacity. Standard temperature and pressure (STP) power curves are shown below. Note that for the Homer analysis, site elevation was adjusted to -150 meters to reflect the measured mean annual air density of 1.243 kg/m^3.

Bergey Excel-S



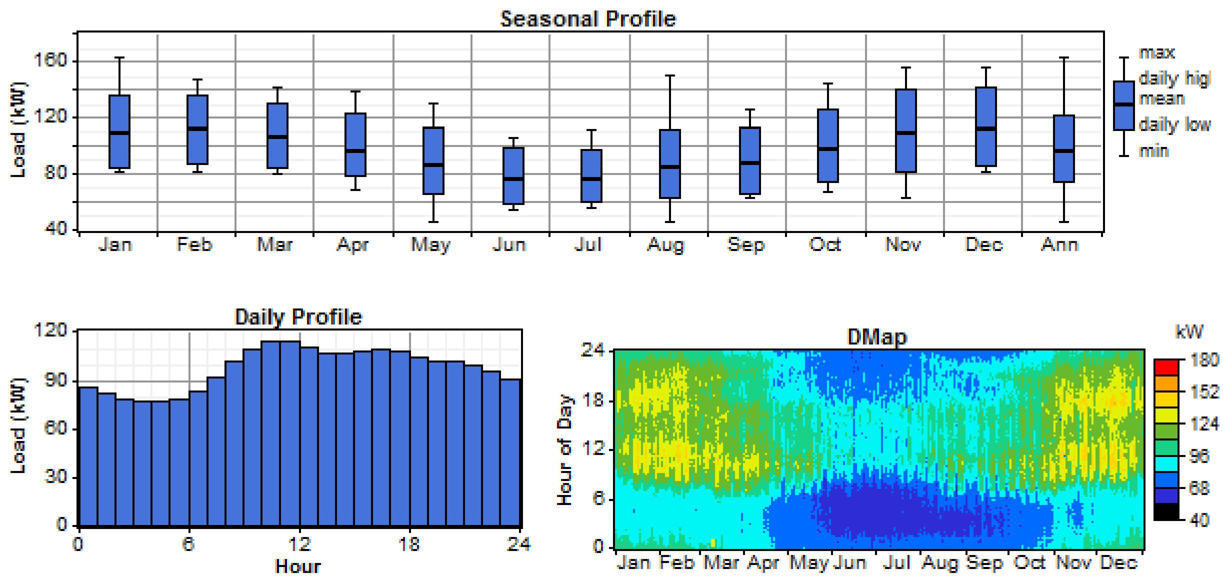
Eocycle 25



Electric Load

Eek electric load data, collected from 1/1/2013 to 4/20/2015 was collected via automated logging by AVEC. These data are in 15 minute increments and represent total electric load demand during each time step. The data were processed by adjusting the date/time from UTC to Yukon/Alaska time, converting from kWh to kW, and creating a January 1 to December 31 fifteen-minute interval load for export to HOMER software. The resulting load is shown graphically below. Average load is 96.9 kW with a 163 kW peak load and an average daily load demand of 2,325 kWh. This compares to a 96.5 kW average load reported to the RCA for the 2014 PCE report.

Electric load



Thermal Load

The Eek power plant is equipped with a recovered heat system that is not functional at present. Given that only very low wind penetration options are presented in this analysis, no excess wind energy will be produced, hence thermal load is not a relevant issue at this time.

Diesel Generators

The HOMER model was constructed with all three Eek diesel generators. For cost modeling purposes, AEA assumes a generator O&M cost of $0.020/kWh. Other diesel generator information pertinent to the HOMER model is shown below. Individual generator fuel curve information is available but Homer modeling with generator-specific fuel curves indicated fuel efficiency of 13.1 kWh/gal in the base case (no wind turbines). This is slightly lower than AVEC's reported fuel efficiency of 13.7 kWh/gal to Regulatory Commission of Alaska for the 2014 Power Cost Equalization Report, and higher than Eek's 12.2 kWh/gal efficiency documented in AVEC's 2013 annual generation report.

Diesel generator HOMER modeling information

Diesel generator	Cummins LTA10	Detroit Diesel S60K4	Caterpillar D342
Power output (kW)	168	236	175
Intercept coeff. (L/hr/kW rated)	0.04	0.04	0.04
Slope (L/hr/kW output)	0.22	0.22	0.22
Minimum electric load (%)	15.0% (25 kW)	15.0% (35 kW)	15.0% (26 kW)

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

Modeling Assumptions

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

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

The base or comparison scenario is the existing power plant with no functional heat recovery loop. Note that wind turbines installed in Eek will operate in parallel with the diesel generators. Excess wind energy is not expected and not provisions will be made to serve thermal loads via a secondary load controller and electric boiler. Installation cost of wind turbines assumes construction of single phase power distribution to the selected site, plus civil, permitting, integration and other related project costs.

Model Results

HOMER energy modeling software was used to calculate wind turbine energy production. Wind turbine energy production in this analysis is calculated at 82 percent net.

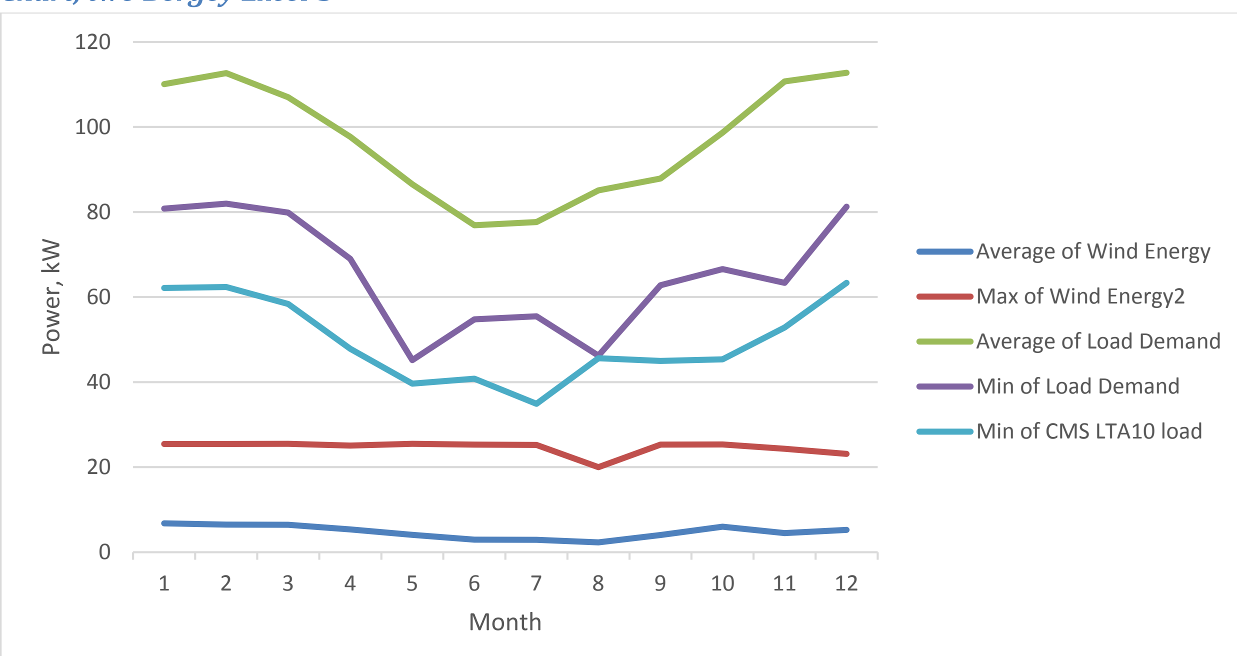
Bergey Excel-S, two (2) turbines

This configuration is two 10 kW Bergey Excel-S wind turbines at a 30 meter hub height at the proposed Eek wind turbine site. The simulation models wind energy production at 80 net (or 80 percent of gross annual). Note that Homer software predicts a maximum 41% instantaneous wind power penetration in this configuration scenario.

Energy table, two Bergey Excel-S, 80% net AEP

Month	Wind Energy, Avg (kW)	Wind Energy, Max (kW)	Electric Load, Avg (kW)	Electric Load, Min (kW)	Min of CMS LTA10 load (kW)
1	6.80	25.5	110.1	80.8	62.2
2	6.49	25.5	112.7	82.0	62.4
3	6.45	25.5	107.0	79.9	58.4
4	5.35	25.1	97.7	69.0	47.8
5	4.08	25.5	86.5	45.2	39.6
6	2.95	25.3	76.9	54.7	40.8
7	2.90	25.2	77.6	55.5	34.9
8	2.31	20.0	85.1	46.2	45.6
9	4.03	25.3	87.9	62.8	45.0
10	6.01	25.3	98.7	66.6	45.4
11	4.48	24.3	110.7	63.3	52.8
12	5.26	23.1	112.8	81.3	63.3
Annual	4.75	25.5	96.9	45.2	34.9

Chart, two Bergey Excel-S



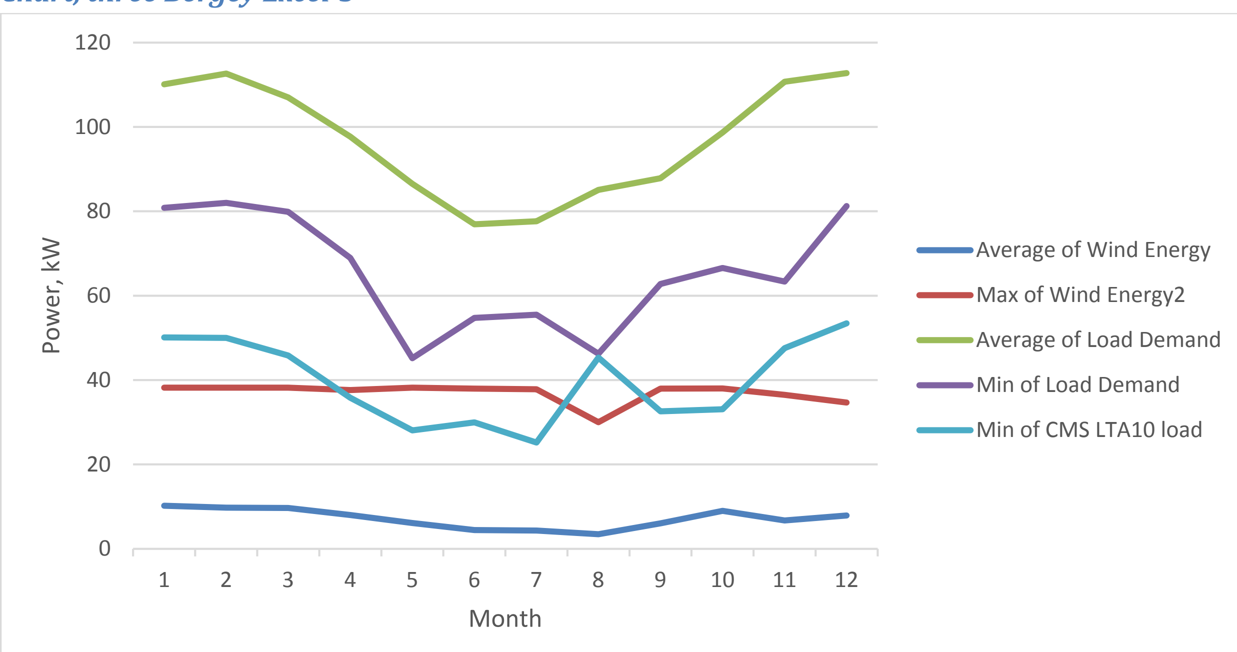
Bergey Excel-S, three (3) turbines

This configuration is two 10 kW Bergey Excel-S wind turbines at a 30 meter hub height at the proposed Eek wind turbine site. The simulation models wind energy production at 80 net (or 80 percent of gross annual). Note that Homer software predicts a maximum 61% instantaneous wind power penetration in this configuration scenario. Note that this configuration is potentially unstable in that wind energy exceeds minimum diesel load occasionally during the summer months, necessitating turbine curtailment to control grid frequency.

Energy table, three Bergey Excel-S, 80% net AEP

Month	Wind Energy, Avg (kW)	Wind Energy, Max (kW)	Electric Load, Avg (kW)	Electric Load, Min (kW)	Min of CMS LTA10 load (kW)
1	10.20	38.2	110.1	80.8	50.1
2	9.74	38.2	112.7	82.0	50.0
3	9.68	38.2	107.0	79.9	45.8
4	8.02	37.6	97.7	69.0	35.8
5	6.13	38.2	86.5	45.2	28.1
6	4.43	38.0	76.9	54.7	30.0
7	4.35	37.8	77.6	55.5	25.2
8	3.47	30.0	85.1	46.2	45.3
9	6.05	38.0	87.9	62.8	32.6
10	9.01	38.0	98.7	66.6	33.1
11	6.72	36.5	110.7	63.3	47.6
12	7.89	34.7	112.8	81.3	53.5
Annual	7.13	38.2	96.9	45.2	25.2

Chart, three Bergey Excel-S



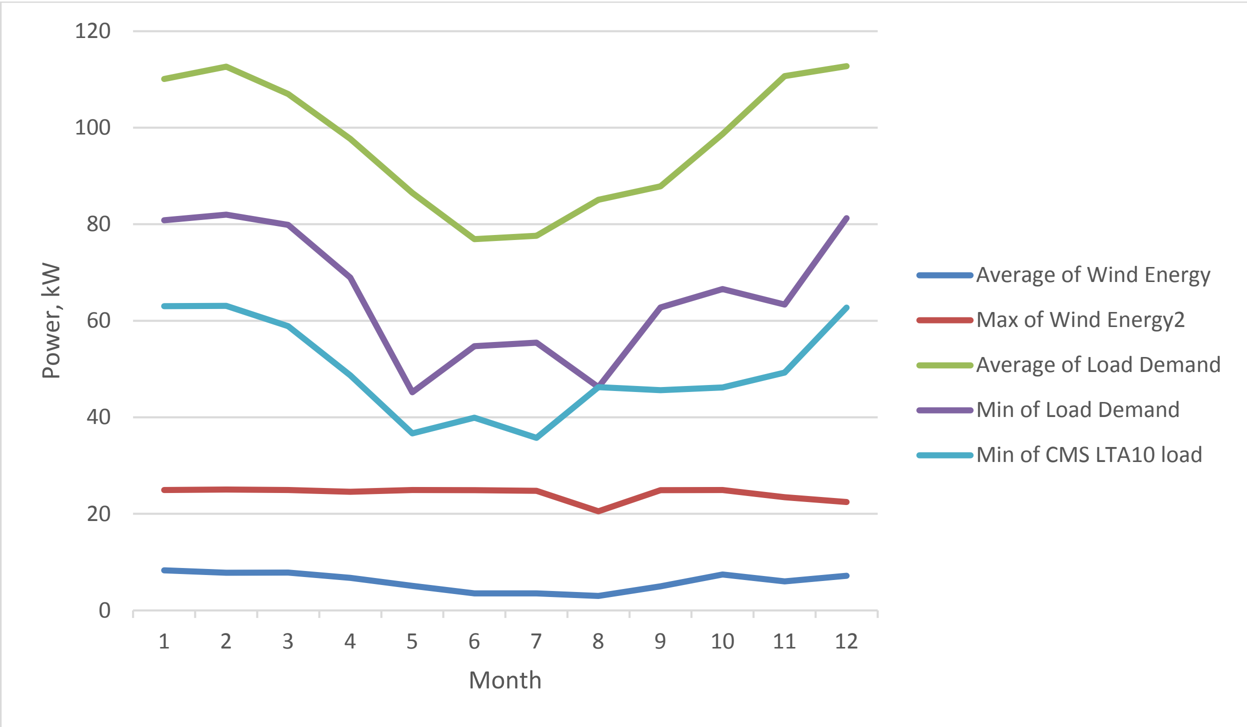
Eocycle 25, one turbine

This configuration is one 25 kW Eocycle 25 wind turbine at a 30 meter hub height at the proposed Eek wind turbine site. The simulation models wind energy production at 80 net (or 80 percent of gross annual). Note that Homer software predicts a maximum 39% instantaneous wind power penetration in this configuration scenario.

Energy table, one Eocycle 25, 80% net AEP

Month	Wind Energy, Avg (kW)	Wind Energy, Max (kW)	Electric Load, Avg (kW)	Electric Load, Min (kW)	Min of CMS LTA10 load (kW)
1	8.31	25.0	110.1	80.8	63.0
2	7.81	25.0	112.7	82.0	63.1
3	7.83	25.0	107.0	79.9	58.9
4	6.75	24.6	97.7	69.0	48.7
5	5.09	25.0	86.5	45.2	36.7
6	3.52	24.9	76.9	54.7	39.9
7	3.51	24.8	77.6	55.5	35.7
8	2.99	20.5	85.1	46.2	46.2
9	4.98	24.9	87.9	62.8	45.6
10	7.43	24.9	98.7	66.6	46.2
11	6.00	23.5	110.7	63.3	49.3
12	7.18	22.4	112.8	81.3	62.7
Annual	5.94	25.0	96.9	45.2	35.7

Chart, one Eocycle 25



Economic Analysis

Installation of wind turbines in medium penetration mode is evaluated in this report to demonstrate the economic impact of these turbines with the following configuration: turbines are connected to the electrical distribution system with first priority to serve the electrical load. Because the recovered heat system is not operational and given the low penetration configuration of the proposed wind system, a secondary load controller and electric boiler is not planned, hence thermal load offset will not be possible. Economic valuation is by the 2014 ISER cost model Excel spreadsheet, *2014_06-R8Prototype_AEA_Final_2014-08-07.*

Wind Turbine Costs

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

Project cost estimates

Turbine	No. Turbines	HDL Estimated Project Cost	Installed kW	Cost per kW	Tower Type	Tower Height (meters)
Bergey Excel-S	2	$361,250	24	$18,062	Tilt-up lattice	30
Bergey Excel-S	3	$476,733	24	$15,891	Tilt-up lattice	30
Eocycle 25	1	$523,700	25	$20,948	Monopole	30

Fuel Cost

A fuel price of $5.20/gallon was chosen for the initial HOMER analysis by reference to the *2014_06-R8Prototype_AEA_Final_2014-08-07* Excel spreadsheet, written by ISER. This price reflects the average value of all fuel prices between the 2017 (the assumed project start year) fuel price of $4.60/gallon and the 2036 (20 year project end year) fuel price of $5.95/gallon using the medium price projection analysis with an average CO_2-equivalent allowance cost of $0.62/gallon included.

By comparison, the fuel price for Eek (without social cost of carbon) reported to Regulatory Commission of Alaska for the 2014 PCE report was $3.91/gallon, without inclusion of CO2-equivalent allowance. Assuming a CO_2-equivalent allowance of $0.41/gallon (ISER *Prototype* spreadsheet, 2013 value), Eek's 2013 diesel fuel price was $4.32/gallon.

Heating fuel displacement by excess energy diverted to thermal loads would be valued at $6.14/gallon as an average price for the 20 year project period, but the project proposal does not anticipate heating oil offset. Heating oil price was determined by reference to the *2014_06-R8Prototype_AEA_Final_2014-08-07* Excel spreadsheet where heating oil is valued at the cost of diesel fuel (with CO_2-equivalent allowance) plus $0.94/gallon, assuming heating oil displacement between 1,000 and 25,000 gallons per year.

Fuel cost table (CO_2-equivalent allowance included)

ISER med. projection	2015 (/gal)	2034 (/gal)	Average (/gallon)
Diesel Fuel	$4.60	$5.95	$5.20
Heating Oil	$5.54	$6.88	$6.14

Economic Valuation

Economic modeling and valuation is by the ISER method, *2014_06-R8Prototype_AEA_Final_2014-08-07* Excel spreadsheet. Modeling assumptions are detailed in the table below.

ISER cost model assumptions

Economic Assumptions (ISER)	
Project life	20 years (2017 to 2036)
Discount rate	3%
Operating Reserves (Homer)	
Load in current time step	10%
Wind power output	50% (Homer setting to force diesels on)
Diesel Generators (ISER and Homer)	
O&M cost	$0.020/kWh (ISER, 2014)
Diesel generator efficiency (ISER)	13.7 kWh/gal (2014 PCE report)
Minimum diesel load	15% rated capacity, 10-min time period
Wind Turbines (ISER and Homer)	
Net AEP	80%
O&M cost	$0.050/kWh (ISER, 2014)
Wind speed	6.49 m/s at 30 m, met tower/turbine site 6.00 m/s at 30 m at turbine site, 82% net AEP
Energy Loads (Homer)	
Electric	2.32 MWh/day average Eek power plant load

Project economic valuation

			(in $ thousands						
Turbine	No.	Wind Capacity (kW)	Project Cost	NPV Benefits	NPV Costs	B/C Ratio	Diesel Fuel Saved (gal/yr)	Heating Oil Saved (gal/yr)	Total Fuel Saved (gal/yr)
Bergey Excel	2	24	361.3	194.8	330.6	0.59	3,038	-	3,038
Bergey Excel	3	36	476.7	292.2	436.3	0.67	4,557	-	4,557
Eocycle 25	1	25	523.7	243.6	479.3	0.51	3,800	-	3,800

Conclusion

Eek has a very good wind resource for wind power development. Wind behavior is desirable with low turbulence, low wind shear, and low extreme wind probability.

The analysis in this report considered configurations of two and three 10 kW Bergey Excel S wind turbines and one 25 kW Eocycle 25 wind turbine in very low penetration configuration with no electrical storage and no excess energy for heat. The three turbine Bergey Excel S configuration presents the highest benefit-cost ratio and should be considered the preferred options for design and subsequent construction. But, this particular configuration is potentially unstable without turbine curtailment control. Without turbine curtailment control, either the two turbine configuration Bergey Excel S configuration or the single Eocycle 25 configuration is suitable for Eek. The preferred project site is on the runway of the old airport.

The reader is cautioned, however, that the predicted economic benefit documented in this report is highly conservative and given the considerable uncertainty in many assumptions, does not reflect a possible range of economic benefit, much of which may indicate higher value.