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TO: **Scott Abbett, Sustainable Energy Developments, Inc.**
FROM: **Mike Markus, Chief Meteorologist, AWS Truepower, LLC,**
Matt Eberhard, Senior Meteorologist, AWS Truepower, LLC
DATE: **March 18, 2011**
RE: **Nantucket, MA Tall Tower Summary Report**

METEOROLOGICAL DATA

Sustainable Energy Developments (SED) provided AWS Truepower with data from a single meteorological tower, designated Mast 0010, which is located on the western portion of Nantucket Island, about 48 km south of Cape Cod, Massachusetts. Mast 0010 has approximately 14 months of observed data recorded between August 2005 and October 2006. The data were recorded using an NRG Symphonie data logger; SED sent the raw binary data files to AWS Truepower via email. The files included 10-minute averages of wind speed, direction, and temperature records, as well as standard deviations of each quantity. Table 1 presents basic information about the mast including its geographic coordinates, elevation, period of record, and sensor heights. The anemometers used in the measurement program were calibrated NRG #40. However, we employed the consensus transfer function (0.765 m/s/Hz and 0.35 m/s) to convert the raw logger counts from all anemometers to speed values because our research indicates that the results agree more closely with Class I anemometers, like the WindSensor P2546A, than when the calibrated (measured) coefficients are used. An experienced AWS Truepower meteorologist screened the data for completeness and reasonableness and examined all suspect values. After validation, the data recovery fraction was 99.6%.

The response of NRG #40 anemometers to turbulence differs from that of Class I anemometers used for turbine power performance testing and certification. High turbulence causes NRG #40 anemometers to overspeed (measure higher mean speeds) compared to Class I sensors because they respond more quickly to rising gusts than to falling gusts. Conversely, at very low turbulence, speeds reported by NRG #40 anemometers tend to be below Class I sensor speeds.

Based on its research[1], AWS Truepower has computed the following correction factor to adjust the NRG #40 wind speed data for turbulence:

$$V_{corrected} = V_{observed} / (0.095 * TI + 0.992).$$

The free-stream wind flow at the mast is characterized by low turbulence intensity. Consequently, the corrections are low. All NRG #40 speed values in this report include this adjustment. The adjustments made to the top-level NRG #40 anemometer(s) on the tower are +0.1%.

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[1] Filippelli, M.V., et al., "Adjustment of Anemometer Readings for Energy Production Estimates," Proceedings of Windpower 2008, June 2008.

LONG-TERM WIND SPEED ESTIMATION

We estimated the long-term wind climate at Mast 0010 through a standard measure-correlate-predict (MCP) technique, using a linear regression between the mast and data from the Buzzards Bay C-MAN station located about 71 km to the west-northwest of the site. Hourly wind speed, direction, and temperature data was obtained for this station from the National Data Buoy Center (NDBC). The long-term trend of Buzzards Bay is confirmed with data from the Nantucket National Weather Service station, shown in Figure 1.

The regression used concurrent daily mean wind speeds between Mast 0010 and Buzzards Bay. A moderate correlation (r^2 = 0.76) was found between the tall tower and Buzzards Bay. The linear regression equation between the two is as follows:

Mast 0010 99-m Wind Speed = 1.039 * Buzzards Bay 24.8-m Wind Speed + 1.280 m/s

The annualized wind speed at Buzzards Bay is 7.72 m/s from April 1997 through January 2011. Substitution of this value into the regression equation above yields a 99-m long-term wind speed of 9.30 m/s. This value is approximately 3.7% lower than the observed annualized mean speed of 9.66 m/s at Mast 0010. A scatterplot showing the regression relationship is presented in Figure 2.

The wind speeds at the remaining two heights were estimated in a similar manner; the corresponding long-term speed projections are presented in Table 2. This method was used in order to fully utilize data collected at each monitoring level, each of which are very near each of the proposed hub heights discussed below.

EXTRAPOLATION TO HUB HEIGHT

We extrapolated the long-term mean wind speed to 50 m, 70 m, and 90 m hub heights using the power law equation. This equation is an empirical relationship that is widely employed in wind resource assessment. The extrapolated wind speed values for the three hub heights are summarized in Table 3. The observed wind shear value of 0.294 was used to estimate the wind speed at each height. It should be noted that the values presented for each hub height were sheared up or down from the closest measurement height.

50-YEAR 3-SECOND MAX GUST

SED also requested that AWS Truepower determine the 50-year return period 3-second maximum wind gust at the same heights. Based on hurricane and tropical storm reports obtained from the National Hurricane Center in the vicinity of the project area, as well as regional tall tower data records, we estimate the 70 m 3-second maximum wind gust to be 55 m/s. The 3-second maximum gusts for the remaining heights are summarized in Table 4.

WIND SPEED UNCERTAINTY ANALYSIS

The following is a summary of the uncertainty elements associated with the long-term wind speed estimate. For this purpose, the uncertainty is defined as the standard error for a normal probability distribution.

1. Measurement Accuracy: This is the uncertainty in anemometer readings of the free-stream wind speed. It reflects not just the uncertainty in the sensitivity of the instruments when operating under wind-tunnel conditions but also their performance in the field where they may be subject to turbulent and off-horizontal winds; the possible effects of the tower on observed speeds; and problems such as icing that may be missed in the validation. We estimate the overall measurement uncertainty to be 1.7%.

2. Representativeness of Monitoring Period: This uncertainty addresses how well the site data may represent the historical average. A study of historical wind records suggests a standard error of 4% for about one year of data. Based on the on-site tall tower data record and the correlation with the Buzzards Bay reference station, we estimate the uncertainty for the meteorological mast to be 2.0%.

3. Project Life Wind Resource Uncertainty: This uncertainty is associated with how closely the wind resource over the project life may match the long-term site average. Assuming a 10-year life, 4% variation in the annual mean speed, and a 0.5% uncertainty associated with climate change, the uncertainty is 1.4%.

4. Wind Shear Estimate: The wind shear uncertainty contains the following two components: the uncertainty in the observed wind shear due to possible measurement errors, and the uncertainty in the change in wind shear above mast height. Assuming an average relative measurement uncertainty of 1.1% and an uncertainty in the change in wind shear exponent above mast height equal to 10% of the observed shear, we arrived at an overall uncertainty in the shear exponent of 0.041. The uncertainty in the wind speed at 50 m, 70 m, and 90 m extrapolated from the mast monitoring heights is estimated to be 0.5%.

5. Modeling Uncertainty: The uncertainty estimates presented herein are representative of the hub-height wind speed estimates at the selected point. Additional uncertainty for the modeling of wind speeds across the project area has not been considered for this analysis.

The individual uncertainties were combined using the square root of the sum of squares to yield a total wind speed uncertainty of 3.0% for each hub height. The total and individual uncertainties for 50 m, 70 m, and 90 m are shown in Table 5.

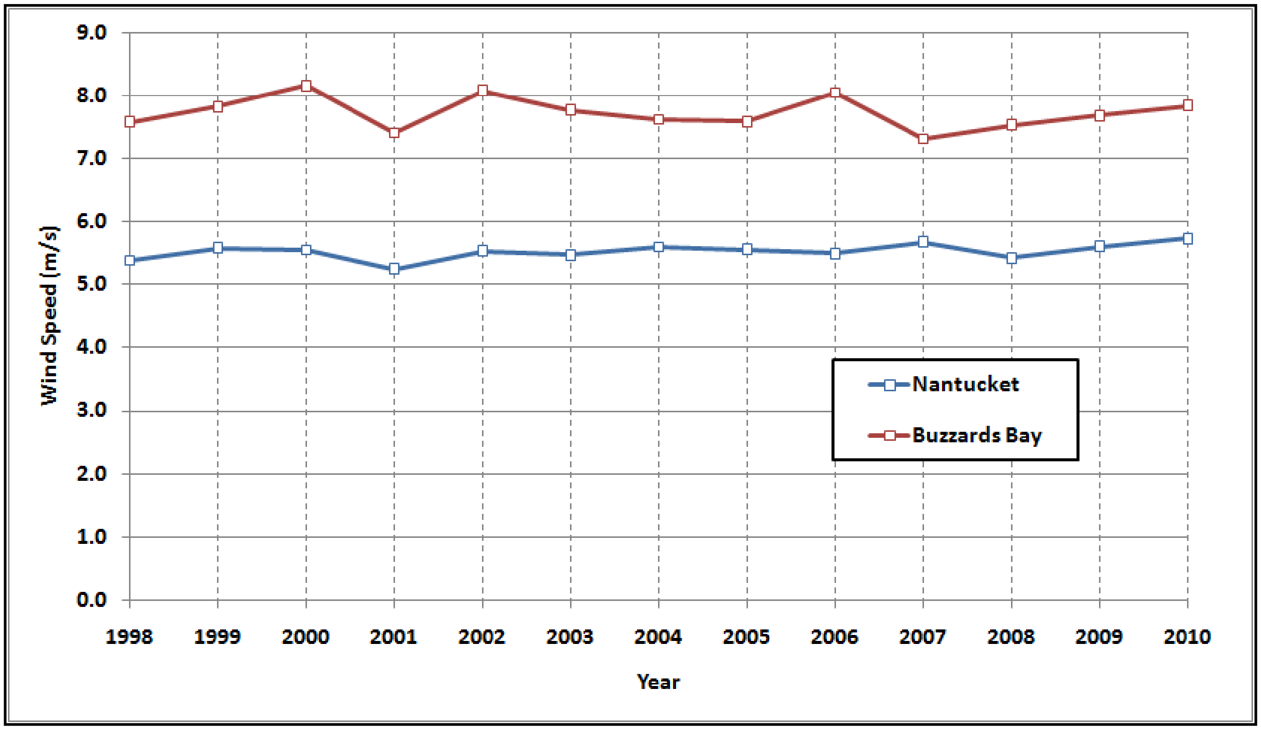

Figure 1. Reference Station Annual Wind Speeds

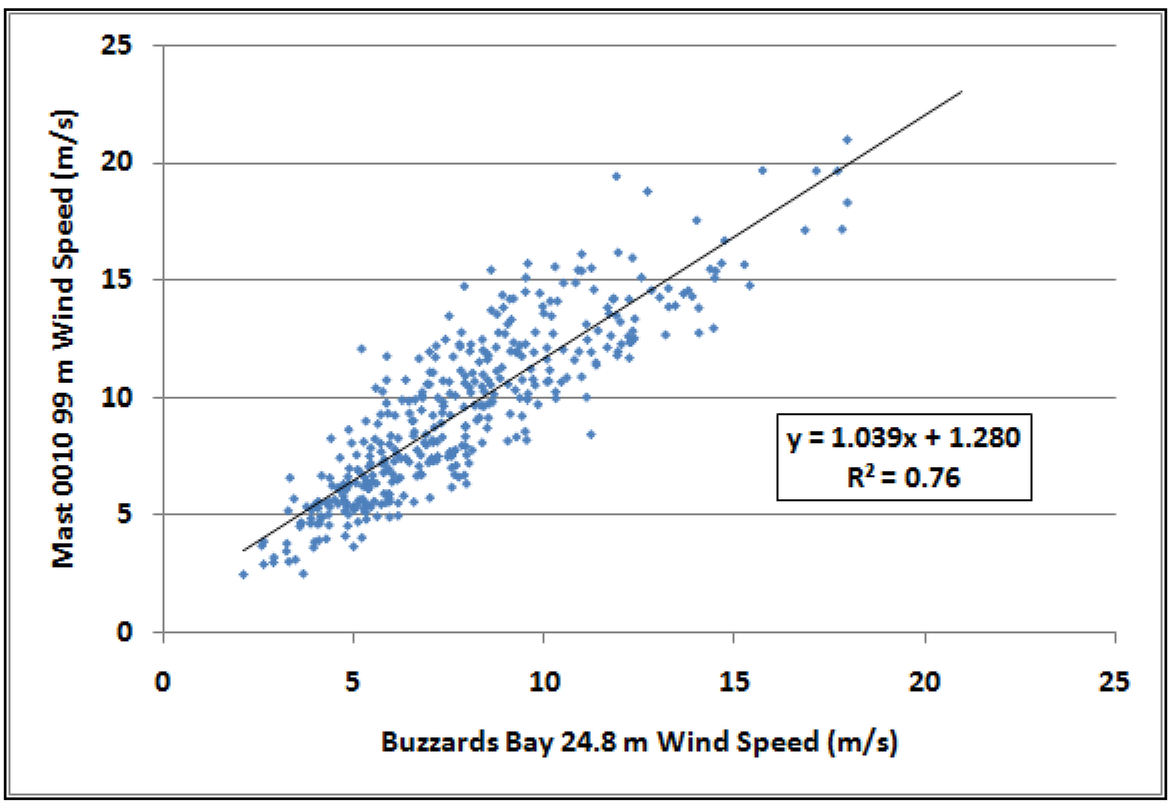

Figure 2. Scatterplot of Mast 0010 and Buzzards Bay Daily Mean Wind Speeds

Table 1. Monitoring Mast Information

Mast	Site Lat/Lon Coordinates (WGS 84)	Elevation (m)	Period of Record	Monitoring Heights (m)		
				Wind Speed	Wind Direction	Temp
0010	41.281° N 70.169° W	3	7/22/2005- 10/3/2006	99, 68, 58	99, 68, 58	N/A

Table 2. Long-Term Projection Summary

Monitoring Height (m)	Climate-Adjusted Speed (m/s)
99	9.30
68	8.39
58	7.97

Table 3. Extrapolation of Climate-Adjusted Speed to Hub Height

Wind Shear	Projected 50-m Speed (m/s)	Projected 70-m Speed (m/s)	Projected 90-m Speed (m/s)
0.294	7.63	8.46	9.04

Table 4. 50-Year 3-Second Maximum Gust Estimates

50-m Max Gust (m/s)	70-m Max Gust (m/s)	90-m Max Gust (m/s)
53	55	56

Table 5. Wind Speed Uncertainty Summary

Uncertainty Source	50-m Wind Speed		70-m Wind Speed		90-m Wind Speed	
	%	m/s	%	m/s	%	m/s
Anemometer Accuracy	1.7	0.13	1.7	0.15	1.7	0.16
Long-Term Average	2.0	0.16	2.0	0.17	2.0	0.18
10-Year Uncertainty	1.4	0.10	1.4	0.12	1.4	0.12
Wind Shear	0.5	0.04	0.5	0.04	0.5	0.05
Modeling	0.0	0.00	0.0	0.00	0.0	0.00
Combined All Sources	**3.0**	**0.23**	**3.0**	**0.26**	**3.0**	**0.28**