RESEARCH & DEVELOPMENT

Study of Wind Energy Generation Potential along North Carolina Highways

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16. Abstract

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Renewable energy generation offers opportunities for state agencies, such as the North Carolina Department of Transportation (NCDOT) to reduce costs as well as to reduce their carbon footprint. Additionally, renewable energy provides electrical power for highway services such as lighting and signage, in areas for which the electrical grid is either unavailable or for which interconnection would be complicated and/or expensive. The Project Team at the North Carolina Clean Energy Technology Center (NCCETC) installed anemometers along three heavily travelled corridors in three NCDOT Highway Divisions. These anemometers were intended to simulate the potential for traffic-generated turbulence to produce wind energy. Anemometers were in-place at each site for a period of one-to-two months during which wind speed and direction data were recorded and logged. Utilizing power curves from three prototype Vertical Axis Wind Turbines (VAWTs) potential wind energy generation was modeled by both the VAWT technology provider and by the NCCETC Project Team. Results indicate that there is considerable potential to generate electricity from traffic-generated turbulence. Current cost of turbulence-generated wind energy was found to exceed equivalent generation of renewable solar energy, though it is believed that larger-scale deployment of VAWT technology will reduce costs in the future. Based on the results of this study, the proposed next steps in this research includes a recommendation for deployment of one or two VAWTs on high traffic corridors in North Carolina to obtain real-time, actual electric generation data which will facilitate a much more-refined technology and economic feasibility assessment of the viability of this mode of renewable energy generation to support highway electrical demands.

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Study of Wind Energy Generation Potential along North Carolina Highways

Prepared by the North Carolina Clean Energy Technology Center
North Carolina State University
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NC CLEAN ENERGY
TECHNOLOGY CENTER

Preface

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The Center is a public service center in the College of Engineering at North Carolina State University. The North Carolina General Assembly generously provides core funding for the Center by direct appropriation through the Department of Environmental Quality. The Center receives additional funding from fees for training and technical assistance and from numerous federal, state and private research grants. The Center is also supported by the N.C. Clean Energy Technology Center Foundation, a part of the NC State Engineering Foundation.

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Executive Summary

The North Carolina Department of Transportation (NCDOT) provided funding to the North Carolina Clean Energy Technology Center (NCCETC) at North Carolina State University (NCSU) to research the potential for producing renewable electricity from wind generated along high traffic corridors on North Carolina highways. For this study, staff at the NCCETC were assisted by Mr. Charles Wright, a wind energy expert, at Onyx, LLC. (collectively referred to as the project team).

The specific objective of the study was to characterize vehicle-induced wind patterns to assess and empirically quantify the potential for wind energy-based electric generation for remote power applications along North Carolina interstate highways. Per guidance provided by the NCDOT, the study focused on highway corridors within NCDOT Highway Divisions 5, 6 and 7. The project team developed a site ranking matrix that incorporated several important criteria which were necessary for meeting project objectives. Using these criteria along with online tools such as Google Earth, an initially large list of potential sites were reduced to about 15. The project team then visited each site, populating the matrix at each location. Once all sites were visited, they were all ranked based on the weighting factors assigned in the selection matrix. After completing the ranking process, the three sites selected for Divisions 5, 6 and 7 were U.S. 1 Northbound in southern Wake County, I-95 Southbound in Lumberton and I-40/I-85 Eastbound in eastern Guilford County, respectively.

Anemometers were installed to simulate the power generating potential of a given site. For this project two sets of anemometers and data logging equipment were purchased, facilitating concurrent wind measurement at two sites. The initial installations were at the sites within Division 6 and 7. After approximately two months of data collection, the installation in Division 7 was decommissioned and relocated to the Division 5 site in Wake County. The measured wind data was accessed and reviewed by the project team on a frequent basis as part of a rigorous quality assurance process. Following approximately one month of data collection at each site, the project team began analyzing the wind data to model wind energy generation potential. The analysis evaluated wind energy potential from a 300, 1,500 and 3,000 watt vertical axis wind turbine (VAWT). The data produced in the study also facilitates the correlation of energy potential to traffic patterns, providing a basis for determining optimum placement of wind energy generation systems along highways.

The modeling indicated that potential energy production varied widely from site to site based on a variety of factors, including number of lanes of traffic, median or center barrier type, roadside barrier type, and traffic volume and vehicle type. Based on the modeling conducted, a single 3,000 watt VAWT at the site with the best potential (Guilford County) could generate 818,000 watt-hours of electricity annually. The annualized cost to generate wind energy from the 3,000 watt VAWT was in the range of $100 per kWh. Like many new renewable energy technologies, the

lifetime costs will decease with increased deployments. Although this study estimates that wind energy costs are higher than solar generation, it is recommended that the NCDOT consider a Pilot installation of at least one VAWT that could be placed at multiple locations across NCDOT Highway Divisions This would facilitate a more refined assessment of the energy potential and cost under a larger-scale deployment scenario.

The bottom line findings of this study suggest that there is harnessable renewable wind energy produced by highway traffic.

Section 1 - Review of Literature

The concept of harnessing wind energy from highways, while present for some time now, has not yet been used to its complete potential. Lapointe and Gopalan [1] performed a two-dimensional computational fluid dynamics (CFD) study on the flow field over mini wind turbines placed near highways. In their study, four flow case scenarios were considered:

1. one car behind another car;
2. one truck behind a car;
3. one car behind a truck; and
4. one truck behind another truck.

Their study concluded that the power output increased by an average of 317% for all scenarios when compared with the isolated (no vehicle) turbine case.

Wenlong Tian et al. [2] performed three-dimensional CFD simulations based on Reynolds-Averaged Navier Stokes equations to evaluate the performance of vertical axis wind turbines (VAWTs). Their study considered two types of vehicles - cars and buses. The vertical axis wind turbines were designed to be placed on the median of the highway and considered five scenarios:

1. one car in the passing lane;
2. one bus in the passing lane;
3. two cars moving in opposite directions in the passing lane;
4. one car in the fast main lane; and
5. one bus in the fast main lane.

Based on their analysis, the VAWT rotor generated the highest power coefficient from the wake of a bus on the passing lane which was approximately 7.5 percent higher than the scenario with one car traversing the passing lane. Their study also revealed that the VAWT rotor could not generate power from vehicles on the fast main lane due to weak wakes created due to the larger distance between the rotor and the vehicle in comparison to the other lanes.

Shreyas S Hegde et al. [3] (2016) developed a model to study the power generated from horizontal axis wind turbines mounted on overhead shafts. Their study included a CFD analysis to determine the height at which turbines could be mounted on highways to harness the energy from the pressure difference generated around moving vehicles. Structural analysis of the turbine was also done to determine a light weight low cost material for the turbine. Based on their analysis of a moving vehicle with speeds up to 95 miles per hour, 1.167 to 2.28 kilowatts (KW) of power was generated when the turbines were placed at 18 feet. Based on their structural analysis, Epoxy-glass was deemed as the appropriate choice for turbine material. Their study concluded that an average of 42,000 cars would be required to charge a 12 volt 40 amp-hour battery. According to the US Department of Transportation, the average annual daily traffic among the most travelled urban highways is around 300,000 [4]. This would allow for seven such batteries to be charged which would be sufficient for providing power for a variety of purposes.

Taskin et al. [5] designed a combined solar and wind system to be planted on the median of the highway. Their system used a multi-stage Savonius rotor to generate power from the wind produced by cars. The primary goal of this study was to select the optimum number of solar panels, wind turbines and batteries to meet annual power requirements. According to their study, 16 solar photovoltaic (PV) panels, 5 wind turbines and 278 batteries (12volt, 6 amp-hours) were optimal for energy requirements per kilometer of highway.

Bani-Hani et al. [6] assessed the feasibility of highway energy harvesting using a vertical axis wind turbine. Their study found that moving highway vehicles can produce wind speeds up to 24 meters per second depending on size and speed of vehicles. This translates into wind hitting the turbine blades at speeds of up to 6 meters per second with an average wind speed of 4.4 meters per second. The study found an optimal height for maximum wind energy harvesting at 1.5 meters from the ground where average wind speeds reaching the turbine were 5 meters per second. Through experimental testing on King Fahad Bin Abdul Aziz highway, the turbine had an overall efficiency of 34.6 percent for low wind speeds below 5 meters per second.

Venkatesh et al. [7] investigated modified Savonius wind turbines in curtain arrangements located in the middle of a highway. Wind data is collected with and without vehicles and shows an average increase of 1.8 meters per second in wind speed from light vehicles and an average increase of 2.4 meters per second from heavy vehicles. These values are compared to a base average of 6 meters per second wind speeds with no vehicles. The study also concluded that implementation of vertical axis wind turbines on road dividers can provide effective power output and can be installed on many highways as only width is a design constraint.

Mashyal et al. [8] researched and analyzed the design of highway wind electric generation. They designed a wind turbine to be integrated with highway medians using the wind draft created by passing vehicles to generate electricity. Using average vehicle speeds of 70 kilometers per hour and an average wind speed of 4.5 meters per second, the electricity generation is approximately 200 Watt-hours. The researchers concluded that, while a single turbine is unlikely to generate meaningful power, a collection of wind turbines on a long strip of highway has the potential to generate large amounts of energy which can be used to power public amenities or sold back to the grid.

Anjum et al., 2016 [9] designed and tested a combination of common vertical axis wind turbines specifically for the sites having low wind speed availability. This combination of Savonius and Darrieus rotor blades on a common shaft provides the benefits of both low cut-in wind speeds and good efficiency. This combination has been used to capture the wind power available on the highways due to the movement of the vehicles. Savonius rotor blades being self-starting at low wind speeds help the Darrieus rotor blades to rotate which have greater efficiency than the Savonius configuration. Average wind speed available at the highway during this study was 4.8 meters per second. Up to 37 percent efficiency is achieved by using this combination at a tip speed ratio of 0.9 and with no overlap conditions. With the increase in tip speed ratio, the overall efficiency and power coefficient increases. At high wind speeds, the tip speed ratio and power coefficient decreases.

Jong-Jo Lee and Jae-Kyoo Lim, 2013 [10] studied a hood-type vertical axis wind turbine embedded on highway median strip. This study analyzed the potential for wind turbines to produce electricity generated from wind by passing cars and buses. Also, using CFD and an interpreter program, the study evaluated wind turbine performance and applied the twist-savonius blade. The results of this study anticipates that this wind turbine system is expected to produce the power required for safety lamps on the road.

Santhakumar, S. et al., 2019 [11] designed, fabricated, and tested a wind turbine for power generation applications in rural areas. Vertical Axis Wind Turbines were selected to harness the energy from wind through the drag forces induced due to vehicular movements. Various parameters were analyzed for the design of a low-cost wind turbine. A Savonius blade was selected for the design, which could be accommodated on the median of highways. By using recycled materials, a low-cost wind turbine was fabricated at a cost of approximately $117.50. The wind turbine was placed on the houses and on the highway medians to test the power output at various operating conditions. The calculated average electricity demand during power cuts in the selected rural houses was approximately 0.2–0.6 kilowatt-hours per day. Average generated electricity from the turbine at highway locations was observed to be around 0.67 kilowatt-hours per day. The levelized cost of electricity (LCOE) of the generated electricity from the proposed wind turbines on highways was calculated at approximately $0.04/kWh. The LCOE of the proposed design is relatively cheaper when compared with the conventional horizontal axis wind turbines. The energy demand during power outages was met completely when the wind turbine was placed on the highways.

Section 2 - Analysis for Determining Sites for Data Collection

This section of the report addresses the process undertaken to identify potential candidate sites for deployment of anemometers. The anemometers measure wind speed and direction and are intended to quantify turbulent wind patterns in the wake of passing large vehicles, particularly tractor-trailers travelling at a high rate of speed. The anemometers are thus the best surrogate for determining the power generating potential of a given site. To fulfill the mission of the project, anemometers were installed at carefully selected locations along either an interstate highway or heavily-travelled corridor along a United States (U.S.) highway.

Candidate sites were evaluated within the project area of study, which included NCDOT Highway Divisions 5, 6 and 7. The specific counties associated with these highway divisions are as follows:

Table 2-1 Highway Counties

Counties in NCDOT Highway Division 5	Counties in NCDOT Highway Division 6	Counties in NCDOT Highway Division 7
Durham	Bladen	Alamance
Franklin	Columbus	Caswell
Granville	Cumberland	Guilford
Franklin	Harnett	Orange
Vance	Robeson	Rockingham
Wake		
Warren		

Characteristics of Candidate Sites

The basic attribute of a candidate site is one that is along a highway corridor that has a high volume of truck traffic and that has a speed limit that facilitates the traffic to travel at a high rate of speed. The combination of high-volume truck traffic travelling at a high rate of speed maximizes the potential to generate turbulent wind flow which is optimum for power generation. Other key site factors that were considered in the selection of candidate sites included:

- Proximity to existing highway lighting infrastructure;

- Presence of a guard rail for protection of anemometers and data logging equipment and to preclude traffic incursions;
- Sufficient and reasonably level terrain behind the guard rail to ensure secure and safe installation of equipment;
- Availability of mobile data reception to support transmission of measured wind data to the HoboLink server; and
- Site-specific factors that could impact frequency and/or speed of truck traffic in the vicinity of the anemometers and/or that could impede or enhance turbulent wind flow, including:
    - The number of lanes along specific highway corridors;
    - General wind obstructions (such as trees or other natural or man-made obstacles);
    - Proximity to highway ingress and egress points such as exit and entrance ramps, rest stops, truck weigh stations, etc., that result in traffic moving away from the right lane; and
    - Bridges, overpasses and underpasses.

Key highway corridors evaluated in each NCDOT Highway Division include:

- Highway Division 5:
    - Interstate 85 in Durham, Granville, Vance and Warren Counties;
    - Interstate 540 in northern Wake County
    - U.S. Highway 1 in southern Wake County between U.S. Highway 64 and the I-40/440 Junction;
- Highway Division 6:
    - Interstate 95 in southern Cumberland and Robeson Counties;
- Highway Division 7:
    - Interstate 40/85 in western Orange, Alamance and eastern Guilford Counties, between the initial merging of I-85 and I-40 in Orange County and the splitting of these two roadways in Guilford County.

Based on the siting criteria described above, the three sites selected for wind measurement installations are shown in Table 2-2.

Table 2-2 Site Locations for Anemometer Installations

NCDOT Highway Division	Location Description	County	Closest Mile Marker	Site Latitude (°N)	Site Longitude (°W)
5	U.S. Highway 1 Northbound	Wake	101	35.76°	78.76°

6	Interstate 95 Southbound	Robeson	21	34.65°	79.01°
7	Interstate 40/85 Eastbound	Guilford	135	36.06°	79.61°

It should be noted that since two sets of equipment were purchased for this project, two anemometer installations collected data concurrently at any given time. As such, the dates for each installation were:

- NCDOT Highway Division 7 (Guilford County) – 16 April 2019
- NCDOT Highway Division 6 (Robeson County) – 17 April 2019
- NCDOT Highway Division 5 (Wake County) – 19 June 2019

It should be further noted that the equipment installed in Division 5 was relocated from Division 7 after approximately two months of data collection at the former site. This facilitated an extended timeline for collecting data in Division 6, as will be discussed in more detail below.

Pictures of the anemometer installation sites in Highway Divisions 5, 6 and 7 can be found in Figure 2-1, Figure 2-2 and Figure 2-3, respectively.

Figure 2-1 Anemometer Installation: NCDOT Highway Division 5, U.S. Highway 1 Northbound - Cary, Wake County

Figure 2-2 Anemometer Installation – NCDOT Highway Division 6, Interstate 95 Southbound - Lumberton, Robeson County

Figure 2-3 Anemometer Installation – NCDOT Highway Division 7,
Interstate 40/85 Eastbound - Whitsett, Guilford County

As previously mentioned, the project team decided to extend the timeline for measuring wind data in NCDOT Highway Division 6 in order to investigate the potential benefits of installing the anemometer installation in a highway median versus along the shoulder per the project's protocol. After reviewing several sites along Interstate 95 and conferring with NCDOT, it was decided to relocate the Division 6 anemometer installation from the shoulder of Interstate 95 southbound in Lumberton to the grassy median of Interstate 95 just north of interchange 31 (NC Highway 20) in St. Pauls, Robeson County. Due to presence of the ingress onto I-95 from NC Highway 20, it was decided to locate one of the anemometers closer to the (left-most) southbound lane to capture the faster moving vehicles while the second anemometer was positioned near the center of the median. This installation is shown in Figure 2-4.

Figure 2-4 Anemometer Installation – NCDOT Highway Division 6, Interstate 95 Median - St. Pauls, Robeson County

The Interstate 95 site was selected because the median was narrow allowing the wind to be captured from both directions. While this site ranked high for siting criteria factors, the measured wind speeds were less favorable than the Lumberton site along the shoulder of Interstate 95, ten miles to the south. One potential cause for the less-favorable wind conditions could be related to the flat open and un-obstructed median, as discussed above, and the combative nature of opposing traffic directions, that is discussed further in Section 4. As such, the data captured from this site was not included in the analysis of potential wind generation.

Section 3 - Test Equipment Selection, Specification, and Calibration

As discussed in Section 2 of this report, anemometer installations were placed at carefully-selected sites along roadways in NC Highway Divisions 5, 6 and 7. After researching equipment options, it was determined that the most prudent approach to developing a robust data set included siting two anemometers at each site. This approach facilitated:

- Collection of back-up data in case of an equipment malfunction;
- Assessment of highway-generated wind measurements at two heights; and
- Study of experimental configurations against a base-case measurement scenario (to be discussed in more detail later in this section).

For each installation site, the following equipment requirements were outlined as a guideline for identifying the appropriate supplier:

1. The ability to record wind speed and direction in at least two (2) locations at each selected test site;
2. Local data logging and recording capability;
3. Remote data monitoring and collection capability;
4. Self-powering to allow for continuous autonomous operation; and
5. Ability to set up, use, and break down at multiple locations with a minimum of time, effort and personnel.

The company that was determined to be best-suited to providing the equipment, service and expertise to meet the objectives of this project was Onset Computer Corporation, based in Bourne, Massachusetts. Once the project team had defined the specific equipment needs for each site, Onset's sales team was consulted to help compile a complete list of materials and equipment that met the required specifications.

The following parts list (Table 3-1) was compiled for each wind measurement installation based on the requirements of maximizing efficiency of the testing program as laid out above (see Appendix C – Technology Specification Sheets for details). Each set of wind measurement equipment was specified to consist of:

1. A central weather station/data logger for collecting and transmitting data collected by connected sensors;
2. A solar panel to power the weather station data collection and transmission system;
3. Two remote anemometers to measure wind speed and direction at different locations, heights, and potential orientations/configurations; and
4. Tripods and associated support for mounting the equipment specified above.

Table 3-1 Detailed List of Supplies for NC Highway Wind Project

Supply Description	Number of Units Required
RX3000 Remote Monitoring Station-RX3003-00-01	2
Communication: Cellular Unit-Included Service Plan: US Max-Connect Plan - RX3000-SP-807	2
15 Watt Solar Panel-SOLAR-15W	2
Davis Wind Speed and Direction Smart Anemometers-S-WCF-M003	2
Wireless Sensor Receiver-RXMOD-RXW-900	2
Wireless Wind Speed and Direction Anemometer-RXW-WCF-900	2
Weather Station 3-Meter Tripod Kit-M-TPA-KIT	4
3m mast [extension]-M-MPA	2
Cable Caddy [cable organizer]-M-CDY	2
Reolink Go Cam*1 + Solar Panel *1 4G+LTE Camera	2
Prepaid Unlimited 4G+LTE Data plan for camera (4 months)	2
Safety Equipment for Installation	1

- **RX3000 Remote Monitoring Station:** the RX3000 is the basis for the entire Onset Data Logging system. It contains the wireless communication points, onboard memory for local data recording, and is the connection point for the anemometers.
- **Communication Criteria – US Max-Connect Plan:** to allow for the remote connection from the remote monitoring station through the Hobolink website, a data plan was needed to provide the connection. Onset's connection plan uses 3G wireless network protocol for this connection, which provides greater reliability and wider coverage than a newer 4G network.
- **15-Watt Solar Panel:** provides power to the remote monitoring station. The onboard battery has a four-day capacity, and the 15W solar panel is sufficient to recharge the entire battery in a day of full sun.
- **Davis Wind Speed and Direction Anemometer:** wind measurement device for the roadway installation system. Each installation includes two colocated anemometers connected to a remote monitoring station utilizing the Hobolink software.

- **Wireless Sensor Receiver:** connection point for the remote anemometer via Bluetooth connection. This allows for more flexibility for locating the second anemometer further away from the monitoring station and collocated local sensor.
- **Wireless Wind Speed and Direction Anemometer:** the remote sensor unit for the weather station setup. Specified and ordered to provide the ability to measure winds at two separate locations in the same vicinity for selected sites, to gather more data on potential wind patterns, and varying conditions.
- **Weather Station 3 Meter Tripod Kit:** mounting equipment to connect the anemometers and remote monitoring station. To improve equipment reliability, each tripod kit includes electrical grounding for the system, and guy wires for support from extreme winds or inclement weather. A height of 3 meters for the tripod provides a wide range of options for heights at which to mount the anemometers.
- **3 Meter Mast Extension:** another mounting option to provide greater flexibility for measurement of wind levels at varying heights based on site location. The taller mast also allows for greater flexibility for mounting additional equipment on the tripods, such as cameras, other sensors, the solar panel, etc.
- **Cable Caddy Organizer:** because of the cabling that is included with the locally-mounted anemometer, solar panel, and monitoring station, the cable caddy was ordered to keep everything orderly and prevent loose cables or wires snagging or leading to potential damage to other components.
- **REOLink Go*Camera Package:** a 4G wireless camera and self-contained solar panel was specified to monitor traffic and the weather station equipment. This allows monitoring of traffic patterns, to verify any correlation between wind speeds and heavy traffic. Additionally, the camera provides the ability to ensure the physical security of the weather station site or any potential obstructions.

Following receipt of the selected equipment, the project team assembled the system and commenced a series of bench tests to confirm proper operation. A large fan was employed to test the operation of each anemometer. The fan was placed at varying distances and directions relative to each of the four assembled anemometers to confirm that measured wind speeds and directions were accurate and that the data was recorded correctly. Additionally, the bench testing process included logging into the HOBOnet site to assure remote access of recorded data. Once the bench testing was completed, the system was partially dis-assembled to facilitate transport to the installation sites.

Section 4 - Installation and Takedown

Prior to each installation, the project team coordinated with the specific NCDOT Highway Division to provide a safety patrol vehicle to assist with the safe installation of equipment. The NCDOT safety patrol vehicle parked immediately upstream of where the equipment installation occurred which provided protection to project team personnel.

Per NC State University policy, a project safety plan was developed to assure that best practices were implemented to minimize risk to project team personnel during equipment installation. The safety plan closely followed NCDOT's Workplace Safety Manual, specifically the document's Form M-3 Safety Checklist. Each project team member that participated in site equipment installations were provided with hardhats, appropriate safety vests and steel-toe shoes. Additionally, safety gloves were made available if needed.

As discussed in Section 2 of this report, the anemometers and data logging systems were deployed as follows:

- NCDOT Highway Division 7 (Guilford County) – 16 April 2019
- NCDOT Highway Division 6 (Robeson County) – 17 April 2019
- NCDOT Highway Division 5 (Wake County) – 19 June 2019

Each of the above sites were determined to meet the criteria previously discussed for this project. The anemometers were situated approximately three feet behind the roadway guardrail. The primary anemometers were installed at a height of approximately 5.5 feet above ground level while the secondary anemometers were installed at a height of approximately 7.5 feet above ground level. The two anemometers were horizontally separated by approximately 15 to 17 feet. It should be noted that if vertical axis wind turbines are installed along North Carolina highways, they would need to be a minimum of 5.5 feet from the face of guardrail, unless the guardrail post spacing is reduced to 3'-1 1/2". With reduced post spacing, the wind turbine can be mounted 3.5 feet behind the face of guardrail.

Within the first month of data collection, the project team met several times per week to review the information collected, to assure that the collected wind data was properly logged, and to commence discussion on the data analysis methodology. Additionally, wind speed and direction data was downloaded from the National Weather Service observation stations closest to the Highway Division 6 and 7 sites. The purpose of this activity was to compare data recorded at the two highway measurement sites to the NWS observations to see if it can be determined if the measured wind along the highways was being dominated by vehicle-generated turbulence or the ambient wind patterns. The NWS sites used for this comparison were the Burlington Alamance Airport in Alamance County, located approximately 7 miles northeast of the Division 7 site and the Laurinburg-Maxton Airport in Scotland County, located approximately 19 miles southwest of the Division 6 site. From review of the NWS observations it was determined that the measured wind data at the highway anemometers were a combination of both factors. Using the installed cameras at the anemometer sites, it was evident that measured wind speeds at both Division 6 and Division 7 sites increased after approximately 7 am, which correlated with an increase in the frequency of truck traffic on these roadways. Conversely, a noted decrease in measured wind speed occurred after 9 pm, correlating with a marked decrease in the frequency of truck traffic at each site.

The field study revealed that in order to collect data from anemometers in a bi-directional wind flow environment, a wind vane or wind guidance system may be required. Therefore, in order to maximize the impact of turbulence-generated wind flow on the anemometers, a wind guidance apparatus (WGA) was added to the anemometers for this study. The WGA was fabricated by Onyx using thin sheet metal that could be mounted on the anemometer structure and was configured to maximize wind capture. The WGA was added for two reasons, the first being to maximize the capture of the turbulent air flow from the specific direction that it was created. The second reason, was to attempt to block combative turbulent air flows from opposing traffic flows, that would be present in the median. This study excluded data measured from the median of I-95 because the measured wind speeds were much lower. Further analysis would allow the testing of a hypothesis, where in a WGA for both directions of traffic would be installed to maximize capture from both directions of traffic travel, while limiting the reductive interaction of opposing wind directions. Finally, the WGA was installed on the primary anemometer only to enable a more robust comparison between an anemometer with and without the appurtenance. Further WGA design work is needed to improve wind capture and wind turbine application processes. Onyx will continue to investigate methods to facilitate the collection of this data and review what WGA designs can be applied to VAWTs.

As discussed above, on June 19, 2019, the Division 7 site was relocated from I-40/I-85 in Guilford County to a site on U.S. 1 North in Wake County, just south of I-40 (in Division 5). To collect additional data from the Division 6 site, this system remained operational through June 26 when that installation was relocated to the median of Interstate 95, immediately north of Exit 31 in Robeson County. Also, as previously discussed and for reasons previously postulated, the wind data collected at this site exhibited lower average speeds and lower gust speeds, and as such was not utilized in the wind energy modeling discussed in Section 6.

During September 2019, it was determined that a sufficiently large amount of data had been collected, and the anemometer installations located in Division 5 and Division 6 were dismantled, thus terminating all data collection activities for this project.

Section 5 - Vertical Axis Wind Turbine Research and Cost

Technical Background

Vertical-axis turbines were specifically chosen for this application, as the turbulent flow generated by air displacement from large vehicle traffic will not provide a consistent direction of airflow. Vertical axis turbines, unlike horizonal axis turbines, can accept wind from any direction without changing their orientation while also accepting turbulent air flow much more efficiently. The following are other inherent advantages of vertical axis wind turbines making them more desirable for the project application:

- Cheaper production and procurement costs than comparably-sized axial flow turbines
- Smaller physical footprint than comparably-rated axial(horizontal) flow wind turbine
- Better suited for installing in large arrays, i.e. more able to "stage" multiple turbines in line at a single site.

Technical Definitions

- **Cut-in speed** is the minimum wind speed at which a rotating wind turbine will begin to generate electricity. This speed will vary based on the size of the turbine and generator, number and design of the blades, and the type of turbine (axial or vertical).
- The **rated wind speed** is the speed at which the wind turbine will produce its rated output power. This is also a function of the size and type of generator, in the same fashion as the cut-in speed.
- **Maximum Speed** is the highest wind speed the wind turbine will generate power at before shutting off to protect itself from excessive forces due to extreme wind speeds.
- **Cut-out speed** is the speed at which a wind turbine's over speed protection features will engage to prevent damage to the wind turbine and attached generator. There are several ways this can be implemented, including mechanical brakes, electrical shunt trips, or blade feathering. By design, there is usually a range at which these protective devices will begin engaging depending upon specific conditions and wind turbine configuration.
- **Rated Output** is the design power available at the rated wind speed of the turbine. This is also referred to as **nameplate rating and does not necessarily represent the maximum potential output of the unit**
- **Rotor Diameter** is the distance across the circle traced by the blade tips of the turbine.
- **System Height** is measured overall height of the wind turbine assembly, from ground level of the mounting system to the top of the turbine hub, in meters.

Market Background

Based on research conducted in support of this project, the market for small, commercially-available wind turbines in the 300- 1,000 watt range is currently limited to a small number of manufacturers with very few product offerings. Further, most of the current offerings are from overseas distributors with very little technical information available and very little real-world operating data. Vertical axis wind turbines are well suited for the project at hand since they can accept wind omni-directionally simultaneously. However, there is a relatively limited market for such turbines at a reasonable power rating and size for the application at hand.

Basis of Design Selection

Based on the above concerns, Colite Technologies, a manufacturer based in Columbia, South Carolina, was approached to use their turbines as the project's design basis. Colite is the first American wind turbine manufacturer to have one of their designs certified by the Small Wind Certification Council (ICC-SWCC), a member of the international code council. The turbine that was certified was the Colite DS-3000, a 3,000 watt vertical axis turbine. Due to the credibility this certification provides for their products, they were contacted to use their three main products as the basis for calculating potential output based on the collected wind data.

The DS series all have cut-in wind speeds of approximately 3 meters per second (6.71 mph) and rated rated wind speeds of less than 15 meters per second (33.55 mph). Table 5-1 below provides more information on the specifications of the three models that were used to calculate potential power generation, and Figure 5-1 through Figure 5-3 provide the power curves for each turbine.

Table 5-1 Colite Wind Turbine Specifications

Model	DS-300	DS-1500	DS-3000
Cut-in Wind Speed	< 3 m/s	< 3 m/s	< 3 m/s
Rated Wind Speed	13.5 m/s	12 m/s	12 m/s
Maximum Speed	15.5 m/s	15 m/s	15 m/s
Rated Output	300 W	1.5 kW	3 kW
Rotor Diameter	1.24 m	2.8 m	4 m
System Height	5.06 m	6.9 m	8.16 m
Turbine Cost	$3,585	$18,825	$26,625

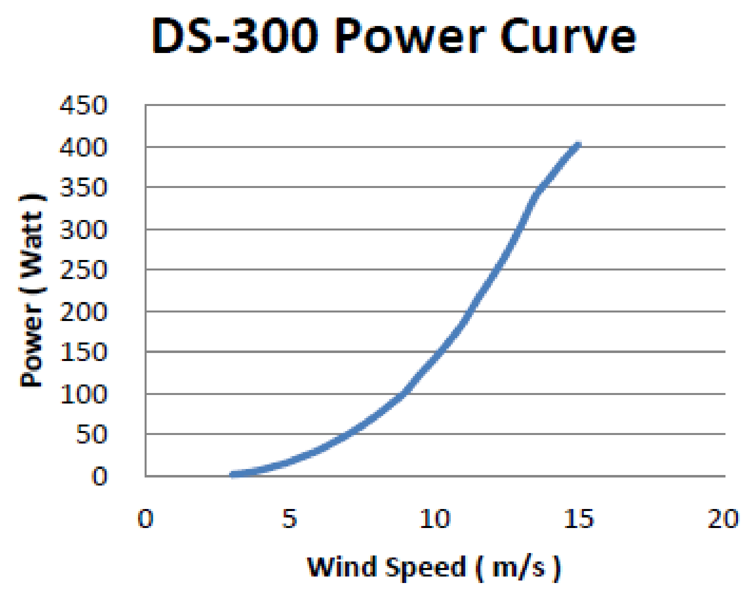

Figure 5-1 Colite DS-300 vertical axis wind turbine wind speed power curve

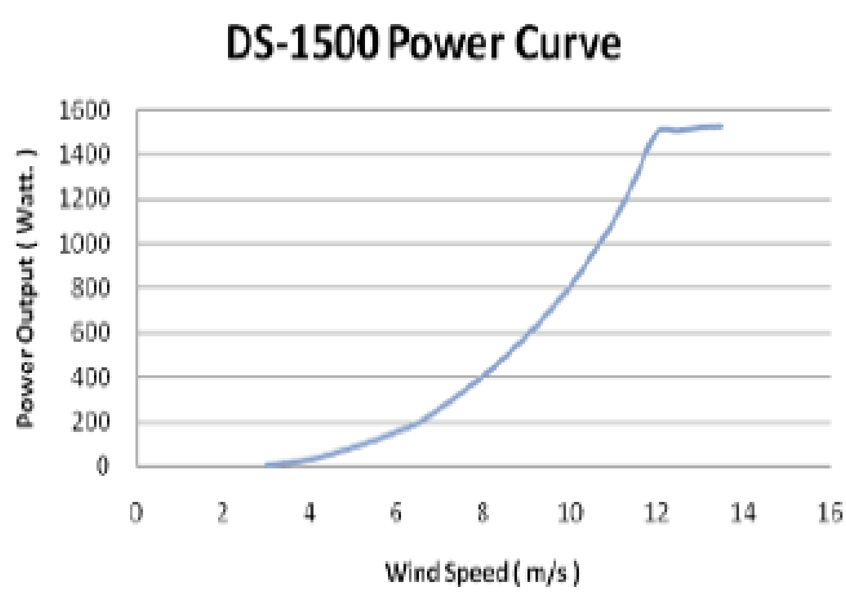

Figure 5-2 Colite DS-1500 vertical axis wind turbine wind speed power curve

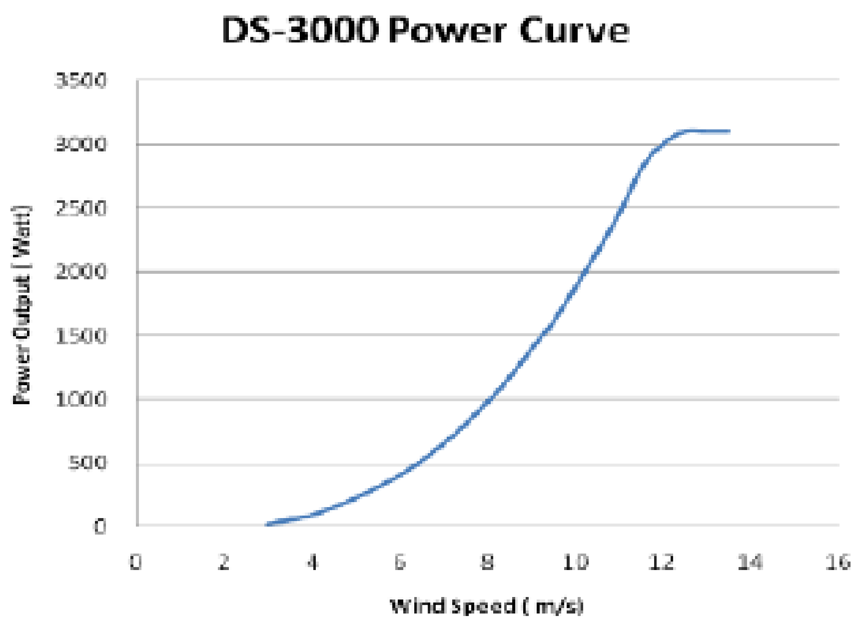

Figure 5-3 Colite DS-3000 vertical axis wind turbine wind speed power curve

Full data sheets and cost quotes for the three wind turbine models specified above can be found in the Appendix B – Colite analysis & Specifications.

Section 6 - Data Capture and Analysis

With all the specified equipment installed per the discussion in sections 2 through 5, the data analysis phase of the project began. The anemometers collected the average wind speed, gust, and direction data in real time via the remote monitoring stations (RMS). The data was then uploaded hourly to Hobolink's servers, which also provide an interface to review real-time site information, including connection status, latest data upload date and time, and any alarm conditions at the RMS. The Hobolink website also provided an interface for changing system settings such as units of measurement, update rates for the anemometers and monitoring station, and component names and ID information. Images of typical Hobolink data displays are shown below (Figure 6-1& Figure 6-2).

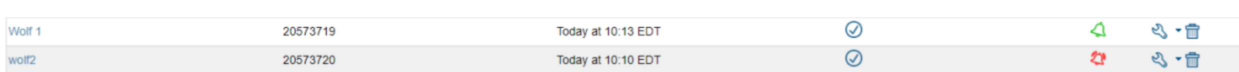

Figure 6-1 Default Hobolink Dashboard Display

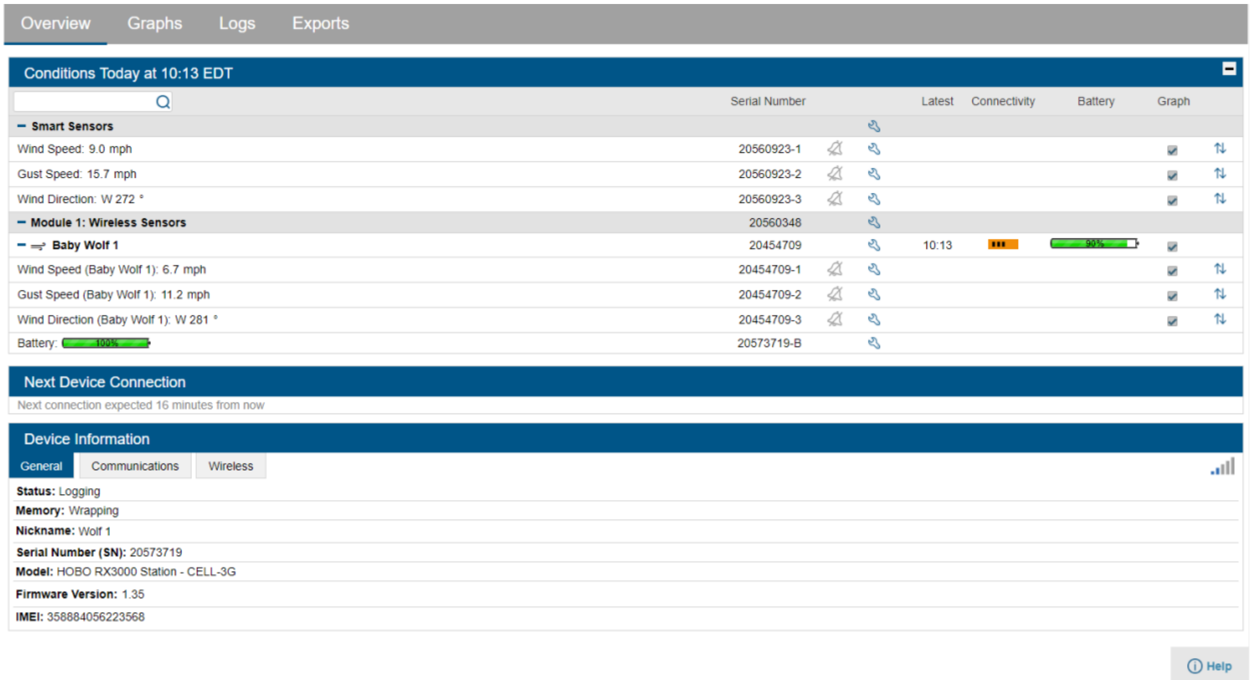

Figure 6-2 Device Status and Dashboard for a Weather Station in Hobolink

Data Sampling Terms and Rates

To provide a better context for how data were collected, recorded, calculated and analyzed, a brief description of related terms and system interactions follows.

- Logging Interval is the rate at which the data logger (the RX3000 RMS for this study) records data sent from the sensors. The minimum interval available is one minute.
- Sampling Interval is how often a measurement taken by the sensor (in this case the two Davis anemometers) is sent to the data logger for recording.
- To measure average wind speed, the anemometers average the wind speed over the length of the logging interval.
- To measure gust speed, the anemometers take the highest three-second wind speed recorded during the logging interval.

Data Sampling Frequency

As discussed in Section 4, during initial setup and deployment of the RMS, the sampling intervals were set via the Hobolink site interface to one minute, and the logging intervals to five minutes for all anemometers. Early in the data collection process the project team discussed concerns about the precision of the recorded wind data with respect to the potentially large quantities of wind information that could avoid being captured due to the one-minute sampling interval. By definition, turbulent wind flow exhibits high temporal and spatial variability. Therefore, the magnitude of a turbulent flow is best measured by maximizing data resolution (i.e., minimizing the sampling intervals). This initial concern was validated by observing a large differential between the measured average wind speed and gust speed. Theoretically, as the sampling interval is reduced, the difference between the observed average wind speed and average gust speed should trend toward zero.

As a result of these observations and concerns about the low resolution of the data being collected, the team changed the sampling rates for wind speed and gust data to the minimum available interval of ten seconds, and the logging interval was reset to the minimum allowable of one minute for both test sites on 24 May 2019. Within a few days of this adjustment, the larger data sets indicated a closer correlation of average wind speed with wind gust speed.

Testing Apparatus Modifications

In an effort to more efficiently capture wind from passing traffic in a single direction (due to the shape and configuration of the anemometers and the fact that the system was installed on the shoulder of the roadways) it was proposed to install a WGA around the anemometers to eliminate wind effects from directions other than oncoming traffic. This WGA was installed on the primary anemometer at the Guilford County (Highway Division 7) site on 29 April 2019 and the Robeson County (Highway Division 6) site had the WGA installed on 18 May 2019. The Guilford County location saw an increase in average wind speed and gust speed following the installation. The Robeson site exhibited a more modest increase in wind speed but a decrease in average gust speeds. A decrease in average the gust speed from the installation of anemometer WGA can be seen in (Table 6-1). The comparisons occurred over the following periods:

- Guilford County pre-WGA period – 17 April 2019 through 28 April 2019
- Guilford County post- WGA period – 30 April 2019 through 11 May 2019
- Robeson County pre- WGA period – 18 April 2019 through 17 May 2019
- Robeson County post- WGA period – 19 May 2019 through 31 May 2019

Initial findings indicate that the installation of a WGA did result in an increase in the average recorded wind speed. That said, quantifying and confirming the correlation between the installation of the WGA and an increase in wind speed would require a longer-term co-located and concurrent operation of both a guided and un-guided anemometer.

Table 6-1 Comparison of the average gust and average wind speed before and after installation of a WGA

	Site Location (County)			
	Guilford		Robeson	
Avg. Wind Speed (mph)	**Average**	**Gust**	**Average**	**Gust**
Before WGA	4.94	11.31	3.86	9.90
After WGA	6.77	15.16	4.08	9.04

Given the fact that the anemometer WGA had a net positive impact on the amount of wind energy captured, the WGA was included as part of the Region 5 (Wake County) installation in June 2019. It should be noted that the average wind speeds shown in Table 6-1 represent daily averages which includes nighttime periods when wind speeds drop off considerably, with many of those hours exhibiting values below the wind turbine cut in speeds. The diurnal variability of the measured wind speed is shown graphically (for the Guilford County site) in Figure 6-3. The vast majority of the wind energy generation potential occurs during the daytime hours due to the combined effect of higher traffic volumes and naturally higher ambient wind speeds during this period.

Observed Wind Patterns

There were several observations that could be made from a review of the wind data compiled from all of the sites:

1. The average wind speed and gust levels followed a diurnal pattern, as is illustrated with the data in Figure 6-3. The diurnal nature of the wind speed, defined by a noticeable drop off in the evenings and overnight, follows a logical pattern that correlates to the amount of traffic on the road. There is a potential that, ambient wind speeds during the summer months in North Carolina, which typically decrease dramatically after sunset and then gradually increase during the first few hours after sunrise, are also playing a factor.

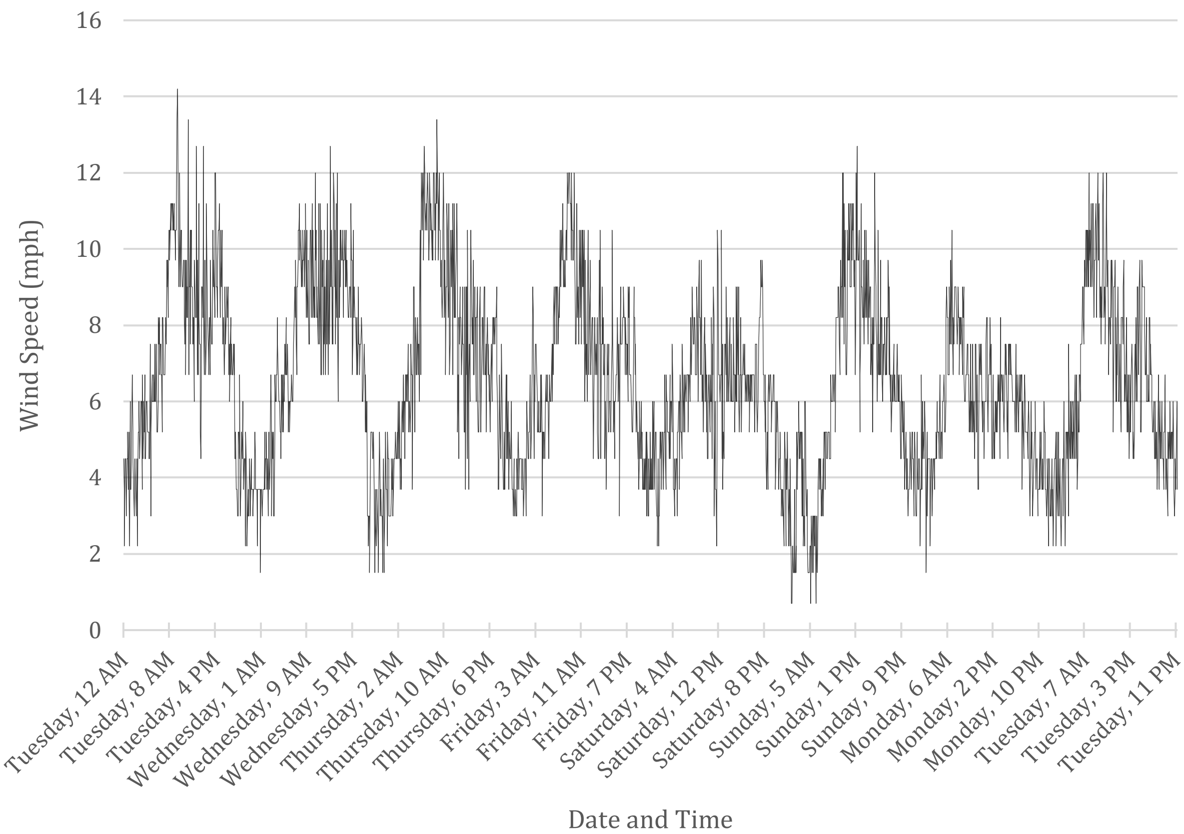

Figure 6-3 Sample wind speed data at Guilford County Site (post WGA) showing the diurnal wind pattern

2. The average wind speeds appear to be slightly higher during the week than during the weekend, which correlates well with the fact that truck traffic volumes are higher on weekdays compared to weekends. The correlation between weekday and weekend wind variation was not highly significant at all the sites however (see Table 6-2), and further testing may be necessary to confirm, disprove and/or better quantify the robust nature of this observation.

Table 6-2 Average wind speed for all three sites broken out into weekdays, weekends, and overall

	Site Location (County)		
Average Wind Speed (mph)	**Guilford**	**Robeson**	**Wake**
Weekday	6.09	4.15	4.25
Weekend	5.28	3.52	2.45
Overall	5.85	3.99	3.76

Colite Analysis

As mentioned in Section 4, the project team initiated discussions with the wind turbine technology provider, Colite, in May 2019, after it was determined that their vertical axis wind turbines were best suited as a basis for design for calculating usable power outputs based on the wind data that had been collected. Using wind data provided to Colite by the project team, the Chief Engineering Manager for Colite was able to model projected outputs for each of their turbine models at selected locations, using a methodology internal to their organization. The projected results from this modeling have been included in Table 6-3. In addition, the full data results are included in

Appendix B – Colite analysis & Specifications.

Table 6-3 Colite power production analysis for all three sites and all three turbines, including an internal annualized energy cost (for cost data refer to Table 6-5)

Site Location	Modeled Wind Turbine	Testing Start Date	Testing End Date	Potential Energy Produced (Wh)	% Energy from Gusts	Capacity Factor	Annualized Energy Cost, $/kWh
Guilford County	DS300	5/25	6/18	6,517	60%	3.77%	$ 54.26
Robeson County	DS300	5/25	6/22	4,211	72%	2.09%	$ 97.96
Robeson County	DS1500	5/25	6/25	24,944	99%	2.24%	$ 96.15
Robeson County	DS3000	5/25	6/25	34,972	76%	1.57%	$ 96.99
Wake County	DS300	7/9	7/27	2,398	65%	1.85%	$ 110.59
Wake County	DS1500	7/9	7/27	9,961	72%	1.54%	$ 139.80

Wake County	DS3000	7/9	7/27	19,619	71%	1.51%	$ 100.39

Since the purpose of the research is to study the effects of wind created by vehicle traffic to power wind turbines, it was determined that incorporating the gust component measured by the anemometers would provide a more realistic projection of potential output. As shown in Table 6-3, Colite's simulation accounted for the gust impacts. Wind data for the Guilford site was collected between 5/25/19 and 6/18/19; data for the Robeson site was collected between 5/25/19 and 6/25/19; and data for the Wake site was collected between 7/9/19 and 7/27/19.

Internal Analysis

In addition to the analysis conducted by Colite's engineering team, and in order to verify the Colite results, the NCSU/Onyx project team conducted an internal analysis. Our internal analysis utilized the power curve data supplied by Colite for their three turbine models. All three site locations were analyzed, calculating the total potential energy output for each VAWT model for a given time period. These calculations largely produced results that were of the same magnitude of the results provided by Colite, and can be found in Table 0-4 (full analysis presented in Appendix A – Internal turbine analysis). Unlike the Colite modelling, the internal analysis did not utilize the wind gust data. However, the intent of this particular analysis was to validate the robustness of the Colite results which it is believed to be achieved via this analysis. While the energy production values are not exactly the same, without gust data the values are within a reasonable error margin for different models. Furthermore, the gust values are in part accounted for in the average wind speed values and are therefore not neglected, but the wind gusts full potential may not be accounted for.

Table 0-4 Internal power production analysis results for all three sites and turbines

Location	Turbine Type	Testing Period (Days)	Potential Energy Production for Testing Period (Wh)	Annualized Energy Production (Wh)
Guilford	DS300	25	5,432	79,307
	DS1500		20,448	298,536
	DS3000		56,046	818,269
Robeson	DS300	32	4,024	45,900
	DS1500		14,866	169,566
	DS3000		40,696	464,187
Wake	DS300	67	2,652	14,446
	DS1500		10,178	55,448
	DS3000		27,868	151,820

Deployment Considerations

It should be noted that the wind generation modeling results presented in Tables 6-3, 6-4 and 6-5 are based on a single VAWT. When considering VAWT deployment it should be recognized that the technology is scaleable and thus multiple turbines can be deployed over a small area to produce additional electricity.

All models have inherent weaknesses, mostly due to not accounting for certain parameters that can impact what the model is simulating. When reviewing the modeling methods for projected turbine power output, there were a few factors that both the Colite and internal modeling efforts did not account for:

- Wind energy density – The amount of power present in wind, amongst other factors, is dependent on the volume and speed of the air displaced. This is to say that a larger vehicle such as a tractor trailer will produce a more energy dense wind than a small motorcycle. While wind speed registered by the anemometer accounts for some portion of this factor since a denser wind will travel further and create a higher wind speed further from its origin, the data gathered does not account for wind density. As a large wind turbine has a higher moment of inertia and greater mass than a smaller one, a smaller turbine would be affected more by the wind generated from both a passing tractor-trailer and a passing motorcycle, but produce a small amount of power. Meanwhile a larger turbine would produce more power with larger gusts of wind, but may not produce any power with a lower density wind caused by smaller vehicles. Therefore, the power output for the same wind data would not be directly correlated to the power curve, but also with the density of the wind produced. As the anemometer is such a small device, the wind speed and gusts registered, while technically correct, may not fully represent the actual amount of energy available in the wind for the variety of turbine sizes analyzed.
- Volume & duration of traffic – A long line of traffic can potentially create a cumulative wind effect that would keep a wind turbine generator set spinning faster and longer than a smaller anemometer, due in part to the larger rotational inertia of the turbine than the anemometer. The anemometer's blade velocity will decrease much quicker than a larger turbine's would, much in the same way that it will start with less energy dense wind as explained above. Since there wasn't real-time monitoring of traffic patterns at any of the sites while wind data was being collected, the cumulative effects of high volumes of traffic, especially larger truck traffic, couldn't be accounted for in the calculated wind power output.
- Instrument height variation – One of the goals of the project was to measure differences in available wind energy at different heights. It was believed that these differences could be quantified by placing two anemometers at different heights at each installation. However, after analyzing several months of cumulative data, it is concluded that for a robust

determination to be made, the two wind turbines would have to be co-located. Even though the two anemometers were horizontally separated by only about 15 feet, the large spatial variation of turbulent flow rendered this analysis as inconclusive.

Average Cost of Wind Generation

Wind speeds varied widely between test sites due to a variety of conditions driving the average cost of generation in $/Watt-hour to vary greatly as well. Since the price quotes from Colite were only for the turbine itself, to include the costs of installation, inverters, conduit, conductors, and other material costs, a 50% adjustment factor has been added to the overall cost of each turbine. This adjusted price point has been incorporated into the cost model that was used to calculate an annualized cost of generation. The costs were annualized assuming that the time period over which the wind data was collected would be representative of the entire year, and thus 365 days of wind energy was extrapolated. The cost breakdown by site and turbine type can be found in Table 0-5.

Table 0-5 Financial analysis for all three sites and turbines analyzed using the internal model and Colite's cost data and levelized for a single year

Site	Generator	Nameplate AC Capacity (W)	Potential Energy Production (Wh)	Annualized Energy Production (Wh)	Turbine Cost	Adjusted Installed Cost	Annualized Energy Cost, $/kWh
I-40/85 Guilford County	DS300	300	5,432	79,307	$ 3,585	$ 5,378	$ 67.81
	DS1500	1,500	20,448	298,536	$ 18,825	$ 28,238	$ 94.59
	DS3000	3,000	56,046	818,269	$ 26,625	$ 39,938	$ 48.81
I-95/ Robeson County	DS300	300	4,024	45,900	$ 3,585	$ 5,378	$ 117.16
	DS1500	1,500	14,866	169,566	$ 18,825	$ 28,238	$ 166.53
	DS3000	3,000	40,696	464,187	$ 26,625	$ 39,938	$ 86.04
US-1 Wake County	DS300	300	2,652	14,891	$ 3,585	$ 5,378	$ 361.13
	DS1500	1,500	10,178	57,154	$ 18,825	$ 28,238	$ 494.06
	DS3000	3,000	27,868	156,491	$ 26,625	$ 39,938	$ 255.21

The financial values found in Table 0-5 and Table 6-3 use the same financial basis. Annualized energy cost from the internal models and Colite model varied from as low as $54.26/kWh to as high as $494.06/kWh. This range can be explained by the variability in modeling energy output for a single year. It is worth noting that the annualized energy cost is not the levelized cost of energy for the turbines over its life. It is assumed that the cost of the project is only spread over one year. This was done to enable a comparison against other technologies on a one-year basis since the life of different projects varies a great deal.

The economic analysis discussed above is based on the retail cost for the three VAWT models purchased from Colite and does not account for the possibility of lower cost VAWTs being available directly from manufactuers. Onyx has conducted separate research and engaged in discussions with Colite. From these discussions,Onyx asserts that it could be possible to obtain a DS3000-equivalent model at a cost of $12,500 with an additional $7,500 needed to make the system operation ready, if purchased directly from a manufacturer At this price, the installed system may cost as little as $20,000, which would yield a slightly better annualized energy costs as shown in Table 0-6.

Table 0-6 Financial analysis for the DS3000 for an installed cost of $20,000, using Colite's Production Data

Site	Generator	Nameplate AC Capacity (W)	Measured Potential Energy Production (Wh)	Normalized Annual Energy Production (Wh)	Installed Cost	Annualized Energy Cost, $/kWh
I-40/85 Guilford County	DS3000	3,000	56,046	818,269	$ 20,000	$ 24.44
I-95/ Robeson County	DS3000	3,000	40,696	464,187	$ 20,000	$ 43.09
US-1 Wake County	DS3000	3,000	27,868	156,491	$ 20,000	$ 127.80

The viability of obtaining systems at this cost at scale has not been confirmed and is representative of the discussions that Onyx has undertaken. Furthermore, it is unclear if this cost includes any overhead, engineer design, or installation costs, which would increase the final cost for any systems that are installed for more than testing.

Solar Economic Comparison

To provide a basis for comparison between two technologies that might operate similarly in an isolated fashion and serve a small load, a solar system was designed and modeled. The comparison between similar generation capacities with alternative economic viability was completed at the same location as the test site on I-95 at exit 31. This site was selected due to the space available in the median of Interstate 95 at this location.

The modeling for the solar array was completed using the software Helioscope. Helioscope is a photovoltaic specific solar modeling software that considers all of the locational system impacts and provides system specifications and performance metrics which include the nameplate capacity and the system's annual energy output. The system designed had a capacity of 730 Watts (see Appendix D – Solar Comparison Model for full model details). For a direct comparison, the solar energy production and costs are also annualized. The solar energy production and cost are shown in Table 0-7.

Table 0-7 Financial analysis for a solar system located at the Robeson county location for comparison

Site	Generator	Nameplate DC/AC Capacity (W)	Capacity Factor	Calculated Annual Production (Wh)	Average Cost, $/W-dc	Total System Cost	Annualized Energy Cost, $/kWh
I-95/ Robeson County	Solar PV	730/1,000	14.91%	953,300	$ 3.00	$ 2,190	$ 0.77

The costs provided for both the wind system and the solar system exclude a battery which would be necessary to provide uninterrupted power to whatever electrical load was being serviced. It is assumed for the purpose of this study that the battery would be the same size (and therefore, of similar costs). As the focus of this study was wind and not storage, and since the battery would be the same capacity for either solar or storage, its exclusion is justified and enables a clear and simple comparison between energy production costs of two technologies. It should also be noted that the economic comparisons of wind versus solar power generation does not factor in the land-use requirements of each technology. Additionally, the analysis of the viability of solar generation does not include the type of detailed site selection process that was undertaken for selection of the anemometer installations.

Conclusion

Potential energy production varied widely from site to site based on a variety of factors, including number of lanes of traffic, median or center barrier type, roadside barrier type, and traffic volume and vehicle type. Given these factors, wind energy production was shown to be inconsistent in terms of output and periods of active generation at all of the test sites examined. The energy produced at the study sites were consistent with the traffic patterns. It was noted at all sites examined in this study that usable wind levels dropped over weekends, and there were consistently lower wind levels at night.

The lack of power generation at night is particularly noteworthy since one reason for exploring wind as an option for electrical generation was due to the potential for generating power at night, when solar photovoltaic is unable to produce power. One benefit that wind offers is an extended period of electric generation into the early nighttime hours associated with the traffic patterns. However, like solar, wind does not offer sustained overnight power generation. In order for wind, or solar, to provide consistent rural and/or off-grid services, energy storage would be required to smooth generation output as well to compensate for extended outage intervals such as during low-traffic or sunless periods.

Another key consideration worth noting is that in accordance with NCDOT siting requirements, placement of VAWTs might have to be installed at heights and/or horizontal separation distances that are different than the criteria used for locating the anemometers. As such, the wind-generation effect created by passing traffic could be impacted (positively or negatively) by siting requirements. Furthermore, if a turbine was to be installed in the median, there would be a need for a WGA in order to effectively capture the traffic-generated wind. A WGA specifically designed for the median would need to be custom engineered and fabricated, adding cost and complexity to a system. Therefore, currently, it would appear that the exterior road side, and not the median, are the appropriate positions for siting wind turbines configured to capture vehicle generated wind.

The economic model from this study shows that the overall system cost for any of the wind turbines modeled here would exceed the cost for a similarly-sized solar installation, even when considering lack of daylight hours, shading, and other periods where production would not be possible for a solar PV installation. The economics are difficult for wind given two main factors. First, small scale wind remains relatively expensive, at almost 5 times the capital cost of solar on a per watt basis. Secondly, at the current cost, the amount, speed, and variability of the wind patterns created by traffic preclude these systems from producing low-cost energy on a per killowatt basis.

That said, VAWTs deployed for highway electric generation from vehicles is a young application. This presents an opportunity to NCDOT to be an industry leader and reap the benefits of reduced costs associated with a larger scale deployment.

Next Steps

This study made conclusions utilizing the best available data in order to empirically model VAWT power generation from highway traffic. However, the findings do not fully quantify the potential benefits that could be accrued from such a system. A success of this project was identifying the further technical and other data needs required to more accurately quantify the energy potential and value of roadside wind. Keeping the aforementioned conclusions in mind, it is believed that a follow up study would be highly beneficial.

A more thorough study, using an actual wind turbine set up in realistic field conditions could provide precise data and answer many of the questions uncovered or unanswered in this study. Factors that could be answered include actual energy output versus wind speed, impact that distance from the roadway has on power output, impact that turbine height has on power output, and how site-specific factors, such as median type and bi-directional traffic flow affect actual power output. Furthermore, an actual installation would validate modeled power output and help identify how wind gusts can positively impact generation. Therefore the project team has concluded that it would be beneficial to deploy one or more VAWTs across NCDOT highway divisions to provide clarity regarding energy production, system costs and energy savings. A further project would provide the opportunity to undertake further iterative research to advance this topic to the next milestone.

Section 7 – Funding Opportunities

The project team investigated several known Government and private sector funding sites and did not identify any immediate outside funding opportunities. The team will continue to monitor opportunities to fund a Pilot demonstration of VAWTs on North Carolina roadways.

References

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Appendix A – Internal turbine analysis

Table A-1 Guilford County Site Calculated Energy Data

Wind Speed	**DS300**		**DS1500**		**DS3000**	
(m/s)	**Avg Power**	**Gust power**	**Avg Power**	**Gust power**	**Avg Power**	**Gust power**
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00
3	1124.67	33.89	2249.33	67.78	5623.33	169.46
4	965.33	57.20	2413.33	143.00	9653.33	572.00
5	1824.33	234.53	9121.67	1172.67	22804.17	2931.67
6	1324.75	562.39	5677.50	2410.25	15140.00	6427.33
7	145.83	323.17	729.17	1615.83	2187.50	4847.50
8	38.75	460.50	206.67	2456.00	516.67	6140.00
9	8.33	279.50	50.00	1677.00	120.83	4052.75
10	0.00	95.90	0.00	548.00	0.00	1301.50
11	0.00	31.67	0.00	191.67	0.00	416.67
12	0.00	7.92	0.00	47.50	0.00	95.00
13	0.00	1.03	0.00	5.00	0.00	10.33
14	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**5,432.00**	2,087.70	**20,447.67**	10,334.70	**56,045.83**	26,964.21

Table A-2 Robeson County Site Calculated Energy Data

Wind Speed	**DS300**		**DS1500**		**DS3000**	
(m/s)	**Avg Power**	**Gust power**	**Avg Power**	**Gust power**	**Avg Power**	**Gust power**
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00
3	1022.00	73.47	2044.00	146.93	5110.00	367.33
4	599.83	82.60	1499.58	206.50	5998.33	826.00
5	1036.00	253.57	5180.00	1267.83	12950.00	3169.58
6	1032.50	474.66	4425.00	2034.25	11800.00	5424.67
7	220.83	238.00	1104.17	1190.00	3312.50	3570.00
8	96.25	348.13	513.33	1856.67	1283.33	4641.67
9	16.67	224.33	100.00	1346.00	241.67	3252.83
10	0.00	115.03	0.00	657.33	0.00	1561.17
11	0.00	51.93	0.00	314.33	0.00	683.33
12	0.00	12.08	0.00	72.50	0.00	145.00
13	0.00	2.07	0.00	10.00	0.00	20.67
14	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**4,024.08**	1,875.87	**14,866.08**	9,102.35	**40,695.83**	23,662.25

Table A-3 Wake County Site Calculated Energy Data

Wind Speed	**DS300**		**DS1500**		**DS3000**	
(m/s)	**Avg Power**	**Gust power**	**Avg Power**	**Gust power**	**Avg Power**	**Gust power**
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00
3	528.00	36.95	1056.00	73.90	2640.00	184.75
4	429.50	36.15	1073.75	90.38	4295.00	361.50
5	828.33	114.20	4141.67	571.00	10354.17	1427.50
6	637.58	235.03	2732.50	1007.25	7286.67	2686.00
7	144.17	124.42	720.83	622.08	2162.50	1866.25
8	77.50	187.00	413.33	997.33	1033.33	2493.33
9	6.67	118.00	40.00	708.00	96.67	1711.00
10	0.00	67.67	0.00	386.67	0.00	918.33
11	0.00	22.48	0.00	136.08	0.00	295.83
12	0.00	12.50	0.00	75.00	0.00	150.00
13	0.00	4.65	0.00	22.50	0.00	46.50
14	0.00	1.18	0.00	5.00	0.00	10.33
15	0.00	0.65	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00
Sum	**2,651.75**	960.88	**10,178.08**	4,695.19	**27,868.33**	12,151.33

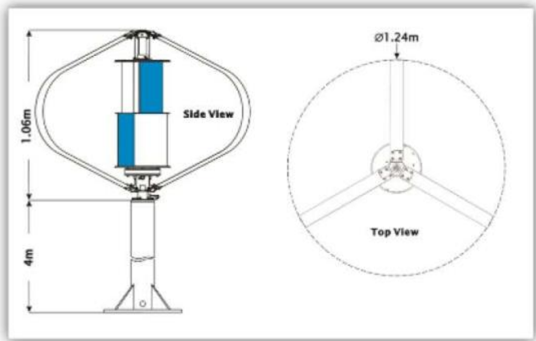
Appendix B – Colite analysis & Specifications

Vertical Axis Wind Turbine Power System
Model number: DS300

PRODUCT SPECIFICATIONS

General Specifications			
Rated Power	300W	**Rated Wind Speed**	13.5 m/s
Rated Speed	835 rpm	**Cut in Wind Speed**	<3 m/s
Cut out Wind Speed	15.5 m/s	**Survival Wind Speed**	60 m/s

Dimensions/Weight	
Rotor Diameter	1.24 m
Rotor Height	1.06 m
Tower Height	4.00 m (minimum)
Total Height	5.06 m (minimum)
Turbine Weight	25.5 kg w/o tower



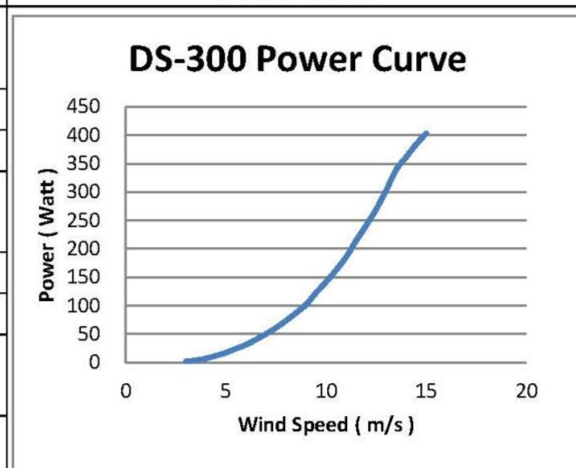
Rotor Specifications	
External Darrieus	3 blades
Internal Savonius	2 layers
Blades Material	Anodized aluminum
Axis Material	Galvanized steel SS400

Generator Specifications	
Generator Type	AC, 3phase, Synchronism PMG
Rated Output	300W

Braking System	
Automatic	3-phase short circuit braking system
Manual	Optional

Operation Conditions	
Ambient Temperature	-10~40℃
Ambient Humidity	95% max.

Power Curve

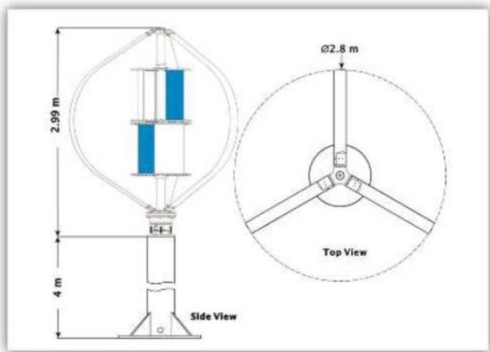


Vertical Axis Wind Turbine Power System
Model: DS1500

PRODUCT SPECIFICATIONS

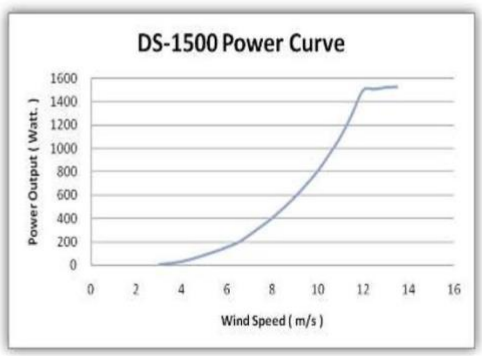
General Specifications			
Rated Power	1.5kW	**Rated Wind Speed**	12 m/s
Rated Speed	290 rpm	**Cut in Wind Speed**	<3 m/s
Cut out Wind Speed	15 m/s	**Survival Wind Speed**	60 m/s

Dimensions/Weight	
Rotor Diameter	2.8 m
Rotor Height	2.9 m
Tower Height	4.0 m
Total Height	6.9 m
Turbine Weight	380kg w/o tower
Rotor Specifications	
External Darrieus	3 Blades
Internal Savonius	2 layers
Blades Material	Anodized Aluminum
Axis Material	Galvanized Steel SS400



Generator Specifications	
Generator Type	AC, 3phase,
	Synchronism PMG
Rated Output	1.5kW
Braking System	
Automatic	Automatic dump-load and 3-phase short circuit braking system
Manual	Mechanical Drum Brake
Operation Conditions	
Ambient Temperature	-10~40℃
Ambient Humidity	95% max.

Power Curve



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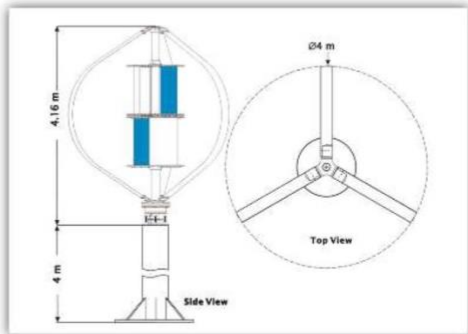
Vertical Axis Wind Turbine Power System
Model: DS-3000W

PRODUCT SPECIFICATIONS

General Specifications			
Rated Power	3kW	**Rated Wind Speed**	12 m/s
Rated Speed	230 rpm	**Cut in Wind Speed**	<3 m/s
Cut out Wind Speed	15 m/s	**Survival Wind Speed**	60 m/s

Dimensions/Weight	
Rotor Diameter	4m
Rotor Height	4.2m
Tower Height	4 m (minimum)
Total Height	8.2m (minimum)
Turbine Weight	680kg w/o tower

Rotor Specifications	
External Darrieus	3 blades
Internal Savonius	2 layers
Blades Material	Anodized aluminum
Axis Material	Galvanized steel SS400

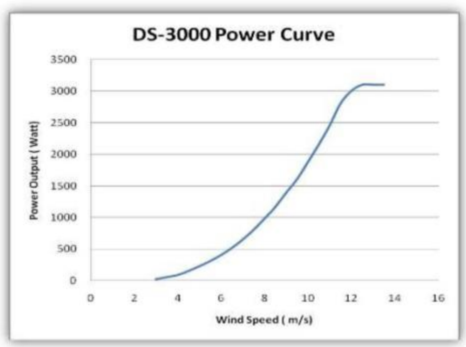


Generator Specifications	
Generator Type	AC, 3phase, Synchronism PMG
Rated Output	3kW

Braking System	
Automatic	Automatic dump-load and 3-phase short circuit braking system
Manual	Mechanical drum brake

Operation Conditions	
Ambient Temperature	-10~40℃
Ambient Humidity	95% max.

Power Curve



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Columbia, SC 29203
Phone: (803) 926-7926
Fax : (803) 926-8412

Quote

Quote Number: 10193
Print Date: 6/27/2019
Project #:
PM:

Site:
N.C. State University
College of Engineering
Raleigh NC 27695
USA

Site Contact:
Site Email:

Customer:
N.C. State University
College of Engineering
Raleigh NC 27695
USA

Customer Contact: Ted Spencer
Customer Email: emspenc2@ncsu.edu

Terms: 50% Dep Bal DUR
Date Quoted: 6/27/2019
Date Expires: 7/27/2019

Salesperson: Kirby Oblachinski
Email: koblachinski@Colitetech.com
PO Number:

This quote does not include install.

Line	Part	Description	Quantity	Unit Price	Net Price
1	WIND-DS-300	DS-300 Vertical Axis Wind Turbine	1.00 EA	3,585.00	3,585.00

Total: USD 3,585.00

PAYMENT TERMS: 50% DOWN; BALANCE 50% DUE UPON RECEIPT

NOTE: THIS PROPOSAL MAY BE WITHDRAWN IF NOT ACCEPTED WITHIN 90 DAYS. WORK WILL NOT BEGIN UNTIL DOWN PAYMENT AND WRITTEN ACCEPTANCE IS RECEIVED.

TERMS AND CONDITIONS

SCOPE OF APPLICATION: These General Terms and Conditions apply to any and all goods and services supplied ("Product") by Colite Technologies under any quotation, purchaser order or other related order by Customer.
CHANGES IN SCOPE: Should modifications be necessary to the scope of work due to permitting authorities, Customer requested engineering changes, code changes, or additional information, Colite Technologies reserves the right to modify the scope of work, and related pricing, accordingly via addendum to this contract.
PERMITS: Colite Technologies acquires necessary permits and licenses, when required, as a convenience for our Customers. If Colite Technologies offers installation services, the costs for permits, variance approvals, staff time, and any necessary local engineering fees required to obtain permits are included in the price. Customer will provide to Colite Technologies any documents required for permitting purposes, including but not limited to: Site Plan, Building Elevations, Letter of Authorization, Notice of Commencement, and Legal Property Description. If permits are denied for any reason after reasonable efforts to obtain, both parties shall be released from this contract. Customer will be required to pay Colite Technologies for any costs incurred to date in performance of the contract. If the Customer chooses not to procure installation services from Colite Technologies, all necessary permits or other local approvals will be the responsibility of the Customer.
PERFORMANCE & DELIVERY: Colite Technologies requires a purchase order (or equivalent) and agreed deposit from

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Customer to begin work, and permit approval where applicable, as well as landlord approval, to begin production. Typical delivery time is twelve to fourteen weeks following permit approval. Colite Technologies is not responsible for delays caused by permitting authorities, acts of God, war, fire, or other conditions beyond its control. Failure of Customer to pay any amounts due prior to manufacture or delivery will delay performance accordingly.

DELAYS: Colite Technologies will begin production immediately following permit approval if applicable. If installation is included, some site installation related activities may also occur immediately following permit approval. Final installation is expected to occur immediately following Product completion unless otherwise specified. If, by no fault of Colite Technologies, production is delayed more than 90 days after acceptance of this contract, or delivery (installation if included) does not occur within six months of the date of acceptance of this contract, Colite Technologies reserves the right to adjust the product, delivery, and installation pricing based on applicable cost increases. Colite Technologies will submit all price adjustments to Customer in writing. Customer also agrees to pay any additional charges incurred from freight carriers due to Customer's delay in accepting delivery of goods.

CANCELLATION: In the event the Customer chooses to cancel this order after executing a signed proposal and paying a required deposit, the Customer will be billed for work performed up to and including the cancellation date. The rate is $150 per hour, and a minimum of $1500.00 will be billed. The cost is to cover such things as, but not limited to, payment processing time, permit research and application, project management time, and lost manufacturing time. If the Product is in manufacturing at the time of cancellation, the Customer is responsible to pay Colite Technologies the full unit price.

INSTALLATION: Colite Technologies installation price, if included, is based upon standard conditions of undisturbed soil, free from underground obstructions, with a subterranean water table of no higher than the bottom of the foundation. Customer shall be responsible for any additional costs and extra charges which result from unusual installation conditions, including but not limited to poor soil conditions, rock, landfill, special footing requirements, or excavation through an asphalt or concrete surface for free-standing structures. Customer will ensure the site is accessible and fully prepared for installation by the agreed installation date. Colite Technologies is not responsible for any landscape restoration unless specified in the contract. If new structures or fixtures are installed upon existing supports, poles, or foundations at Customer's request, Colite Technologies assumes no responsibility for the structural integrity of the existing structure(s), and Customer agrees to hold Colite Technologies harmless from any damages arising from the full or partial failure of such support structures, including but not limited to bodily injury and damages to the installed unit or other property. It is the Customer's responsibility to ensure the installation site is accessible and fully prepared for installation by the agreed installation date. Unless otherwise agreed, any non-standard conditions such as obstacles, after hours work, road blockage, or site inaccessibility may lead to additional installation costs.

REMOVAL and REPAIR: Removal or repair of any existing structure is not included in quoted pricing unless expressly stated in the contract. Any work such as patching or repainting existing structures, either necessary or requested, during installation is not standard and appropriate charges will apply.

SECURITY INTEREST: Title and ownership of all property contained in this contract shall remain with Colite Technologies until all amounts due under the contract have been paid in full. It is expressly understood that all property will remain tangible personal property, and in no way be construed as real property, whether installed on real property or not, until the contract is paid in full. All risk of loss transfers to the Customer upon installation or delivery if installation is not included in the contract.

PAYMENT TERMS: Standard terms require 50% deposit due upon contract execution with remainder (including any additional charges and all applicable sales taxes) billed upon completion and due Net 30. Payment terms are subject to vary in accordance with a standard review of Customer's Dunn & Bradstreet report, or prior payment experience with Colite Technologies. Payment is to be in the currency specified in this proposal. Customer agrees to reimburse Colite Technologies for any losses incurred on currency exchange due to late payments. Colite Technologies accepts credit card payments with the following convenience fees: VISA and MASTERCARD will incur a 2% fee, and AMERICAN EXPRESS will incur a 3% fee.

TAXES AND DUTIES: Customs charges and import duties ARE included in quoted pricing unless specifically stated otherwise. Sales/use taxes and certain foreign taxes are NOT included unless specifically stated. For sites within the United States, appropriate sales tax will be added to all invoices unless an exemption certificate is presented to Colite Technologies for each corresponding tax jurisdiction. For shipments to, or installations in Canada, appropriate GST/PST/HST will be added to all invoices. For shipments to, or installations in the United Kingdom or Germany, appropriate VAT will be added to all invoices. Customer agrees to remit to Colite Technologies any amounts that are withheld at source so that the full balance due is received by Colite Technologies.

INTERNATIONAL: It is Customer's responsibility to ensure transaction is in compliance with all local regulations that may prevent full and proper payment according to contract terms. Customer accepts that Colite Technologies may, at its discretion, contract with local companies to manufacture certain components, and Customer agrees to pay Colite Technologies in accordance with quoted pricing. Colite Technologies will not accept purchase orders from countries under

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trade sanctions by the United States government.

DEFAULT: Customer is considered to be in default if it fails to fulfill any of its obligations under this contract, if any liens are placed against the property contained in this contract prior to full payment, or if bankruptcy or insolvency proceedings are begun prior to full payment. Upon default, all balances owed become immediately due and payable. Colite Technologies or its agent(s) may, at its discretion, enter Customer's property and take possession of unpaid items or render it unusable until default is resolved. Customer shall pay any costs incurred by Colite Technologies in enforcing its rights upon Customer's default, including attorney's fees, collection agency fees, and any costs associated with taking possession of signs.

LIMITED WARRANTY: Subject to the other conditions of this Limited Warranty, if any equipment or parts manufactured by Colite Technologies constituting part of the Product prove defective in material or workmanship within five years after the date of delivery of the Product to Customer, Colite Technologies shall repair or replace such parts free of cost. The warranty shall not extend beyond five years after the date of delivery of the Product to Customer regardless of any replacements which may be made. Customer's sole and exclusive remedy against Colite Technologies for any alleged defects in the Product shall be as provided in this Limited Warranty.

Colite Technologies obligations under this Limited Warranty are conditioned upon Customer (i) giving prompt written notice of alleged defects, and (ii) upon Colite Technologies request, returning allegedly defective items to a designated facility, freight prepaid, for Colite Technologies inspection.

Colite Technologies shall have no obligation or liability, under this Limited Warranty or otherwise, in the event of improper installation of the Product unless and until the installation is corrected and proper. However, in no case shall Colite Technologies have any obligation or liability beyond five years after the date of delivery of the Product to Customer. Colite Technologies reserves the right, without obligation, to inspect all installations of the Product or the Product itself for the protection of both Customer and Colite Technologies.

In no event shall Colite Technologies have any obligation or liability, under this Limited Warranty or otherwise, resulting in whole or in part from (i) Customer's failure to properly use the Product, or (ii) damage to or defects in the Product caused by accident, repairs, alterations, abuse, misuse, malicious mischief, fires, floods, acts of God, casualty, improper handling or the negligence of Customer or others.

DISCLAIMER OF OTHER WARRANTIES: EXCEPT FOR THE EXPRESS LIMITED WARRANTY SET FORTH IN THE LIMITED WARRANTY ABOVE, COLITE TECHNOLOGIES EXPRESSLY DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, ARISING FROM COURSE OF DEALING OR USAGE OF TRADE, OR STATUTORY, INCLUDING BUT NOT LIMITED TO THE IMPLIED CONDITIONS AND WARRANTIES OF MERCHANTABILITY, QUALITY, FITNESS FOR A PARTICULAR PURPOSE, CORRESPONDENCE WITH DESCRIPTION OR QUALITY, TITLE, QUIET POSSESSION AND NON-INFRINGEMENT.

LIMITATIONS OF LIABILITIES: IN ANY EVENT AND IN NO CASE SHALL COLITE TECHNOLOGIES BE LIABLE FOR ANY SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES (INCLUDING WITHOUT LIMITATION LOST PROFITS, ANY LOSS OF USE, OR INTERRUPTION OF BUSINESS) BASED UPON BREACH OF CONTRACT, NEGLIGENCE, STRICT LIABILITY, TORT, OR ANY OTHER LEGAL THEORY, EVEN IF COLITE TECHNOLOGIES IS NOTIFIED OF THE POSSIBILITY OF SUCH DAMAGES. IN ALL CASES, COLITE TECHNOLOGIES'S MAXIMUM LIABILITY ARISING OUT OF OR RELATING TO THIS AGREEMENT, REGARDLESS OF THE LEGAL THEORY, SHALL NOT EXCEED THE CONTRACT PRICE ACTUALLY PAID BY CUSTOMER IN RESPECT OF THE PRODUCT SUPPLIED BY COLITE TECHNOLOGIES TO WHICH SUCH LIABILITY RELATES. COLITE TECHNOLOGIES SHALL NOT BE LIABLE FOR ANY LOSS, DAMAGE, DETENTION OR DELAY DUE DIRECTLY OR INDIRECTLY TO CAUSES BEYOND ITS REASONABLE CONTROL, SUCH AS ACTS OF GOD, ACTS OF CUSTOMER, ACTS OF CIVIL OR MILITARY AUTHORITY, FIRES, STRIKES, FLOODS, EPIDEMICS, WAR, RIOT, DELAYS IN TRANSPORTATION, GOVERNMENT RESTRICTIONS OR EMBARGOES, OR DIFFICULTIES IN OBTAINING NECESSARY LABOR, MATERIALS, MANUFACTURING FACILITIES OR TRANSPORTATION DUE TO SUCH CAUSES. THE FOREGOING LIMITATIONS OF LIABILITY ARE INDEPENDENT OF ANY EXCLUSIVE REMEDIES FOR BREACH OF WARRANTY SET FORTH IN THIS AGREEMENT.

THIS PROPOSAL DOES NOT BECOME EFFECTIVE UNTIL SIGNED AND DATED BY THE COMPANY.

THE ABOVE PRICES, SPECIFICATIONS, AND CONDITIONS ARE SATISFACTORY AND ARE HEREBY ACCEPTED. YOU ARE AUTHORIZED TO DO THE WORK AS SPECIFIED. PAYMENT WILL BE MADE AS OUTLINED ABOVE.

SALESPERSON:______________________________ DATE:____________________
ACCEPTED BY:______________________________ TITLE:____________________
SIGNATURE:________________________________ DATE:____________________

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Quote

Quote Number: 10194
Print Date: 6/27/2019
Project #:
PM:

Site:
N.C. State University
College of Engineering
Raleigh NC 27695
USA

Site Contact:
Site Email:

Customer:
N.C. State University
College of Engineering
Raleigh NC 27695
USA

Customer Contact: Ted Spencer
Customer Email: emspenc2@ncsu.edu

Terms: 50% Dep Bal DUR
Date Quoted: 6/27/2019
Date Expires: 7/27/2019

Salesperson: Kirby Oblachinski
Email: koblachinski@Colitetech.com
PO Number:

This quote does not include install.

Line	Part	Description	Quantity	Unit Price	Net Price
1	WIND-DS-1500	DS-1500 Vertical Axis Wind Turbine	1.00EA	18,825.00	18,825.00

Total: USD 18,825.00

PAYMENT TERMS: 50% DOWN; BALANCE 50% DUE UPON RECEIPT

NOTE: THIS PROPOSAL MAY BE WITHDRAWN IF NOT ACCEPTED WITHIN 90 DAYS. WORK WILL NOT BEGIN UNTIL DOWN PAYMENT AND WRITTEN ACCEPTANCE IS RECEIVED.

TERMS AND CONDITIONS

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PERFORMANCE & DELIVERY: Colite Technologies requires a purchase order (or equivalent) and agreed deposit from

colite technologies
5 Technology Circle
Columbia, SC 29203
Phone: (803) 926-7926
Fax : (803) 926-8412

Quote

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DISCLAIMER OF OTHER WARRANTIES: EXCEPT FOR THE EXPRESS LIMITED WARRANTY SET FORTH IN THE LIMITED WARRANTY ABOVE, COLITE TECHNOLOGIES EXPRESSLY DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, ARISING FROM COURSE OF DEALING OR USAGE OF TRADE, OR STATUTORY, INCLUDING BUT NOT LIMITED TO THE IMPLIED CONDITIONS AND WARRANTIES OF MERCHANTABILITY, QUALITY, FITNESS FOR A PARTICULAR PURPOSE, CORRESPONDENCE WITH DESCRIPTION OR QUALITY, TITLE, QUIET POSSESSION AND NON-INFRINGEMENT.
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SALESPERSON:______________________ DATE:______________
ACCEPTED BY:______________________ TITLE:______________
SIGNATURE:________________________ DATE:______________

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Quote

Quote Number: 10194
Print Date: 6/27/2019
Project #:
PM:

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Columbia, SC 29203
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Quote

Quote Number: 10195
Print Date: 6/27/2019
Project #:
PM:

Site:	Customer:
N.C. State University College of Engineering Raleigh NC 27695 USA	N.C. State University College of Engineering Raleigh NC 27695 USA
Site Contact:	**Customer Contact:** Ted Spencer
Site Email:	**Customer Email:** emspenc2@ncsu.edu

Terms: 50% Dep Bal DUR	**Salesperson:** Kirby Oblachinski
Date Quoted: 6/27/2019	**Email:** koblachinski@Colitetech.com
Date Expires: 7/27/2019	**PO Number:**

This quote does not include install.

Line	Part	Description	Quantity	Unit Price	Net Price
1	WIND-DS-3000	DS-3000 Vertical Axis Wind Turbine	1.00 EA	26,625.00	26,625.00

Total: USD 26,625.00

PAYMENT TERMS: 50% DOWN; BALANCE 50% DUE UPON RECEIPT

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SALESPERSON:______________________________ DATE:____________________
ACCEPTED BY:______________________________ TITLE:____________________
SIGNATURE:________________________________ DATE:____________________

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Quote

Quote Number: 10195
Print Date: 6/27/2019
Project #:
PM:

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Quote

Quote Number: 10193
Print Date: 6/27/2019
Project #:
PM:

Site:
N.C. State University
College of Engineering
Raleigh NC 27695
USA

Site Contact:
Site Email:

Customer:
N.C. State University
College of Engineering
Raleigh NC 27695
USA

Customer Contact: Ted Spencer
Customer Email: emspenc2@ncsu.edu

Terms: 50% Dep Bal DUR
Date Quoted: 6/27/2019
Date Expires: 7/27/2019

Salesperson: Kirby Oblachinski
Email: koblachinski@Colitetech.com
PO Number:

This quote does not include install.

Line	Part	Description	Quantity	Unit Price	Net Price
1	WIND-DS-300	DS-300 Vertical Axis Wind Turbine	1.00 EA	3,585.00	3,585.00

Total: USD 3,585.00

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In no event shall Colite Technologies have any obligation or liability, under this Limited Warranty or otherwise, resulting in whole or in part from (i) Customer's failure to properly use the Product, or (ii) damage to or defects in the Product caused by accident, repairs, alterations, abuse, misuse, malicious mischief, fires, floods, acts of God, casualty, improper handling or the negligence of Customer or others.

DISCLAIMER OF OTHER WARRANTIES: EXCEPT FOR THE EXPRESS LIMITED WARRANTY SET FORTH IN THE LIMITED WARRANTY ABOVE, COLITE TECHNOLOGIES EXPRESSLY DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, ARISING FROM COURSE OF DEALING OR USAGE OF TRADE, OR STATUTORY, INCLUDING BUT NOT LIMITED TO THE IMPLIED CONDITIONS AND WARRANTIES OF MERCHANTABILITY, QUALITY, FITNESS FOR A PARTICULAR PURPOSE, CORRESPONDENCE WITH DESCRIPTION OR QUALITY, TITLE, QUIET POSSESSION AND NON-INFRINGEMENT.

LIMITATIONS OF LIABILITIES: IN ANY EVENT AND IN NO CASE SHALL COLITE TECHNOLOGIES BE LIABLE FOR ANY SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES (INCLUDING WITHOUT LIMITATION LOST PROFITS, ANY LOSS OF USE, OR INTERRUPTION OF BUSINESS) BASED UPON BREACH OF CONTRACT, NEGLIGENCE, STRICT LIABILITY, TORT, OR ANY OTHER LEGAL THEORY, EVEN IF COLITE TECHNOLOGIES IS NOTIFIED OF THE POSSIBILITY OF SUCH DAMAGES. IN ALL CASES, COLITE TECHNOLOGIES'S MAXIMUM LIABILITY ARISING OUT OF OR RELATING TO THIS AGREEMENT, REGARDLESS OF THE LEGAL THEORY, SHALL NOT EXCEED THE CONTRACT PRICE ACTUALLY PAID BY CUSTOMER IN RESPECT OF THE PRODUCT SUPPLIED BY COLITE TECHNOLOGIES TO WHICH SUCH LIABILITY RELATES. COLITE TECHNOLOGIES SHALL NOT BE LIABLE FOR ANY LOSS, DAMAGE, DETENTION OR DELAY DUE DIRECTLY OR INDIRECTLY TO CAUSES BEYOND ITS REASONABLE CONTROL, SUCH AS ACTS OF GOD, ACTS OF CUSTOMER, ACTS OF CIVIL OR MILITARY AUTHORITY, FIRES, STRIKES, FLOODS, EPIDEMICS, WAR, RIOT, DELAYS IN TRANSPORTATION, GOVERNMENT RESTRICTIONS OR EMBARGOES, OR DIFFICULTIES IN OBTAINING NECESSARY LABOR, MATERIALS, MANUFACTURING FACILITIES OR TRANSPORTATION DUE TO SUCH CAUSES. THE FOREGOING LIMITATIONS OF LIABILITY ARE INDEPENDENT OF ANY EXCLUSIVE REMEDIES FOR BREACH OF WARRANTY SET FORTH IN THIS AGREEMENT.

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SALESPERSON:____________________ DATE:____________
ACCEPTED BY:____________________ TITLE:____________
SIGNATURE:____________________ DATE:____________

colite technologies
5 Technology Circle
Columbia, SC 29203
Phone: (803) 926-7926
Fax : (803) 926-8412

Quote

Quote Number: 10193
Print Date: 6/27/2019
Project #:
PM:

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technologies
5 Technology Circle
Columbia, SC 29203
Phone: (803) 926-7926
Fax : (803) 926-8412

Quote

Quote Number: 10194
Print Date: 6/27/2019
Project #:
PM:

Site:
N.C. State University
College of Engineering
Raleigh NC 27695
USA

Site Contact:
Site Email:

Customer:
N.C. State University
College of Engineering
Raleigh NC 27695
USA

Customer Contact: Ted Spencer
Customer Email: emspenc2@ncsu.edu

Terms: 50% Dep Bal DUR
Date Quoted: 6/27/2019
Date Expires: 7/27/2019

Salesperson: Kirby Oblachinski
Email: koblachinski@Colitetech.com
PO Number:

This quote does not include install.

Line	Part	Description	Quantity	Unit Price	Net Price
1	WIND-DS-1500	DS-1500 Vertical Axis Wind Turbine	1.00 EA	18,825.00	18,825.00

Total: USD 18,825.00

PAYMENT TERMS: 50% DOWN; BALANCE 50% DUE UPON RECEIPT

NOTE: THIS PROPOSAL MAY BE WITHDRAWN IF NOT ACCEPTED WITHIN 90 DAYS. WORK WILL NOT BEGIN UNTIL DOWN PAYMENT AND WRITTEN ACCEPTANCE IS RECEIVED.

TERMS AND CONDITIONS

SCOPE OF APPLICATION: These General Terms and Conditions apply to any and all goods and services supplied ("Product") by Colite Technologies under any quotation, purchaser order or other related order by Customer.
CHANGES IN SCOPE: Should modifications be necessary to the scope of work due to permitting authorities, Customer requested engineering changes, code changes, or additional information, Colite Technologies reserves the right to modify the scope of work, and related pricing, accordingly via addendum to this contract.
PERMITS: Colite Technologies acquires necessary permits and licenses, when required, as a convenience for our Customers. If Colite Technologies offers installation services, the costs for permits, variance approvals, staff time, and any necessary local engineering fees required to obtain permits are included in the price. Customer will provide to Colite Technologies any documents required for permitting purposes, including but not limited to: Site Plan, Building Elevations, Letter of Authorization, Notice of Commencement, and Legal Property Description. If permits are denied for any reason after reasonable efforts to obtain, both parties shall be released from this contract. Customer will be required to pay Colite Technologies for any costs incurred to date in performance of the contract. If the Customer chooses not to procure installation services from Colite Technologies, all necessary permits or other local approvals will be the responsibility of the Customer.
PERFORMANCE & DELIVERY: Colite Technologies requires a purchase order (or equivalent) and agreed deposit from

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Columbia, SC 29203
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Quote

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DELAYS: Colite Technologies will begin production immediately following permit approval if applicable. If installation is included, some site installation related activities may also occur immediately following permit approval. Final installation is expected to occur immediately following Product completion unless otherwise specified. If, by no fault of Colite Technologies, production is delayed more than 90 days after acceptance of this contract, or delivery (installation if included) does not occur within six months of the date of acceptance of this contract, Colite Technologies reserves the right to adjust the product, delivery, and installation pricing based on applicable cost increases. Colite Technologies will submit all price adjustments to Customer in writing. Customer also agrees to pay any additional charges incurred from freight carriers due to Customer's delay in accepting delivery of goods.

CANCELLATION: In the event the Customer chooses to cancel this order after executing a signed proposal and paying a required deposit, the Customer will be billed for work performed up to and including the cancellation date. The rate is $150 per hour, and a minimum of $1500.00 will be billed. The cost is to cover such things as, but not limited to, payment processing time, permit research and application, project management time, and lost manufacturing time. If the Product is in manufacturing at the time of cancellation, the Customer is responsible to pay Colite Technologies the full unit price.

INSTALLATION: Colite Technologies installation price, if included, is based upon standard conditions of undisturbed soil, free from underground obstructions, with a subterranean water table of no higher than the bottom of the foundation. Customer shall be responsible for any additional costs and extra charges which result from unusual installation conditions, including but not limited to poor soil conditions, rock, landfill, special footing requirements, or excavation through an asphalt or concrete surface for free-standing structures. Customer will ensure the site is accessible and fully prepared for installation by the agreed installation date. Colite Technologies is not responsible for any landscape restoration unless specified in the contract. If new structures or fixtures are installed upon existing supports, poles, or foundations at Customer's request, Colite Technologies assumes no responsibility for the structural integrity of the existing structure(s), and Customer agrees to hold Colite Technologies harmless from any damages arising from the full or partial failure of such support structures, including but not limited to bodily injury and damages to the installed unit or other property. It is the Customer's responsibility to ensure the installation site is accessible and fully prepared for installation by the agreed installation date. Unless otherwise agreed, any non-standard conditions such as obstacles, after hours work, road blockage, or site inaccessibility may lead to additional installation costs.

REMOVAL and REPAIR: Removal or repair of any existing structure is not included in quoted pricing unless expressly stated in the contract. Any work such as patching or repainting existing structures, either necessary or requested, during installation is not standard and appropriate charges will apply.

SECURITY INTEREST: Title and ownership of all property contained in this contract shall remain with Colite Technologies until all amounts due under the contract have been paid in full. It is expressly understood that all property will remain tangible personal property, and in no way be construed as real property, whether installed on real property or not, until the contract is paid in full. All risk of loss transfers to the Customer upon installation or delivery if installation is not included in the contract.

PAYMENT TERMS: Standard terms require 50% deposit due upon contract execution with remainder (including any additional charges and all applicable sales taxes) billed upon completion and due Net 30. Payment terms are subject to vary in accordance with a standard review of Customer's Dunn & Bradstreet report, or prior payment experience with Colite Technologies. Payment is to be in the currency specified in this proposal. Customer agrees to reimburse Colite Technologies for any losses incurred on currency exchange due to late payments. Colite Technologies accepts credit card payments with the following convenience fees: VISA and MASTERCARD will incur a 2% fee, and AMERICAN EXPRESS will incur a 3% fee.

TAXES AND DUTIES: Customs charges and import duties ARE included in quoted pricing unless specifically stated otherwise. Sales/use taxes and certain foreign taxes are NOT included unless specifically stated. For sites within the United States, appropriate sales tax will be added to all invoices unless an exemption certificate is presented to Colite Technologies for each corresponding tax jurisdiction. For shipments to, or installations in Canada, appropriate GST/PST/HST will be added to all invoices. For shipments to, or installations in the United Kingdom or Germany, appropriate VAT will be added to all invoices. Customer agrees to remit to Colite Technologies any amounts that are withheld at source so that the full balance due is received by Colite Technologies.

INTERNATIONAL: It is Customer's responsibility to ensure transaction is in compliance with all local regulations that may prevent full and proper payment according to contract terms. Customer accepts that Colite Technologies may, at its discretion, contract with local companies to manufacture certain components, and Customer agrees to pay Colite Technologies in accordance with quoted pricing. Colite Technologies will not accept purchase orders from countries under

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Quote

trade sanctions by the United States government.
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DISCLAIMER OF OTHER WARRANTIES: EXCEPT FOR THE EXPRESS LIMITED WARRANTY SET FORTH IN THE LIMITED WARRANTY ABOVE, COLITE TECHNOLOGIES EXPRESSLY DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, ARISING FROM COURSE OF DEALING OR USAGE OF TRADE, OR STATUTORY, INCLUDING BUT NOT LIMITED TO THE IMPLIED CONDITIONS AND WARRANTIES OF MERCHANTABILITY, QUALITY, FITNESS FOR A PARTICULAR PURPOSE, CORRESPONDENCE WITH DESCRIPTION OR QUALITY, TITLE, QUIET POSSESSION AND NON-INFRINGEMENT.
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SALESPERSON:____________________ DATE:____________
ACCEPTED BY:____________________ TITLE:____________
SIGNATURE:____________________ DATE:____________

colite technologies
5 Technology Circle
Columbia, SC 29203
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Quote

Quote Number: 10194
Print Date: 6/27/2019
Project #:
PM:

Quote

colite technologies
5 Technology Circle
Columbia, SC 29203
Phone: (803) 926-7926
Fax : (803) 926-8412

Quote Number: 10195
Print Date: 6/27/2019
Project #:
PM:

Site:
N.C. State University
College of Engineering
Raleigh NC 27695
USA

Site Contact:
Site Email:

Customer:
N.C. State University
College of Engineering
Raleigh NC 27695
USA

Customer Contact: Ted Spencer
Customer Email: emspenc2@ncsu.edu

Terms: 50% Dep Bal DUR
Date Quoted: 6/27/2019
Date Expires: 7/27/2019

Salesperson: Kirby Oblachinski
Email: koblachinski@Colitetech.com
PO Number:

This quote does not include install.

Line	Part	Description	Quantity	Unit Price	Net Price
1	WIND-DS-3000	DS-3000 Vertical Axis Wind Turbine	1.00 EA	26,625.00	26,625.00
				Total:	USD 26,625.00

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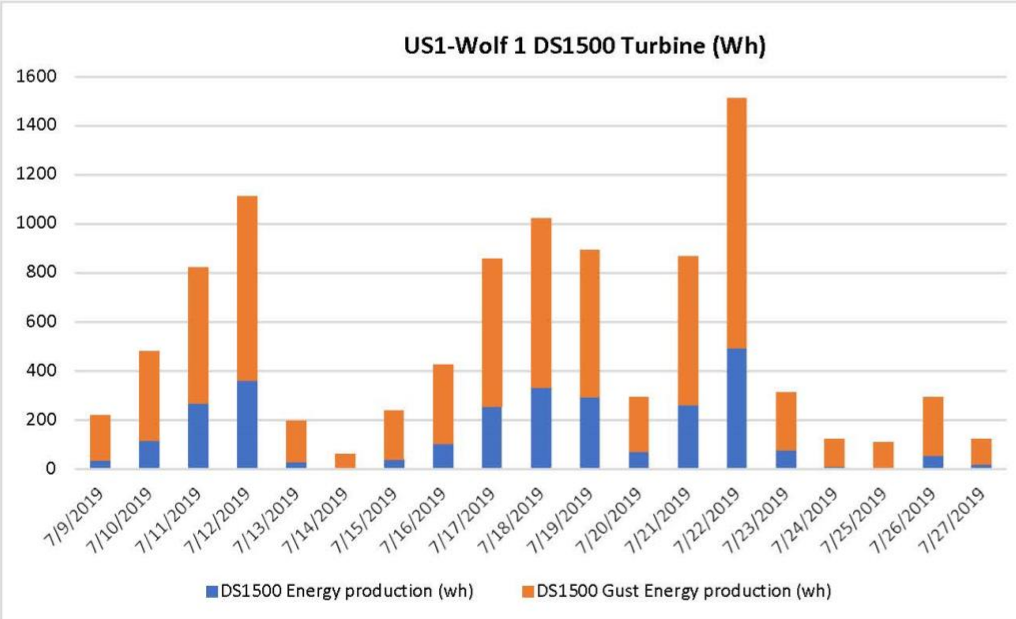
SALESPERSON:____________________________________ DATE:____________________
ACCEPTED BY:____________________________________ TITLE:____________________
SIGNATURE:______________________________________ DATE:____________________

colite technologies
5 Technology Circle
Columbia, SC 29203
Phone: (803) 926-7926
Fax : (803) 926-8412

Quote

Quote Number: 10195
Print Date: 6/27/2019
Project #:
PM:



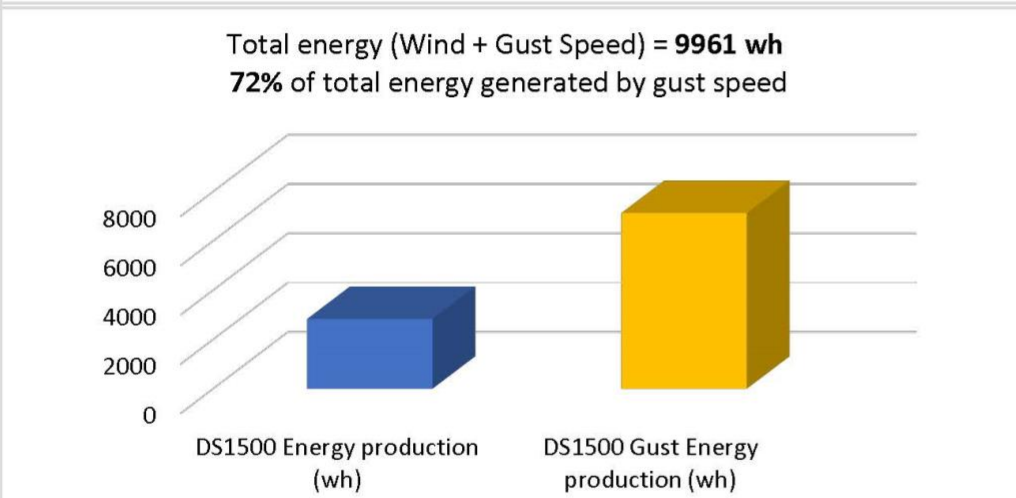
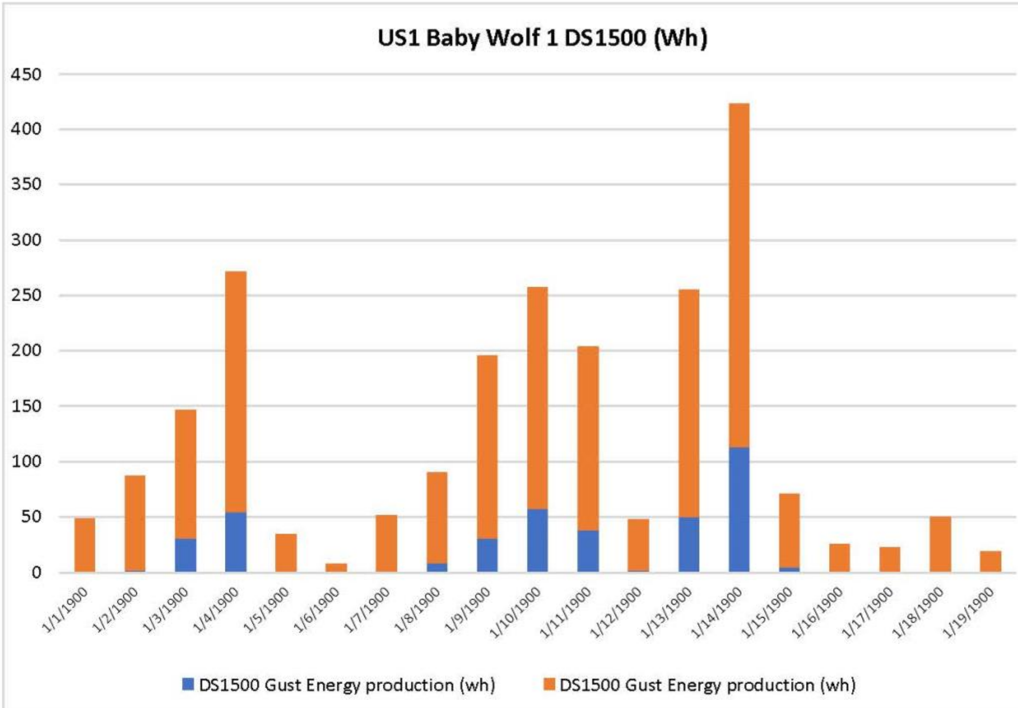


Figure 1. Avg. Speed and Gust Data, US 1/ 64 Site, 9 – 27 July, 2019
Wired Anemometer (Wolf 1), w/ DS1500 Turbine Outputs



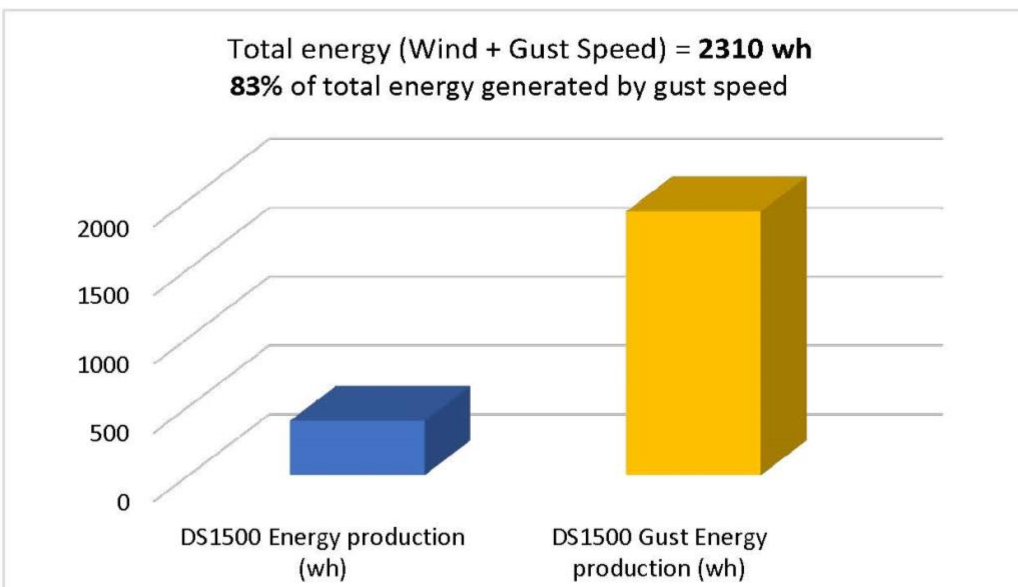
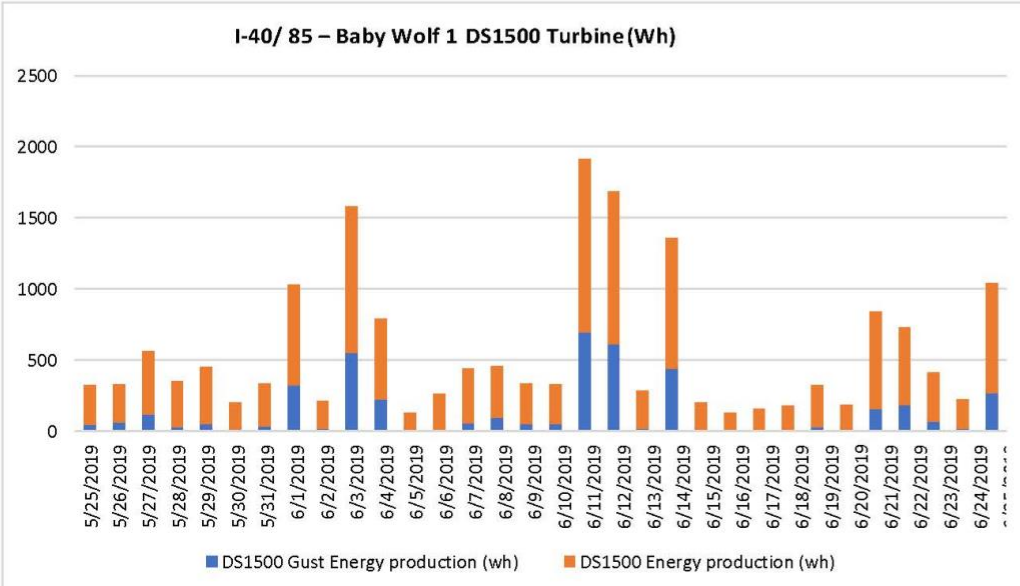


Figure 2. Avg. Speed and Gust Data, US 1/ 64 Site, 9 – 27 July, 2019
Wireless Anemometer (Baby Wolf 1), w/ DS1500 Turbine Outputs



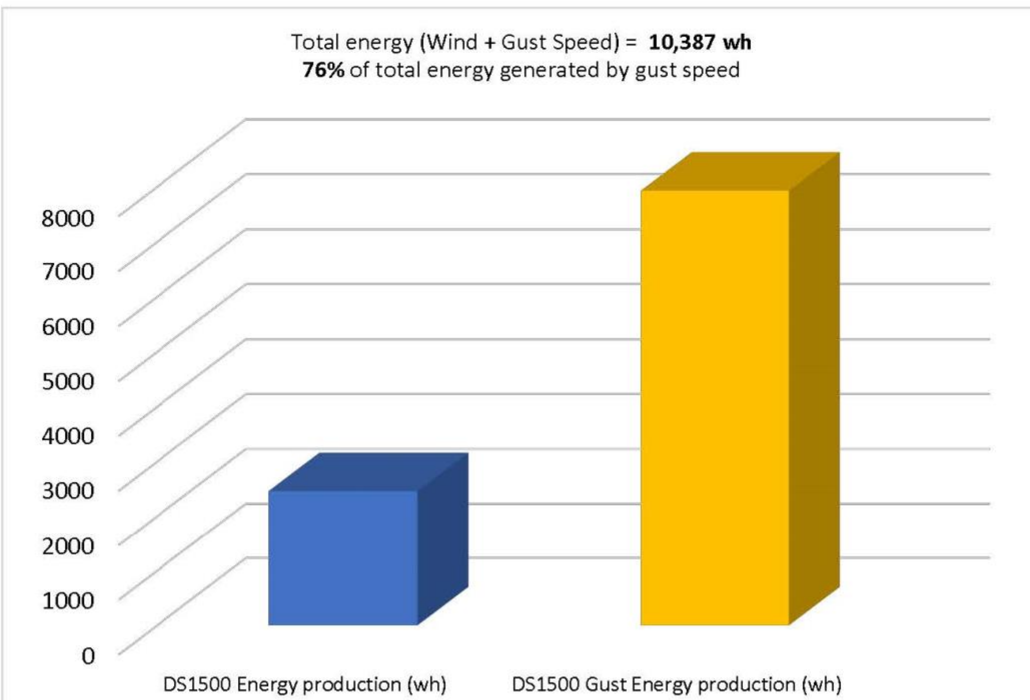
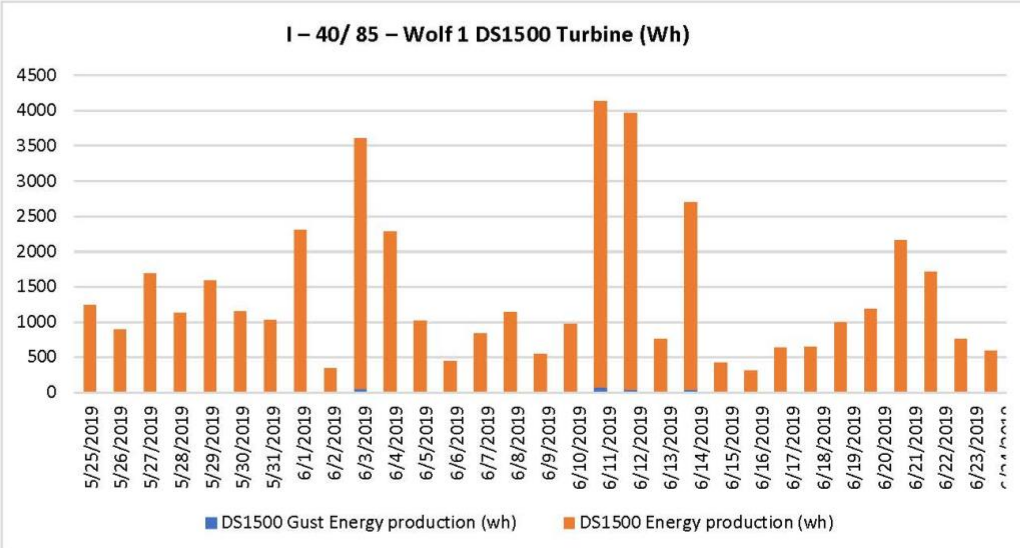


Figure 3. Avg. Speed and Gust Data, I-40/85 Site, 25 May – 25 June, 2019
Wireless Anemometer (Baby Wolf 2), w/ DS1500 Turbine Outputs



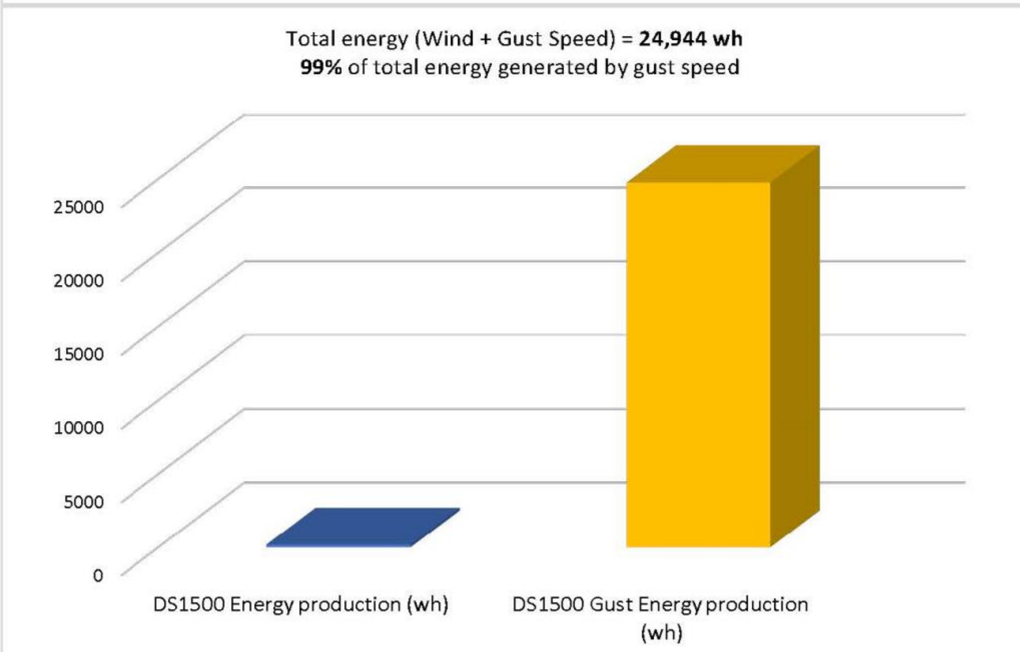


Figure 4. Avg. Speed and Gust Data, I-40/85 Site, 25 May – 24 June, 2019
Wired Anemometer (Wolf 2), w/ DS1500 Turbine Outputs

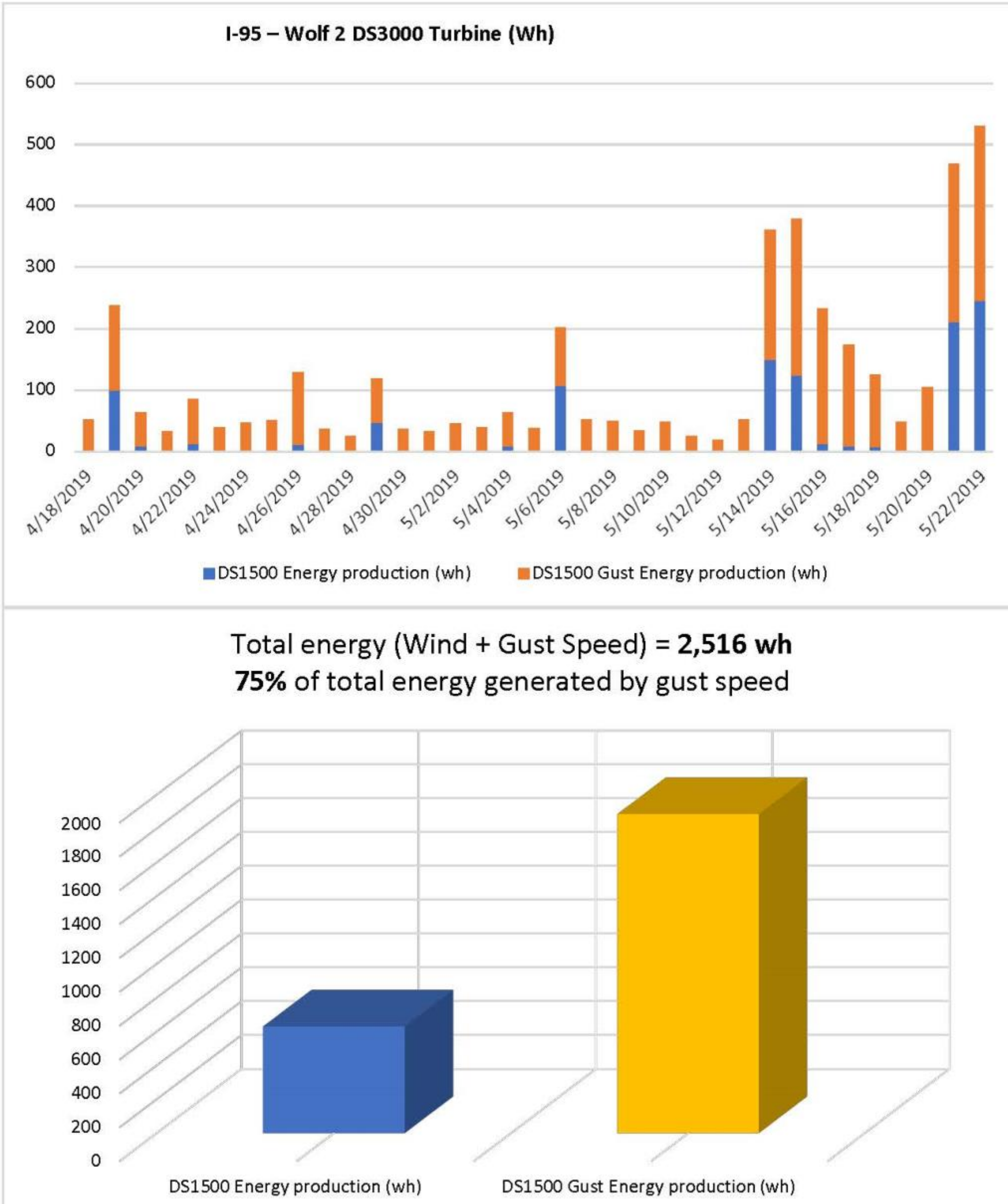


Figure 5. Avg. Speed and Gust Data, I-95 Site, 18 April – 22 May, 2019
Wired Anemometer (Wolf 2), w/ DS3000 Turbine Outputs

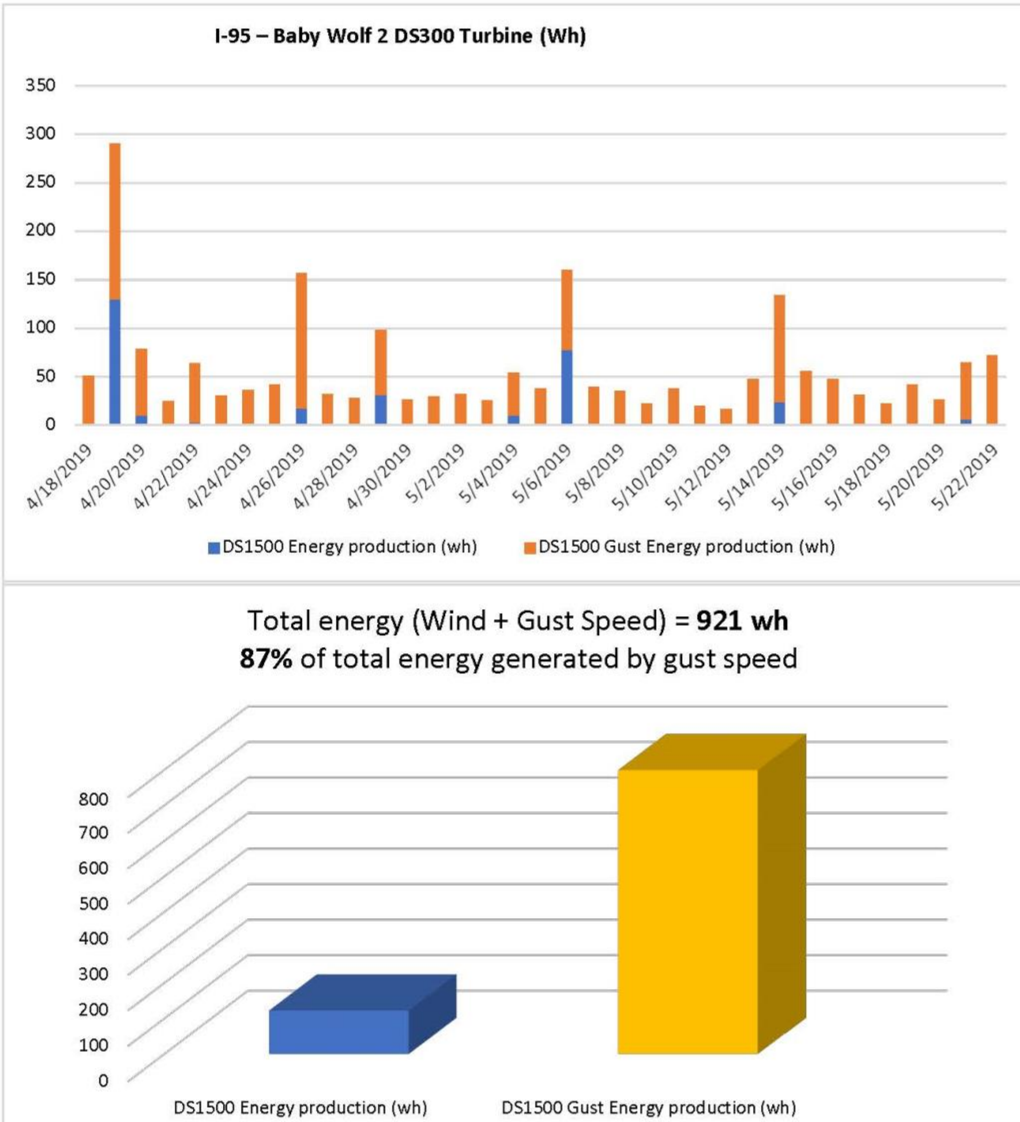
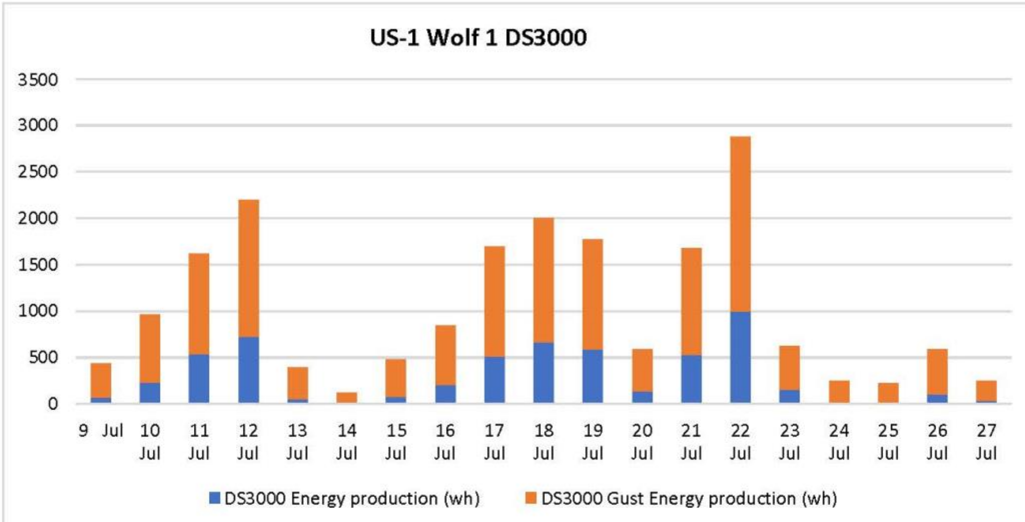


Figure 6. Avg. Speed and Gust Data, I-95 Site, 18 April – 22 May, 2019
Wired Anemometer (Wolf 2), w/ DS300 Turbine Outputs



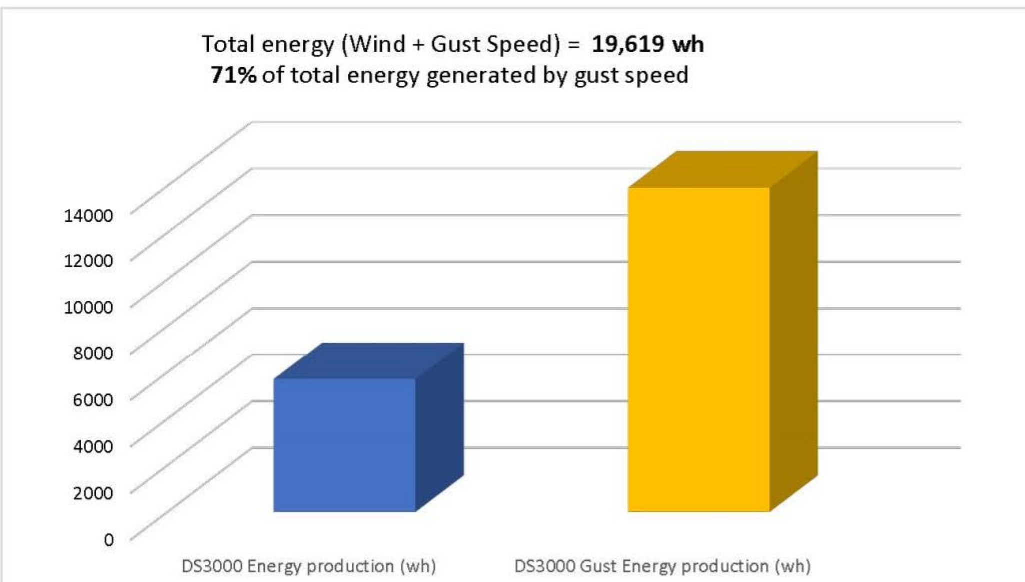
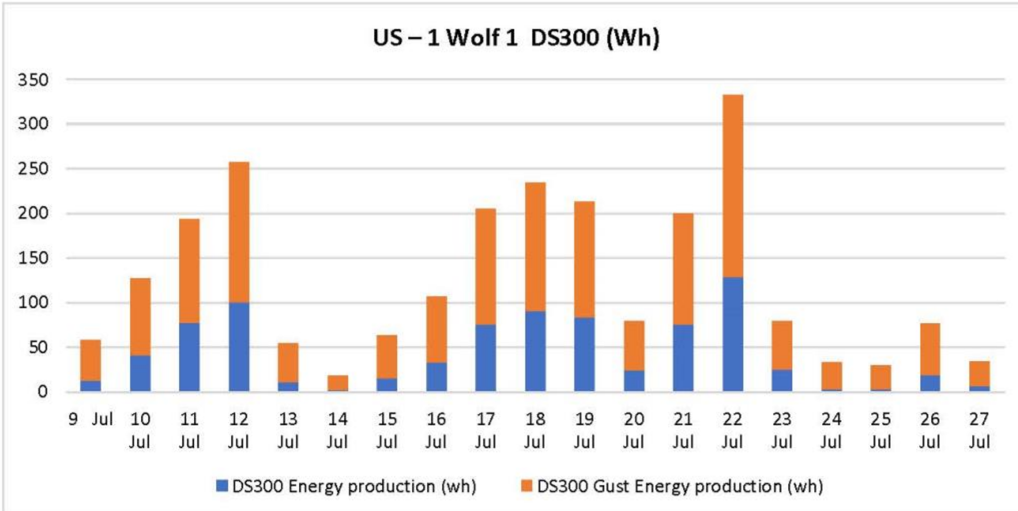


Figure 7. Avg. Speed and Gust Data, US-1 Site, 9 - 27 July, 2019
Wired Anemometer (Wolf 1), w/ DS3000 Turbine Outputs



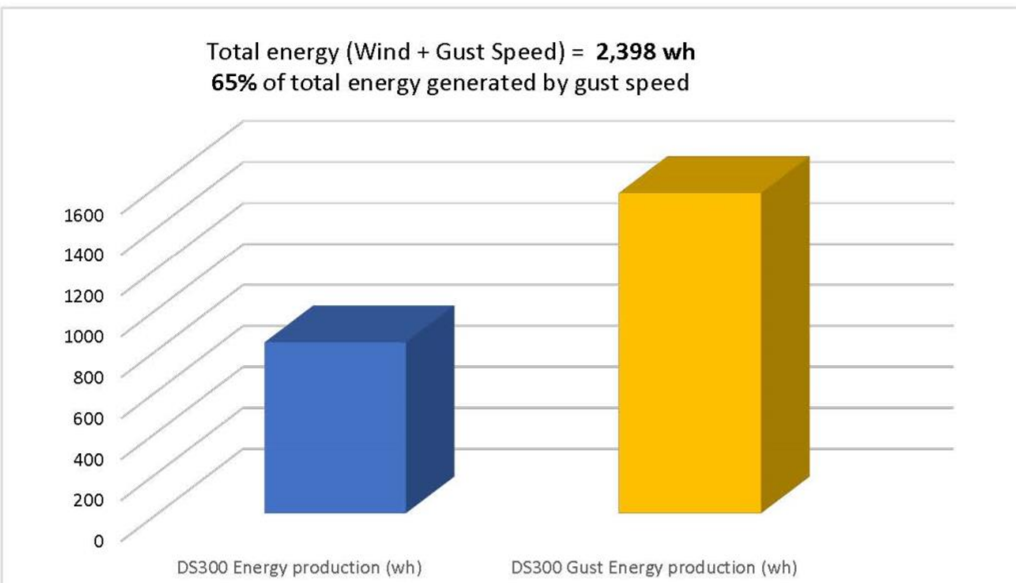
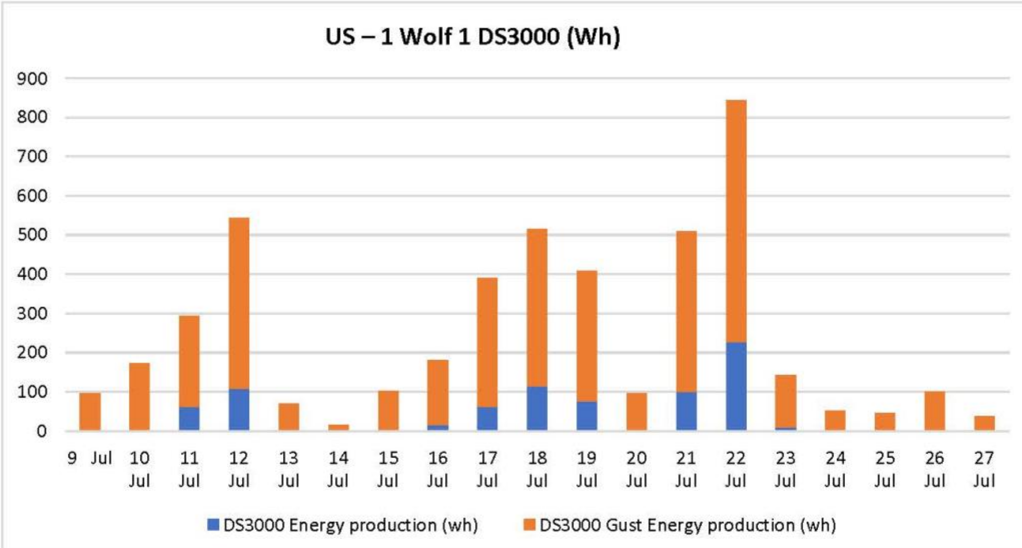


Figure 8. Avg. Speed and Gust Data, US-1 Site, 9 - 27 July, 2019
Wired Anemometer (Wolf 1), w/ DS300 Turbine Outputs



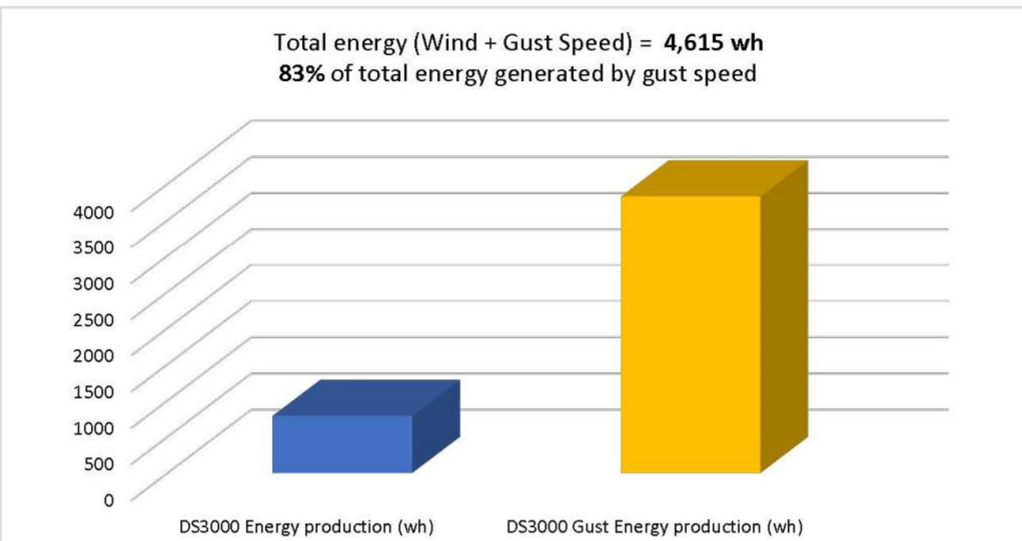
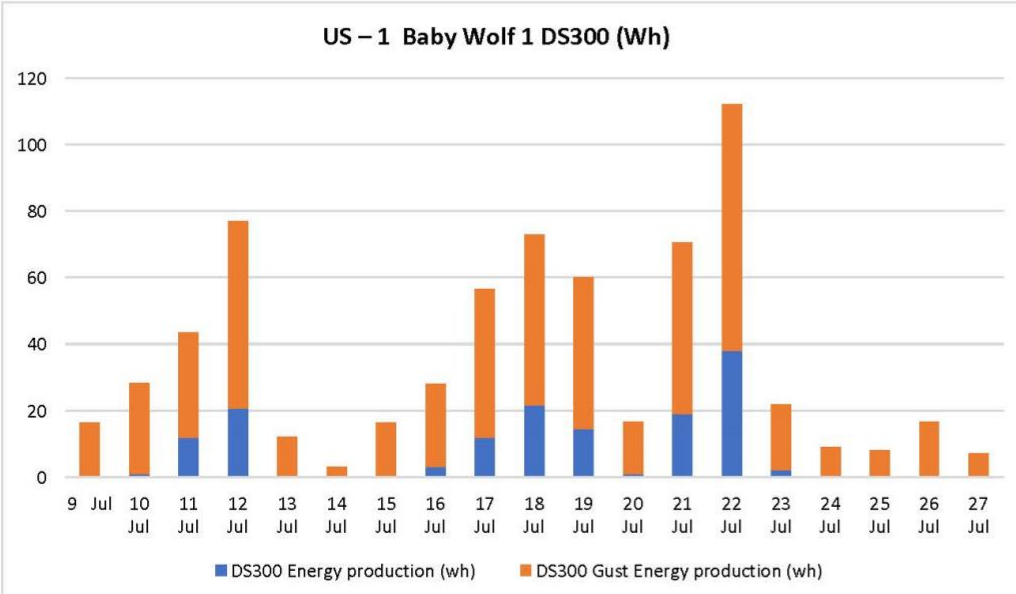


Figure 9. Avg. Speed and Gust Data, US-1 Site, 9 - 27 July, 2019
Wired Anemometer (Wolf 1), w/ DS3000 Turbine Outputs



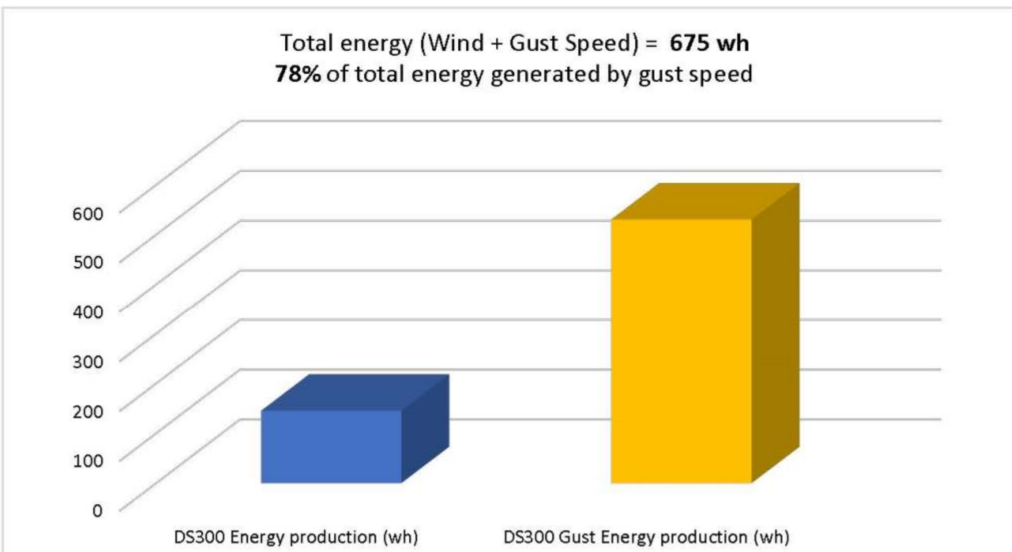
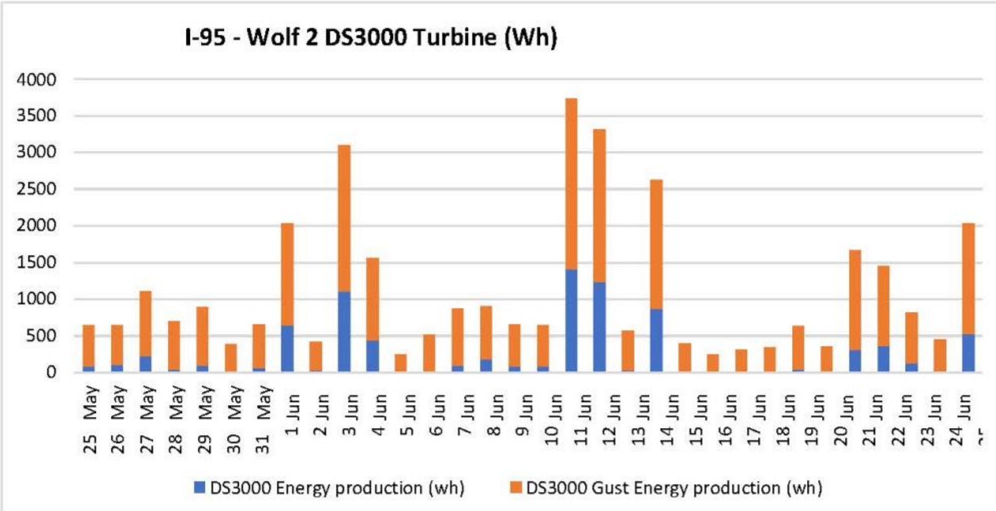


Figure 10. Avg. Speed and Gust Data, US-1 Site, 9 - 27 July, 2019
Wireless Anemometer (Baby Wolf 1), w/ DS300 Turbine



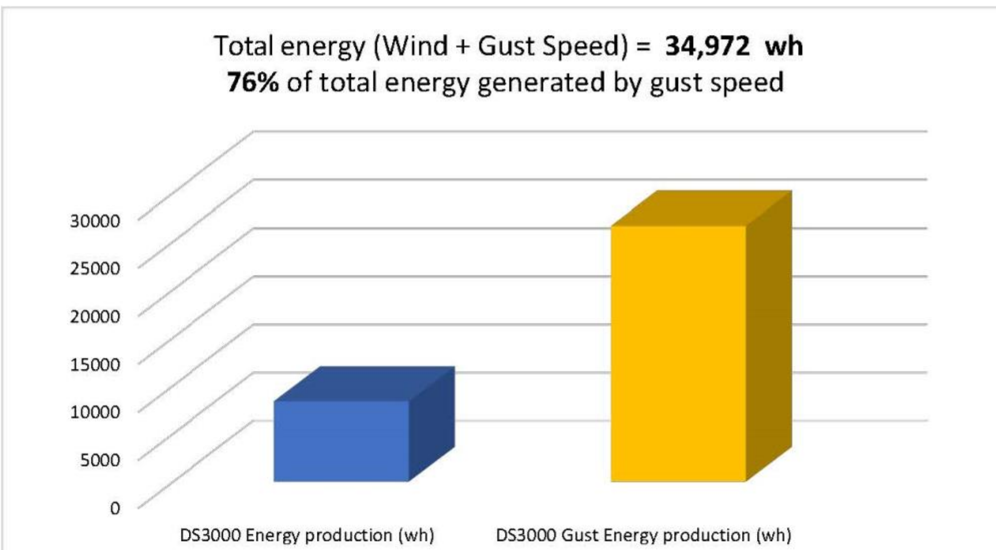
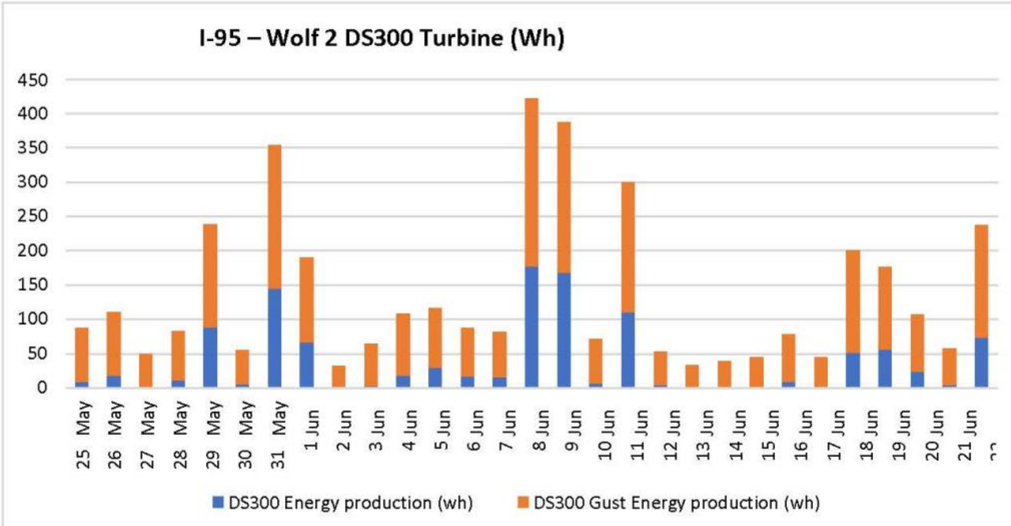


Figure 11. Avg. Speed and Gust Data, US-1 Site, 25 May - 25 June, 2019
Wired Anemometer (Wolf 2), w/ DS3000 Turbine Outputs



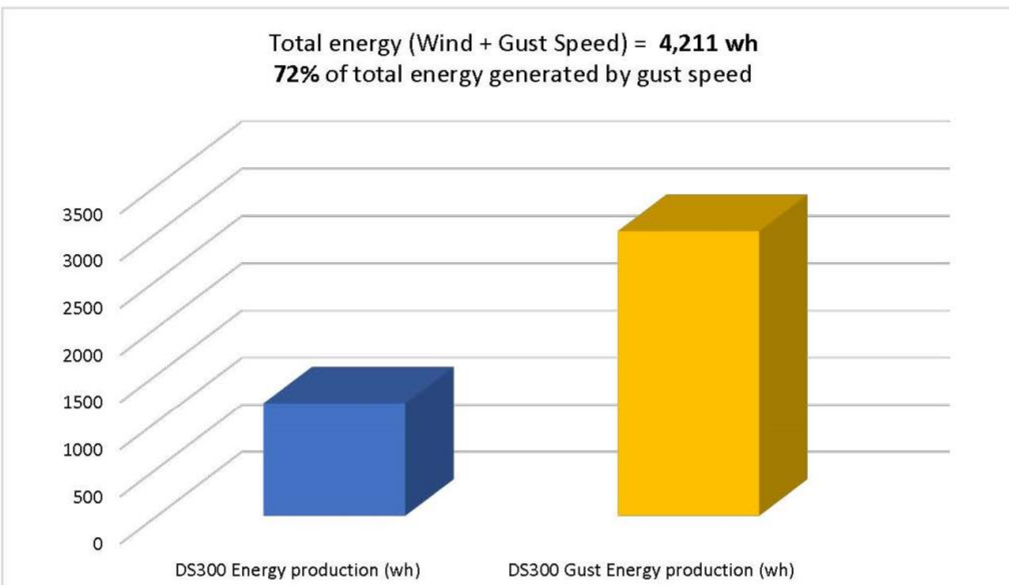
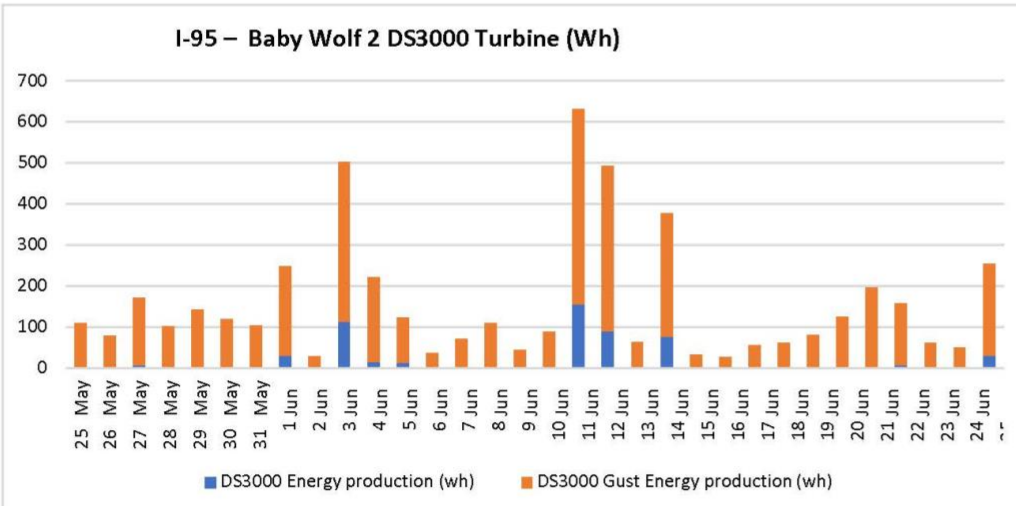


Figure 12. Avg. Speed and Gust Data, I-95 Site, 25 May - 22 June, 2019
Wired Anemometer (Wolf 2), w/ DS300 Turbine Outputs



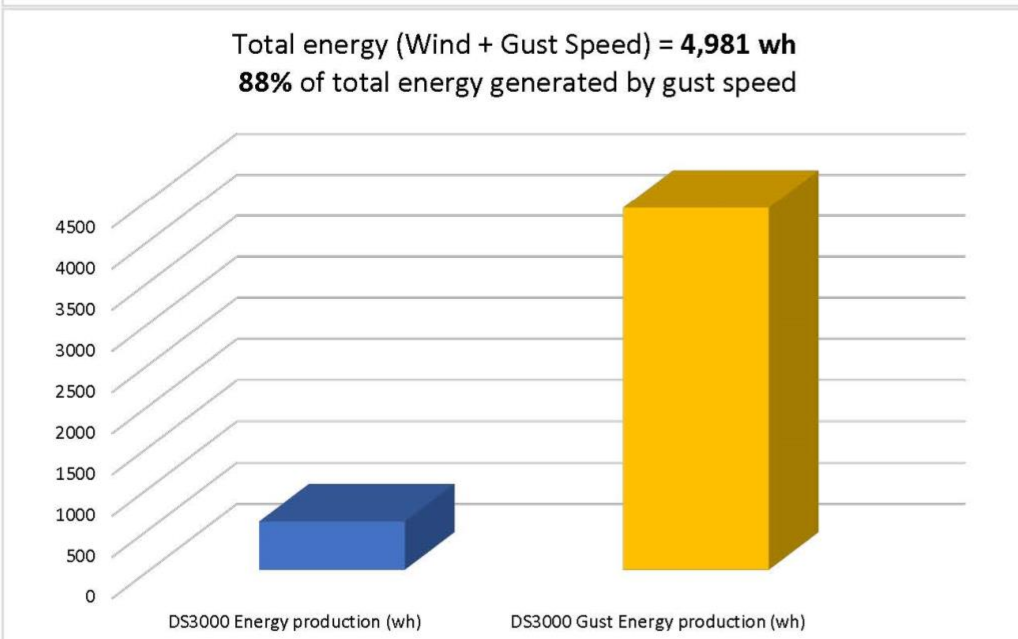
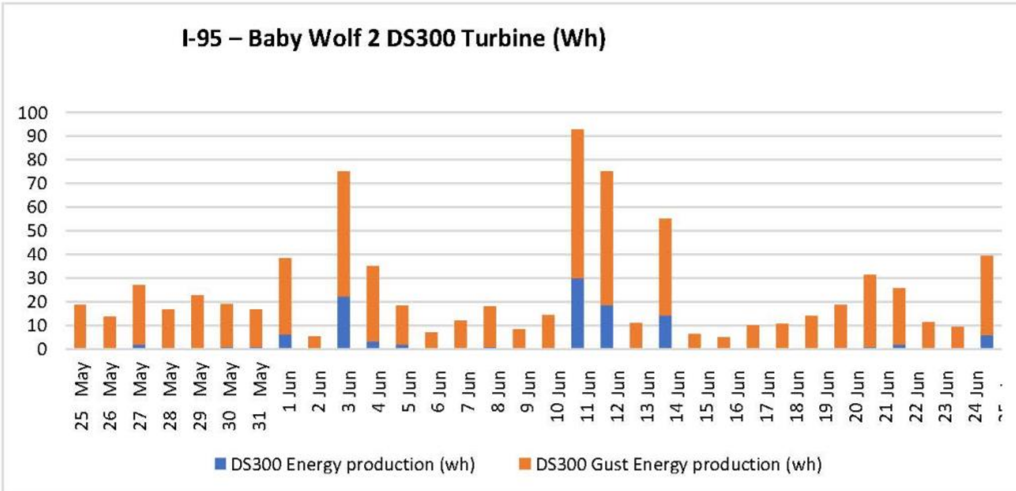


Figure 13. Avg. Speed and Gust Data, I-95 Site, 25 May - 25 June, 2019
Wireless Anemometer (Baby Wolf 2), w/ DS3000 Turbine Outputs



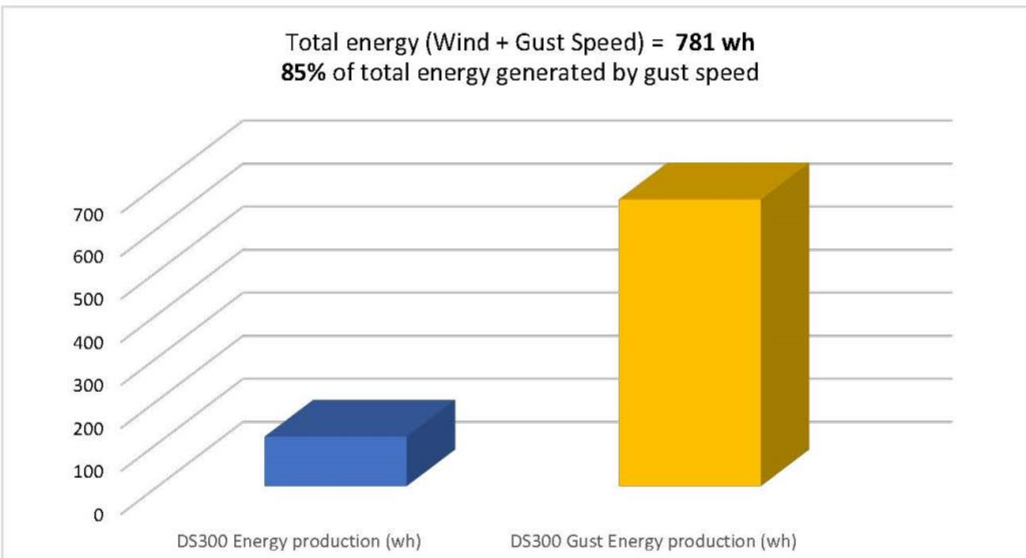
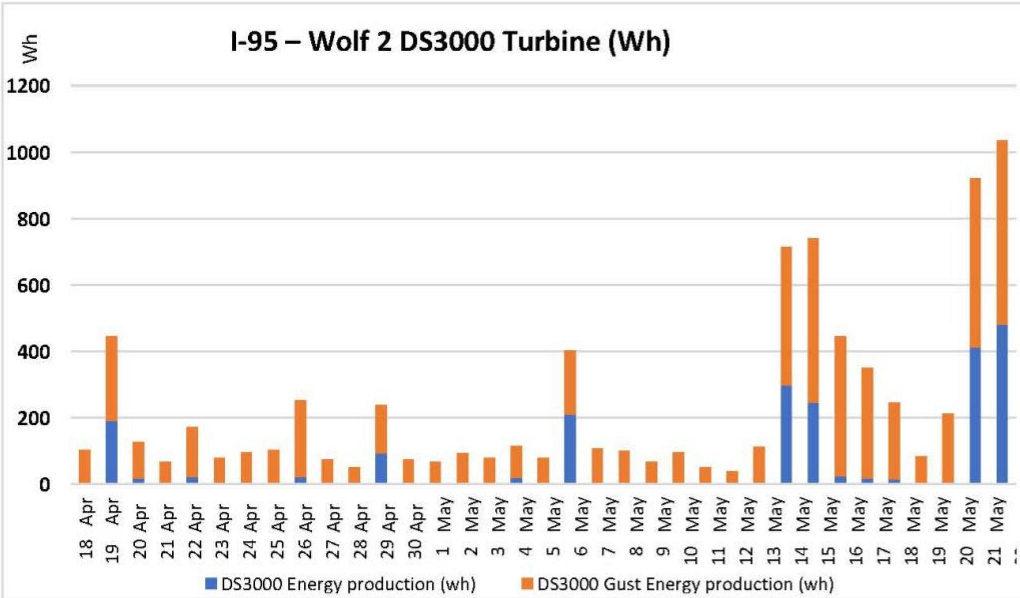


Figure 14. Avg. Speed and Gust Data, US-1 Site, 25 May - 25 June, 2019
Wireless Anemometer (Baby Wolf 2), w/ DS300 Turbine Outputs



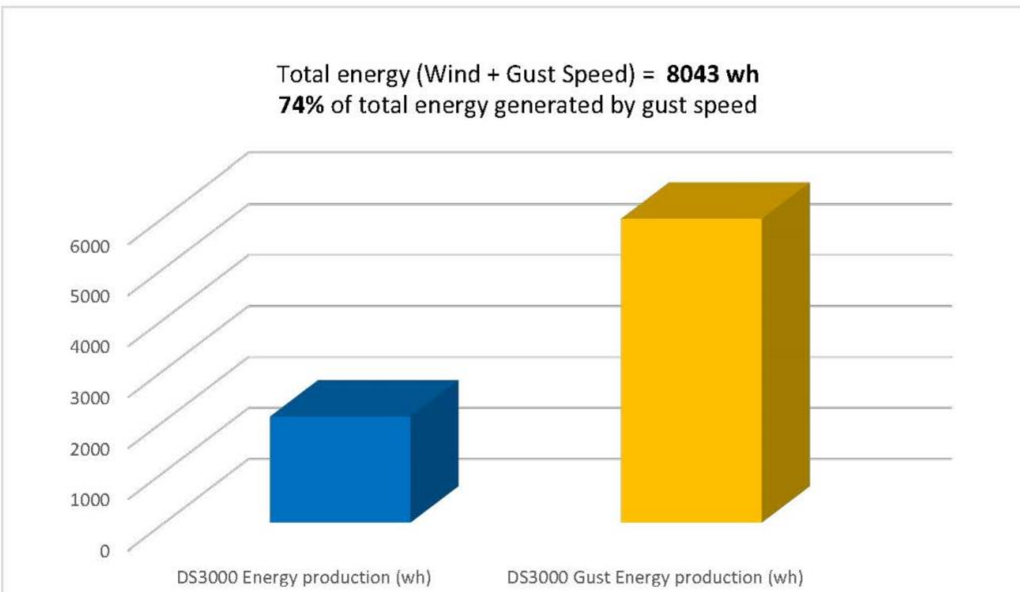
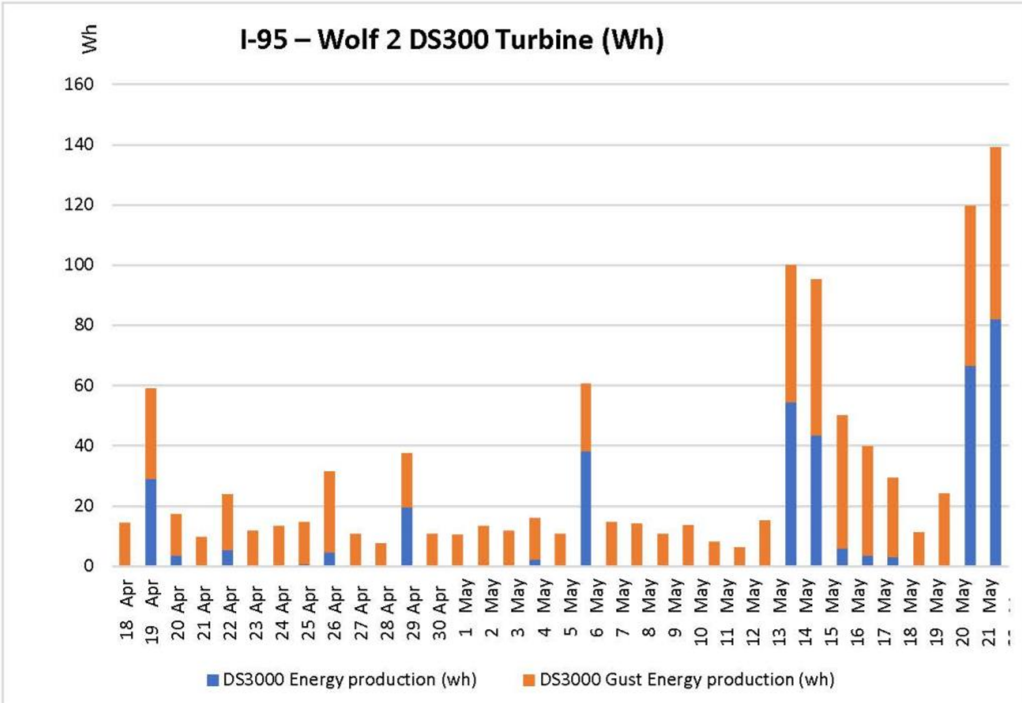


Figure 15. Avg. Speed and Gust Data, I-95 Site, 18 April - 22 May, 2019
Wired Anemometer (Wolf 2), w/ DS3000 Turbine Outputs



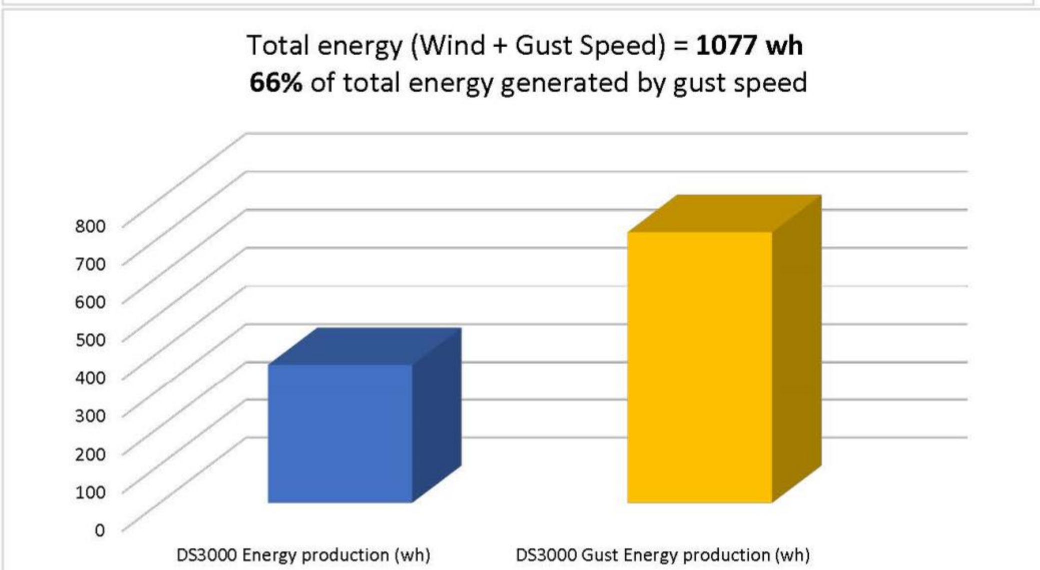
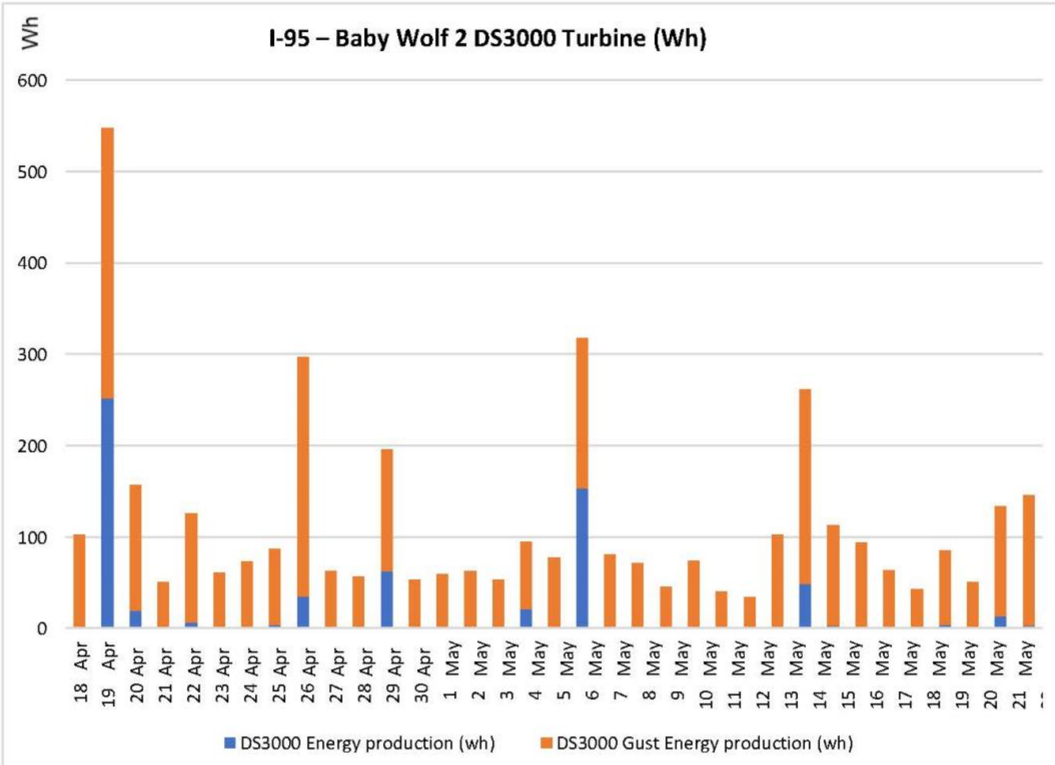


Figure 16. Avg. Speed and Gust Data, I-95 Site, 18 April - 22 May, 2019
Wired Anemometer (Wolf 2), w/ DS300 Turbine Outputs



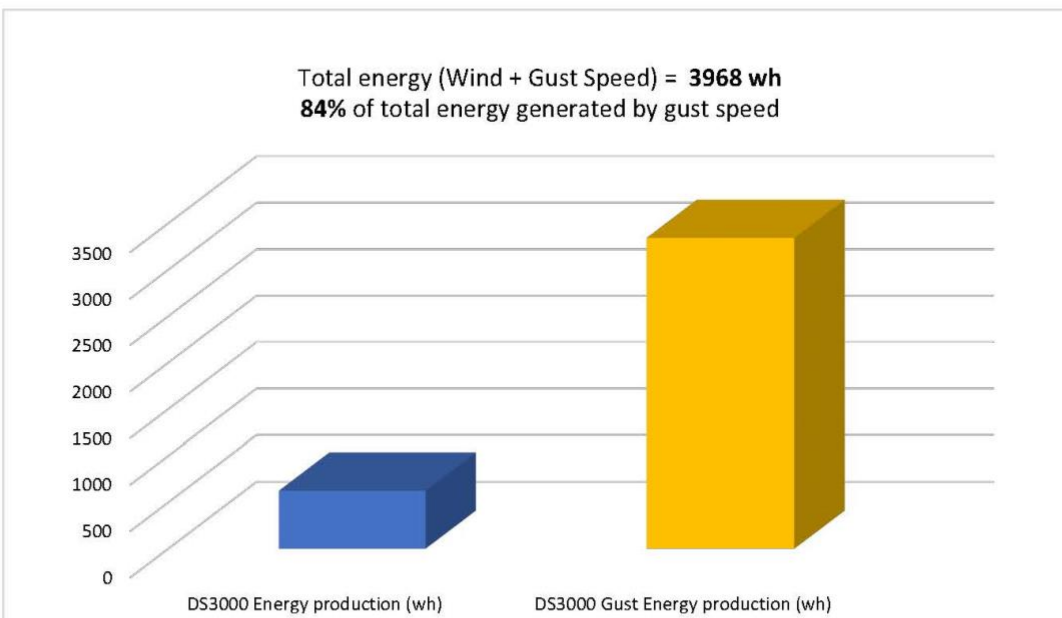
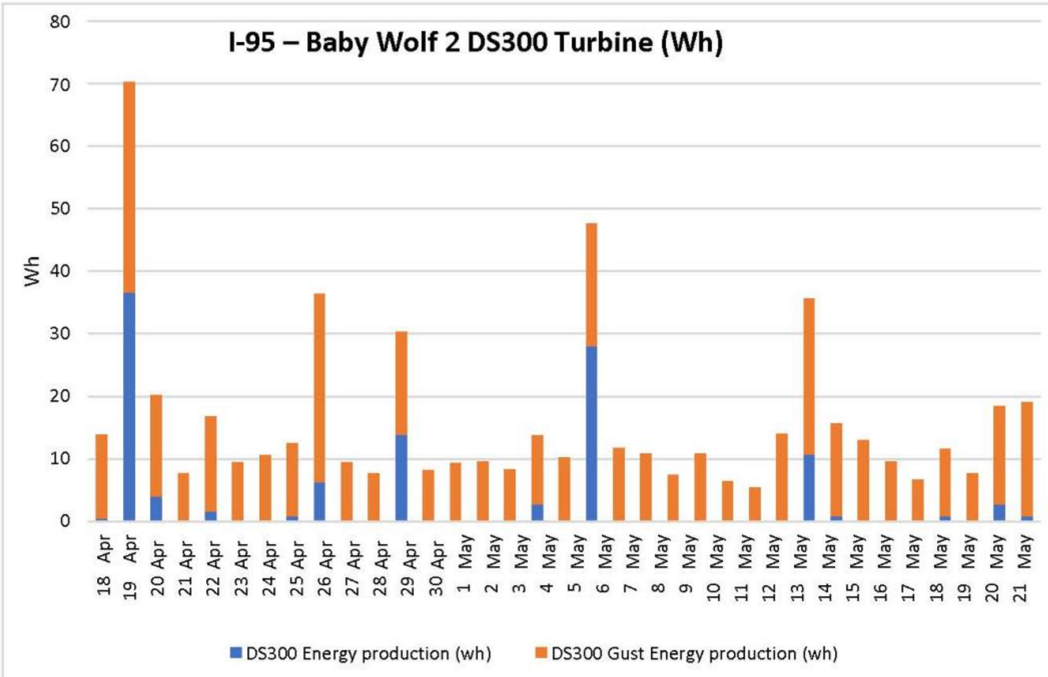


Figure 17. Avg. Speed and Gust Data, I-95 Site, 18 April - 22 May, 2019
Wireless Anemometer (Baby Wolf 2), w/ DS300 Turbine Outputs



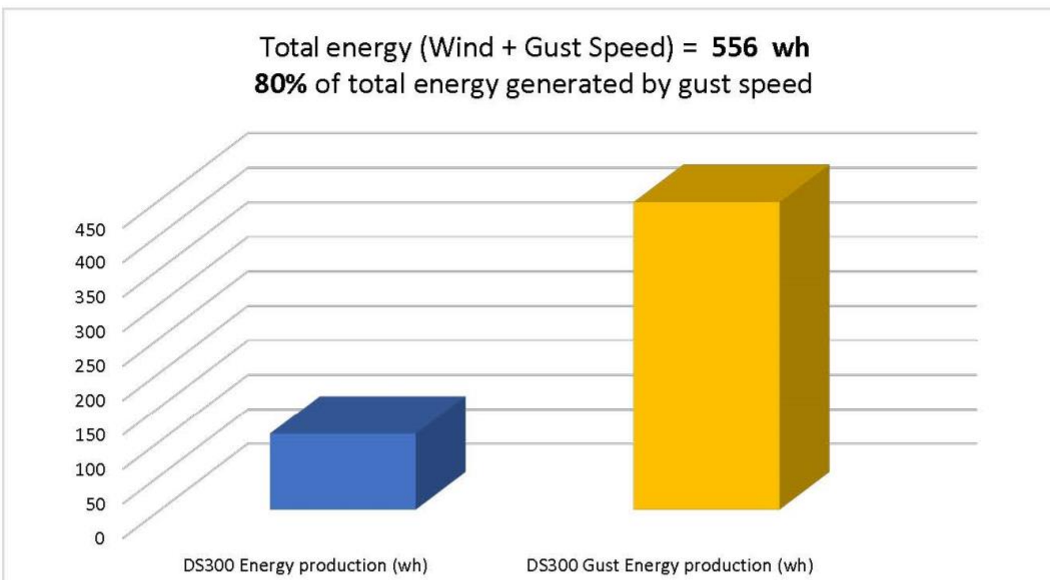
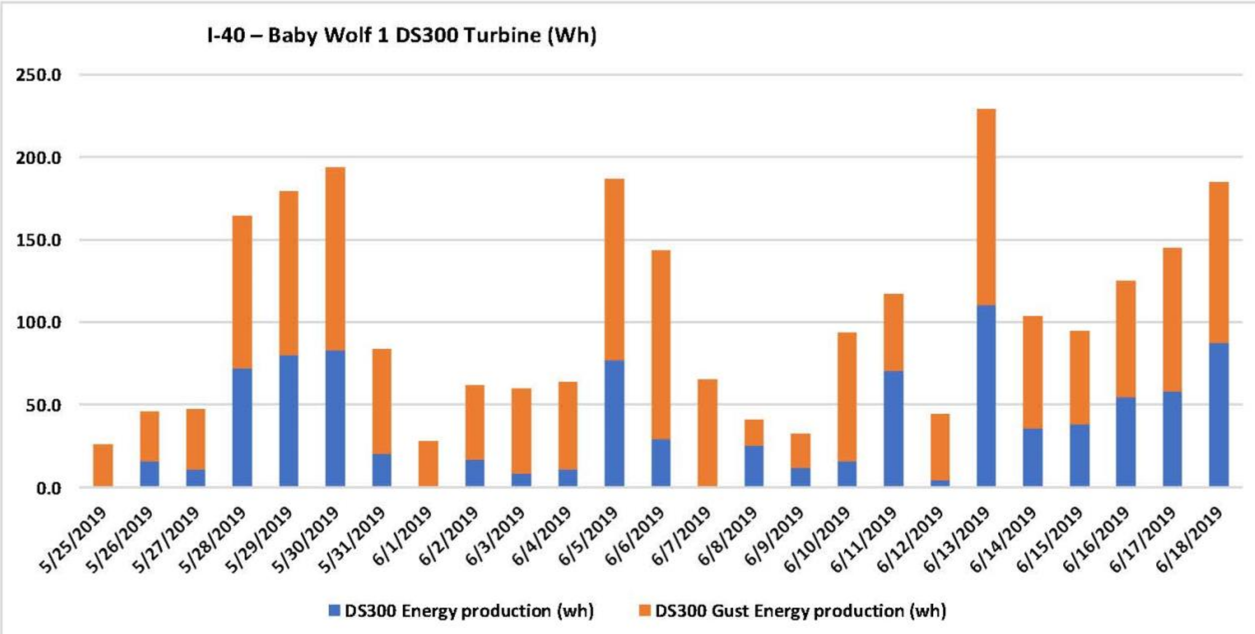


Figure 18. Avg. Speed and Gust Data, I-95 Site, 18 April - 22 May, 2019
Wireless Anemometer (Baby Wolf 2), w/ DS300 Turbine Outputs



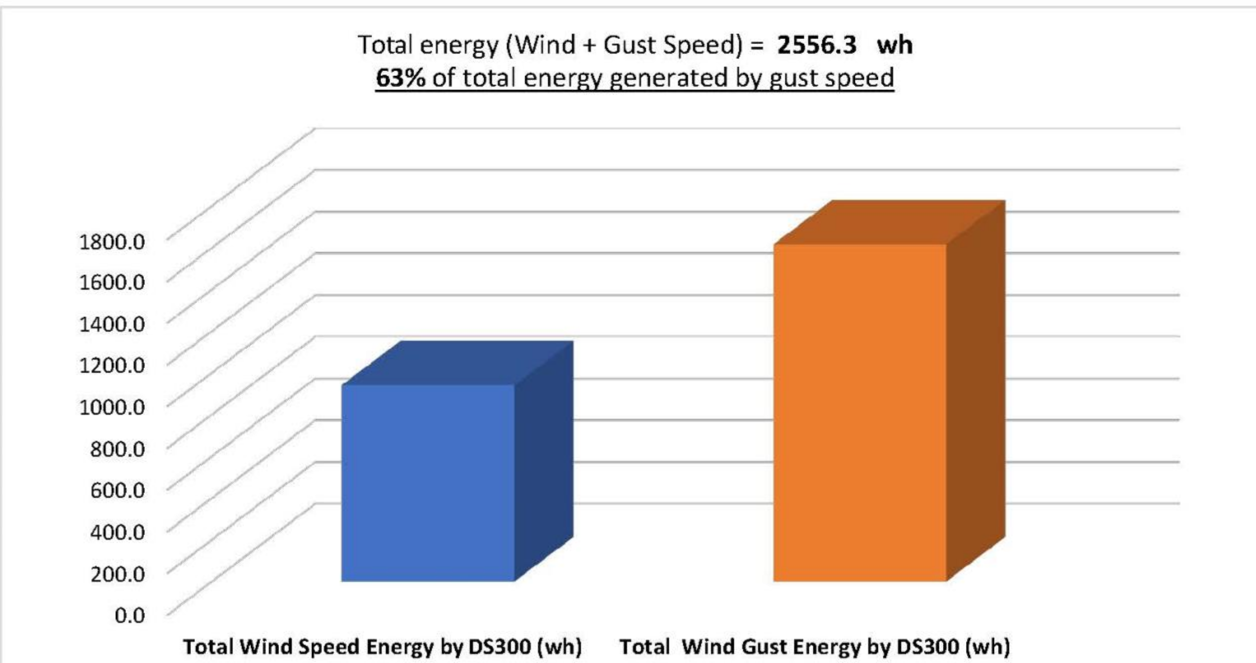
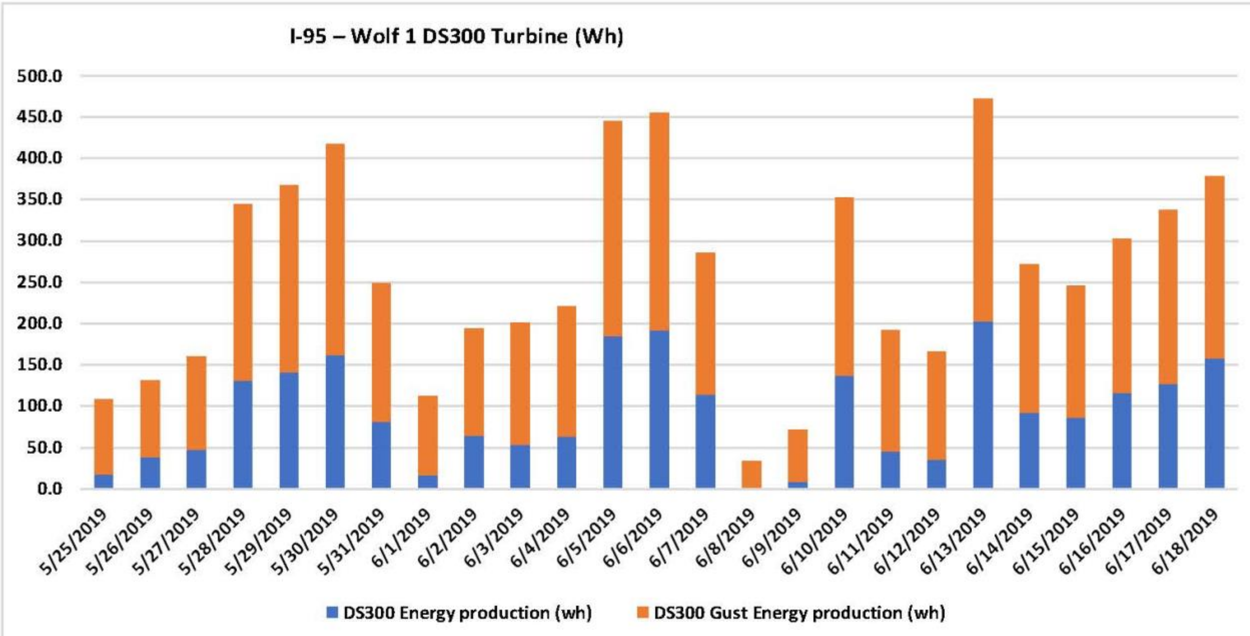


Figure 19. Avg. Speed and Gust Data, I-40/85 Site, 25 May - 18 June, 2019
Wireless Anemometer (Baby Wolf 1), w/ DS300 Turbine Outputs



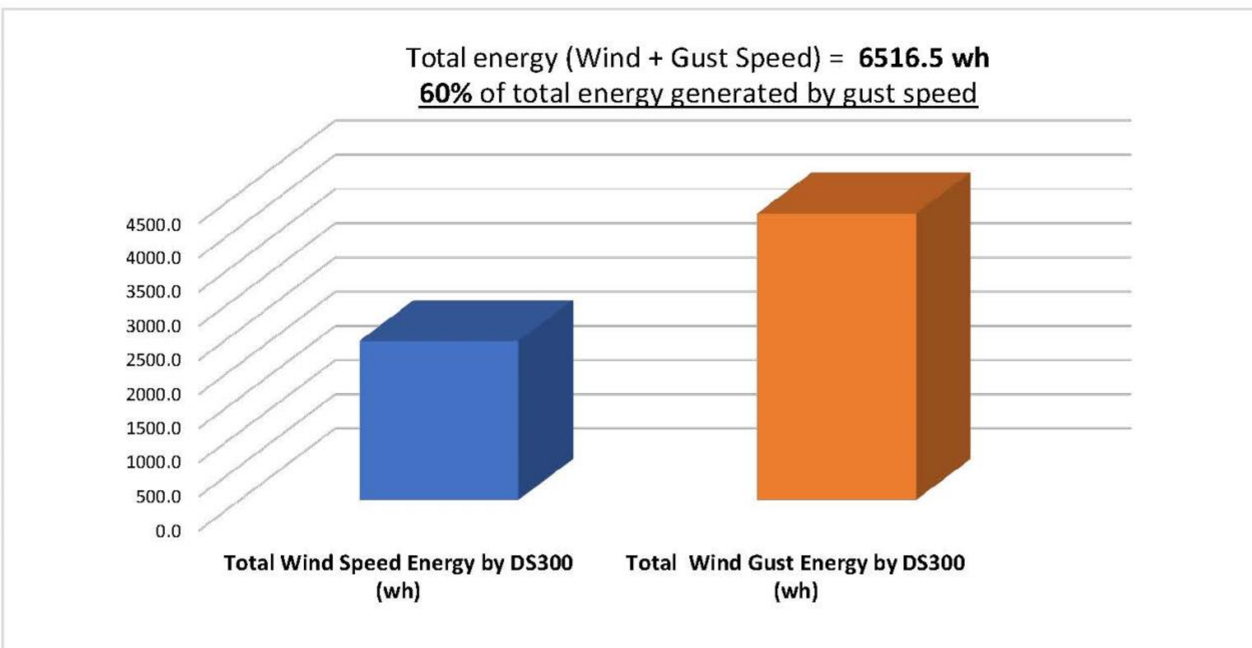


Figure 20. Avg. Speed and Gust Data, I-40/85 Site, 25 May - 18 June, 2019
Wired Anemometer (Wolf 1), w/ DS300 Turbine Outputs

Appendix C – Technology Specification Sheets

ONSET

HOBO® RX3000 Remote Monitoring System

Real-time access to data from any web browser

The HOBO RX3000 is a research-grade data logging station that combines greater measurement flexibility and an on-board LCD display in a rugged, easy-to-deploy package.

Supported Measurements:

Indoor Environmental: Temperature, Relative Humidity, Dew Point, C02, Air Velocity, VOC

Energy/Power: 4-20mA, AC Current, AC Voltage, Amp Hour, Amps, Compressed Air Flow, DC Current, DC Voltage, Differential, Pressure, Gauge Pressure, kW, kWh, Power Factor, Pulse Input, Volt-Amp Reactive, Volt-Amp Reactive Hour, Volt-Amps, Volts, Water Flow, Watt Hours, Watts

Outdoor Environmental: Temperature, Relative Humidity, Dew Point, Solar Radiation, PAR, Rainfall, Wind Speed, Wind Direction, Soil Moisture, Barometric Pressure, Leaf Wetness, 4-20mA, Voltage Input, Pulse Input

Key Advantages:

- Cloud-based data access
- Plug-and-play operation
- Flexible support for a broad range of sensors
- LCD display for easy field deployment
- Alarm notifications via text, email
- Rugged double-weatherproof enclosure
- Cellular, WiFi and Ethernet communications

Minimum System Requirements:

*Requires paid data plan
[1]AC power adapter or solar panel required. For more details, please visit onsetcomp.com, or call us at 1-800-564-4377.

Part number	RX3001-00-01 (ETH)	RX3002-00-01 (WiFi)	RX3003-00-01 (3G)
Smart Sensor Connectors	10 (up to 15 data channels; some sensors use more than one data channel)		
Maximum Number of Sensors	18 (when 2 Analog Modules are configured in the station)		
Smart Sensor Cable Length	100 m (328 ft) maximum		
Module Slots	2 (for optional Analog or Relay module; see manual for detailed module specification)		
Fastest Logging Rate	1 second	1 second	1 minute
Memory	32 MB, 2 million measurements		
Alarm notification latency	Logging interval plus 2-4 minutes, typical		
Environmental Rating	Weatherproof enclosure, NEMA 4X		
Operating Range	-40° to 60°C (-40° to 140°F)		
Power	Onset solar panel, AC charger or user-provided external power supply is required		
Battery Life	Typical 3-5 years; 4 Volt, 10 AHr, rechargeable sealed lead-acid		
Size	18.6 x 18.1 x 11.8 cm (7.3 x 7.1 x 4.7 in.)		
Weight	2.2 kg (4.85 lb)		
Communications	**Ethernet** RJ45/100BaseT	**WiFi** IEEE 802.11 b/g/n	**Cellular** GSM/GPRS/EDGE: Quad band 850/900/1800/1900 MHz, UMTS/HSPA+: Five band 800/850/900/1900/2100 MHz
CE Compliant	Yes		

For more details, please visit onsetcomp.com, or call us at 1-800-564-4377.

Contact Us

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- Email sales@onsetcomp.com
- Call 1-508-759-9500
- In U.S. toll free 1-800-564-4377
- Fax 1-508-759-9100

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- Contact Product Support onsetcomp.com/support/contact
- Call 1-508-759-9500
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RXW-WCF-xxx Sensor

HOBOnet Wind Speed and Direction Sensor

The HOBOnet Wireless Wind Speed and Direction Sensor records wind speed, wind gust, and wind direction. HOBOnet Wireless Sensors communicate data directly to the RX3000 weather station or pass data through other wireless sensors back to the central station. They are preconfigured and ready to deploy, and data is accessed through HOBOlink, Onset's innovative cloud-based software platform.

Supported Measurements:

Evapotranspiration and Wind

Key Advantages:

Sensor Features

- Provides average wind speed, highest 3-second wind gust, and average wind direction for the measurement interval
- Designed to meet World Meteorological Organization (WMO) guidelines

Wireless Features

- 900 MHz wireless mesh self-healing technology
- 450 to 600 meter (1,500 to 2,000 feet) wireless range and up to five hops
- Up to 50 wireless sensors per RX3000
- Simple button-push to join the HOBOnet wireless network
- Onboard memory to ensure no data loss
- Powered by rechargeable AA batteries and built-in solar panel

RXW-WCF-xxx Sensor Specifications

Sensor

	Wind Speed/Gust	Wind Direction
Measurement Range	0 to 76 m/sec (0 to 170 mph)	0 to 355 degrees
Accuracy	±1.1 m/sec (±2 mph) or ±5% of reading, whichever is greater	±7 degrees
Resolution	0.5 m/sec (1.1 mph)	1.4 degrees (0 to 355 degrees)
Starting Threshold	≤1 m/sec (2.2 mph)	1 m/sec (2.2 mph)
Turning Radius	108 mm (4.25 in.)	Approximately 135 mm (5.25 in.)
Measurement Definition	Cup revolutions are accumulated every three seconds for the duration of the logging interval Wind speed: Average speed for the entire logging interval Gust speed: The highest three-second wind recorded during the logging interval	Unit vector averaging used; vector components for each wind measurement are calculated every three seconds for duration of logging interval

Wireless Mote

Operating Temperature Range	-25° to 60°C (-13° to 140°F) with rechargeable batteries -40 to 70°C (-40 to 158°F) with lithium batteries
Radio Power	12.6 mW (+11 dBm) non-adjustable
Transmission Range	Reliable connection to 457.2 m (1,500 ft) line of sight at 1.8 m (6 ft) high Reliable connection to 609.6 m (2,000 ft) line of sight at 3 m (10 ft) high
Wireless Data Standard	IEEE 802.15.4
Radio Operating Frequencies	RXW-WCF-900: 904–924 MHz RXW-WCF-868: 866.5 MHz RXW-WCF-922: 916–924 MHz
Modulation Employed	OQPSK (Offset Quadrature Phase Shift Keying)
Data Rate	Up to 250 kbps, non-adjustable
Duty Cycle	<1%
Maximum Number of Motes	50 motes per one RX Wireless Sensor Network
Battery Type/ Power Source	Two AA 1.2V rechargeable NiMH batteries, powered by built-in solar panel or two AA 1.5 V lithium batteries for operating conditions of -40 to 70°C (-40 to 158°F)
Battery Life	With NiMH batteries: Typical 3–5 years when operated in the temperature range -20° to 40°C (-4°F to 104°F) and positioned toward the sun (see Deployment and Mounting), operation outside this range will reduce the battery service life With lithium batteries: 1 year, typical use
Memory	16 MB
Dimensions	Sensor: 470 x 191 x 121 mm (18.5 x 7.5 x 4.75 in.) Cable length: 3 m (9.8 ft) Mote: 16.2 x 8.59 x 4.14 cm (6.38 x 3.38 x 1.63 inches)
Weight	Sensor and cable: 1.332 kg (2 lb, 15 oz) Mote: 223 g (7.87 oz)
Materials	Sensor: Polycarbonate wind cups, sealed stainless steel bearing, UV-resistant ABS wind vane and black-anodized aluminum anemometer arm Mote: PCPBT, silicone rubber seal
Environmental Rating	Sensor: Weatherproof Mote: IP67, NEMA 6
Compliance Marks	FC RXW-WCF-900 CE RXW-WCF-868 RXW-WCF-922

Contact Us

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- Email sales@onsetcomp.com
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ONSET

RXMOD-RXW-xxx

HOBOnet Manager

The HOBOnet Wireless Manager module is installed in an RX3000 station. Data is transmitted wirelessly from sensors across the network to the RX3000 station and then uploaded to HOBOlink, Onset's innovative cloud-based software platform.

Key Advantages:

- 900 MHz wireless mesh self-healing technology
- 450 to 600 meter (1,500 to 2,000 feet) wireless range and up to five hops
- Up to 50 wireless sensors per RX3000
- Plugs into RX3000 Flex Port

RXMOD-RXW-xxx Specifications

	Wireless Mote
Operating Temperature Range	-25° to 60°C (-13° to 140°F)
Radio Power	12.6 mW (+11 dBm) non-adjustable
Transmission Range	Reliable connection to 457.2 m (1,500 ft) line of sight at 1.8 m (6 ft) high Reliable connection to 609.6 m (2,000 ft) line of sight at 3 m (10 ft) high
Wireless Data Standard	IEEE 802.15.4
Radio Operating Frequencies	RXMOD-RXW-900: 904–924 MHz RXMOD-RXW-868: 866.5 MHz RXMOD-RXW-922: 916–924 MHz
Modulation Employed	OQPSK (Offset Quadrature Phase Shift Keying)
Data Rate	Up to 250 kbps, non-adjustable
Duty Cycle	<1%
Maximum Number of Motes	50 motes per one RX Wireless Sensor Network
Power Source	Powered by the RX3000 station
Dimensions	Mote: 16.2 x 8.59 x 4.14 cm (6.38 x 3.38 x 1.63 inches) Cable length: 2 m (6.56 ft)
Weight	Mote: 159 g (5.62 oz)
Materials	Mote: PCPBT, silicone rubber seal
Environmental Rating	Mote: IP67, NEMA 6
Compliance Marks	FC RXMOD-RXW-900 CE RXMOD-RXW-868 RXMOD-RXW-922

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Appendix D – Solar Comparison Model

Design 4 Solar NCDOT, R267+GG St Pauls, North Carolina

Report

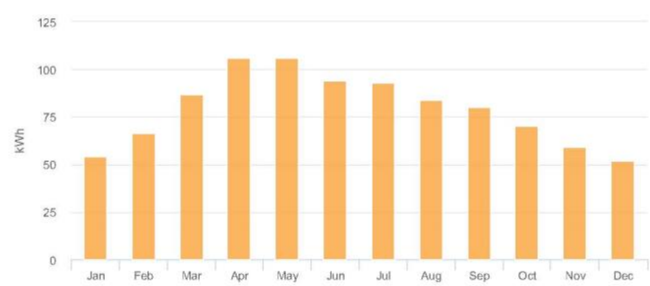
Project Name	Solar NCDOT
Project Address	R267+GG St Pauls, North Carolina
Prepared By	NC Cleantech Center lpanzar@ncsu.edu

System Metrics

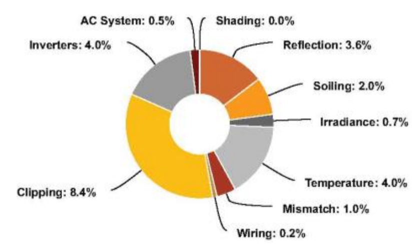
Design	Design 4
Module DC Nameplate	730.0 W
Inverter AC Nameplate	1,000.0 W Load Ratio: 0.73
Annual Production	953.3 kWh
Performance Ratio	77.8%
kWh/kWp	1,305.9
Weather Dataset	TMY, 10km grid (34.85,-78.95), NREL (prospector)
Simulator Version	5aaa168e77-c241cea3f8-0d743b72b3-a541694093

Project Location

Monthly Production



Sources of System Loss



Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	1,652.0	
	POA Irradiance	1,677.8	1.6%
	Shaded Irradiance	1,677.5	0.0%
	Irradiance after Reflection	1,617.6	-3.6%
	Irradiance after Soiling	1,585.2	-2.0%
	Total Collector Irradiance	**1,585.2**	**0.0%**
Energy (kWh)	Nameplate	1,157.1	
	Output at Irradiance Levels	1,149.2	-0.7%
	Output at Cell Temperature Derate	1,103.4	-4.0%
	Output After Mismatch	1,092.1	-1.0%
	Optimal DC Output	1,089.5	-0.2%
	Constrained DC Output	998.0	-8.4%
	Inverter Output	958.1	-4.0%
	Energy to Grid	**953.3**	**-0.5%**
Temperature Metrics			
	Avg. Operating Ambient Temp		19.0 °C
	Avg. Operating Cell Temp		27.3 °C
Simulation Metrics			
	Operating Hours		4669
	Solved Hours		4669

Condition Set

Description	Condition Set 1											
Weather Dataset	TMY, 10km grid (34.85,-78.95), NREL (prospector)											
Solar Angle Location	Meteo Lat/Lng											
Transposition Model	Perez Model											
Temperature Model	Sandia Model											
Temperature Model Parameters	Rack Type	a	b	Temperature Delta								
	Fixed Tilt	-3.56	-0.075	3°C								
	Flush Mount	-2.81	-0.0455	0°C								
Soiling (%)	J	F	M	A	M	J	J	A	S	O	N	D
	2	2	2	2	2	2	2	2	2	2	2	2
Irradiation Variance	5%											
Cell Temperature Spread	4° C											
Module Binning Range	-2.5% to 2.5%											
AC System Derate	0.50%											
Module Characterizations	Module	Uploaded By	Characterization									
	TSM-DEG14C.07 (II) 365 (Trina Solar)	Folsom Labs	Spec Sheet Characterization, PAN									
Component Characterizations	Device	Uploaded By	Characterization									
	1KW Tough TL (AEC)	Folsom Labs	Spec Sheet									

Components

Component	Name	Count
Inverters	1KW Tough TL (AEC)	1 (1,000.0 W)
Strings	10 AWG (Copper)	1 (16.8 ft)
Module	Trina Solar, TSM-DEG14C.07 (II) 365 (365W)	2 (730.0 W)

Wiring Zones

Description	Combiner Poles	String Size	Stringing Strategy
Wiring Zone	12	3-10	Along Racking

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Landscape (Horizontal)	15°	106°	2.9 ft	1x1	2	2	730.0 W

Detailed Layout