ACEP Technical Report

Nome Wind-Diesel System Overview

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Introduction
The Nome Joint Utility System (NJUS) is a municipality-owned utility that provides electricity to the Nome area and its 3700 residents. The utility indicates that it has a mean load of 4 MW and a base load of 2.5 MW (J. Handeland, personal communication). The current wind turbine has been installed in phases, and its capacity is 2.7 MW.

NJUS operates with two Wärtsilä 5.2 MW diesel generators, which alternate to supply power. A 3.6 MW Caterpillar generator is used during the off-peak summer hours when demand is low, and a 1.8 MW Caterpillar generator is used to augment peak loads during winter afternoons. A 0.4 MW diesel generator is used as a black start unit in case of a black out and can support lower temporary peaking requirements. Presently, NJUS operates one of the most efficient diesel powerhouses in Alaska, with an average kWh/gal of 15.8 for the period of July 2015 through June 2016, according to power cost equalization (PCE) records.

In 2008, multiple entities in Nome pursued the installation of wind turbines. These efforts coincided with a significant increase in the cost of diesel fuel and a subsequent rise in the cost of delivered power to the community. The utility’s introduction letter for the Round 1 Renewable Energy Fund grant application describes the circumstances:

> It is with a deep sense of immediacy that this application is submitted on behalf of City of Nome/Nome Joint Utility System (NJUS) as a request for funding through the Alaska Energy Authority’s Renewable Energy Grant Program. As you are very much aware, the energy crisis facing rural Alaska has reached unsustainable levels that threaten the health, security and abilities for residents to maintain the basic necessities of life in a cost effective manner. The community of Nome is no exception to this challenge which can be largely attributed to the escalation of our primary energy source, diesel fuel. Since 2003, the price of diesel delivered to NJUS has increased by more than 250%. As a utility committed to providing reliable and affordable electricity, we have developed a very strong and personal understanding of how these rising costs impact our community. We, like so many other utilities across Alaska, search on a daily basis for ways to reduce these costs that must be passed on to our consumers in order to maintain our system and the reliable delivery of our services.

The first wind project on Banner Peak, about 4.5 miles northwest of downtown Nome, became operational in 2008. The project was developed by two local native corporations that formed an independent power production company and negotiated a power purchase agreement with the City of Nome. Initially the project consisted of eighteen 50 kW Entegrity turbines, of which 15 are still in operation. After the full value of the tax credits was realized by Banner Wind LLC, the company sold the Banner Wind project to NJUS along with the long-term lease for the land, effective January 2015.¹ In 2013, two EWT 900 kW wind turbines were installed by the utility, using funds from the Alaska Renewable Energy Fund program and a contribution from the local fishing community development quota program, Norton Sound Economic Development Corporation. These combined efforts allowed the Nome grid to operate for short periods at wind power penetrations exceeding 50%.

**Wind System Funding and Build Out**

The Renewable Energy Fund (REF) grant program was developed to reduce and stabilize the cost of energy for Alaskans through the implementation of renewable energy projects. To date, the REF has distributed more than $250 million to qualified projects around the state, and this funding has been matched with hundreds of millions of dollars in funding from local sources.\(^2\) In 2008, NJUS submitted three projects to the Alaska Energy Authority for funding under Round 1 of the REF. Their proposal summaries read as follows:

- **Nome Banner Peak Wind Farm Transmission Construction**
  - Located in Nome, this project will install a 2-mile transmission line and an 8-mile fiber control cable to connect a 1 MW wind farm, operated by Banner Wind LLC, an independent power producer (IPP), to the City of Nome/NJUS power distribution grid. The project will place an underground 25 kv distribution line adjacent to a new road, and include a fiber control cable run from the wind generators to the utility power plant. Banner Wind LLC is an IPP formed in partnership with Bering Straits Native Corporation and Sitnasuak Native Corporation. NJUS will be primarily responsible for project construction activities, as well as the reporting and financial control of the intertie project.

- **Nome/Newton Peak Wind Farm Construction**
  - The NJUS REF wind project involves the installation of five 600 kW wind turbines on Newton Peak, located approximately 1 mile north of Nome. The completed project, with a total size of 3 MW, will be owned and operated by NJUS. The wind turbines will be connected to NJUS’s electrical distribution system through a constructed transmission line. The project will offer benefits to the community of Nome and its electric customers through a system-wide reduction and stabilization of energy prices. NJUS has assembled a project team, headed by STG Incorporated, which is prepared to immediately begin work on an accelerated schedule. The project team includes members from Intelligent Energy Systems LLC, DNV Global Energy Concepts Inc., Electrical Power Systems, Duane Miller Associates LLC, Hattenburg Dilley & Linnell LLC, BBFM Engineers, and Aurora Consulting. All aspects of the Final Design/Permitting and Construction project, detailed in the following pages of this application, can be completed by fall 2010.

- **Nome/Banner Peak Wind Farm Construction**
  - The installation of this wind power project will provide a maximum output of 1,170 kW to the Nome Joint Utility electric grid in Nome, Alaska, over a 20-year extendable project timeframe. The owners of the project are committed to sell the energy at a price below the avoided cost calculations, even without any grant funding. Grant funding will allow further reduction in the price of approximately $0.03 per kWh for every $1 million in grant funds. Selling the energy at a rate below

avoided costs will provide savings to the utility to help lower energy costs in the Nome area and provide energy produced locally that is not dependent on imported oil. Furthermore, this project helps enable future village installations in the region by helping with a base of operations, spare parts location, local training facility, and regional hub. Overall, this project provides a cash and tax credit based revenue stream, provides jobs, and keeps money working in the community while increasing overall power generation reliability by producing it locally. Banner Wind LLC (jointly owned by Bering Straits Native Corporation [BSNC] and Sitnasuak Native Corporation [SNC]) owns the wind farm, while the construction and initial operation are managed by Western Community Energy LLC. The profits from the project, which are ultimately distributed to the shareholders of BSNC and SNC, will help provide income to an area where many have very limited incomes.

In 2011, two additional projects were submitted for funding.

- Projects #839 and #898 for the Nome Renewable Energy Expansion/Optimization Project
  - This is a combination of applications 839 and 898. The 839 project involves the expansion of NJUS’ awarded REF Round I wind power project (installation of a 900 kW wind turbine) through the installation of a second 900 kW wind turbine at the planned project site. The project aims to take advantage of economies of scale to incorporate the installation of a second wind turbine generator during the construction of NJUS’ Round I awarded project. At this time, conceptual design and feasibility studies have been completed, and the project is ready to continue with final design, permitting, and construction activities. The 898 project seeks to optimize existing installations and in-progress wind projects in the community. NJUS is utilizing REF–Round I funding to install a 900 KW wind turbine in summer 2012. Another REF–Round I project allowed NJUS to construct a power transmission line to Banner Wind, an independent power producing facility privately owned by Sitnasuak and Bering Straits Native Corporations, from which NJUS purchases wind power under a contract. Through installation of a new wind integration control system and modification of the diesel generation system at NJUS’ power plant, the project focuses on the optimization of existing diesel generation equipment within the community in order to maximize benefits from renewable energy supplies. Under the scope of this project, smaller peaking diesel generator sets will be integrated into Nome’s power plant, and plant controls will be reconfigured to provide system-wide benefits of reduced operating costs, greater stability, and improved efficiency. In the event NJUS or Banner Wind expands wind generation capacity in the future, the community can potentially recognize additional benefit from the project.

**Nome Joint Utility System Components**

The proposals detailed above provided a set of guidelines needed for project funding, but in several cases the actual projects changed from the original proposals. Currently, Nome receives power from a combination of the diesel generators discussed in the introduction, primarily relying on one of the two
Wärtsilä 5.2 MW diesel generators at any given time. The fuel curve for these generators is shown in Figure 1. In 2013, NJUS installed two 900 kW EWT direct-drive wind turbines atop Banner Peak. The power curves for these turbines are shown in Figure 2. In January 2015, NJUS took ownership of the eighteen 50 kW Entegrity turbines that had originally been installed by Banner Wind LLC under an independent power producer arrangement between Banner Wind and NJUS. At the time of their purchase, 15 of the original 18 turbines were operational. A one-line diagram of the entire Nome system is shown in Figure 3.
Figure 1. Wärtsilä 12V32 fuel efficiency curve, +/−2.5% tolerance. This figure shows that the most fuel-efficient zone of operation for the generator is at higher power settings, between 4.5 and 5.5 MW. At lower power settings, the generator produces fewer kWh per gallon of diesel. The challenge for a utility is to maximize both diesel efficiency and the utilization of available wind power.
Figure 2. EWT specs show the manufacturer’s expected power curve. The power curve shows that the turbine starts generating power at wind speeds near 5 m/sec and reaches its rated output at about 13 m/sec.
Figure 3. Nome one-line diagram.
Data Collection Overview/ Monitoring Methodology and Research Questions

In 2015, the Alaska Energy Authority contracted with ACEP to collect and analyze high-resolution data from the Nome REF projects to determine how much wind was being shed and to better understand how wind power impacted the entire utility system. The following research questions were established:

1. What are the seasonal electric load and wind power performance characteristics?
2. How do the wind turbines perform in respect to the manufacturer’s predicted power curve?
3. What is the impact of wind utilization on diesel fuel efficiencies?
4. What are the diesel offsets when engine efficiencies are reduced at low loads?
5. How much wind power curtailment occurs in Nome and under what conditions does curtailment occur?
6. Do high wind contributions affect power quality?
7. What are potential improvements to system management?

System Performance and Analysis

Voltage, frequency, and current data were acquired at approximately 1-second resolution for all generation assets and feeders on the Nome grid. Some analysis involving wind data required cleaning the data and down-sampling to 1-minute averages to account for the time lag between wind speed changes and wind power output. For other types of analysis, such as power quality, the 1-second resolution data were used.

General Load

To calculate the Nome community load, power from all the feeders was summed; any wind generation from Banner Creek was filtered out. The average load for 2015 was 3,613 kW, with a peak load of 5,099 kW that occurred on January 26, 2015, and a minimum load of 2,399 kW that occurred on June 16, 2015.

Figure 4 shows the load for all of 2015. This figure shows that the load was highest in the winter, between mid-November and mid-March. The load was lowest in the summer, between May and approximately mid-August. This load profile is typical for an Alaska community. In general, unless a significant industry is active only in the summer (e.g., fishing in Bristol Bay), loads tend to be higher in the winter than in the summer in rural Alaska. This load matches well the wind profiles of western Alaska, where the windiest and thus most productive months are in fall and winter.
Figure 4. The 2015 Nome electrical load, using 1-minute data collected from feeders around the grid. The load peaks during the winter months and dips during the summer months. The peaks shown in Figure 5 are annotated as A and B in the graph.

A more detailed analysis of the system load is shown in the histogram in Figure 5. The shape of this histogram with its bi-modal features is typical for rural Alaska communities that have distinct differences between winter and summer electrical loads.

Figure 5. A histogram of the Nome load displays a bi-modal shape typical of community loads in rural Alaska with distinctly different winter and summer loads. The peaks annotated as A and B are also shown on the load profile in Figure 4.
As mentioned previously, NJUS has a variety of generators in its powerhouse fleet, but primarily relies on two Wärtsilä generators with a maximum combined output of approximately 5.2 MW. These generators were initially installed when the community was expecting load growth due to the construction of a local gold mine, which ceased operation soon after it was constructed. Figure 6 shows diesel generation by generator. It appears that Generator 15 operated for most of the winter, while Generator 16 operated for most of the summer. The generator numbers refer to the two Wärtsilä generators. Periodic switching between generators was expected for routine maintenance purposes.

\[ \text{Figure 6. Overall production in 2015 of the two Wärtsilä generators that serve as the primary diesel generators in Nome.} \]

**Wind Performance**

What follows is a general discussion of the analysis of performance of the two EWT wind turbines that were installed in Nome during summer 2013. In this analysis, the focus is on the EWT turbines rather than the smaller 50 kW Entegrity turbines, because the EWT turbines produced most of the wind power, and the data for the EWT turbines were much higher in quality.

In 2015, the two EWT wind turbines fed 1.75 million kWh to the Nome power grid. This amount of power was equivalent to 116,000 gallons of diesel fuel at 15 kWh/gal. Figure 7 is an overall representation of the total wind production. Wind speed and, accordingly, production were lower in the
summer months and higher in the winter months. This wind resource is typical for most coastal areas of Alaska.

![Wind Power Production](image)

*Figure 7. Power production from two EWT turbines along with wind speed as measured on the nacelles of each turbine in 2015. Turbine #1 was out of operation during spring 2015.*

Figures 8 and 9 show the energy production for two identical EWT wind turbines at different wind speeds. In a situation where there is no curtailment of the wind turbines, one would expect a curve similar to the manufacturer’s power curve. In Figure 8, the left side of the data generally follows the power curve, shown in red. There is significant data to the right of the power curve as well. Most of these data points to the right of the power curve represent times when the wind was curtailed by the utility. Curtailment can happen for a variety of reasons, but the most common reason is to keep the wind power within certain parameters to maintain minimum diesel loading and proper power quality in a wind-diesel microgrid.
Figure 8. The actual 2015 performance of EWT turbine #1 is shown in blue; the theoretical power curve is overlaid in red.

Figure 9. The actual 2015 performance of EWT turbine #2 is shown in blue; the theoretical power curve is overlaid in red.

In Figure 10, power data from the fourth quarter of 2015 are shown for EWT turbine #1. With the shorter time span showing fewer data points, the details of the graph can be more easily highlighted to show some of the curtailment details. Note in Figure 10 that horizontal trends form at various power outputs. These trends are essentially different limits where power output is being curtailed to maintain a given output regardless of the wind speed. This curtailment likely is controlled by algorithms within the EWT controls. Follow a point on one of the horizontal lines, or from any point inside the power
curve, vertically until it intersects the power curve, to understand approximately what the power production would have been if no curtailment had taken place. Curtailment is discussed in detail later in the report. Over all, the EWT wind turbines appear to be performing according to the manufacturer’s power curve when no curtailment is taking place.

Wind Penetration

In an islanded wind-diesel system, it is difficult to maintain anything more than about 30% wind penetration without significant investment in sophisticated controls, which probably would include storage and/or dump loads. Nome has no energy storage on its system and no dump loads to accept excess wind. Figure 11 and Figure 12 show the wind penetration in Nome. Figure 11 shows an overall graph of wind penetration as a function of time throughout 2015. Figure 12 shows a histogram of wind penetration. Generally, wind contributions are lowest in springtime and highest in late summer, fall, and wintertime. In the histogram, we see that wind contributions between 10% and 25% are common. The frequency of wind contributions greater than 25% drops off quickly.
Figure 11. Wind penetrations during 2015 as a function of time. Penetrations are greatest during late summer, fall, and winter and lowest during springtime.

Figure 12. A histogram of wind penetration using the 1-minute data set shows wind contribution to the Nome system. The y-axis is shown as a logarithmic scale for better detail. Penetrations between 10% and 25% are common in the system; the frequency of penetrations greater than 25% decreases rapidly.

Figure 13 shows the overall wind energy penetration by month for 2015. This graph largely confirms earlier statements, that the highest penetrations occur in fall and winter. In order for energy
penetrations to be high, wind power penetrations need to be high for a prolonged period, which correlates to high-speed, steady winds.

**Figure 13.** Wind energy penetration by month. To arrive at these figures, the total wind energy fed to the grid each month is divided by the total energy generation each month from all generation sources.

**Curtailment**

One of the primary objectives of this data collection effort is to better understand the wind curtailment that occurs in the Nome wind-diesel system. While there was no curtailment data point, we were able to develop algorithms based on the EWT power curve and power production to estimate EWT turbine curtailment.

To estimate curtailment, a curve was created to the right of the EWT power curve (see Figure 14). It was assumed that data points inside the curve were the result of curtailment and that data points to the left and above the curve were part of normal wind operations when curtailment was not taking place. For the data points inside the curtailment zone, the difference between actual power and theoretical power was calculated, referred to here as curtailed power.
Figure 14. Second quarter wind production for EWT #2, shown alongside the theoretical power curve. The curtailment zone is overlaid to show wind data points that correspond to areas of likely curtailment.

Histograms of curtailed power quantities for each turbine are shown in Figure 15 and Figure 16. The horizontal lines highlighted in Figure 10 appear in the histograms as high points, making these histograms subtly multi-modal. Lower power curtailment values occur more frequently than higher curtailment values.
Figure 15. A histogram of the calculated power curtailment from EWT turbine #2 shows increased curtailment counts of higher power levels in general. Within the histogram are multi-modal peaks, highlighted with arrows, which correlate to the horizontal lines shown in the power highlighted in Figure 10.
Total wind energy curtailment is shown by quarter (Q) in Figure 17. In 2015, wind energy curtailment peaked in Q3 and Q1, similar to the wind energy penetrations shown in Figure 13, though not an exact match. Curtailment seems rather constant throughout the year.

It seems clear from this analysis that an electric boiler or some other dump load that could convert excess wind to heat would be an economic option in Nome if the wind that otherwise is curtailed could be sold at a reduced interruptible heating rate. The economics of this situation would depend on the capital costs involved in the installation of such a boiler and associated controls, and on the heat rate at which this energy could be sold.
Figure 17. Total wind energy that was curtailed, summed by quarter (Q).

Figure 18 shows the results of additional analysis, performed to measure curtailment as a function of the Nome electrical load. To perform the analysis, the load was rounded into 10 kW bins and the average curtailment that took place in each load bin was calculated. Figure 18 indicates that the highest average curtailment took place when the load was 3000 kW, which makes sense from a diesel management perspective since 3000 kW is load that occurs commonly in the Nome grid from April through November. Outside of these months, the load is typically above this level. When the load is 3000 kW, the diesel generator is running in a less-than-optimal state, and taking on significant wind would cause it to run near its minimum load levels. In addition, significant wind at these load levels would equate to rather high wind penetration levels for a system with no type of energy storage or dump load.
Wind-Diesel Interaction

Figure 19 and Figure 20 show the interaction between the total load, the diesel engine fuel efficiency, and the wind contribution. The following assumptions were made when calculating the fuel economy shown in these figures:

- 5.2 MW Wärtsilä diesel generators are used for the modeling, using the manufacturer’s fuel curve shown in Figure 1.
- The diesel generators never run below 25% of rated capacity, the minimum value shown on the fuel curve.
- Total load is always less than or equal to the rated capacity of the diesel generator.
- Wind is only curtailed when the total load exceeds the diesel generator's rated capacity.
- Total wind contribution is 1800 kW, the sum of the two EWT turbines.

The fuel displacement by wind production in a wind-diesel system is a function of how much power is produced by the wind as well as where on the efficiency curve the diesel system is operating. Oftentimes a diesel generator operates at lower efficiency during times of high wind penetration in order to balance generation and load. The graphs in Figure 19 and Figure 20 attempt to paint a broad picture of system performance in Nome at various loads, engine performance, and wind performance given the assumptions just detailed. In these examples, the total wind penetration has not been capped. In reality, however, wind penetrations above 50% are often hard to achieve without a dispatchable load or energy storage system; otherwise, power quality can suffer.

Figure 19 and Figure 20 are interesting to compare because Figure 19 shows the efficiency of the diesel engines, while Figure 20 shows the efficiency of the entire wind-diesel system.
Figure 19. The fuel economy of the Wärtsilä diesel generator at various loadings. Loading is a factor of the total system load and the production of the two EWT wind turbines.

Figure 20. Total wind-diesel system fuel economy as a function of total system load and wind production. It is important to note in this theoretical system, regardless of diesel generator efficiency, that the higher the wind penetration, the higher the overall system fuel efficiency.

The takeaway from Figure 19 and Figure 20 is that more wind energy will always displace fuel even though it forces the diesel generator to operate less efficiently, as long as the assumptions detailed
earlier are met. Even when the diesel generator is forced to run lower on the fuel efficiency curve, it does not run inefficiently enough to offset the benefits of wind, meaning that additional wind contribution will always be beneficial for fuel displacement as long as power quality is maintained.

Figure 20 shows that overall system fuel efficiency stays relatively stable across the different wind penetrations, regardless of load.

High loads and high wind contribution result in the highest levels of displaced fuel, as shown in Figure 21. A load of about 5000 kW and a 35% wind penetration will result in about 100 gal/hour offset. It is possible that high contributions of variable generation could increase the maintenance requirements of the diesel engine. These costs are not taken into account here.

![Total Fuel Displaced](image.png)

*Figure 21. Total fuel displaced by wind production each hour, shown as a function of wind production as well as diesel efficiency.*

**Power Quality**

Maintaining proper power quality and system stability is typically one of the most challenging parts of running a high-contribution wind-diesel system. Balancing system production with system demand while maintaining adequate spinning reserve is essential. In order to assess power quality during multiple system conditions, data were analyzed on high-wind contribution days and low-wind contribution days.

Figure 22 and Figure 23 show examples of power quality during high-wind days, which occurred on January 15, 2015, and November 2, 2015. During January 15, the maximum wind speed was just over 20 m/sec along with a mean wind speed of 9.6 m/sec. On November 2, the maximum recorded wind speed was 19.7 m/sec along with a mean wind speed of 12.6 m/sec. Curtailment is observed in the wind system on both days, but overall power quality stayed relatively stable and within the norms seen in rural Alaska.
Figure 22. Power quality for the high-wind day on January 15, 2015. Average wind speed was 9.6 m/sec, with a maximum wind speed of 20.32 m/sec. The EWT #1 maximum frequency was 60.26 Hz, the mean frequency was 60.0 Hz. The EWT #2 minimum frequency was 59.5 Hz, the maximum frequency was 60.4 Hz, and the mean frequency was 59.9 Hz.
Figure 23. Power quality for the high-wind day on November 2, 2015. The maximum wind speed was 19.7 m/sec; the mean wind speed was 12.6 m/sec. For EWT #1, minimum frequency was 59.7 Hz, maximum frequency was 60.3 Hz, and mean frequency was 60.0 Hz. For EWT #2, minimum frequency was 59.7 Hz, maximum frequency was 60.3 Hz, and mean frequency was 60.0 Hz.

Figure 24 and Figure 25 show examples of power quality during the low-wind days of February 4, 2015, and October 21, 2015. On February 4, the maximum wind speed was 3.9 m/sec and the mean wind speed was 1.4 m/sec. On October 21, the maximum wind speed was 6.4 m/sec and the mean wind speed was 2.5 m/sec. During large portions of these days, wind speed was not sufficient to reach the wind turbines cut-in speed to start generating power. The power quality did not deviate any more during these low-wind days than it did during the high-wind days.
Figure 24. During the low-wind day of February 4, the wind maximum was 3.9 m/sec and the wind mean was 1.4 m/sec. For EWT #1, maximum frequency was 60.2 Hz, minimum frequency was 59.8 Hz, and mean frequency was 60.0 Hz. For EWT #2, maximum frequency was 60.2 Hz, minimum frequency was 59.8 Hz, and mean frequency was 60.0 Hz.
Figure 25. On the low-wind day of October 21, the mean wind was 2.5 m/sec and the maximum wind was 6.4 m/sec. For EWT #1, minimum frequency was 59.7 Hz, maximum frequency was 60.6 Hz, and mean frequency was 59.99 Hz. For EWT #2, minimum frequency was 59.8 Hz, maximum frequency was 60.3 Hz, and mean frequency was 59.99 Hz.

System Management Options

The primary management goal for future operation of the Nome wind-diesel system should be to reduce the curtailment of available wind power. An electric boiler or other wind-to-heat-focused options along with associated control systems is the best way to maintain or even increase wind contribution to the Nome electrical grid and take advantage of the wind that the grid is unable to accept by converting it to heat that can be utilized by one or two large customers.
Summary
The Nome system is a high-functioning mid-penetration wind-diesel system. The diesel generators used in that community are among the most efficient (kWh/gal) in Alaska. The average load for 2015 was 3,613 kW, with a peak load of 5,099 kW that occurred on January 26, 2015, and a minimum load of 2,399 kW that occurred on June 16, 2015. The load distribution is bimodal with peaks at 2800 kW and 3800 kW.

Nome has 2550 kW of installed wind potential built at the Banner Creek site. The majority of the wind power is delivered from two 900 kW EWT turbines, although a limited amount of power is delivered from fifteen 50 kW Entegrity turbines. The primary focus of this study was the two EWT turbines. In 2015, the two EWT wind turbines fed 1.75 million kWh to the Nome power grid, which is equivalent to 116,000 gallons of diesel fuel at 15 kWh/gal. The maximum wind power penetrations observed in 2015 were near 40%; the highest monthly wind energy penetration was 10% in December 2015.

Currently, Nome has more wind capacity than the grid is consistently able to absorb while also operating the diesel engines within set parameters. Because of this, wind is often curtailed during periods of high wind and low load. In 2015, the total wind curtailment was approximately 844,581 kWh. Curtailment was steady throughout the year, but slightly more curtailment occurred in the third quarter of the year than in other quarters.

Aside from the curtailment issues, the wind and diesel systems are functioning well together. Two low-wind days and two high-wind days were analyzed to observe power quality differences between the two types of days. The voltage and frequency averages, minimums, and maximums were nearly identical for the days.

Recommendations and Next Steps
The primary recommendation based on the results from this study is to investigate the costs and economic payback of installing an electric boiler. Ideally, a community building such as a swimming pool or a community center could easily utilize the heat. Sending the heat to one location rather than multiple locations would help keep costs down. The 844,000 kWh is conservatively equivalent to 23,000 gallons of heating oil if consumed in a boiler that is 90% efficient.