Ohio Tall Towers
Wind Assessment Initiative

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Bryan Test Site
Study Report

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Disclaimer

The data presented in this report were obtained using modern wind resource assessment standards as outlined in the *Wind Resource Assessment Handbook* (AWS Scientific, Inc., April 1997). All manufacturer guidelines were followed concerning the installation and use of the equipment. Analysis steps are described in this report so that the reader can follow the calculations. Many of the calculations were performed independently by two GEO members to check for consistency. Data from four turbines are presented in this report, for comparison and educational purposes only. Green Energy Ohio does not promote or endorse any particular manufacturer of wind turbine. Though professional standards have been followed, Green Energy Ohio is not and does not claim to be a professional wind resource analysis firm. Green Energy Ohio or its members or staff cannot be held responsible for any decisions made regarding a wind turbine installation.

Executive Summary

In August 2004, Green Energy Ohio (GEO) received a Tall Towers Wind Assessment grant from the **U.S. Department of Energy** as well as additional funding from the **Ohio Department of Development** and the **George Gund Foundation** to acquire wind data at heights up to 100 meters (m) above the ground. (See the news release reproduced below for a description of the DOE project.) Four sites in various parts of the state, Wapakoneta, Bryan, Cuyahoga Falls, and Sullivan, were chosen for monitoring in consultation with the National Renewable Energy Laboratory (NREL). For the first time ever in Ohio, wind speed and directional information at heights up to 100 m were obtained. Lower heights of 40 m and middle heights of 70 m were also instrumented to yield an accurate measure of the wind shear at each location. Data for each site were collected and analyzed for a period in excess of 18 months by a team of local site sponsors as well as GEO wind program team members and volunteers. This report presents the results of the wind energy resource assessment study at the Bryan monitoring site. The report will present additional information from other monitoring sites in Ohio, to provide a comparison of Bryan results to reference data and expected performance based on the Ohio Wind Resource map.[1]

Ohio Department of Development News Release

With the installation of the first two utility-scale turbines in Bowling Green, Ohio in November 2003, wind power entered a new era in the state. Ohio has traditionally been considered a marginal state for wind energy development, but measurements collected by GEO at up to 50 m in Bowling Green revealed a high wind shear for this area of the state. This information along with strong support of the municipal utility, AMP-Ohio, and Green Mountain Energy Company, allowed for the installation of four 1.8 MW Vestas turbines in Bowling Green.. Independently, a new preliminary wind map of Ohio shows that area of the state, among others, to have good wind resources at heights above 50 m. In order to promote accelerated development of wind energy in Ohio, a wind map validated with actual data is needed.

With the exception of wind monitoring studies by GEO, the only measured wind data publicly available in Ohio are airport figures that are significantly flawed for gauging wind energy potential. While new turbines are being installed at heights from 70 to 100 m,, airport data is normally recorded at 10 m or lower – often with roof-mounted instruments affected by turbulence from the building itself. Furthermore, the airport data frequently lack important details such as variation in wind direction, turbulent intensity, appropriate averaging intervals, and temperature readings. Other wind resources include the older Battelle Wind Atlas, which has graphs of Ohio wind speeds, but they are not based on actual measurements at turbine hub heights. The Union of Concerned Scientists' wind resource map of Ohio in *Powering the Midwest* (1993) is based primarily on topography modifications to the Battelle data, and again lacks measurements at appropriate heights.

The new 2004 NREL wind map for Ohio suggests that Ohio's resource is better than previously thought. However, it too, relies on extrapolations – this time on measurements from weather balloons at elevations of 5,000 to 10,000 feet, coupled with state-of-the-art climate modeling. These maps have been prepared for other states and are excellent guides to prospecting for good wind locations. The release of the Ohio wind map in 2004 corresponds well with the timing of this project. This GEO Tall Towers project will help locate three to four promising Ohio sites to monitor. Furthermore, the data obtained can be used to verify the new Ohio Wind Resource Map at 100 m where no data are currently available. Wind developers will proceed with an investment only based on measured data, thus promoting increased wind development in Ohio.

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[1] *Wind Energy Resource Maps of Ohio*, AWS Truewind, LLC, July 13, 2004.

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Bryan Site and Project Description

The process of identifying potential monitoring locations for the Ohio Tall Tower program started with obtaining a list of communication towers registered with the FCC. From the FCC's ASR Antenna Structure Registration website, http://wireless.fcc.gov/antenna/index.htm?job=home, we were able to identify over 1,000 towers in Ohio that exceeded a height of 295 ft. Working from this list of 1,000 sites, the selection process quickly narrowed based on the three key factors: 1) finding tower owners that were willing to partner with GEO through the donation of tower space, 2) identifying communities that had an interest in taking on the role of a local site sponsor, and 3) potential that a utility-scale wind turbine would be installed at or near the site if the resource proved adequate. In terms of local community support, GEO identified three activities that communities can undertake to sponsor a site: 1) negotiation of tower space access, 2) donation of funds to offset installation costs, and 3) assistance with data retrieval.

Figure 1: Boom Installation on Communications Tower at Bryan

Figure 2: Instrumented Booms on Communications Tower at Bryan

On May 16, 2005, GEO completed successful wind monitoring instrumentation on a 400 ft communications tower owned by North West Ohio Public Radio Foundation located 1 mile west of the City of Bryan, Ohio. The City of Bryan and the North West Ohio Public Radio Foundation partnered with GEO on the project, which ran officially through December 31, 2006, although data were continuously collected through May 31, 2007. In all, 20 plus months of wind speed, directional and temperature data were collected at the site at heights of 40 m, 70 m and 100 m (See Appendix A: Bryan Site Specification Log).

The Bryan site was selected for participation in the Tall Towers program based on following selection criteria.

(1) **Tower Height, 250 ft minimum**. The height of North West Ohio Public Radio Foundation tower accommodated the placement of sensors at a height of 330 ft (100 m) which was the target height for monitoring.

(2) **Wind Resources Estimates from maps / computer models**. The Bryan site was predicted to have a wind resource which would be viable for utility scale wind power development. The Ohio Wind Resource Explorer website predicted an annual average wind speed of 5.87 m/s at a height of 50 m (164ft) and 7.05 m/s at a height of 100m (330 ft) with a power density of 354 watts/ meter^2 [W/m^2]. These numbers compared well with the predicted wind resource for the wind farm located just west of Bowling Green, OH.

(3) **Proximity to potential development sites**. Areas located immediately north, northwest, west, southwest and south of the tower site consist of flat, undeveloped and open landscape, that are primarily used for agricultural purposes. The city of Bryan also operates its own municipal electric utility; as such the city could utilize its distribution lines as a cost effective means of connection to a wind power generation site.

(4) **Local community interest**. The city of Bryan demonstrated a strong interest in participating as a local site sponsor in the Ohio Tall Towers program. The city Utility Director, PR Director, and other members of the community were familiar in general with the success of the wind power project in Bowling Green. As a local site sponsor, the city secured an agreement for access to space on the Public Radio Foundation of NW Ohio tower for the monitoring equipment, agreed to contribute funds to support the installation and removal of the monitoring equipment, and participate in retrieving data from the monitoring site on a weekly basis.

(5) **Geographic distribution**. The guidelines from the U.S. DOE to GEO in conducting the Ohio Tall Towers project were to collect data from sites with some geographic diversity around the state. The Bryan site, being located in the northwestern portion of the state, represented a good distinct data point that was adequately spaced from other sites being considered for the program and could serve as a representative data point for the region.

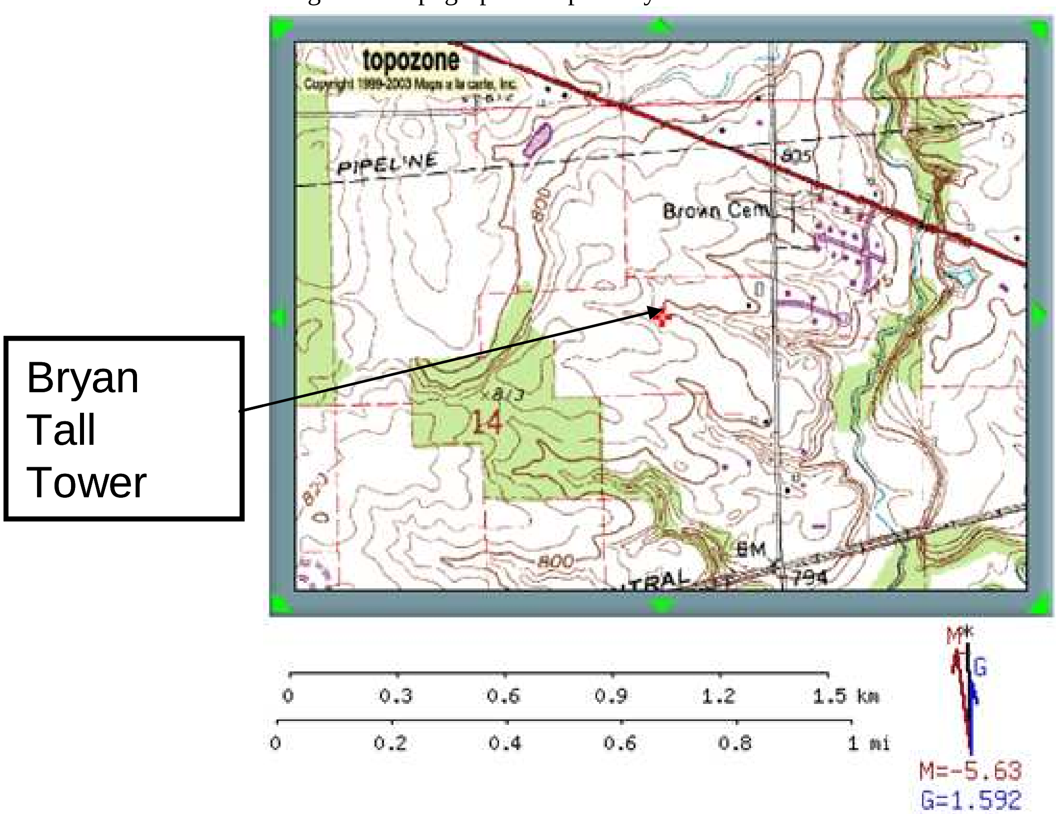
Unlike the Bowling Green study, the Tall Towers program was dependent on using existing tall towers to reach the upper heights of 100 m and thus site selection was motivated by tower availability in addition to site parameters. The location of the site was fixed by the existing tower locations and thus the potential for turbulence caused by the surrounding topography, buildings, and forestry could not be completely avoided. The site at Bryan is located at 41.47972N, 84.59722W with an elevation of 244 m (735 ft) and a tower height of 122 m (400 ft). Sources of turbulence at the Bryan site include patches of trees to the southwest and southeast of the towers. The ariel images shown in Figures 3 and 4, obtained from **Mapquest**, highlight these obstructions.

Figure 3: Ariel Image of Bryan Test Site

Figure 4: Ariel Image (wider view) of Bryan Test Site

A topographic map obtained from **Topozone** indicates the area surrounding the tower is at a higher elevation than the surrounding area.

Figure 5: Topographic Map of Bryan Test Site

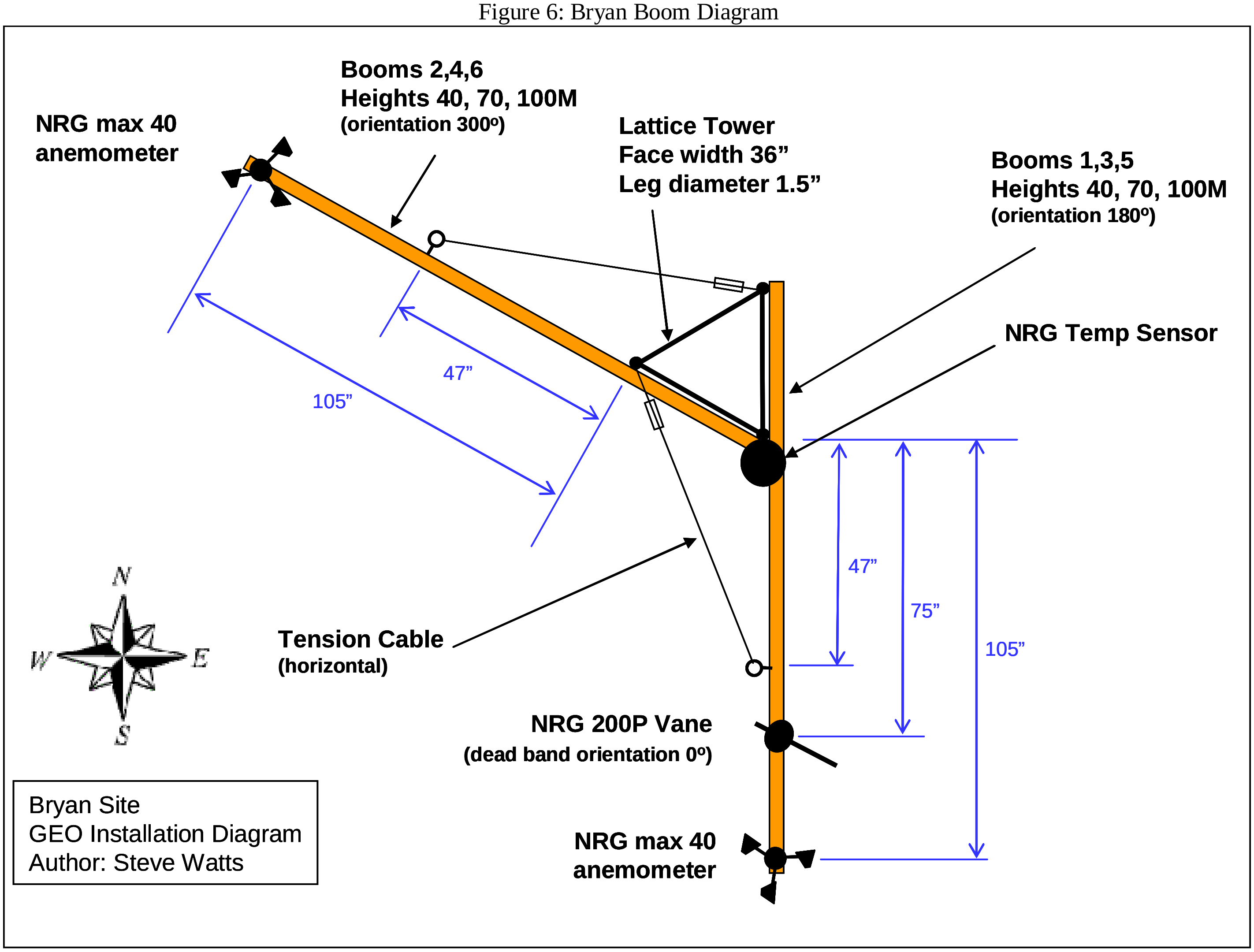


Monitoring Equipment and Installation

The communications tower is a 122 m (400 ft) triangular lattice tower with face widths of 0.9 m (2.9 ft) on each side. The tower was supported by a series of tension cables. Six booms were installed at nominal heights of 40 m, 70 m and 100 m with two booms at each height in the 180° (south) and 300° (northwest) orientation.

Each boom was outfitted with one NRG Maximum Type 40 Anemometer to record the wind speed. Wind direction was measured at each height on the 180° oriented boom using NRG 200P wind vanes. Finally, a temperature sensor was installed at the 100 m level on the tower. All of the data were recorded at 2-second intervals and then averaged to 10-minute periods and stored by the Symphonie data logger. In addition to the speed, direction and temperature mentioned above, the logger calculated the standard deviation, maximum and minimum values for each 10-minute period for each sensor and stored that information. Below is an ariel diagram of the boom placement and dimensions.

Figure 6: Bryan Boom Diagram



Data Recovery and Validation

The study commenced on May 16, 2005 and ended officially on December 31, 2006. However, data were collected after the official end date up until site decommissioning in June 2007. During the official monitoring period, the data recovery from all the sensors was near 100% except as noted in the following paragraphs.

Once the data were downloaded each week they were plotted using excel macros to make sure the sensors were still functional. At the end of the month, visual inspections of the graphs were conducted to flag spurious data. Events related to icing, tower shadowing, sensor malfunctions, low wind values and turbulence were recorded and processed using the excel macros. A monthly summary was conducted after the spurious data had been flagged.

It was in this manner that a problem with the temperature sensor was discovered during the fall of 2005. The temperature sensor was apparently struck by lightening during a storm. The data were flagged and temperature sensor data from a reference site were substituted for the erroneous temperature data during the time period from September 22nd to October 13th, 2005. No other problems were detected with the temperature sensor after it was replaced.

Bryan Site Summary Data

As described in the previous section, wind speed, directional and temperature data were collected at the North West Ohio Public Radio Foundation communications tower in Bryan, Ohio for a period in excess of 18 months. Below is a summary of the 12-month wind statistics for the site at each height tested. The period from Jan. through Dec. 2006 was used for this summary in order to cover a full year's worth of seasonal data so that there was no bias from seasonal variation in the wind data.

Table 1: Bryan Site Summary Statistics

Bryan Summary Statistics (2006)			
	40 m	70 m	100 m
Average Wind Speed [m/s]	4.20	5.29	6.13
Cubic Average Wind Speed [m/s]	4.96	6.13	7.06
Prevailing Wind Direction	SW	SW	SW
Turbulent Intensity [std dev / m/s]	0.197	0.156	0.130
Wind Power Density [W / m^2]	221.30	146.20	78.70
	40 m to 70 m	70 m to 100 m	
Wind Shear Exponent	0.4211	0.4147	

The following sections will discuss an analysis of wind speed, shear, direction, turbulent intensity and wind power density for the Bryan test site.

Wind Speed

As mentioned above, wind speed data were collected using two anemometers at 180 and 300 degrees from north at each of 3 different tower heights of 40 m, 70 m and 100 m. Data were collected at 2-second intervals and then averaged automatically at 10-minute intervals and stored in raw form in the logger. These data were collected each week and monitored for sensor or hardware failures. At the end of each month, macros were run on the raw data to generate monthly averages for each height. The macros were also designed to generate monthly cubic wind speed averages to be used in power density calculations as will be discussed in the section on *Wind Class and Power*. Below are graphs of the monthly wind speed averages and cubic wind speed averages for Bryan during more than 18 months of data collection.

Figure 7: Bryan Monthly Wind Speed Averages

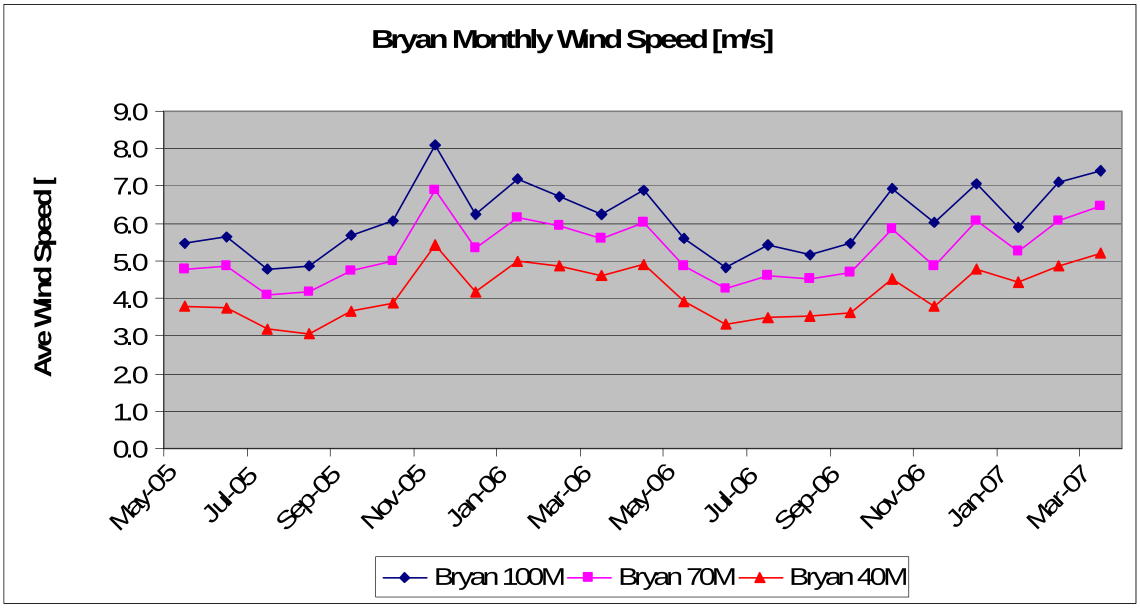
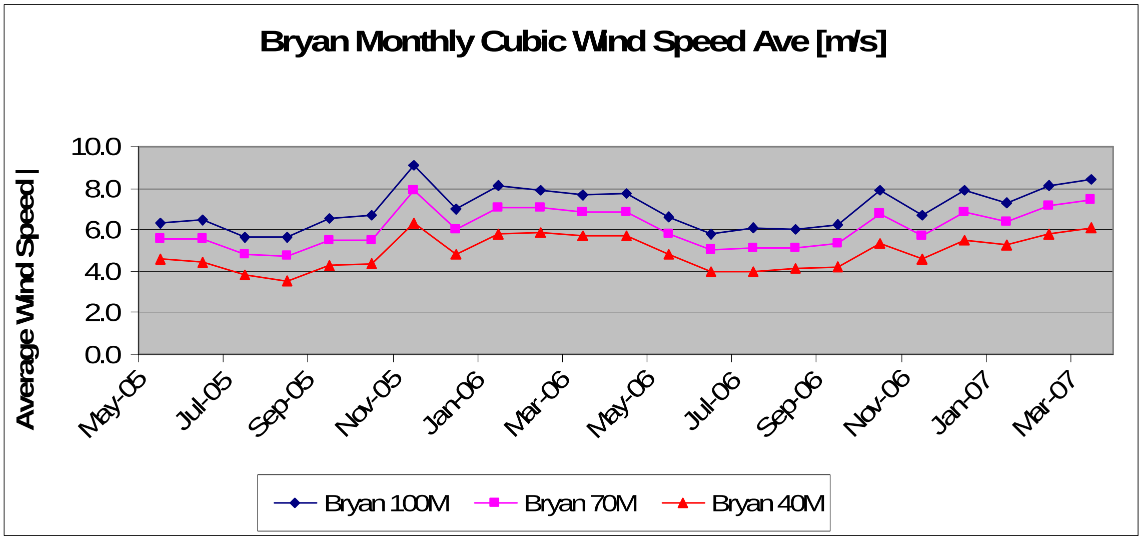
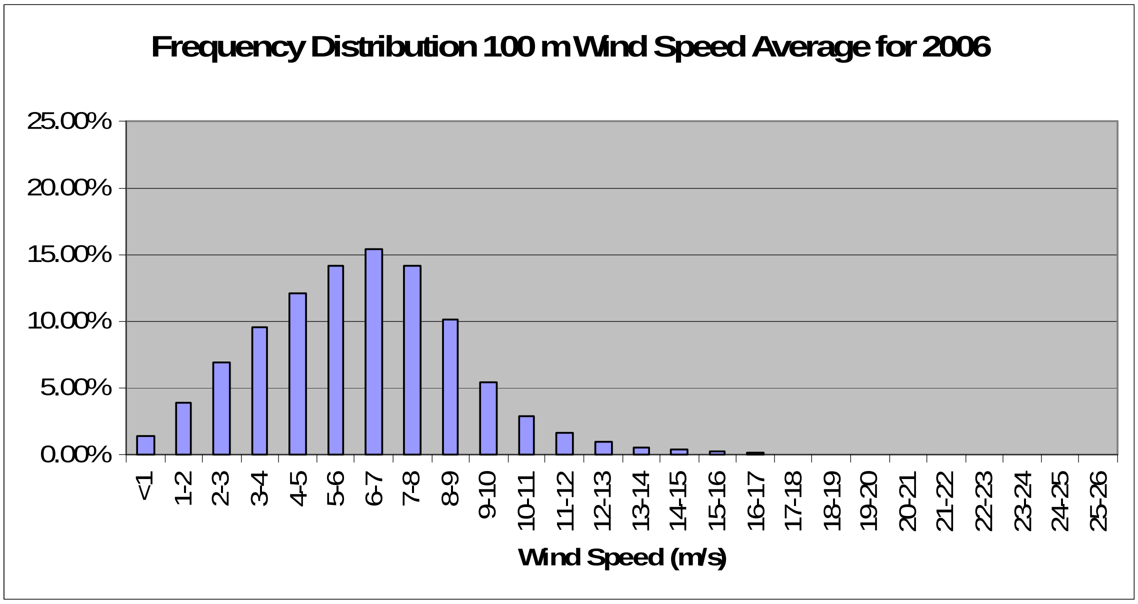


Figure 8: Bryan Monthly Cubic Wind Speed Averages

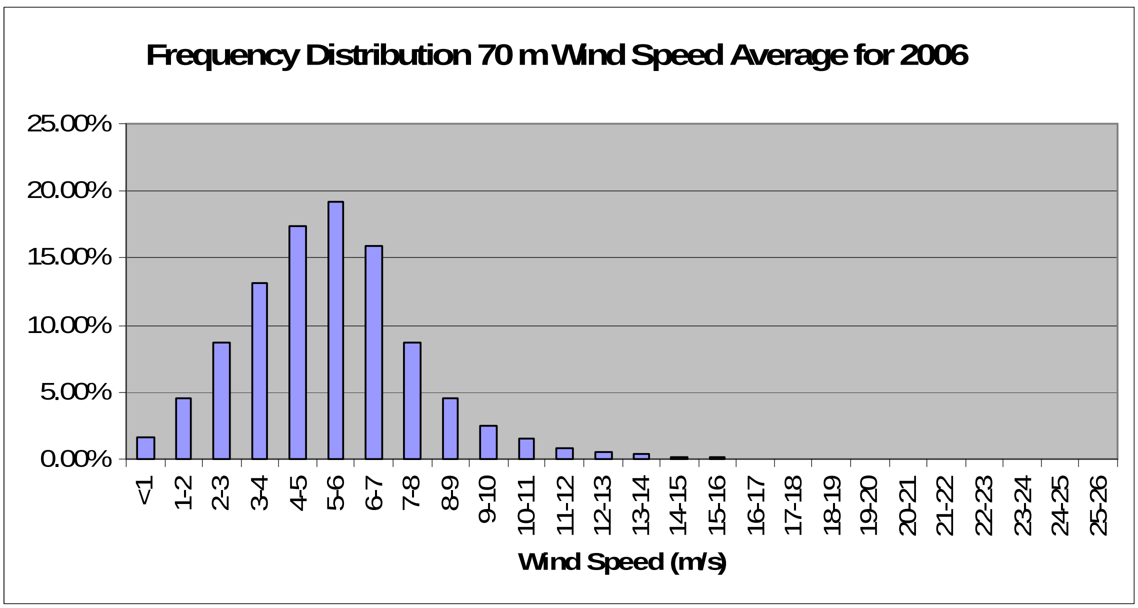


In addition to the monthly averages, a histogram of wind speed frequency over the study period is provided below. This information gives a better idea than the raw averages of the distribution of the wind speed and thus the amount of time the site is expected to be within a certain range of wind speed during the year. This gives an indication of how much of the time a wind turbine at the site might be operational. For example, many large utility-scale turbines have "cut-in" speeds of between 3 and 4 m/s (7 to 9 mph). Such a turbine would therefore be operational only during time periods when the wind speed is greater than the minimum/cut-in threshold for the turbine. This is explored further in a following section where power output is calculated. The histogram also gives information about the highest *sustained* wind speeds that can be expected. That is, the highest wind speeds a turbine would need to withstand during operation which in this case is about 17.4 m/s (39 mph) over a very small part of the year. In other words, the highest wind speeds recorded at the Bryan site were 17.4 m/s; therefore, a turbine placed at that site would need to be designed to handle speeds up to and in excess of 17.4 m/s. Again, please remember that logger data is averaged over a 10-minute period, so the highest wind speeds will likely exceed the 10-minute average highest wind speed.

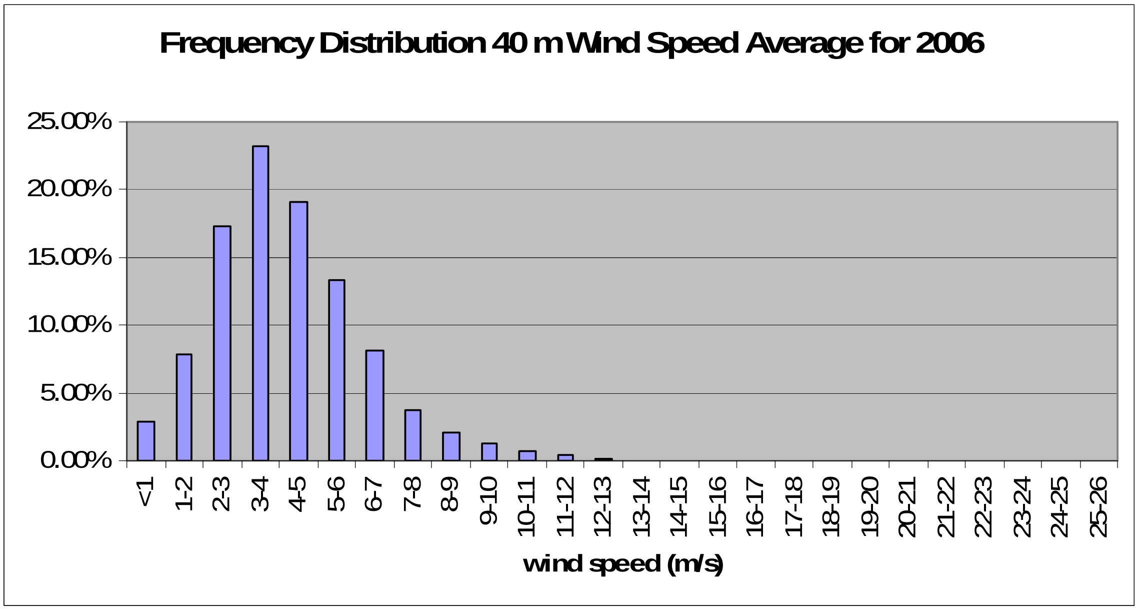
Figures 9a: Wind Speed Frequency Histograms for 100 m Anemometers



Figures 9b: Wind Speed Frequency Histograms for 70 m Anemometers



Figures 9c: Wind Speed Frequency Histograms for 40 m Anemometers



Wind Shear

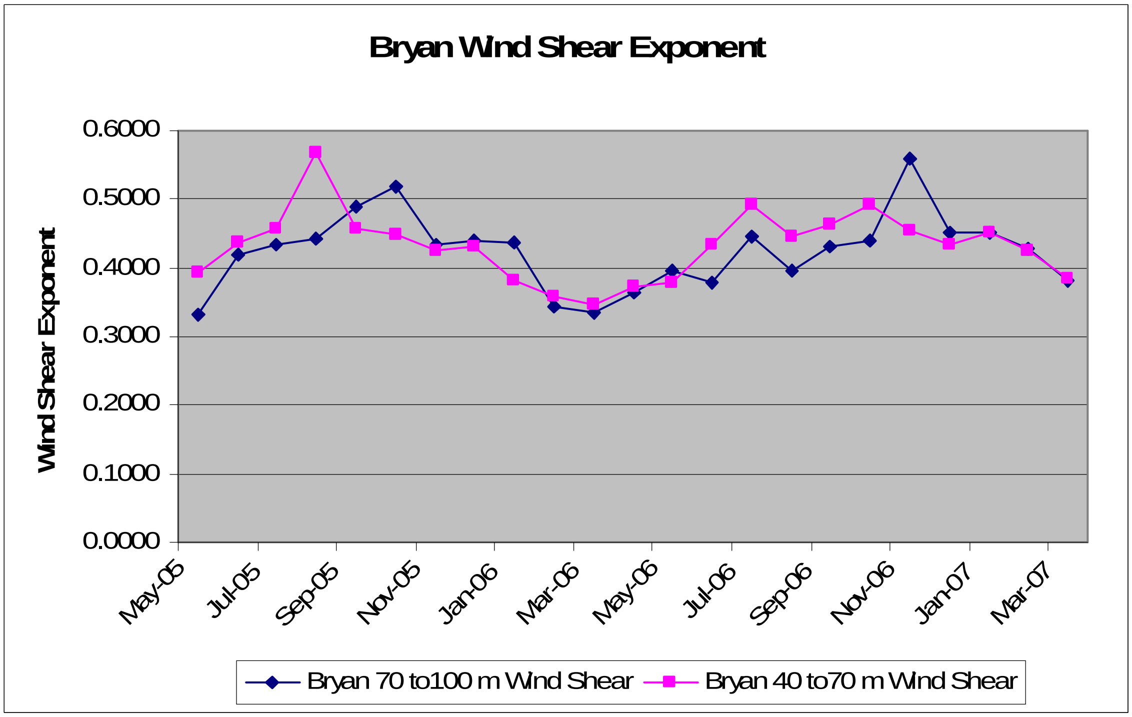
It useful to consider how the wind speed varies with height at a particular location since wind speed generally increases as elevation above the ground's surface increases. This information is used to determine the optimal height of the tower used for the wind turbine, as well as to estimate the variable loading on the blades. Normally an equation of the form:

$$V = V_0 \left(\frac{z}{z_0} \right)^{\alpha}$$

is used to model the increase of velocity with increasing height. Here V is the wind velocity and z is the height. The subscript 0 indicates a reference height. The coefficient α is called the wind shear exponent. Normally it takes a value of approximately 0.143 for clear, topographically level land.[2] At the Bryan Tall Tower Site, we measured shear values that are higher than what would be expected for a clear topographically level landscape, a phenomenon found initially at our Bowling Green site. The shear values measured at Bryan correlate are on the same order as shear values being experienced at other monitoring sites in Northwest Ohio.   The higher calculated shear exponents between the heights of 40 m to 70 m and 70 m to 100 m heights may be attributed to a number of factors including obstructions caused by buildings, trees and topography, as well as naturally occurring climate conditions in Northwest Ohio. Figure 10 below is a graph of wind shear values calculated during the study period.

[2] *Wind Resource Assessment Handbook: Fundamentals for Conducting a Successful Wind Monitoring Program*, AWS Scientific, Inc., April 1997.

Figure 10: Monthly Average Wind Shear Exponent



The 12-month average wind shear exponents for Bryan for the 2006 calendar year were approximately 0.42 from 40 m to 70 m and 0.44 from 70 m to 100 m (see Table 1). As a reference, values measured at the Bowling Green test site in 2000 were 0.32 for 30 m to 40 m and 0.65 for 40 m to 50 m which are significantly higher than the clear topographically level land value (0.143). These calculated wind shear exponents based on actual measured tall tower data at Bryan are much higher than the nominal 0.143 value. Thus models that extrapolate from low level wind speed data might very well underestimate the power density and potential turbine power output at the heights where a utility-scale turbine would be operational without using proper shear exponents.

Wind Direction

Wind direction is important to determine the effect of blockage (see above) or if one turbine will cause a wake that will disturb another one, if several are to be located near one another. In siting a turbine, it is also useful to know from which direction the wind predominantly arrives, and how variable it is. As seen below in Figures 11a and 11b, the predominant wind direction for the Bryan site is from the southwest. As shown in the aerial photographs of the site provided in Figures 3 and 4, there are some forested areas to the southwest of the site which might be a source of turbulence and could affect the measurements at this site.

Figure 11a: Wind Roses (Wind Direction) for Bryan at 100 m

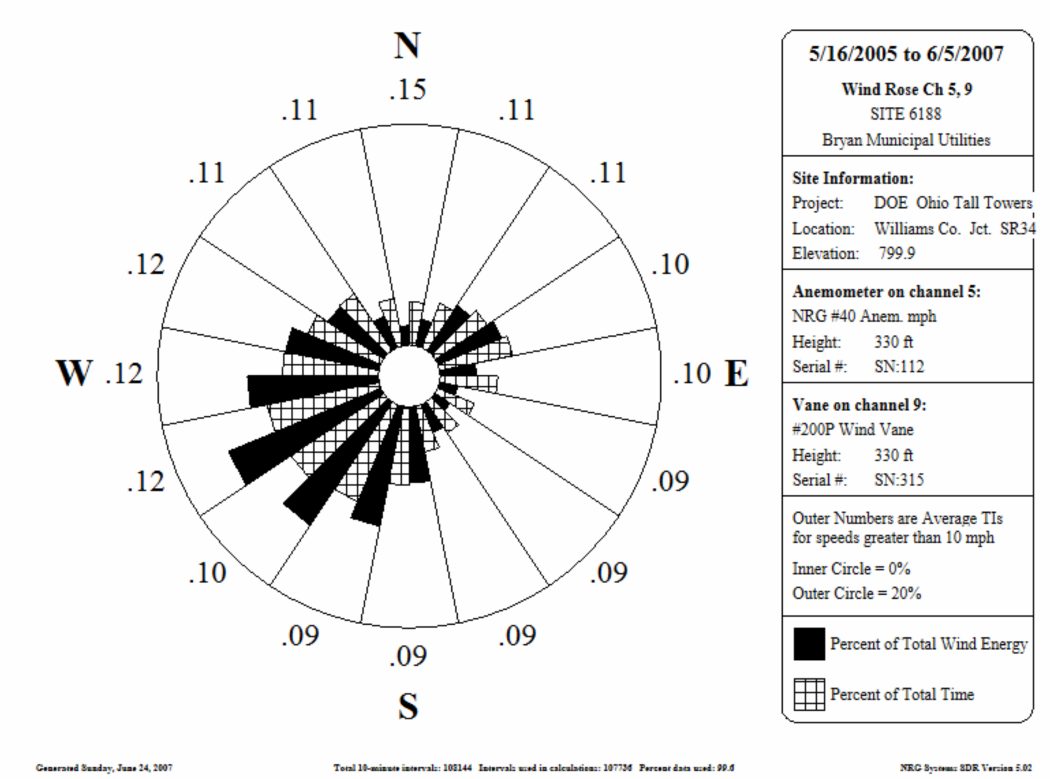


Figure 11b: Wind Roses (Wind Direction) for Bryan at 70 m

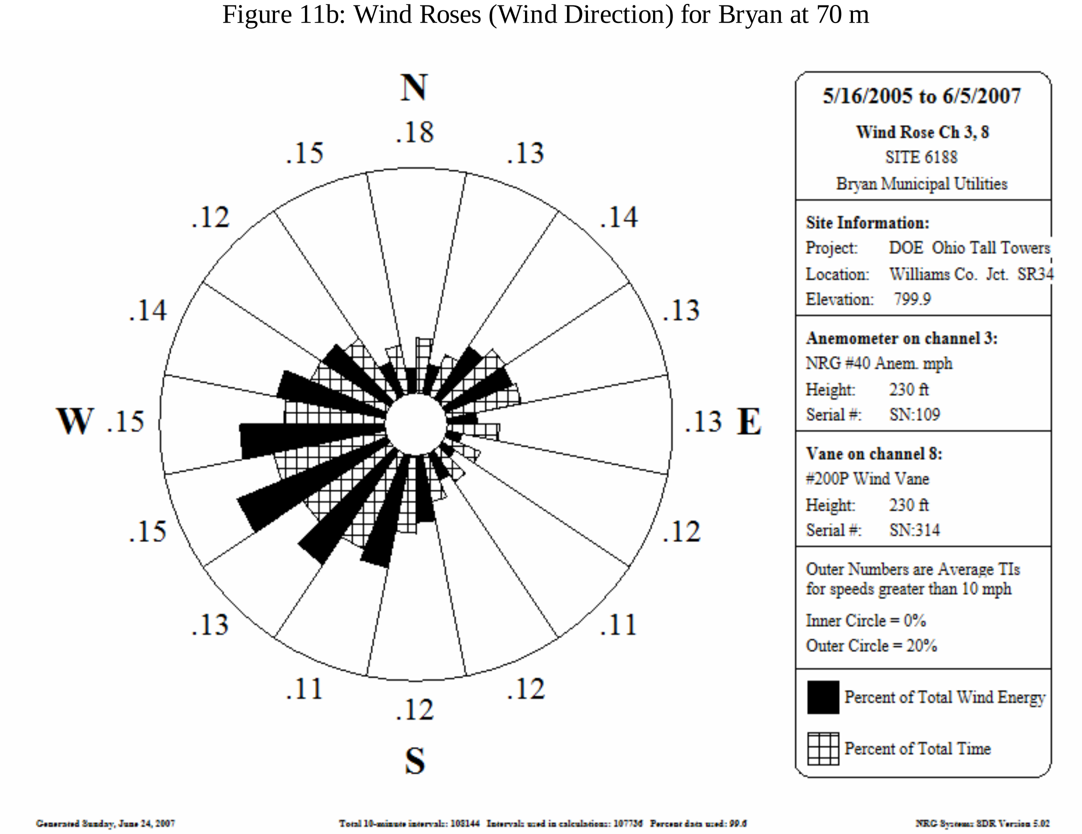
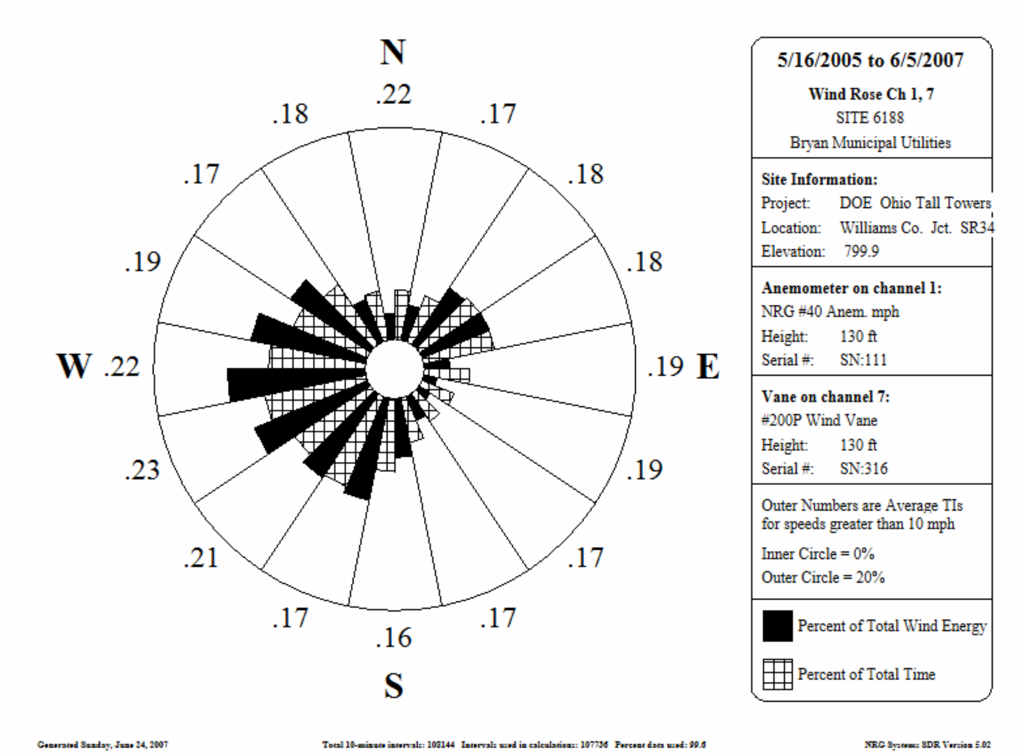


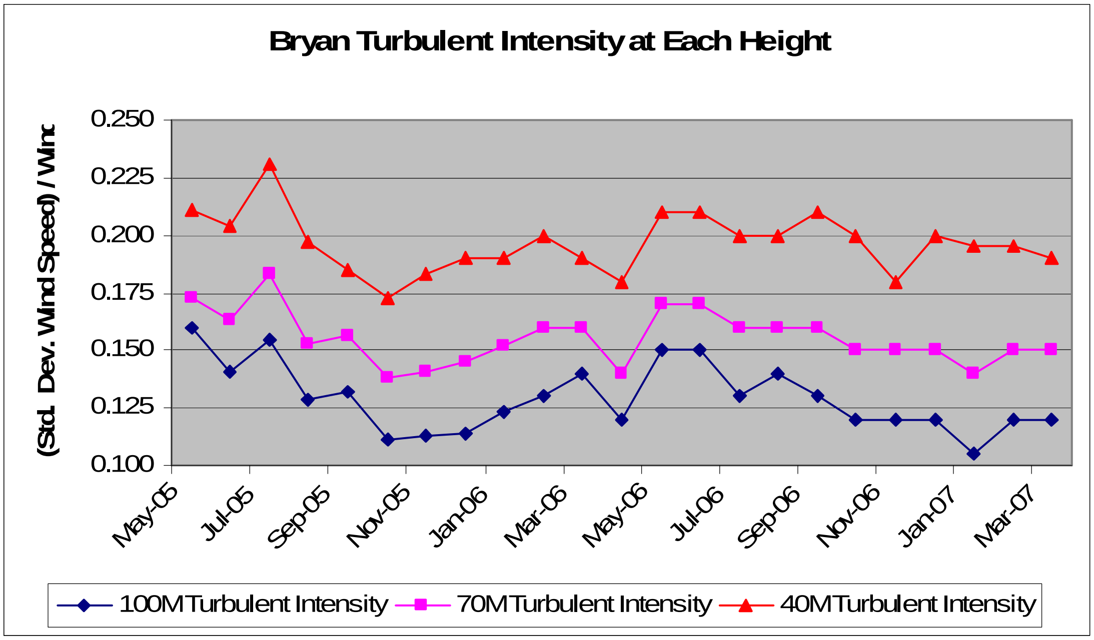
Figure 11c: Wind Roses (Wind Direction) for Bryan at 40 m



Turbulent Intensities

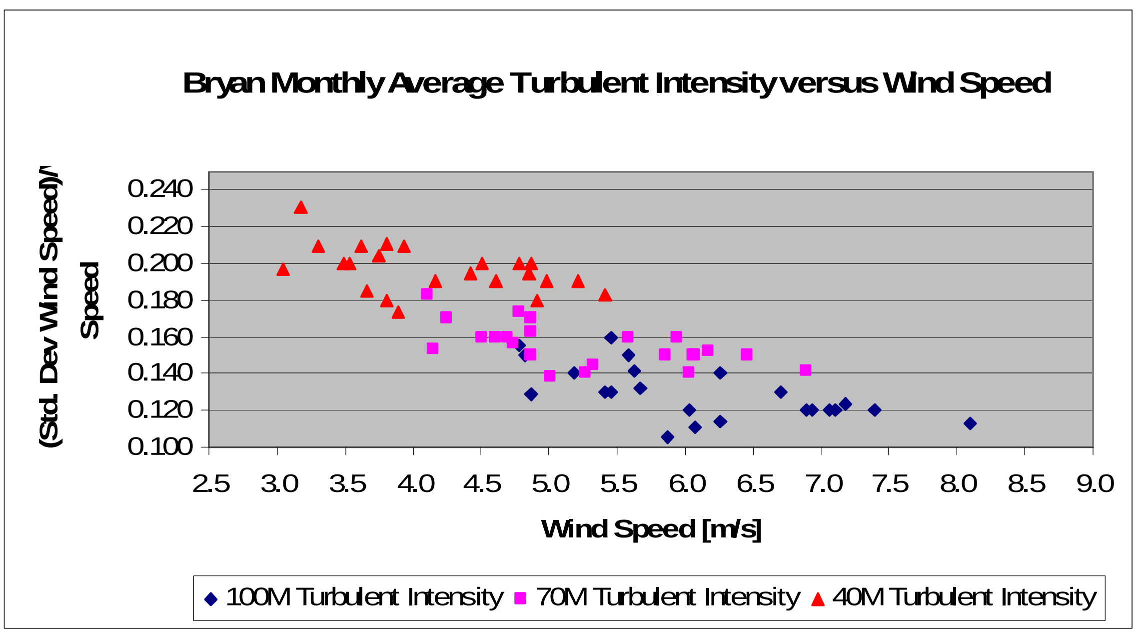
The turbulent intensity is defined as the standard deviation of the wind speed divided by the mean wind speed for the chosen averaging period ($TI = \sigma / \mu$). It is a measure of how turbulent (or how unsteady) the wind is for each period. As mentioned earlier, the data logger calculated standard deviation over the 10-minute average wind speeds as well as the average wind speed for each anemometer. This allows a calculation of the turbulent intensity. The monthly average turbulent intensities for each height are shown below in Figure 12.

Figure 12: Bryan Monthly Average Turbulent Intensity



The turbulent intensities ranged from approximately 10 to 23%, with the summer months having higher turbulence due to thermals and lower average wind speeds. A plot of turbulent intensity versus wind speed (Figure 13) highlights this phenomenon since wind speed averages are lower in the summer months. The graph below shows that turbulent intensity is highest, ~0.20, for wind speeds < 4 m/s (< 9 mph) and taper off to ~0.10 at wind speeds > 6.7 m/s (> 15 mph). It should be noted that the industry standard turbulent intensity value used in power curve calculations is 0.15, which is on average lower than the values found for Bryan.

Figure 13: Bryan Turbulent Intensity versus Wind Speed Averages



Wind Class and Power Produced from the Wind

Next, the average power density of the site was calculated to help determine the site's Wind Class, which is based on a rating system developed by Battelle Northwest Laboratories. The general equation used to calculate power density is:

$$power\ density = \frac{1}{2} \times \rho V^3$$

Here ρ is the air density, and V is the wind velocity. In our model air density was calculated as a function of the temperature at the site, the elevation of the site and the channel height of the specific anemometer in question:

$$\rho = (353.05/(273 + temperature)) * e^{(-0.034*((elevation+channelheight)/(273+temperature))}$$

Here, temperature is the site temperature in Celsius, elevation is the site elevation in meters, channel height is the height in meters above ground of the anemometer in question, and ρ is the air density in kg/m^3.

Figure 14 shown below is a graph of fluctuations in air density at the Bryan site during the data analysis period. The air density is higher in winter months when temperatures are lower, which compounds the effects of higher winter wind speeds to produce substantially higher wind power density in the winter months versus the summer months. Below are graphs of the monthly average air density and wind power density for the Bryan site (Figure 14 and 15).

Figure 14: Bryan Air Density Monthly Averages by Height

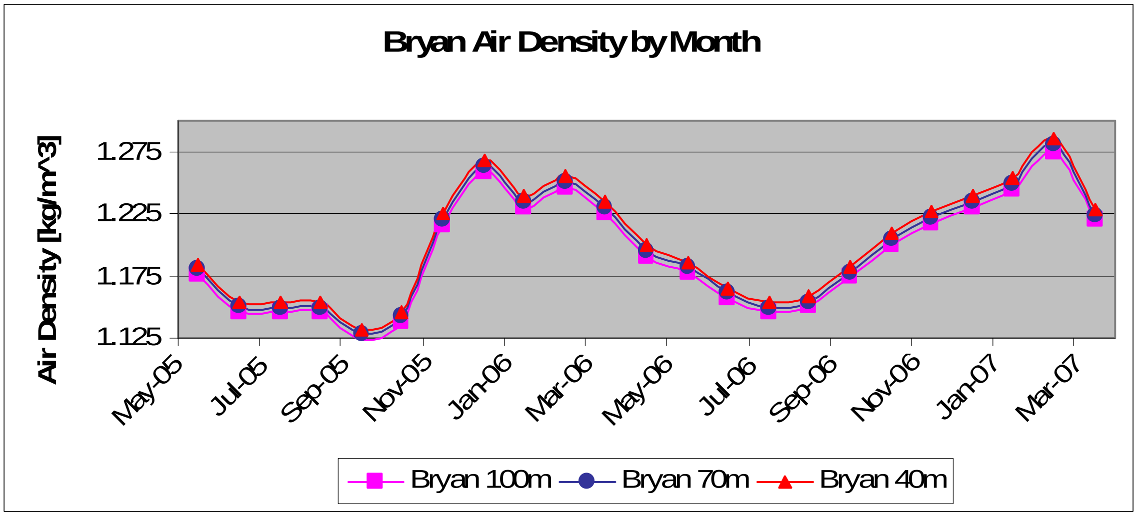


Figure 15: Bryan Power Density Monthly Averages by Height

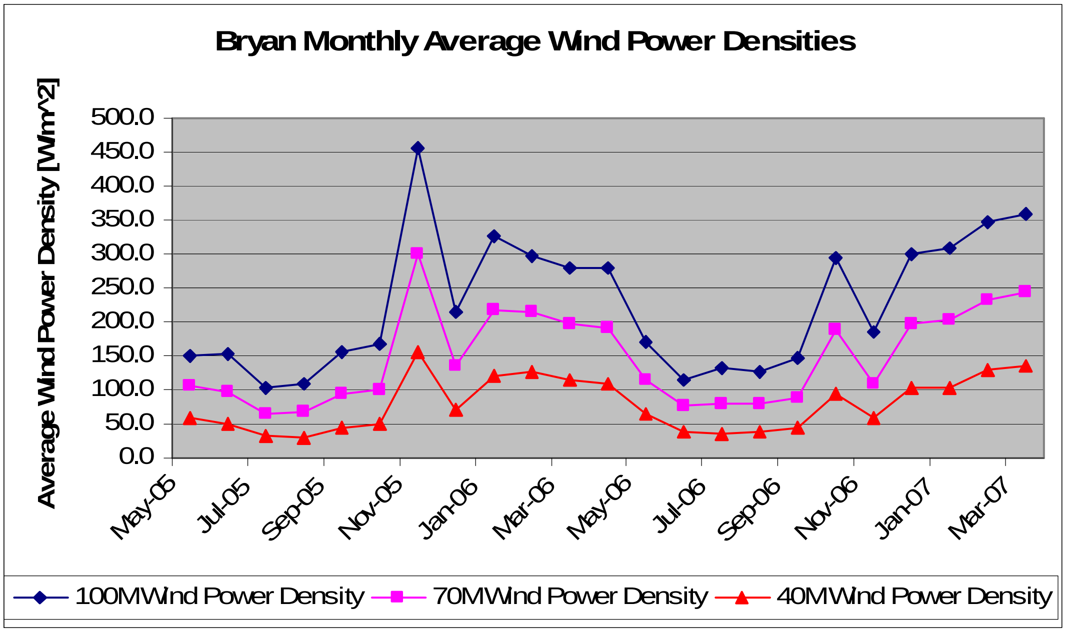


Table 2 below provides a summary for the NREL Wind Classification data at 10 and 50 m. As the table indicates, a site is considered part of a given wind class if its power density is equal to or greater than the value listed for the class at the height of interest (e.g., at least 200 W/m^2 at 50 m to be a Class 2 site). Since these heights do not match the tall tower heights, the correlation to the Tall Tower site Wind Class is only an approximation.

Table 2: NREL Classes of Wind Power Density[3]

Wind Power Class	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density (W/m^2)	Speed[(b)] m/s (mph)	Wind Power Density (W/m^2)	Speed[(b)] m/s (mph)
2	100	4.4 (9.8)	200	5.6 (12.5)
3	150	5.1 (11.5)	300	6.4 (14.3)
4	200	5.6 (12.5)	400	7.0 (15.7)
5	250	6.0 (13.4)	500	7.5 (16.8)
6	300	6.4 (14.3)	600	8.0 (17.9)
7	400	7.0 (15.7)	800	8.8 (19.7)
8	1000	9.4 (21.1)	2000	11.9 (26.6)

The average power density for the Bowling Green study for the year was calculated to be 197 W/m^2. This corresponds to a high Class 1 wind site, as Class 2 begins at 200 W/m^2. However, when historical data were reviewed, the period of this study had wind speeds 5 to 10% lower than the five-year averages for the windiest months, so that the site can be safely classified as Class 2. The average power density for the Bryan over the later 12 months of the study is given below in Table 3.

Table 3: Average Power Density for Bryan

Bryan Avg Power Density [W/m^2]		
100m	70m	40m
230.8	150.3	79.0

[3] http://rredc.nrel.gov/wind/pubs/atlas/tables/A-8T.html (a) Vertical extrapolation of wind speed based on the 1/7 power law. (b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 3%/1,000 m (5%/5,000 ft) elevation.

Even at 70 m, the average power density is 150.3 W/m^2 which would give Bryan a Class 1 rating. However, published information would indicate that Bryan, like Bowling Green, should be a Class 2 Wind Site. This indicates that the period monitored was a low-wind time for Bryan, or that the published data based on computer modeling might be incorrect.

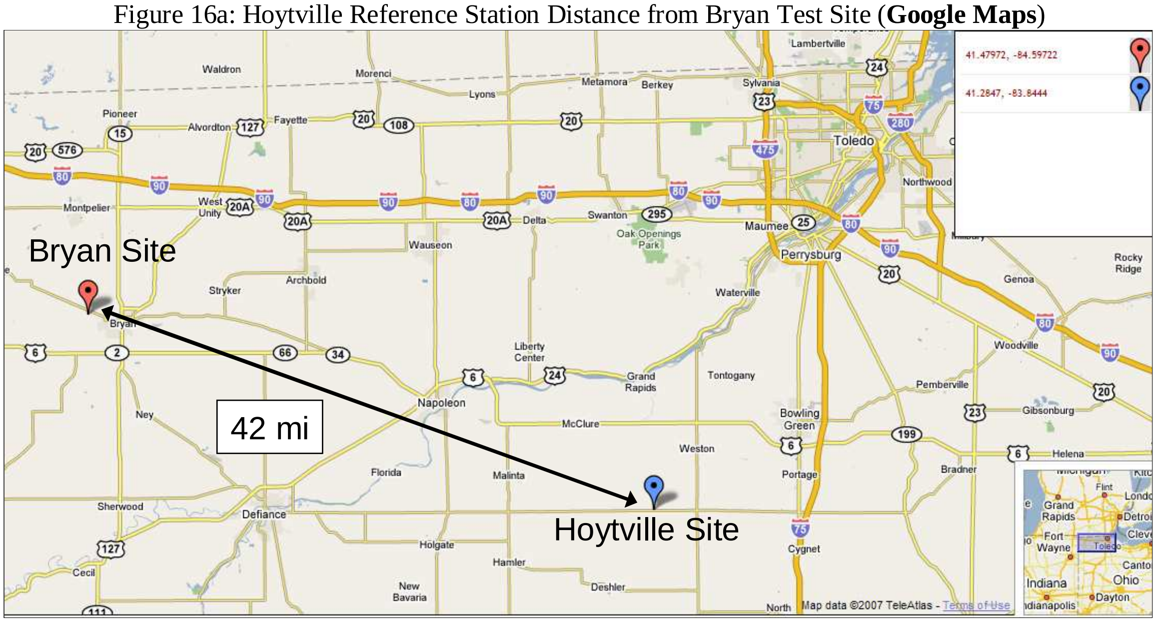
Correlation with Reference Station and Other Monitoring Sites

Along with Bryan, 3 other Tall Tower sites were commissioned across the state of Ohio to help validate wind data for heights up to 100 m. The data from these sites are useful for a comparison in assessing the wind potential at the Bryan site. The following discussion compares data for the Bryan site with data from the other Tall Tower sites and Bowling Green test data from 2000.

As mentioned earlier, a wind monitoring study was performed at Bowling Green for one year from Nov. 1999 to Oct. 2000 prior to the installation of utility-scale wind turbines in 2003. Given the successful nature of this project, the Bowling Green data serves as a good benchmark for comparison to the tall tower reference sites. Also, to generate any long term wind speed estimates for Bryan, the current 18 months of study data must be linked to a long term reference station data set.

Fortunately, various Ohio Agricultural Research and Development Center (OARDC) sites have been collecting wind data at 10 m levels for as long as 23 years. The OARDC site at Hoytville in northwest Ohio was chosen as a reference station because: 1) its relative proximity to the Bryan tower, 2) because of similarities in terrain and land use characteristics, and 3) because a 23-year data set from the site was readily accessible. Figure 16a below shows the location on the OARDC Hoytville reference station with respect to the Bryan monitoring site. At this time, Hoytville is the only reference station data set that GEO has fully reviewed for use with the Tall Towers project.

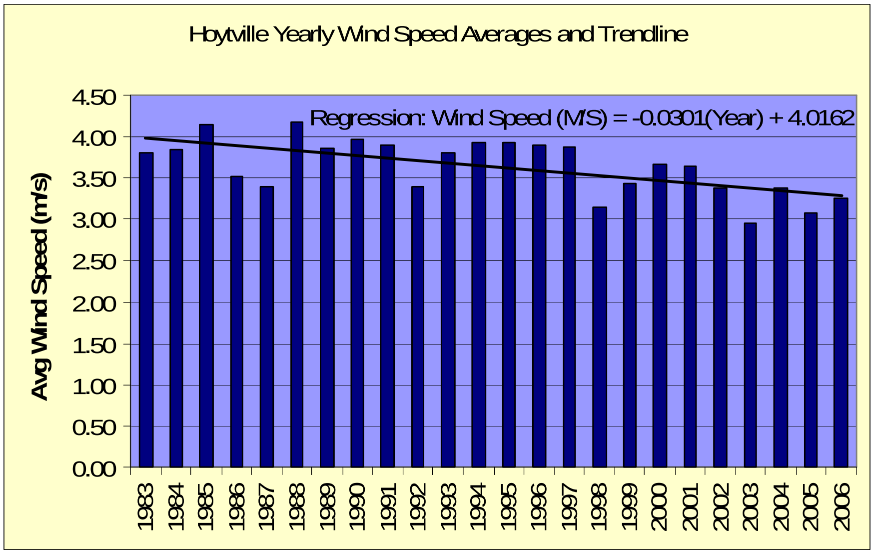
Figure 16a: Hoytville Reference Station Distance from Bryan Test Site (**Google Maps**)



Yearly wind speed averages for the Hoytville reference site are shown below in Figure 16b. Hoytville annual mean wind speeds were examined to determine if any significant trends occurred during the period of record. Such trends could indicate changing climatology conditions around the reference station or changes in other conditions such as: tree growth or clearing, building construction or demolition, or problems with equipment. From the below figure, the annual average wind speeds at Hoytville exhibit a distinct declining trend line over the 23-year period of record, with 2003 and 2005 being the lowest and second lowest years, respectively in the period. This is an area where additional study is required. Data sets from additional reference stations should be evaluated and compared to the trend line at Hoytville.

The National Weather Service operates an Automated Surface Observing System (ASOS) site at the Allen County Airport in Lima. The data set from Lima might be very helpful in validating the long term trend being observed in the Hoytville data. One limitation that exists with the National Weather Service data from Lima is the fact that ASOS stations have only been operational since the mid-1990s. While pre-ASOS data exists for the Lima site, discontinuities between the pre- and post-ASOS data records generally make it inappropriate to mix data sets to define the "long-term" average wind speeds.

Figure 16b: Hoytville Weather Station, 23 year historical wind speed averages (m/s)



Having a 23-year trend of wind speed averages is quite helpful but only if the current Hoytville wind speed data correlate well with the Tall Tower sites. Linear regression analysis was employed to determine the relationship between each of the Tall Tower monitoring sites and the OARDC Hoytville reference station. Concurrent daily wind speed data were used to create scatterplots showing the correlations.

Below are regression results for wind speed of the Bowling Green and the Tall Tower sites compared to the wind speed of the Hoytville reference site. The Bowling Green regression is based on 50 m wind speed data whereas the Tall Tower sites are based on 40 m wind speed data. The reference site data were only available at the 10 m level; however, even with the discrepancy in height, regression fits were encouraging.

Figure 17: Regression Fits of Bowling Green Site to Reference Site at Hoytville

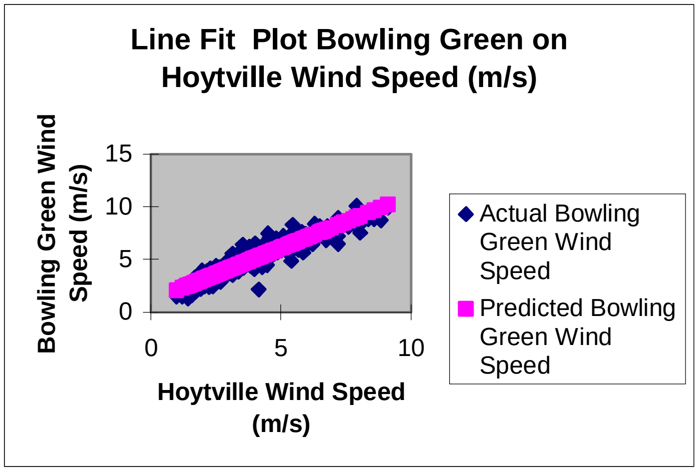


Figure 18: Regression of Tall Tower Sites against Reference Site at Hoytville

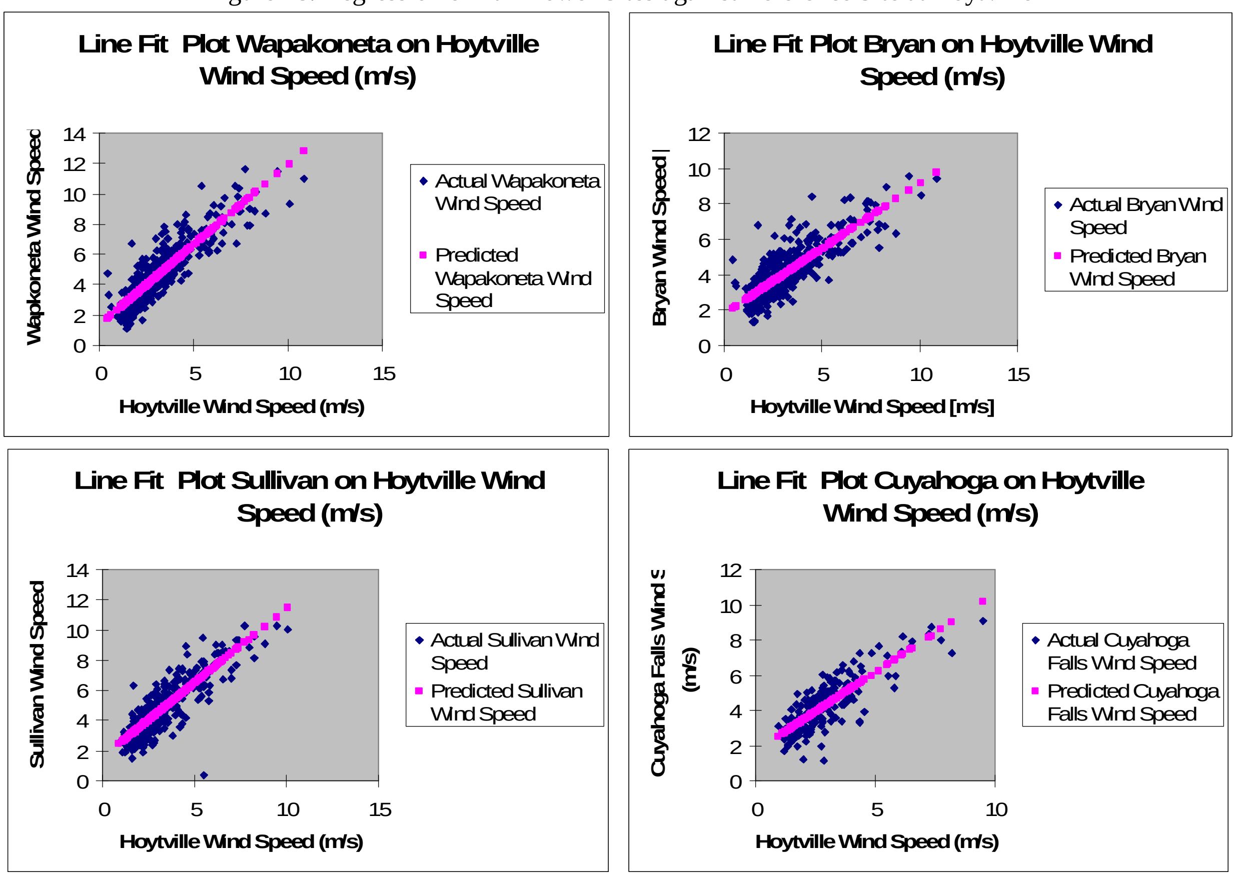


Table 4 below contains the R^2 values of the regression analyses. This value, also known as the coefficient of determination, is defined as the fraction of total squared error in the model (in this case the prediction of wind speeds at a test site based on the knowledge of wind speed at the Hoytville reference site). Thus, higher R^2 values are an indication that the there is a good fit between the reference site and the test site. Empirical studies have shown that an R^2 value ≥ 0.70 is indicative of a sufficient fit for using the reference site for normalization of data to a historical trend, such as the one shown above.[4]

[4] R^2 value of 0.70 based on AWEA 2006 annual conference presentation data.

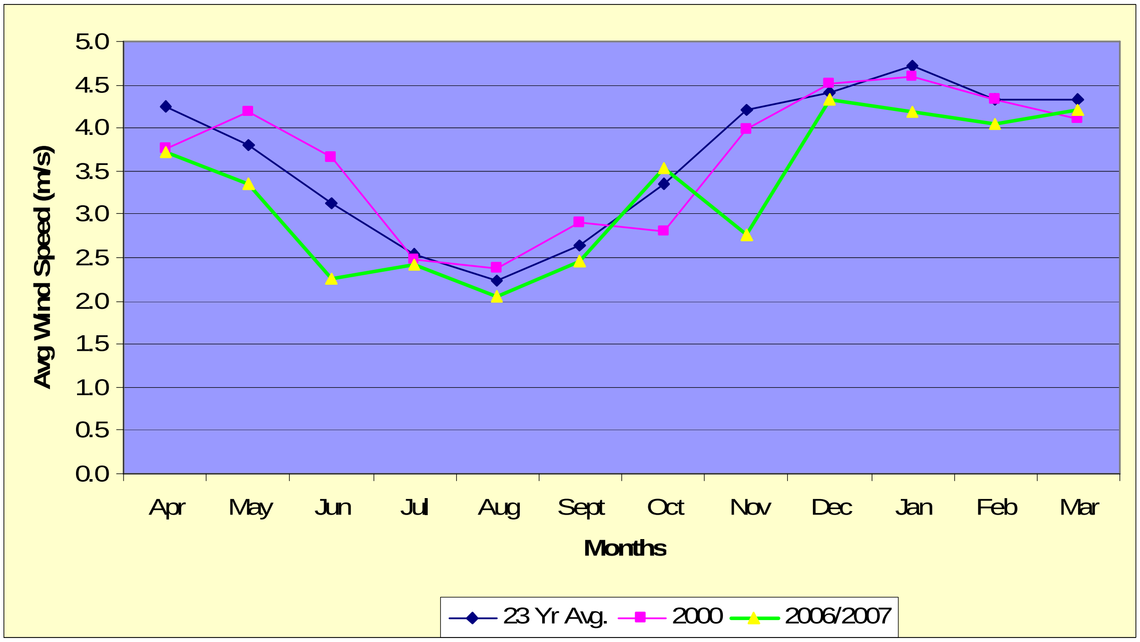
Table 4: Test Site Regression Results

	Regression Results of Test Sites on Hoytville Reference Site				
	Bowling Green	Wapakoneta	Bryan	Cuyahoga Falls	Sullivan
R^2	0.879	0.792	0.701	0.690	0.760
Adjusted R^2	0.879	0.791	0.700	0.689	0.759
Data Range (Dates)	11/1/1999-10/31/2000	07/15/2005 - 10/13/2006	05/16/2005 - 08/12/2006	02/23/2006 - 10/01/2006	12/23/2005 - 12/27/2006

The results outlined above in Table 4 meet the 0.70 standard for Bowling Green and Tall Towers sites. Therefore, the Hoytville site was used as the reference site for normalizing the data to a historical trend so that the Tall Tower site data from 2005-2006 may be compared with the Bowling Green data from 2000-2001. As mentioned above, we are particularly interested in normalizing the Bowling Green data at 50 m to the Tall Tower site data to gauge how well the test sites compare to Bowling Green.

Table 5 below is a summary table which shows the results of normalizing the Tall Tower Site data to the historical Hoytville trend so that it can be compared with Bowling Green Site data. This was done in a two stage process. First, the test site wind speed data for 40 m was extrapolated to the 50 m height using actual wind shear data. Then, the test site was normalized to the 23-year historical trend of the Hoytville site by a factor of the current month's wind speed versus the historical average wind speed for that month. Figure 19 below is a graph of the current Hoytville wind speeds versus the 23-year historical average and wind speeds for 2000. As indicated in the data below, the 2006-2007 data fall below the 23-year trend.

Figure 19: Hoytville Wind Speed Averages by Month for 23-year trend, 2000 and 2006-2007



For the Bowling Green test site, actual 50 m data were used alone and normalized to the historical trend by a factor of the year 2000 month's wind speed versus the historical average wind speed for that month. Results are shown below of the normalization process along with actual monthly wind speed averages for each site at each height. For readability purposes, only data from the April 2006 through March 2007 are included. This time period was chosen so that 12 months of data for each test site could be used.

Table 5: Actual and Normalized Monthly Wind Speed Averages for All Sites at All Heights

Monthly Average Wind Speed Comparison (m/s)													
Measurement Height		**Apr-06**	**May-06**	**Jun-06**	**Jul-06**	**Aug-06**	**Sep-06**	**Oct-06**	**Nov-06**	**Dec-06**	**Jan-07**	**Feb-07**	**Mar-07**
102 m	Bryan	6.9	5.6	4.8	5.4	5.2	5.5	6.9	6.0	7.1	5.9	7.1	7.4
95.4 m	Wapakoneta	7.1	5.8	4.6	5.3	4.8	5.6	6.9	5.9	7.5	7.2	7.0	7.5
106 m	Sullivan	6.7	6.0	5.1	5.8	5.0	5.8	7.4	6.1	8.1	7.5	7.2	7.3
	Cuyahoga Falls	5.9	5.5	5.0	5.4	4.6	5.4	6.7	5.5	7.0	6.7	6.2	6.6
70.9 m	Bryan	6.0	4.9	4.2	4.6	4.5	4.7	5.9	4.9	6.1	5.3	6.1	6.5
70.7 m	Wapakoneta	6.5	5.3	4.1	4.7	4.3	5.0	6.3	5.3	6.8	6.8	6.4	6.8
79.9 m	Sullivan	6.2	5.5	4.8	5.3	4.6	5.4	6.7	5.5	6.9	7.0	6.6	6.8
	Cuyahoga Falls	5.3	4.8	4.4	4.6	4.0	4.8	5.9	4.7	6.1	5.9	5.6	5.8
	Bryan	6.1	4.8	5.0	4.1	4.2	4.3	4.8	6.4	5.3	5.5	5.7	5.9
		5.3	4.3	3.6	3.9	3.9	4.0	5.0	4.2	5.3	4.9	5.3	5.7
50m (164 ft)	Wapakoneta	6.7	5.3	5.1	4.4	4.1	4.8	5.4	7.3	6.4	7.2	6.4	6.5
		5.8	4.7	3.7	4.2	3.8	4.5	5.7	4.8	6.3	6.3	5.9	6.2
	Sullivan	6.1	5.4	5.7	4.7	4.2	4.9	5.4	7.1	6.5	6.9	6.2	5.7
		5.3	4.7	4.1	4.4	3.9	4.6	5.7	4.7	6.4	6.1	5.7	5.5
50m (164 ft)	Cuyahoga Falls	5.4	4.9	5.3	4.3	3.8	4.5	4.9	6.3	5.6	6.0	5.4	5.4
normalized		4.7	4.3	3.8	4.1	3.5	4.2	5.1	4.2	5.5	5.3	5.1	5.2
	Bowling Green	6.9	5.7	5.0	4.5	4.1	4.9	6.1	6.8	6.5	6.9	6.5	6.6
		6.0	6.3	5.9	4.4	4.4	5.4	5.1	6.5	6.6	6.7	6.4	6.2
40.4 m	Bryan	4.9	3.9	3.3	3.5	3.5	3.6	4.5	3.8	4.8	4.4	4.8	5.2
40.5 m	Wapakoneta	5.4	4.4	3.4	3.9	3.5	4.2	5.3	4.4	5.9	6.0	5.5	5.9
40.2 m	Sullivan	4.9	4.4	3.8	4.1	3.5	4.2	5.2	4.3	5.9	5.7	5.4	5.5
	Cuyahoga Falls	4.7	4.3	3.8	4.1	3.5	4.2	5.1	4.2	5.5	5.3	5.1	5.2

Table 6 below is a summary of 12-month wind speed averages for each Tall Tower site and the Bowling Green site as well the normalized averages.

Table 6: Summary of Wind Speed Averages

Average Wind Speed (m/s) Summary (Study to Date)					
	No. of	Measurement Height (meters)			
Monitoring Site	Months	40	70	100	50
Bryan 4/06 - 3/07	12	4.2	5.3	6.1	5.2
Wapakoneta 4/06 - 3/07	12	4.8	5.7	6.3	5.8
Sullivan 4/06 -3/07	12	4.7	5.9	6.5	5.7
Cuyahoga Falls 4/06-3/07	12	4.5	5.2	5.9	5.2
Bowling Green 4/99- 3/00	12				5.9

The summary statistics indicated that both Wapakoneta and Sullivan show strong actual and normalized wind averages that are on par with the Bowling Green data from 2000, which indicates these sites should receive a Class 2 rating as did Bowling Green. Cuyahoga Falls and Bryan show wind speed averages that are lower than the Wapakoneta and Sullivan as well as the Bowling Green averages. Figures 19 and 20 below offer a visual perspective of the differences in performance indicated above.

Figure 20: Actual Monthly 50 m Wind Speed Averages

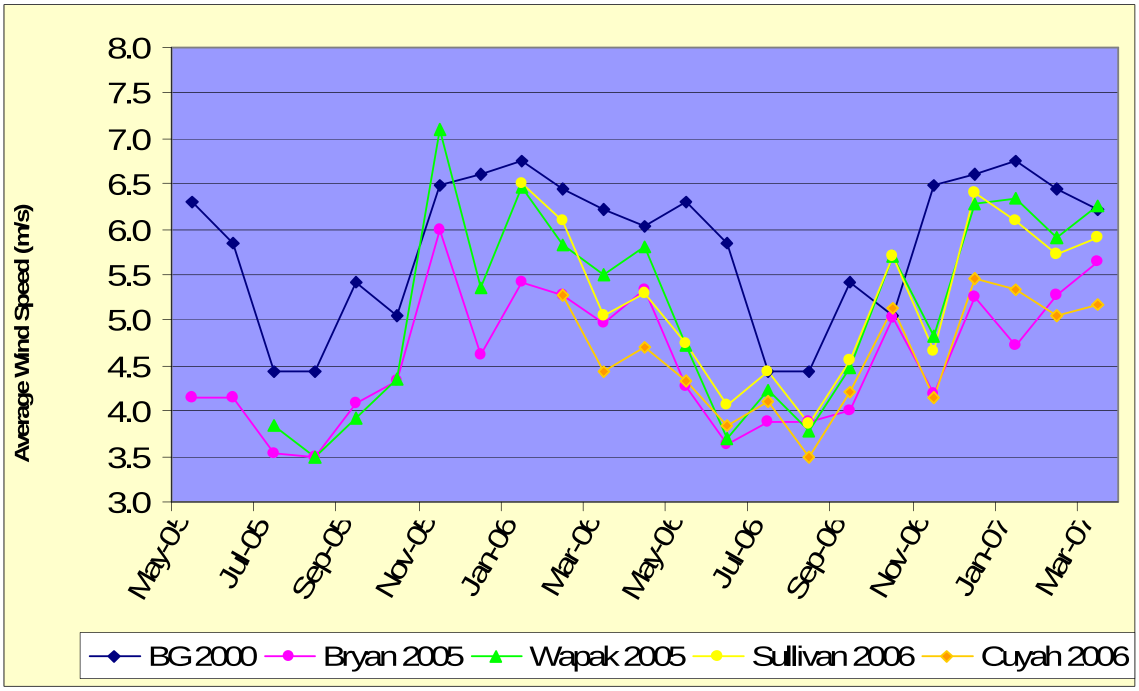


Figure 21: Normalized Monthly 50 m Wind Speed Averages

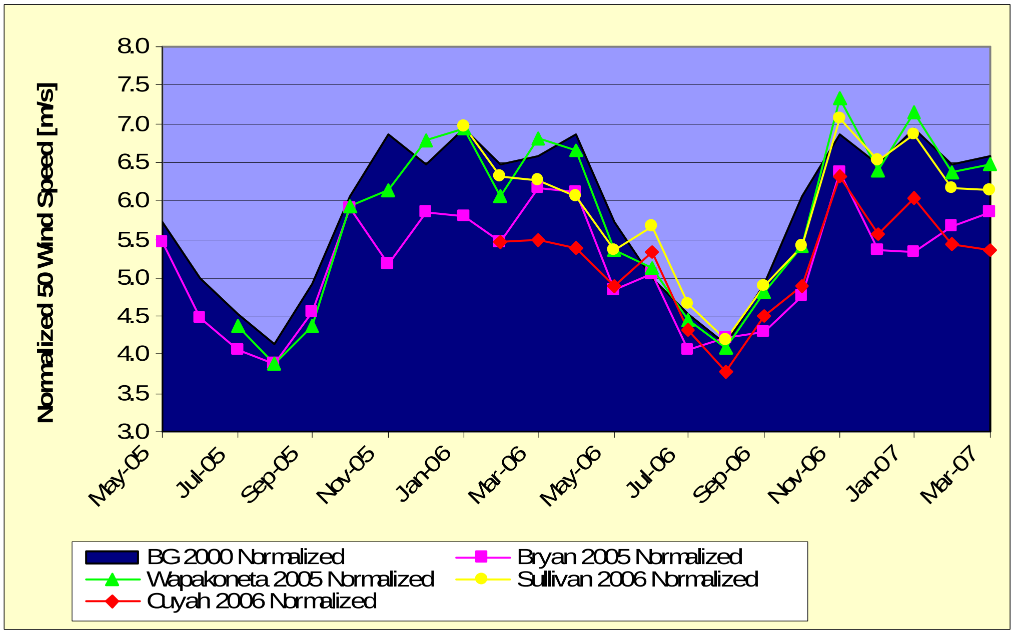


Figure 22: 100 m Wind Power Density for Tall Tower Sites

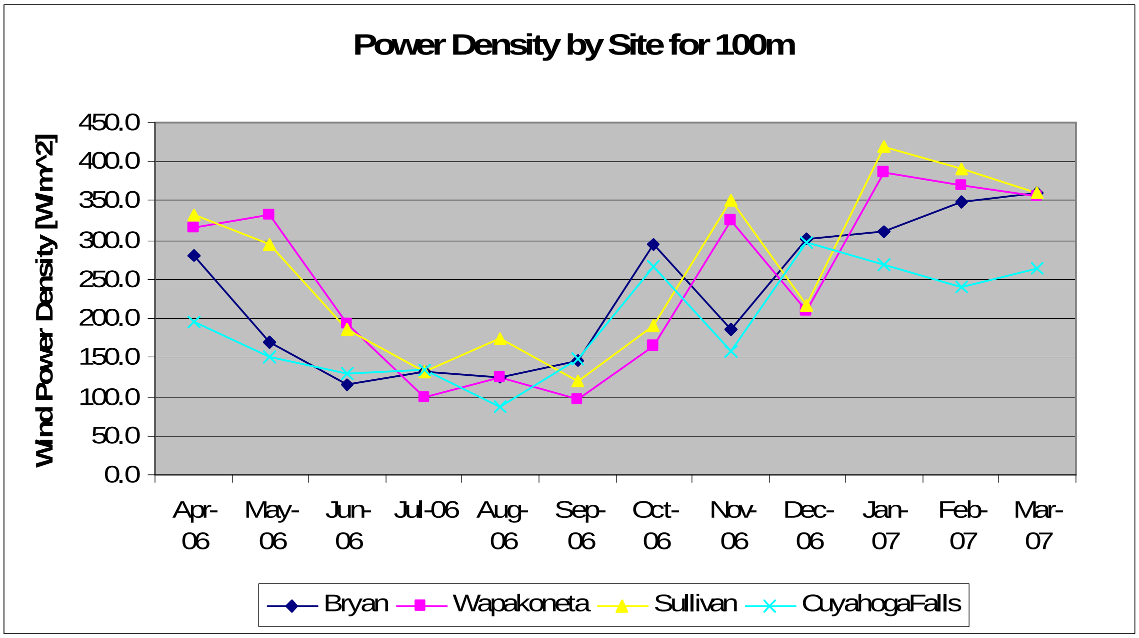


Table 7: Air density by site

Air Density 12-month averages	100 m	70 m	40 m
Bryan	1.199	1.203	1.207
Wapakoneta	1.189	1.193	1.197
Sullivan	1.179	1.183	1.189
Cuyahoga Falls	1.186	1.191	1.194

Based purely on wind speed averages, Wapakoneta and Sullivan show the strongest performance. After normalization to the Hoytville historic trend line, Wapakoneta and Sullivan show wind speeds that are similar to those experienced in Bowling Green. Bryan and Cuyahoga Falls do not demonstrate as strong of performance based solely on measures of wind speed. However, after factoring in temperature and elevation effects and their impact on air density, the performance between the sites converges and all sites begin to look like Class 2 sites. This is larger to do with the fact that Bryan and Cuyahoga Falls test sites are farther north and thus experience lower temperatures and increased air density as compared to Wapakoneta and Sullivan sites. Below is a comparison of the sites based on other factors that influence performance of the sites such as turbulent intensities and wind shear exponents. Wind shear factors for Bryan and Cuyahoga Falls are also higher than those for Wapakoneta and Sullivan sites while Turbulent Intensities vary for all sites.

Figure 23: Monthly Turbulent Intensities for Tall Tower Sites

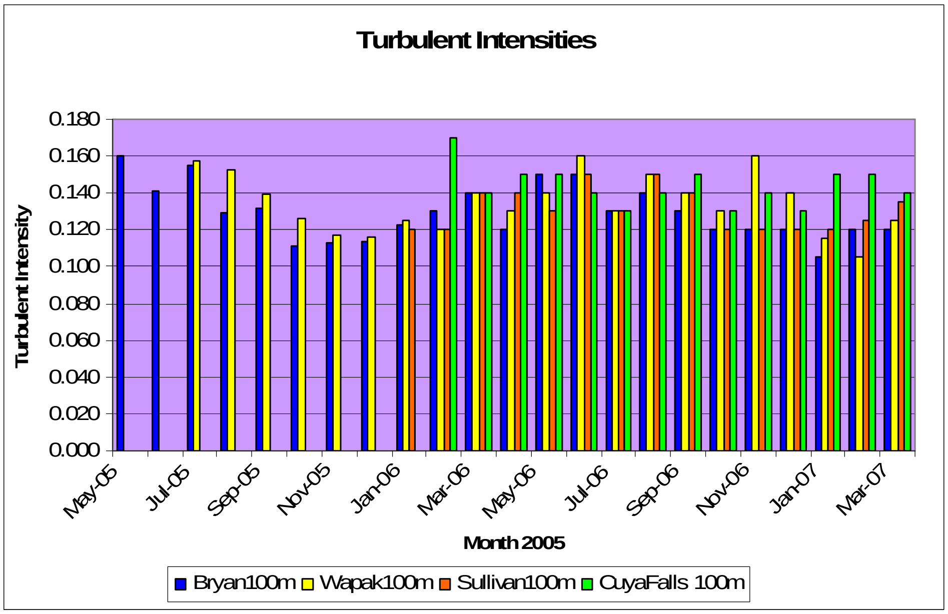


Table 8: Tall Tower Wind Shear Averages

Average Wind Shear Exponent				
	Bryan	Wapakoneta	Sullivan	Cuyahoga Falls
40 to 70M	0.4231	0.3257	0.3348	0.4000
70 to 100M	0.4188	0.3365	0.2901	0.4074

Commercial Wind Generator Analysis

To determine how much power can be produced from the wind at this site, several typical wind turbine power curves were obtained from manufacturers. As an important note before beginning this discussion, mph wind speeds are used in this section in addition to m/s units. This is because the data were recorded by the logger in mph which allows for a higher resolution of wind speed data and thus more accurate calculations of energy output. The original power curve information for the turbines was given in both m/s and mph. See Appendix B for graphical representations of the turbine power curves used in this analysis in m/s units. The turbine power curves are valid for a particular air density, which in turn depends on air pressure and temperature. Only one manufacturer, Vestas, provided turbine ratings at various air densities, the other turbine is given for a standard density of 1.225 kg/m^3. However, the air density varies substantially by height and temperature as discussed in previous sections. The average air density for Bryan over twelve months during the 2006 calendar year is shown below in Table 9.

Table 9: Bryan Yearly Average Air Density by Height over 12-month period

Bryan Avg Air Density [kg/m^3]		
100m	70m	40m
1.199	1.203	1.207

Although in winter months, the air density can reach as high as 1.225 kg/m^3, the air density is typically much lower at the Tall Tower heights of interest. For this study, a height of 100 m was chosen as the turbine hub height for the power production estimates. The relatively modest wind class (Class 1 to 2 at 50 m) and relatively high wind shear, are factors in this decision. The higher wind shear values indicate that there will be a noticeable increase in power production as the height increases in elevation to a 100 m hub height. In addition, the operational experience gained in Bowling Green, where the turbine hub heights are currently 80 m, has influenced the thinking of project managers towards the use of 100 m hubs heights in the future projects.

If using a hub height of 100 m, a better approximate air density value would be 1.199 kg/m^3 for the Vestas turbine. However, as indicated in appendix B, the difference in energy output due to the variance in air density is not very high. Thus, the standard air density of 1.225 kg/m^3 will be used so that comparison between energy output from the different turbines can more easily be made. Appendix B contains graphical information to compare the Vestas turbine power curve at the Bryan 12-month average 100 m air density of 1.199 kg/m^3 with the standard air density performance.

Using the standard air-density of 1.225 kg/m^3 and a hub height of 100 m combined with the measured mph 10-minute average wind speeds at that height, power output for each model could be determined over the 12-month period during the 2006 calendar year. Table 10 below is a summary table of those results for each turbine type.

Table 10: Summary of Turbine Characteristics, Energy Output for 12 Month Period and Capacity Factor

Bryan Energy Output and Turbine Characteristics							
				Using M/S data in 1 mps step		Using MPH data in 1 mph step	
Manufacturer	Model	Capacity	Rotor Diameter	12 month Energy Output (kWh)	% Capacity	12 month Energy Output (kWh)	% Capacity
GE	1.5xle	1500kW	82.5 m	3,246,695	20.59%	3,644,378	23.11%
Vestas	V80	1800kW	80 m	2,900,428	18.39%	3,400,668	21.57%

The % Capacities, or capacity factors, are what would be expected for a Class 2 to Class 3 wind site for turbines installed at the 100 m hub height. The m/s estimates are slightly lower than for the mph estimates (a 2-3% difference in each case) due to the resolution issue as mentioned previously; breaking down the m/s data to half steps of 0.5 m/s would likely result in % capacity values closer to those generated my using mph data. As was mentioned previously, the wind power density calculations based on the NREL table indicated that Bryan was a Class 1 site, but the capacity factor indicates that Bryan is actually a higher class as would be expected based on current wind maps. The capacity is a better indication and confirmation of wind class status for Bryan.

From the information above, it can also be noted that based on our measured data for 2006, the GE turbine outperforms the larger Vestas turbines used at Bowling Green. The GE turbine is more efficient for the lower wind speeds and therefore results in a larger energy output even though its rated capacity is lower. This illustrates the fact that smaller turbines, which are designed for low-speed operation, can actually perform better depending on the site of installation. Newer models of low-speed turbines have been developed and may improve upon the results above with respect to energy output and % capacity. Figures 24-27 below are graphical representations of the energy output that would be expected for the Bryan site for each of the two turbines for both mph and m/s units. The calculations are based on a hub height of 100 m and an air density of 1.225 kg/m^3. Using a lower air density of 1.189 kg/m^3 has a negligible impact on the results; the resulting 12-month energy output remains the same. A graphical representation of the lower air density energy output calculations is also shown below in Figure 28.

Figure 24: Vestas V80 Turbine 12-month Energy Output (kW) Based on Wind Speeds (mph) at 100m

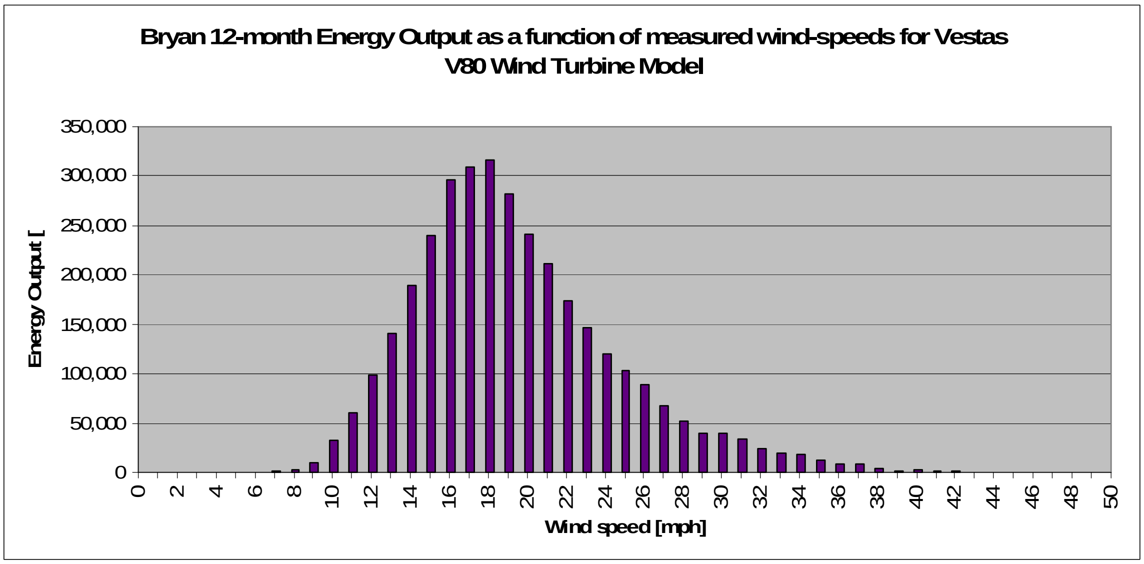


Figure 25: Vestas V80 Turbine 12-month Energy Output (kW) Based on Wind Speeds (m/s) at 100m

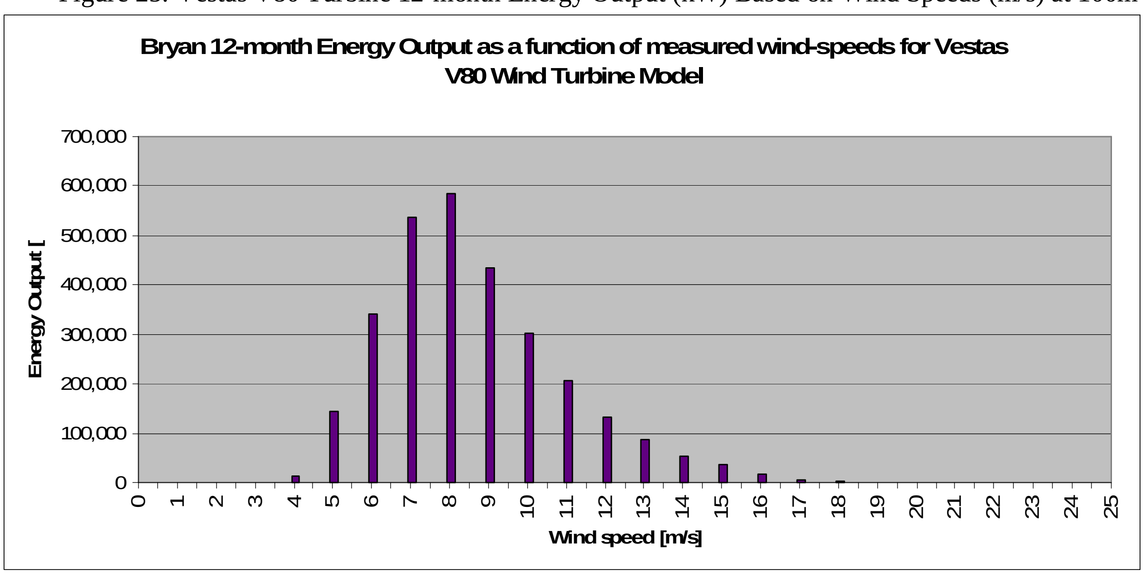


Figure 26: GE 1.5xle Turbine 12-month Energy Output (kW) Based on Wind Speeds (mph) at 100m

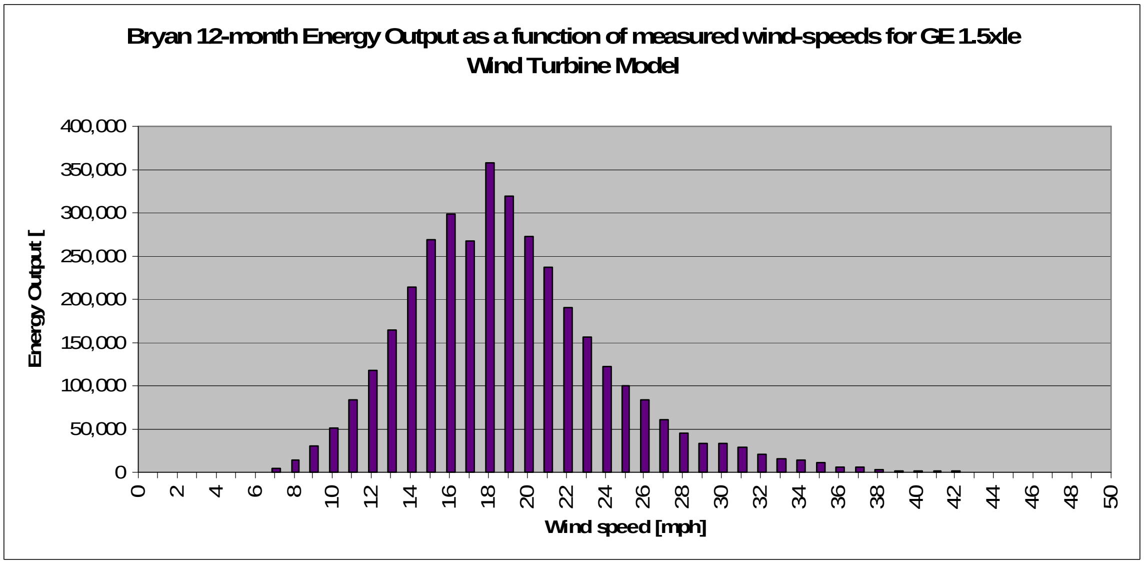


Figure 26: GE 1.5xle Turbine 12-month Energy Output (kW) Based on Wind Speeds (m/s) at 100m

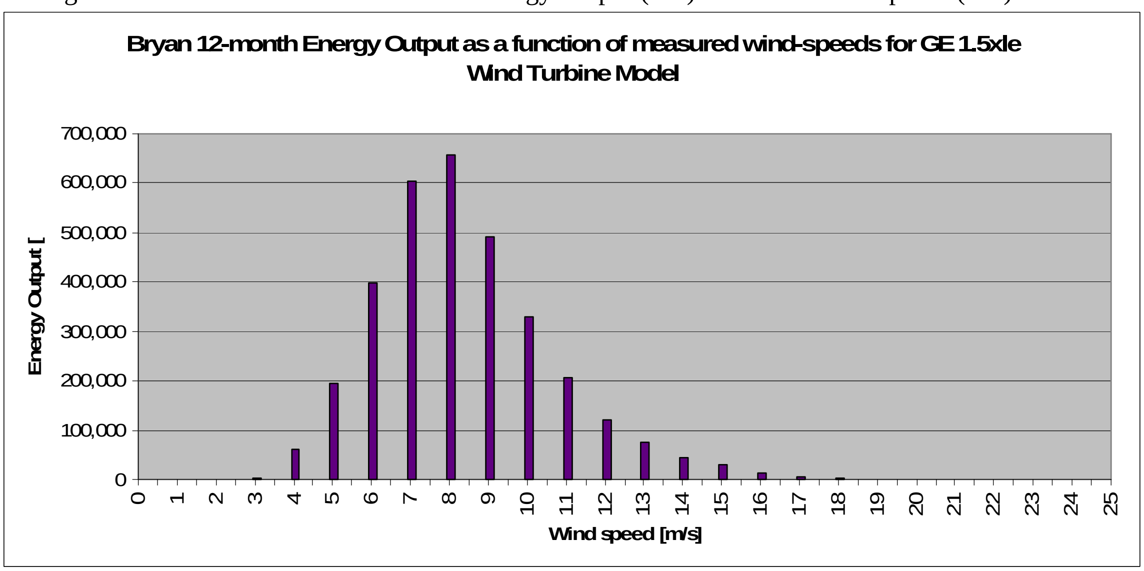
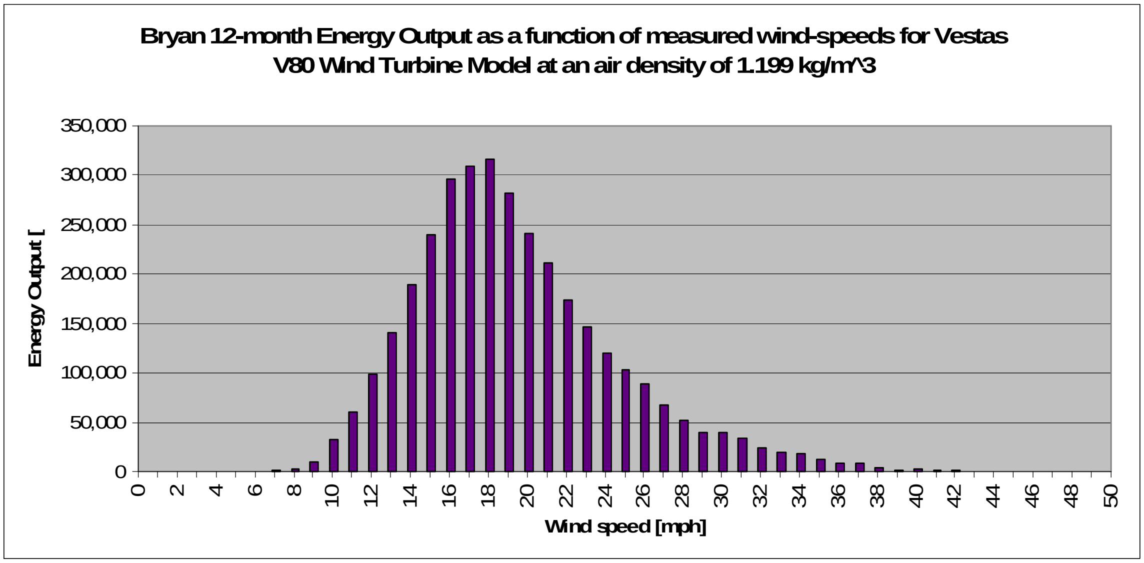


Figure 26: Vestas V80 Turbine 12-month Energy Output (kW) Based on Measured Wind Speeds at 100m and an air density of 1.199 kg/m^3



Conclusions

This report has described the results of a study by volunteers from Green Energy Ohio to determine the feasibility of wind power in Bryan, Ohio. In general, the findings confirmed the status of Bryan as a Class 2 wind site at a height of 100 m. This classification means that wind speeds are high enough to merit analysis for development of commercial wind applications using turbines with a hub height at or around 100 m. However, the introduction of newer turbine models, which are optimized for lower speeds, might enhance the feasibility of using wind power for electricity generation at lower hub heights for Bryan where wind speeds are more typical of a class 1 site.

The performance of Bryan was not as strong when compared to the other Tall Tower sites and when normalized to a 23-year trend in wind speed data. Bryan demonstrates normalized wind speeds 1-2 m/s lower than for the Bowling Green site where wind applications already exist for utility-scale electricity generation. However, the power density calculations for Bryan are as strong as the other Tall Tower sites, which are indicative of higher air density at the Bryan site due to lower measured temperatures. This study, however, represents only the initial steps in assessing the potential for utility-scale wind at Bryan. The final decision regarding whether to develop the site must rest on a detailed economic analysis which considers factors such as available funding options, green power premiums that might be paid, and the payback amount desired. Only then will sufficient conditions be met to determine the potential for moving forward with a wind development project in the region near the Bryan Tall Tower site.

Appendix A: Bryan Site Specification Log

Ohio Tall Towers Wind Assessment Initiative
Site Data - Bryan

SITE

Site Name:	Bryan
Installation Date:	May 16, 2005
Tower Owner: Contacts:	Public Radio Foundation of NW Ohio Dan Niedziecki, Chief Engineer
Local Site Sponsor: Contacts:	Bryan Municipal Utilities Steve Casebere, Utility Director Lou Pendelton, PR Director

TOWER

FCC Tower Registration:	1002572
Site Location (description):	Williams Co.; 0.32 miles SW of intersection SR34 and CR12
Site Location (GPS coordinates):	41.47972N, 84.59722W
Ground Elevation:	243.8 M
Height of structure:	122.0 M
Nominal Boom Heights:	40M, 70M, 100M

INSTRUMENTATION

Data Logger: NRG Symphonie, S/N 30906188

Sensors:

Logger Channel	Instrument	S/N	Height (ft)	Boom Orientation (degrees)	Deadband Orientation (degrees)
1	NRG Max 40 Anemometer	111	132.7	180	
2	NRG Max 40 Anemometer	110	133.6	300	
3	NRG Max 40 Anemometer	109	232.7	180	
4	NRG Max 40 Anemometer	108	233.9	300	
5	NRG Max 40 Anemometer	112	332.7	180	
6	NRG Max 40 Anemometer	21175	333.9	300	
7	NRG 200P Vane	316	132.7	180	0
8	NRG 200P Vane	314	232.7	180	0
9	NRG 200P Vane	315	332.7	180	0
10	NRG Temp Sensor	205	332.6	180	

INCIDENT LOG

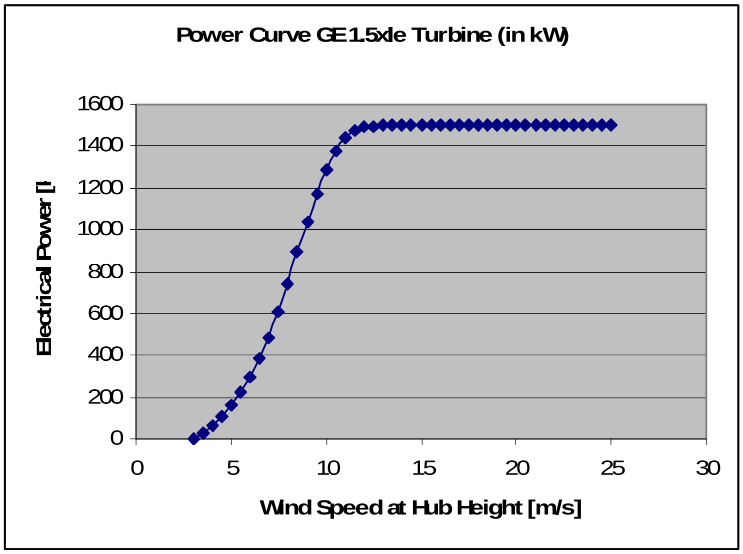
September 22, 2005 **-** Failure of temperature sensor, temperature sensor was apparently struck by lighting during a storm. A replacement temperature sensor was mounted on the tower on October 13, 2005 at a height of 15 ft. Effected data were flagged in the site database

Appendix B: Turbine Power Curves

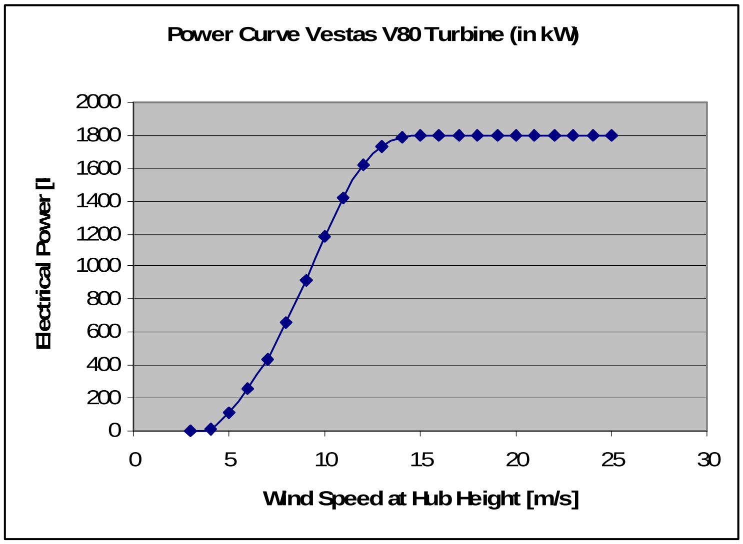
This Appendix contains the turbine power curves used to calculate the power produced. The information regarding power production was generally obtained from the manufacturers in the form of a table which is then plotted to give a graphical perspective of power production at different wind speeds. The manufacturer models assumed a turbulent intensity of 10-15% and an air density at sea level at 1 atm of 1.225 kg/(m^3). In addition, a cut-in wind speed of at least 3 m/s is typical of turbines from various manufacturers.

The two representative turbines selected are a GE 1.5xle turbine capable of generating 1.5 MW of power for speeds above 13 m/s (or 29 mph) and a Vestas V80 turbine capable of generating 1.8 MW of power for speeds above 15 m/s (or 34 mph). The Vestas V80 turbines are currently being used by the Bowling Green Municipal Utility for wind power electricity production and the GE 1.5xle is a comparable American model.

GE 1.5xle: 82.5 m Rotor Diameter



Vestas V80: 80 m Rotor Diameter



Vestas V80: 80 m Rotor Diameter, for different air density values