PANTEX

Wind Resource Assessment Report

Prepared for:

Department of Energy's
Federal Energy Management Program

By:
Robi Robichaud, Senior Engineer
National Renewable Energy Laboratory
March 2, 2011

TABLE OF CONTENTS

SECTION PAGE

TABLE OF FIGURES

TABLE OF TABLES

TABLE OF EQUATIONS

1. EXECUTIVE SUMMARY

The Department of Energy (DOE) is interested to facilitate projects generating renewable energy at its own facilities. DOE has asked the National Renewable Energy Laboratory (NREL) to provide technical assistance in the analysis of wind feasibility at the PANTEX plant in Amarillo TX.

This report describes the wind resource measured at the Washburn 100 m met tower ~14-16 km (~9-10 mi) south of the PANTEX facility. The data set analyzed in this report includes a general validation and summarization of the 10-minute data taken from September, 2003 through December, 2009.

The wind resource assessment for the 100 m met tower at the Washburn site has been completed using collected wind data at the site over a period of 6.3 years and within ~14-16 km of the PANTEX facility.

The overall wind resource is very good with a Mean Annual Wind Speed of 8.8 m/s at 100 m. The site has a Wind Power Density of 468 W/m^2 at 50 m and 672 W/m^2 at 100 m. The site is considered a Class 4 wind resource at 50 m.

Table 1 Mean Annual Wind Speed and Wind Power Densities at Washburn Tower Site #152 in TX

Variable	Units	WS 5 ave 100m	WS 6 ave 100m	WS 3 ave 75m	WS 4 ave 75m	WS 1 ave 50m	WS 2 ave 50m
Measurement height (m)	(m)	100	100	75	75	50	50
Mean wind speed (m/s)	(m/s)	8.8	9.0	8.5	8.6	7.8	8.1
Weibull k		2.448	2.33	2.558	2.536	2.55	2.583
Weibull c (m/s)	(m/s)	9.889	10.097	9.603	9.692	8.806	9.152
Mean power density (W/m²)	(W/m2)	642	701	574	592	444	494

It is expected that the resource at PANTEX is very similar with the on-site buildings being the primary potential source of interference or ground clutter that may negatively impact the wind resource.

Potential wind turbine output was modeled using the existing wind data from the Washburn met tower. Simple paybacks ranged between 6 – 16 years, assuming a cash purchase for the wind turbines and the foregoing of PTC, accelerated depreciation and US Treasury grants.

There are other factors to consider for a wind turbine project beyond wind resource and economics. The wind resource assessment provides the framework for the subsequent economic analysis. Consideration of factors such as base operations, visual impacts, environmental impacts, etc. are necessary in scoping a wind turbine project, but are beyond the scope of this wind resource assessment.

To do an appropriate cost analysis, an RFP should be issued citing the appropriate class of wind turbine and the best available wind data for the site. The proposals in response to the RFP should be analyzed with factors such as installed cost, constructability, timeframe, O&M, track record of bidder, etc. taken into consideration. NREL would be happy to participate in the development of the RFP, the analysis of the submitted proposals or any other technical assistance that may be needed to get this project in the ground.

2. STATION LOCATIONS

The Alternative Energy Institute (AEI) of the West Texas A&M University has been monitoring the wind resource in the Amarillo TX area for over a decade. AEI maintains a web site[1] where some of the data they have collected is now publicly available. This publically available data was used in this analysis. Three sites were identified as being in close enough proximity to PANTEX to be a viable wind data resource.

Table 2 Nearby Met Towers with Publically Available Wind Data

Site Name	Site #	Met Tower Height (m)	Time Frame
Tall Tower North - Washburn	52	100	01/01/2003 - 12/31/2009
White Deer	14	50	08/01/1994 - 04/31/2004
Amarillo	6	40	06/01/1995 - 12/31/2010

A detailed analysis was undertaken using the data collected from the Tall Tower North – Washburn location, Site #52. The met tower at this site has redundant anemometers at 100, 75 and 50 m and represents a quality wind data source for estimating the wind resource near PANTEX. Approximate grid coordinates are: N 35° 10’ 26.1”, W 101° 32’ 41.0” at an elevation of 1074 m. The elevation at PANTEX is essentially the same. And it is ~14-16 km (~9-10 mi) from PANTEX to the Washburn tower. The Washburn monitoring location is shown in Figure 1 along with PANTEX. The general terrain in close proximity to the met tower is relatively flat with crops, grassland and small brush.

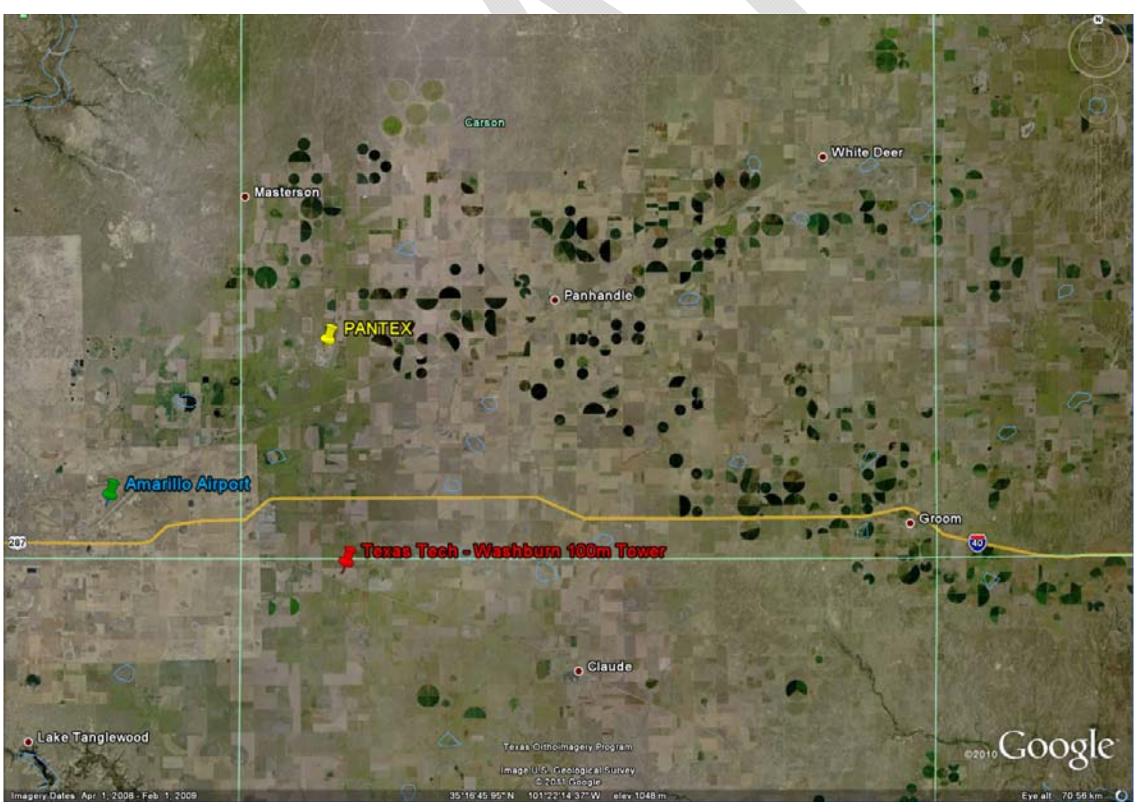


Figure 1 Washburn 100 m Met Tower, PANTEX and Amarillo Airport Locations
Source: ***http://www.Googlemaps.com***

[1] Web source: Hhttp://www.windenergy.org/datasites/H

The table below summarizes the details of the monitoring station over the collection period July 23, 2009 through September 27, 2010. The data was processed using Windographer[2] software.

Table 3 Data Set Summary at Washburn Tower Site #152 in TX

Variable	Value
Latitude	N 35°10'26.1"
Longitude	W 101°32'41.0"
Elevation	1074 m
Start date	10/1/2003
End date	12/31/2009
Duration	6.3 years
Length of time step	60 minutes
Calm threshold	3 m/s
Power density at 50m	468 W/m^2
Wind power class	4
Power law exponent	0.137
Surface roughness	0.0459 m
Roughness class	1.35

3. WIND IN TEXAS

There has been interest in wind energy applications in Texas since the 1990's. As can be seen in the wind power density map below, there is a considerable wind resource in West Texas and in the Texas Panhandle, where PANTEX is located.

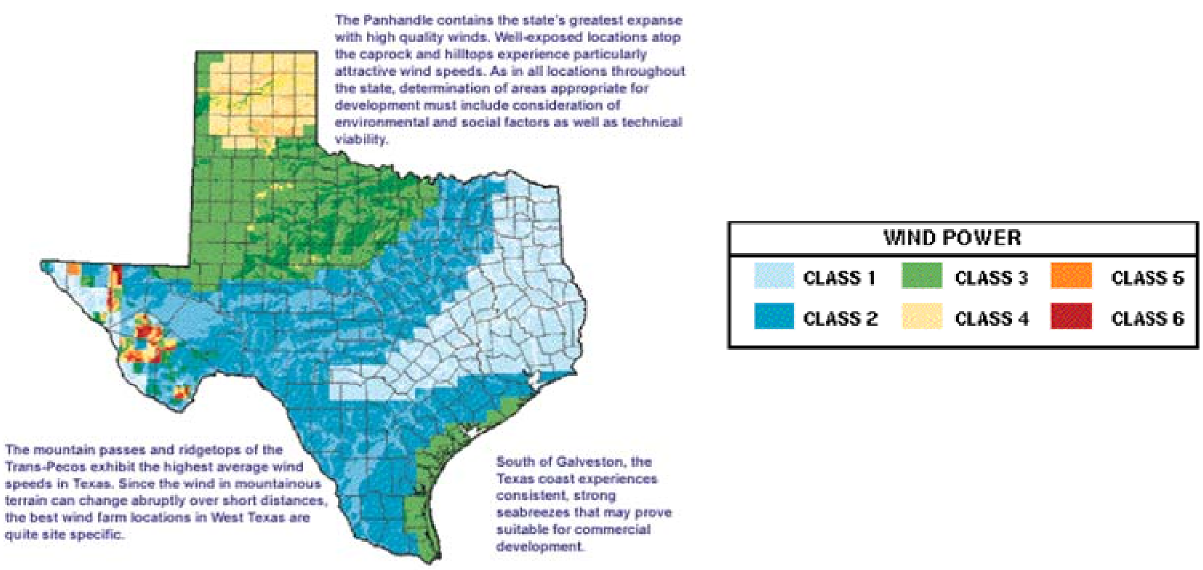


Figure 2 Wind power density map of Texas[3]

[2] Web source: **H**http://www.mistaya.ca/
[3] http://www.infinitepower.org/reswind.htm

Wind resources are very site specific. Different sites in close proximity to each other, but with varying vegetation (i.e., tall trees vs. grassland or cropland), topographical features (ridges vs. valleys; canyons vs. mountains, etc), and surface roughness (i.e., city skyscrapers vs. flat or rolling farmland), may have entirely different wind regimes. One may prove to be economic, and one may not. Wind maps are useful for determining from a high level view where the wind usually blows. Wind maps are not used to site large wind turbines/farms, as they do not have a high enough resolution in terms of local wind speed. They are used to determine where it is merited to further investigate the wind with installation of an on-site wind monitoring station.

4. INSTRUMENTATION AND EQUIPMENT

Details of the particular sensors used in the measurement campaign were not readily available. The details of the sensor configuration were and they are summarized in Table 4 below. There are redundant pairs of the anemometers, at 100, 75, and 50 m along with wind vanes at the same heights.

Table 4 Instrumentation Summary at North Washburn Met[4]

Site name:	**North Washburn Tall Tower**			
Elevation:		1074	m	
Latitude:		35°10'261"		
Longitude:		101°32'410"		
Levels of sensors:		3		
Wind Speed Sensors, Labels and Heights				
WS LEVEL 1	WS1	50	m	
WS LEVEL 1	WS2	50	m	
WS LEVEL 2	WS3	75	m	
WS LEVEL 2	WS4	75	m	
WS LEVEL 3	WS5	100	m	
WS LEVEL 3	WS6	100	m	
Wind Vanes, Labels and Heights				
WD LEVEL 1	WD 1	50	m	
WD LEVEL 2	WD 2	75	m	
WD LEVEL 3	WD 3	100	m	

5. WIND SPEED SENSOR SUMMARY

The table below provides an overview of a number of key parameters of the collected data.

The collected data was analyzed and screened for anomalies and to determine the effects of tower on the wind speeds recorded at each anemometer height. The tower can influence the wind speed that is measured by the anemometers through an effect known as tower shading. The effect can most easily be seen mathematically or graphically by comparing the wind speed ratios of the redundant anemometers. In other cases, there was a sensor failure and this data has been flagged and excluded from subsequent analysis.

Table 5 Wind Speed Sensor Summary at Washburn Tower Site #152 for 9/2003 – 12/2009

[4] Alternative Energy Institute, West Texas A&M University. http://www.windenergy.org/datasites/template.html

Variable	Units	WS 5 ave 100m	WS 6 ave 100m	WS 3 ave 75m	WS 4 ave 75m	WS 1 ave 50m	WS 2 ave 50m
Measurement height (m)	(m)	100	100	75	75	50	50
Mean wind speed (m/s)	(m/s)	8.8	9.0	8.5	8.6	7.8	8.1
MoMM wind speed (m/s)	(m/s)	8.8	9.0	8.5	8.6	7.8	8.1
Median wind speed (m/s)	(m/s)	8.8	9.1	8.5	8.6	7.8	8.1
Max wind speed (m/s)	(m/s)	27.2	74.8	27	60.8	26.1	26.3
Weibull k		2.448	2.330	2.558	2.536	2.550	2.583
Weibull c (m/s)	(m/s)	9.889	10.097	9.603	9.692	8.806	9.152
Mean power density (W/m^2)	(W/m^2)	642	701	574	592	444	494
MoMM power density (W/m^2)	(W/m^2)	647	703	569	592	447	489
Mean energy content ($kWh/m^2/yr$)	($kWh/m^2/yr$)	5,624	6,138	5,025	5,184	3,892	4,330
MoMM energy content ($kWh/m^2/yr$)	($kWh/m^2/yr$)	5,671	6,154	4,987	5,187	3,920	4,285
Frequency of calms (%)	(%)	6.1	7.3	5.5	5.9	6.4	5.8
Possible records	(#)	54,815	54,815	54,815	54,815	54,815	54,815
Valid records	(#)	47,893	28,023	45,375	41,553	48,293	47,001
Missing records	(#)	6,922	26,792	9,440	13,262	6,522	7,814
Data recovery rate (%)	(%)	87.4	51.1	82.8	75.8	88.1	85.7

The wind speeds for two anemometers at the same height are expected to be the same or very close to the same. When they are not, it is cause for further investigation. The ratio of the wind speeds of these two anemometers should typically be 1 or very close to 1. Predictable impacts of the tower can be seen when the wind must go around the tower (aka, ‘in the tower shadow’) to reach one of the anemometers. When one anemometer is in the tower shadow, the data from the other one is typically used. The data not used is “flagged”. Table 6 below shows the data that was flagged. Unless otherwise noted, all graphs and tables have the flagged data removed.

Table 6 Flagged Data Summary at Washburn Tower Site #152 for 9/2003 – 12/2009

Data Column	Unflagged Data - Valid Records	Low Quality	Tower Shading
WS 1 ave 50m	48,293	0	2,775
WS 1 std	49,279	0	2,775
WS 2 ave 50m	47,001	0	1,714
WS 2 std	47,986	0	1,716
WS 3 ave 75m	45,375	0	3,241
WS 3 std	46,402	0	3,243
WS 4 ave 75m	41,553	2,218	1,528
WS 4 std	45,974	2,218	1,580
WS 5 ave 100m	47,893	0	2,795
WS 5 std	49,110	0	2,812
WS 6 ave 100m	28,023	3,118	1,890
WS 6 std	39,434	3,118	2,048
WS 5 ave 100m TI	47,886	0	2,795
WS 6 ave 100m TI	28,016	3,118	1,890
WS 3 ave 75m TI	45,368	0	3,241
WS 4 ave 75m TI	41,546	2,218	1,528
WS 1 ave 50m TI	48,286	0	2,775
WS 2 ave 50m TI	46,994	0	1,714
WS 5 ave 100m WPD	47,893	0	2,795
WS 6 ave 100m WPD	28,023	3,118	1,890
WS 3 ave 75m WPD	45,375	0	3,241
WS 4 ave 75m WPD	41,553	2,218	1,528
WS 1 ave 50m WPD	48,293	0	2,775
WS 2 ave 50m WPD	47,001	0	1,714

6. WIND RESOURCE SUMMARY

Wind Speed Data

Wind speed data was collected at 100, 75, and 50 m with a redundant wind speed sensor at each height. The wind direction data was collected at the same heights as the wind speed data. A box plot indicating the monthly maximum wind speed, the daily high, the monthly mean, the daily low and monthly minimum wind speed of the collected 75 m data is shown in the figure below.

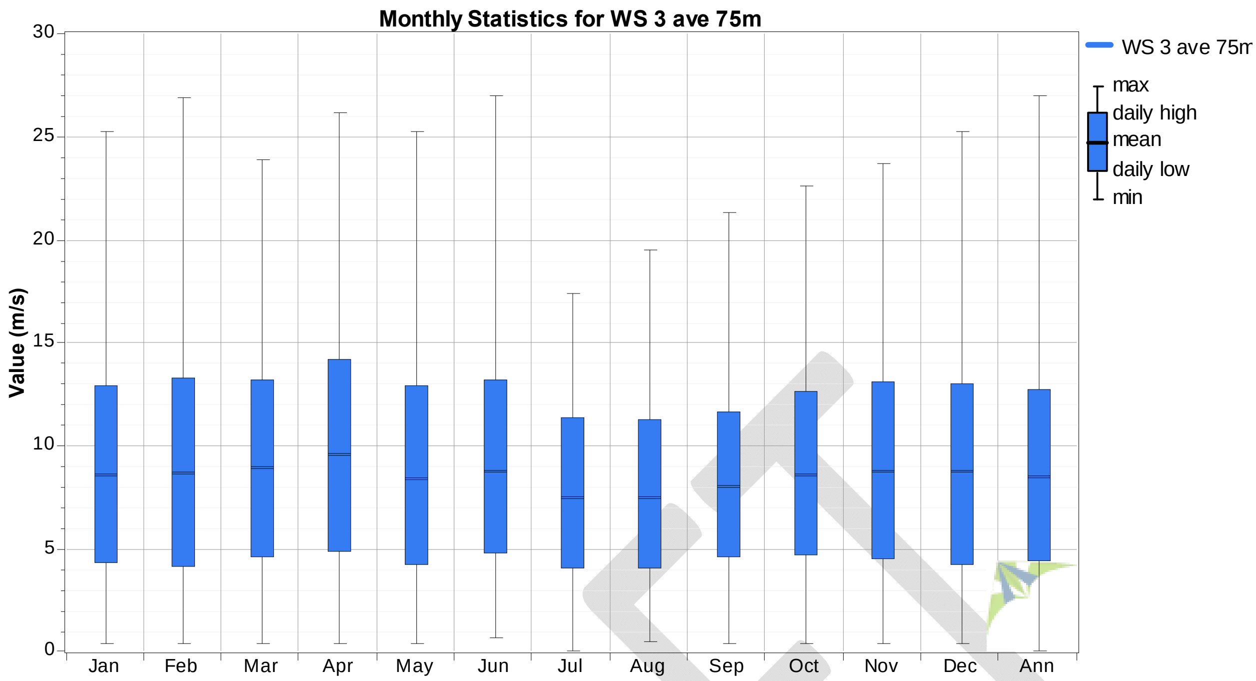


Figure 3 Boxplot of the Wind Speed Data at 75 m at Washburn Tower Site #152 for 9/2003 – 12/2009

In Figure 5 below, the wind speeds at each anemometer height are plotted against time to depict the seasonal trends. Wind speed at a location typically increases with increased height above the ground. The collected data follows that pattern. The months October through June represent months with only a single month of data while July through September have data from both 2009 and 2010.

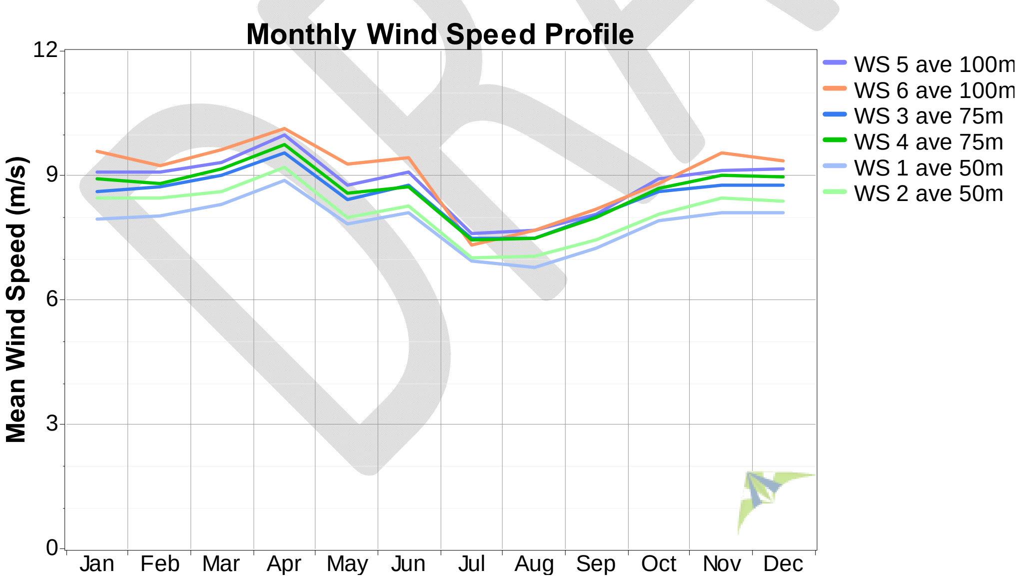


Figure 4 Seasonal Wind Speed Profile at Washburn Tower Site #152 for 9/2003 – 12/2009

Figure 6 below shows the annual average diurnal (daily) profile for the site. In general the winds increase during the afternoon and into early evening. Late evening through early morning tend to be the calmest.

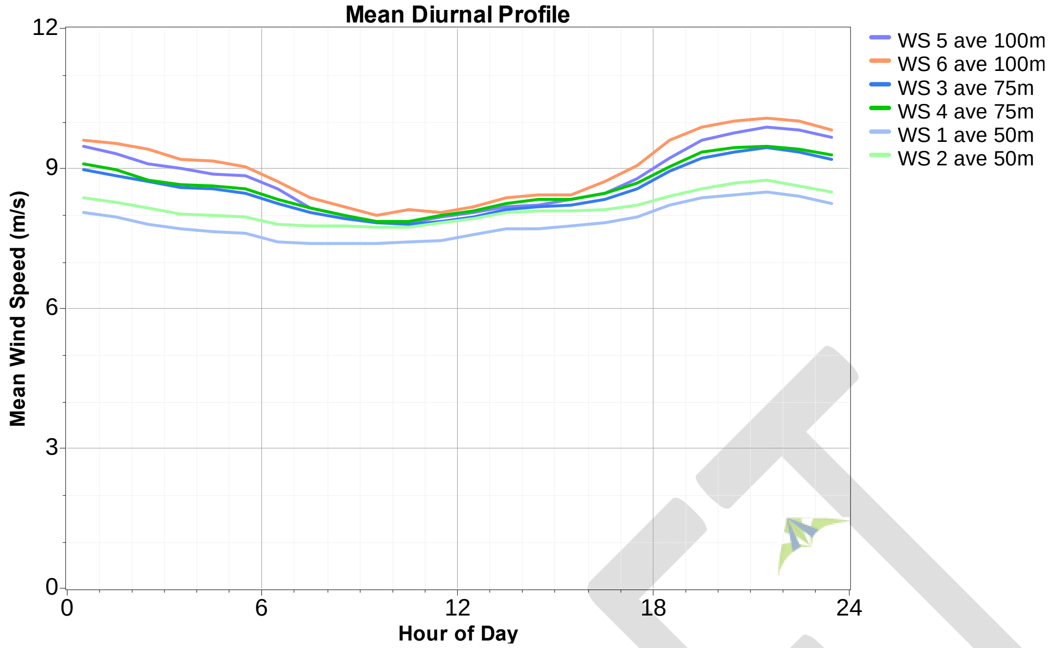


Figure 5 Diurnal Wind Speed Profile at Washburn Tower Site #152 for 9/2003 – 12/2009

The graphic below depicts the diurnal (daily) wind pattern by month.

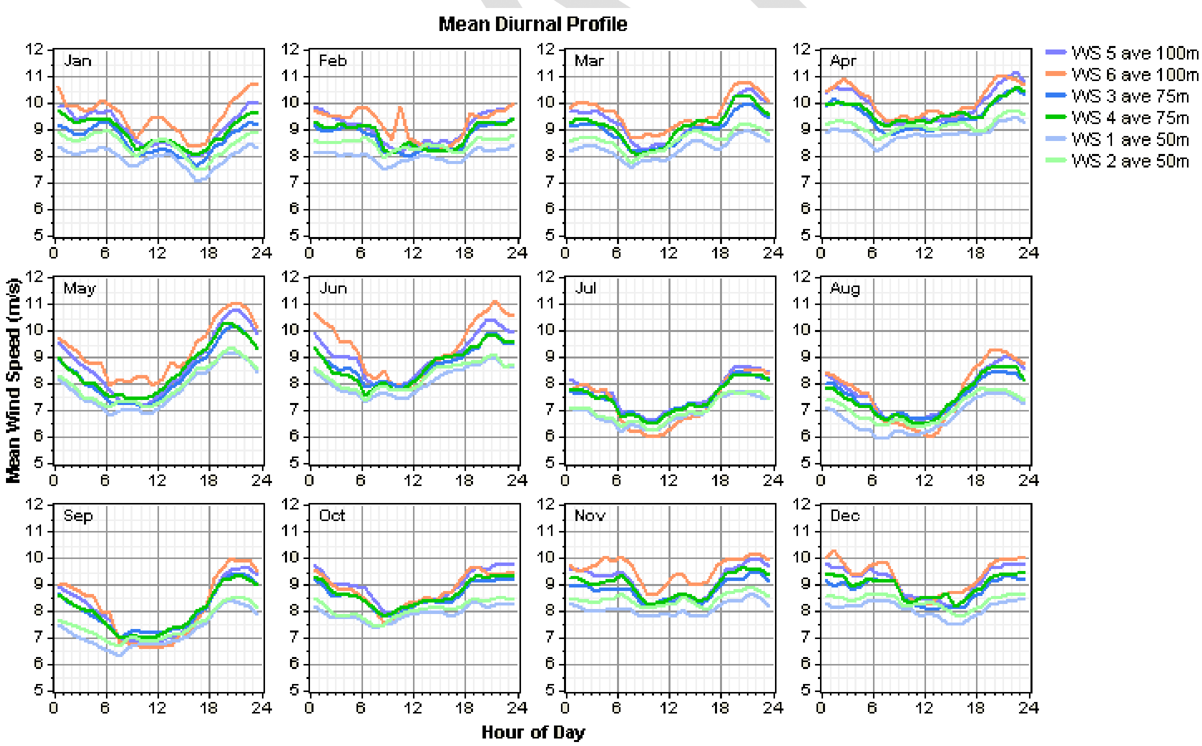


Figure 6 Diurnal Wind Speed Profile by Month at Washburn Tower Site #152 for 9/2003 – 12/2009

Wind Direction Data

The Wind Frequency Rose at left below shows the frequency the wind blows from each direction as measured at 100 m. As can be seen, the winds most frequently come from the southeast sector. The Mean Wind Speed Rose on the right indicates the mean (average) wind speeds from all directions. As shown, the stronger winds tend to come from all directions, except when from the north-through-east sector.

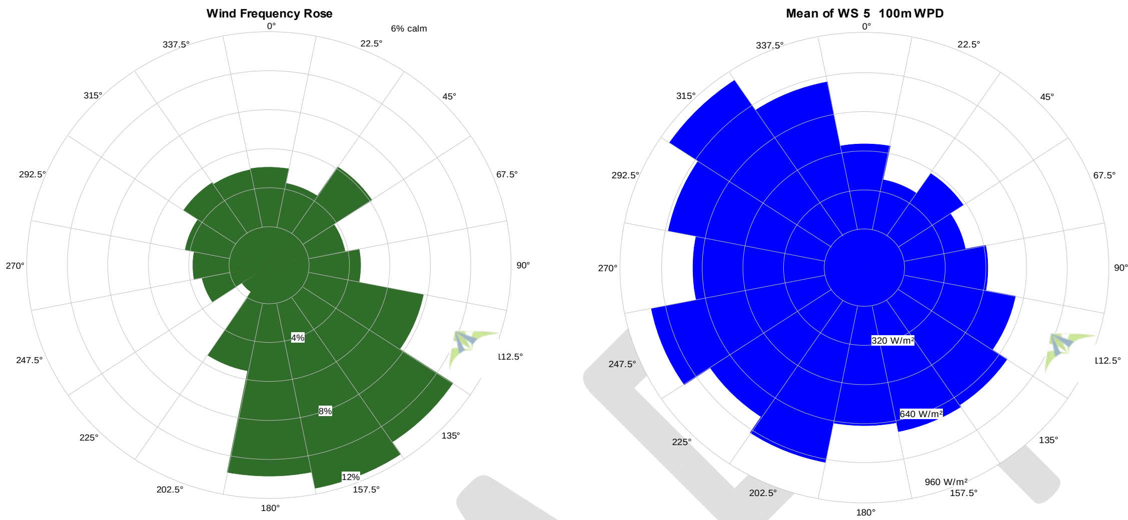


Figure 7 Wind Frequency and Wind Speed Rose at Washburn Tower Site #152 for 9/2003 – 12/2009

The Total Wind Energy Rose below indicates that most of the wind energy during the course of the year comes from the southeast-through-south direction.

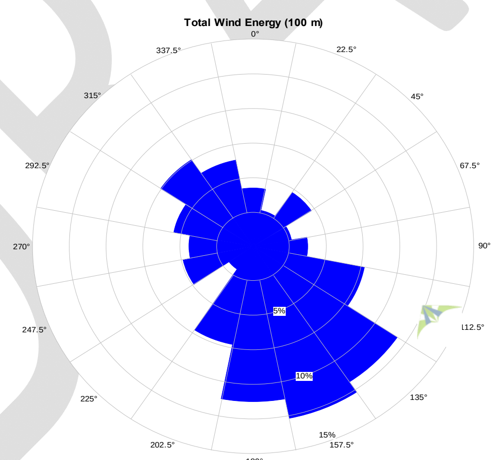


Figure 8 Wind Power Density Rose at Washburn Tower Site #152 for 9/2003 – 12/2009

The graphic below shows how the Total Wind Energy Rose varies by month. A “common scale” is used in this analysis which means the relative size of the wind resource in October is considerably smaller than in June, as shown graphically. There is also a considerable variance in the prevailing wind direction during both August and September with a significant portion of the wind coming from the northeast, while in November significant wind comes from the Northwest.

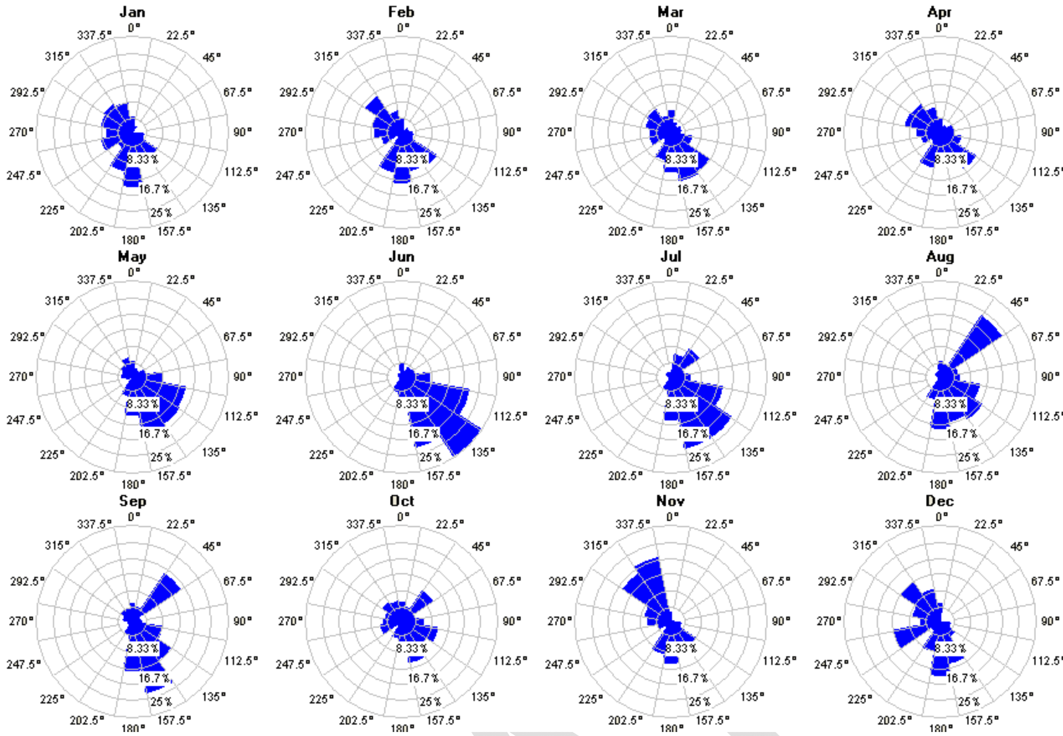


Figure 9 Wind Rose at 100m by month at Washburn Tower Site #152 for 9/2003 – 12/2009

Wind Frequency (Probability) Distribution

The figure below illustrates the frequency (%) of time that the wind (at 100m) is at a given wind speed. This probability distribution function is called a Weibull distribution. There are two commonly used factors to describe the characteristics of the distribution function, the Weibull c and Weibull k factors. The Weibull c is the scale factor for the distribution related to the annual mean wind speed. The Weibull k value is a unitless measure indicating how narrowly/widely the wind speeds are distributed about the mean with values ranging from 1.0 – 3.0.

The best fit Weibull distribution parameters for the measured data are k = 2.45 and c = 9.89 m/s. The distribution below shows that the most frequent winds are between 8-11 m/s as measured by the wind sensor at 100 m.

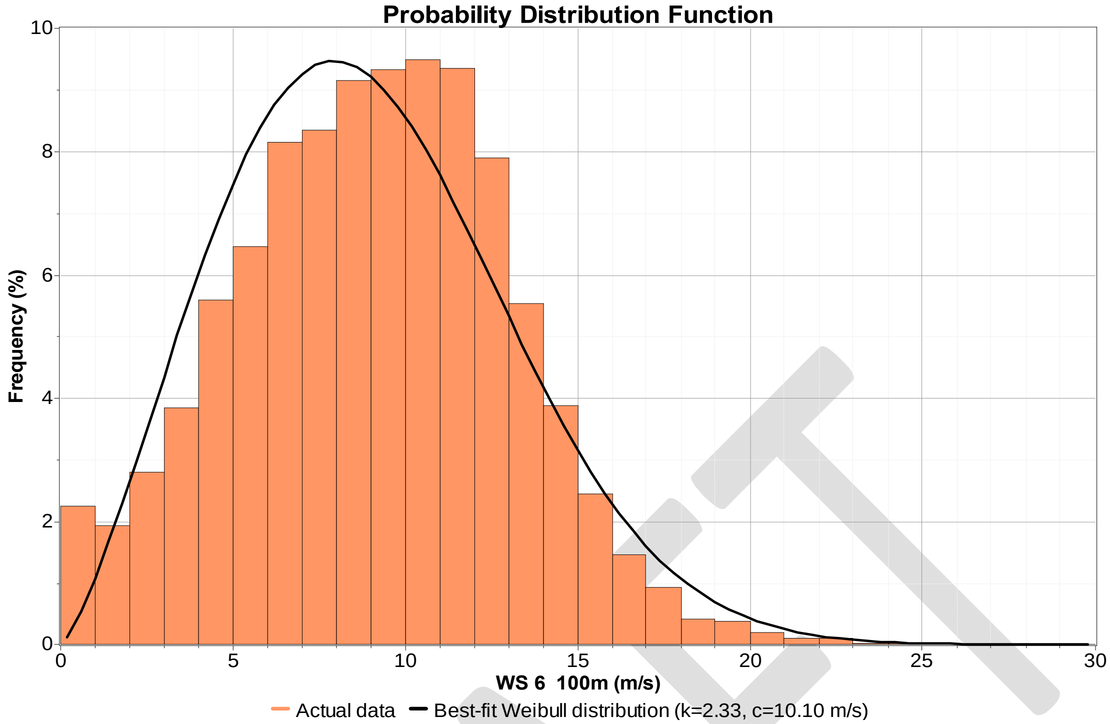


Figure 10 Wind Speed Distribution at 100 m at Washburn Tower Site #152 for 9/2003 – 12/2009

The figure below illustrates how the wind speed distribution varies throughout the year.

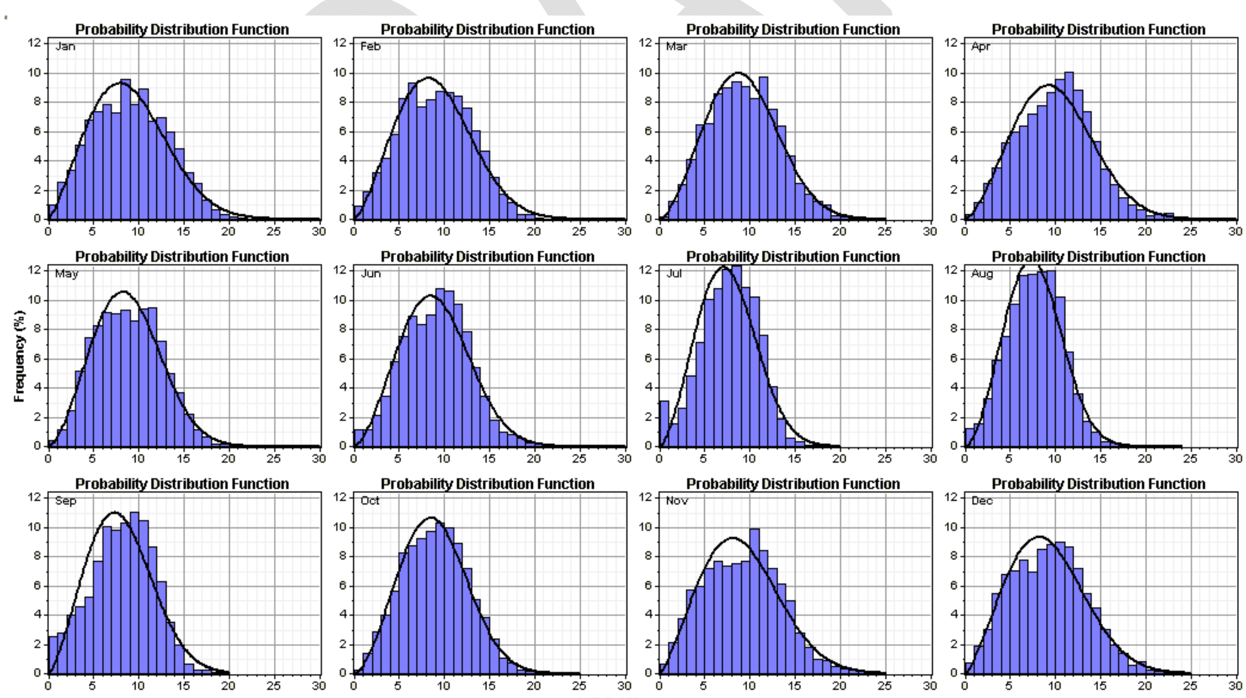


Figure 11 Monthly Wind Speed Distributions at 100 m at Washburn Tower Site #152 for 9/2003 – 12/2009

Vertical Wind Shear

Vertical wind shear is defined as the change in wind speed with the change in height. Typically, wind speed increases as the height above the ground increases. This variation of wind speed with elevation is called the vertical profile of the wind speed or vertical wind shear. In wind turbine engineering, the determination of vertical wind shear is an important design parameter, since: (1) it directly determines the productivity of a wind turbine on a tower of certain height, and (2) it can strongly influence the lifetime of a turbine rotor blade as it provides an indication of different wind speeds acting on different parts of the rotor.

Analysts typically use one of two mathematical relations to characterize the measured wind shear profile:

- Power law profile, aka *power law*
- Logarithmic profile, aka *log law*

The Power Law equation is shown below. Depending upon what data is known and what is sought, the equation can be manipulated to solve for any of the variables.

Equation 1 Power Law Equation

$$V = V_{ref}\left(\frac{Z}{Z_{ref}}\right)^{\alpha}$$

V = wind speed at height of interest (e.g., hub height)
V_{ref} = wind speed measured at height Zref
Z = height of interest (e.g., hub height)
Z_{ref} = height of measured data
α = wind shear exponent

The wind shear exponent, α, is often referred to as the vertical wind shear factor. It defines how the wind speed changes with height. When the actual wind shear value is not known, a typical value used to estimate the wind shear exponent is 0.14 (aka $1/7^{th}$ power law). When wind speed readings are available at multiple heights, the wind shear factor can be calculated using the power law equation. That is what was done with the collected data at Pearl City. The tables below show the calculated wind shear values between the various anemometer heights.

The vertical wind shear factors from several heights with known wind speeds are used to estimate both the vertical wind shear factor and wind speed at other heights of interest above the measured data (e.g., turbine hub height). Depending upon the type of terrain and surface roughness features, the wind shear factor may vary from 0 to 0.4.

The Logarithmic Law uses a parameter known as the surface roughness length (measured in meters) in predicting the wind shear profile. Smooth surfaces such as calm, open sea have very low wind shear values (e.g., 0.0002m), crops are a little higher at 0.05m of surface roughness length. Areas with a few trees have surface roughness of about 0.1m while cities with tall buildings would be about 3.0m.

The surface roughness parameter is ‘solved for’ from the existing wind speed data at various heights. The resultant surface roughness characterization may not always match the actual surface conditions, but it serves as a descriptor of the vertical wind shear profile. The resultant surface roughness lengths have been calculated for the area surrounding the Washburn Tower and are shown in the tables below.

The figures shown for both the Power Law Exponent and Surface Roughness were calculated between valid data for both anemometers between 50, 75 and 100 m.

Table 7 Power Law exponent and Surface Roughness Length at Washburn Tower Site #152 for 9/2003 – 12/2009

Speed Sensor	Actual Height	Mean Wind Speed	Power Law Exponent	Surface Roughness
	(m)	(m/s)	(unitless)	(m)
WS 6 100m	100	8.980	**0.0948**	**0.00228**
WS 5 100m	100	9.108		
WS 4 75m	75	8.807		
WS 3 75m	75	8.791		
WS 2 50m	50	8.254		
WS 1 50m	50	8.210		

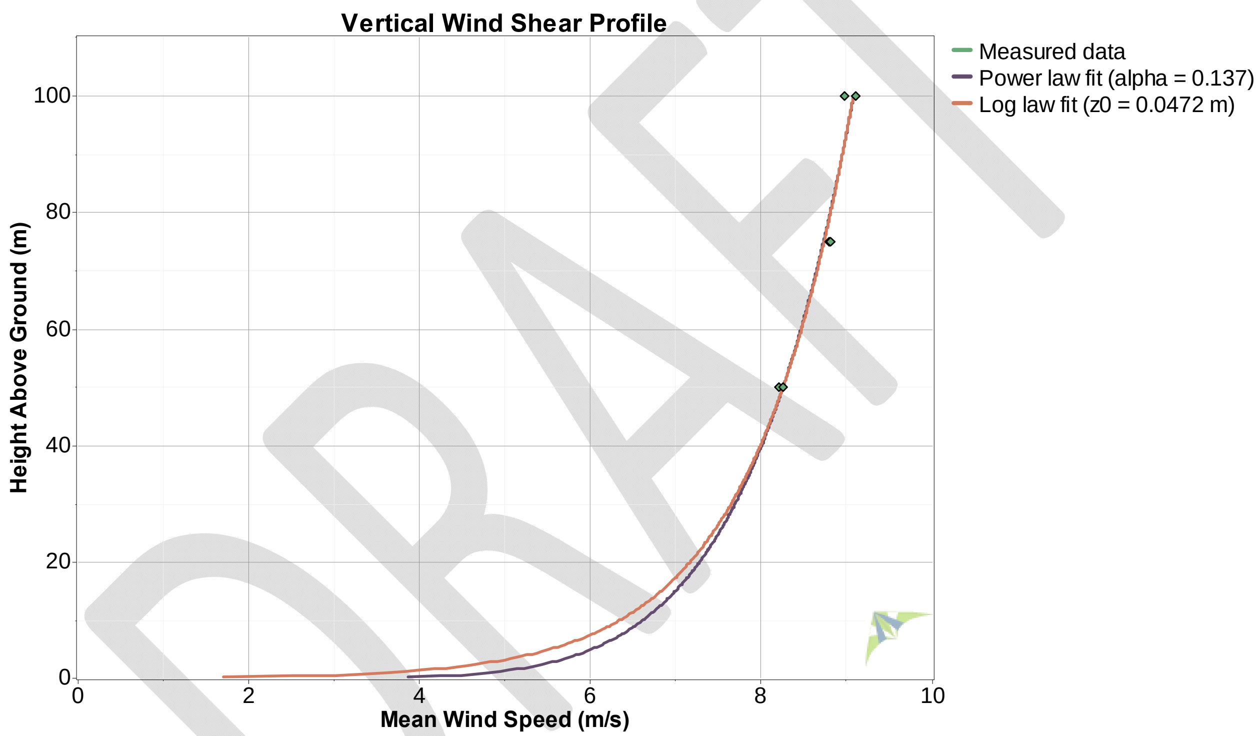


Figure 12 Vertical Wind Shear Profile with Power Law and Logarithmic Law at Washburn Tower Site #152 for 9/2003 – 12/2009

In the table below, the mean wind speeds at each height, power law exponent and surface roughness calculation are shown for each direction sector taken from the wind vane at 100 m.

Table 8 Power Law Exponent and Surface Roughness Length by Direction at Washburn Tower Site #152 for 9/2003 – 12/2009

		Mean Wind Speed (m/s)						Best-Fit	
Direction Sector	Time Steps	WS 5 100m	WS 6 100m	WS 3 75m	WS 4 75m	WS 1 50m	WS 2 50m	Power Law Exp	Surface Roughness (m)
345° - 15°	1,298	8.29	7.90	8.04	7.99	7.55	7.65	0.0940	0.0015
15° - 45°	0								
45° - 75°	1,116	7.74	7.68	7.37	7.43	6.79	6.90	0.1720	0.2084
75° - 105°	1,643	8.20	8.01	7.84	7.74	7.32	7.25	0.1550	0.1096
105° - 135°	3,187	9.32	9.34	8.97	8.99	8.45	8.39	0.1490	0.0860
135° - 165°	4,154	9.68	9.64	9.32	9.32	8.68	8.65	0.1580	0.1237
165° - 195°	3,111	9.44	9.45	9.00	9.26	8.34	8.59	0.1600	0.1314
195° - 225°	458	9.78	9.20	9.36	9.25	8.40	8.55	0.1670	0.1675
225° - 255°	770	9.56	9.15	9.21	9.19	8.46	8.46	0.1490	0.0820
255° - 285°	1,252	8.87	8.61	8.71	8.69	8.14	8.14	0.1080	0.0060
285° - 315°	1,524	9.22	9.01	9.12	9.02	8.66	8.68	0.0750	0.0001
315° - 345°	1,688	9.20	9.02	9.01	8.93	8.51	8.63	0.0890	0.0009

The daily wind shear profile for each month of the year can be seen in the figure below. Generally, the wind shear variation is relatively consistent month to month with a consistent diurnal pattern indicating higher shear overnight and lower shear during the day.

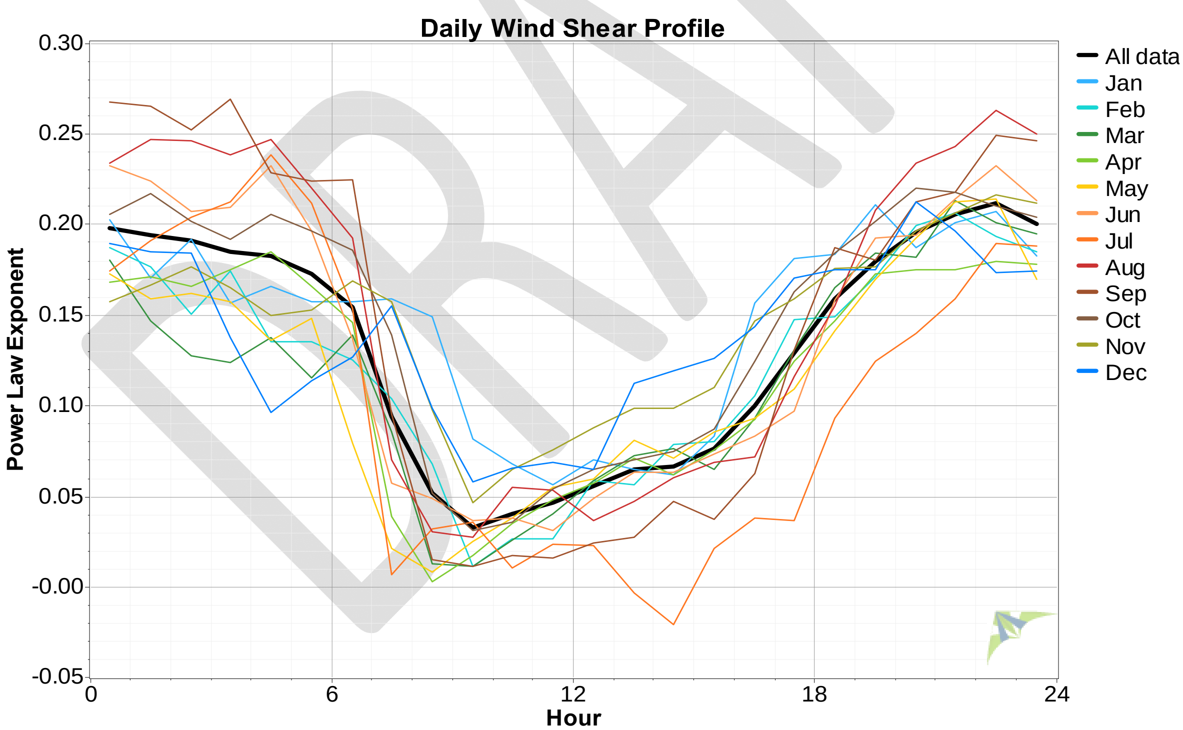


Figure 13 Daily Wind Shear Profile by Month at Washburn Tower Site #152 for 9/2003 – 12/2009

Turbulence Intensity

To determine the class of suitable turbines for this site, the turbulence intensity must be analyzed. The International Electrotechnical Commission (IEC) is the recognized international body for standards development activities. The IEC 61400 is focused on wind turbines. Standards for wind turbine design are developed by working groups of Technical Committee-88 (TC-88). The table below shows the design wind speeds for the reference wind speed, the annual average wind speed, the 50-year return gust and 1-year return gust. The collected wind speeds indicate that a Class I turbine is designed to withstand the wind loads that correspond to the wind speeds shown in the cells shaded orange in Table 9 below.

Table 9 IEC Wind Speed Parameter for Wind Turbine Classes[5]

IEC Wind Turbine Classes						
Wind Turbine Class		**I**	**II**	**III**	**IV**	
Characteristic	**Nomenclature**					**unit**
Reference Wind Speed	U_{ref}	50	42.5	37.5	30	(m/s)
Annual Average Wind Speed	U_{ave}	10	8.5	7.5	6	(m/s)
50-year Return Gust Speed	$1.4 * U_{ref}$	70	59.5	52.5	42	(m/s)
1-year Return Gust Speed	$1.05 * U_{ref}$	52.5	44.6	39.4	31.5	(m/s)
Notes: 10-minute Averages, Hub Height Wind Speed. Air Density: 1.225 kg/m^3						

IEC61400-1 edition 3[6] identifies the turbulence intensity parameters for classes of wind turbines. The comparison of edition 2 parameters to edition 3 parameters can be seen in Table 11. The Class C reference turbulence (Iref), which is equal to the mean turbulence intensity, indicates the turbulence must be below 0.12 at 15m/s.

Table 10 Turbulence Categories Defined in IEC 61400-1 3rd Edition[7]

IEC61400-1 Edition 2			**IEC61400-1 Edition 3**		
Class	**I15**	**a**	**Class**	**Iref**	**a**
A	0.18	2	A	0.16	3
B	0.16	3	B	0.14	3
S	Designer Specifies		C	0.12	3
			S	Designer Specifies	

The figure below shows the representative and mean turbulence intensities (TI) as a function of wind speed at 100 m. The turbulence intensity, or TI, is defined as the standard deviation of the wind speed within a time step divided by the mean wind speed over that time step and is a measure of the gustiness of the wind. High turbulence can lead to increased turbine wear and potentially increased O&M costs. At lower wind speeds, the calculated turbulence intensity is often higher as can be seen in the figure below. At low wind speeds, the turbulence is of little consequence to the wind turbine itself. Turbulence at higher winds speeds is of greater interest and concern to wind turbine manufacturers. There is a slight increase in turbulence intensity shown at 18-19 m/s. As seen in the table below, there are 6 discrete 10 minute intervals during the entire year that are the source of this turbulence.

---

[5] Burton, T., et al, IEC 61400-1, Wind Energy Handbook, John Wiley and Sons, UK, 2001, p. 210.

[6] Turbulence Modeling, The IEC 61400-1 turbulence model, Hhttp://www.wasp.dk/Products/Wat/WAtHelp/WATmodelling.htmH, accessed January 2010

[7] Turbulence Modeling, The IEC 61400-1 turbulence model, Hhttp://www.wasp.dk/Products/Wat/WAtHelp/WATmodelling.htmH, accessed January 2010.

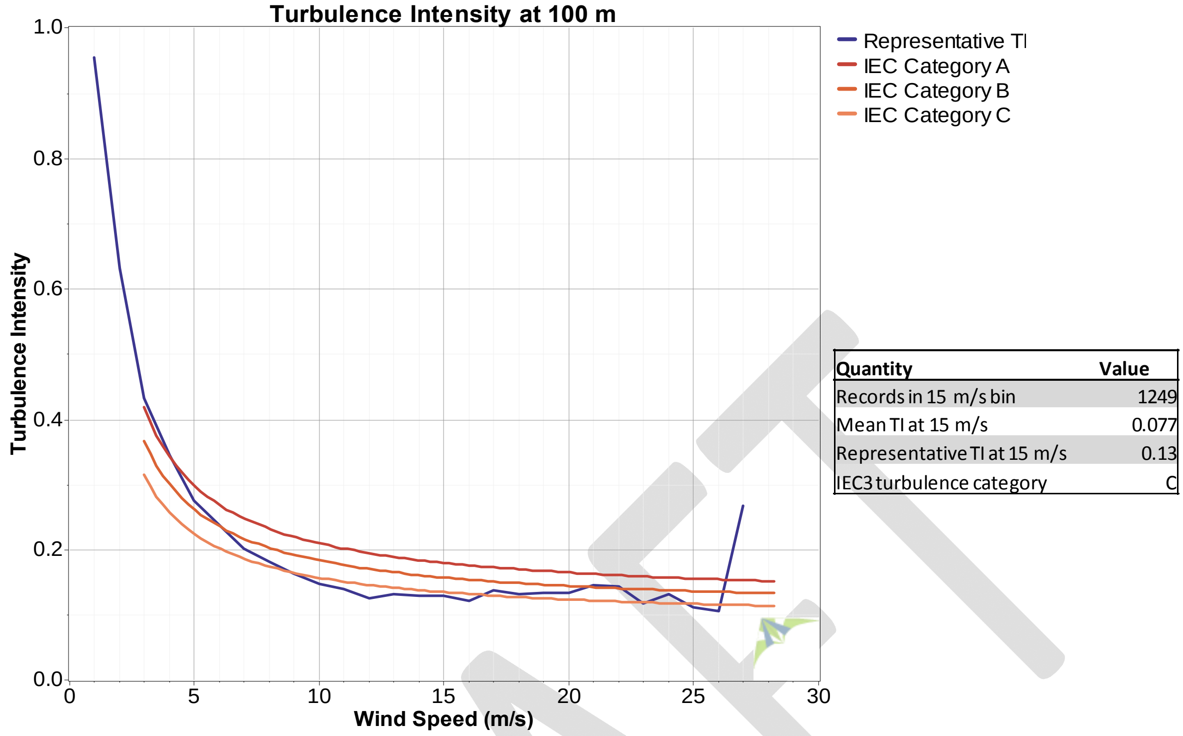


Figure 14 Turbulence Intensity at 100 m at Washburn Tower Site #152 for 9/2003 – 12/2009

The table below displays the relevant turbulence parameters per wind speed bin.

Table 11 Turbulence Analysis at 100 m at Washburn Tower Site #152 for 9/2003 – 12/2009

Bin	Bin Endpoints		Records in Bin	Mean TI	Standard	Representativ	Peak TI
(m/s)	(m/s)	(m/s)	(#)				
1	0.5	1.5	641	0.607	0.271	0.954	2.600
2	1.5	2.5	1,088	0.390	0.189	0.632	1.957
3	2.5	3.5	1,789	0.259	0.136	0.433	1.647
4	3.5	4.5	2,678	0.203	0.111	0.345	1.488
5	4.5	5.5	3,435	0.162	0.088	0.275	1.245
6	5.5	6.5	4,038	0.139	0.076	0.237	1.175
7	6.5	7.5	4,320	0.120	0.063	0.201	0.740
8	7.5	8.5	4,398	0.109	0.056	0.181	0.551
9	8.5	9.5	4,620	0.097	0.053	0.164	0.593
10	9.5	10.5	4,563	0.085	0.048	0.147	0.635
11	10.5	11.5	4,429	0.079	0.047	0.139	0.717
12	11.5	12.5	3,661	0.074	0.040	0.125	0.378
13	12.5	13.5	2,789	0.076	0.043	0.131	0.598
14	13.5	14.5	2,021	0.076	0.042	0.129	0.577
15	14.5	15.5	1,249	0.077	0.041	0.130	0.382
16	15.5	16.5	805	0.079	0.033	0.121	0.272
17	16.5	17.5	475	0.083	0.043	0.138	0.515
18	17.5	18.5	311	0.086	0.036	0.131	0.278
19	18.5	19.5	158	0.089	0.035	0.134	0.249
20	19.5	20.5	97	0.091	0.033	0.134	0.223
21	20.5	21.5	46	0.1	0.036	0.145	0.248
22	21.5	22.5	36	0.101	0.033	0.143	0.217
23	22.5	23.5	25	0.095	0.018	0.118	0.145
24	23.5	24.5	13	0.095	0.029	0.132	0.162
25	24.5	25.5	9	0.094	0.013	0.111	0.124
26	25.5	26.5	6	0.092	0.010	0.105	0.107
27	26.5	27.5	4	0.14	0.1	0.268	0.289
28	27.5	28.5	0				

The scatterplot below provides a visual display of the array of data that are averaged to produce the discrete curves in Figures 14 and 15 above.

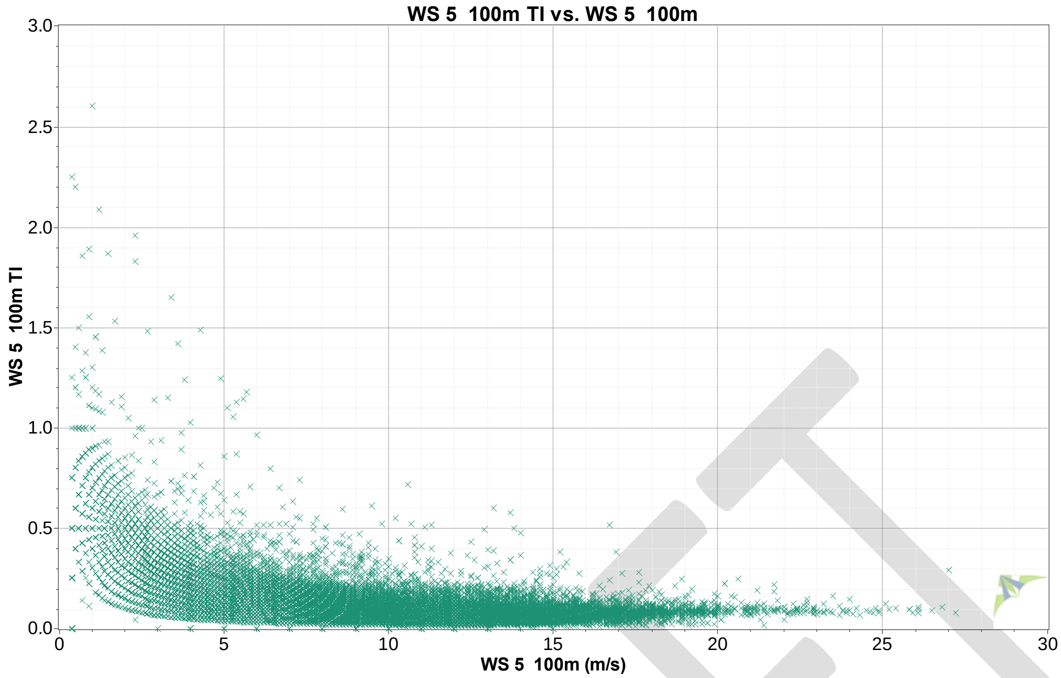


Figure 15 Turbulence Intensity vs. Wind Speed at Washburn Tower Site #152 for 9/2003 – 12/2009

The monthly turbulence intensity factors are displayed below. The summer months of June through September experienced the most turbulence during the period of collected data. It should be noted that July, August and September have the lowest monthly wind speeds during the period of collection.

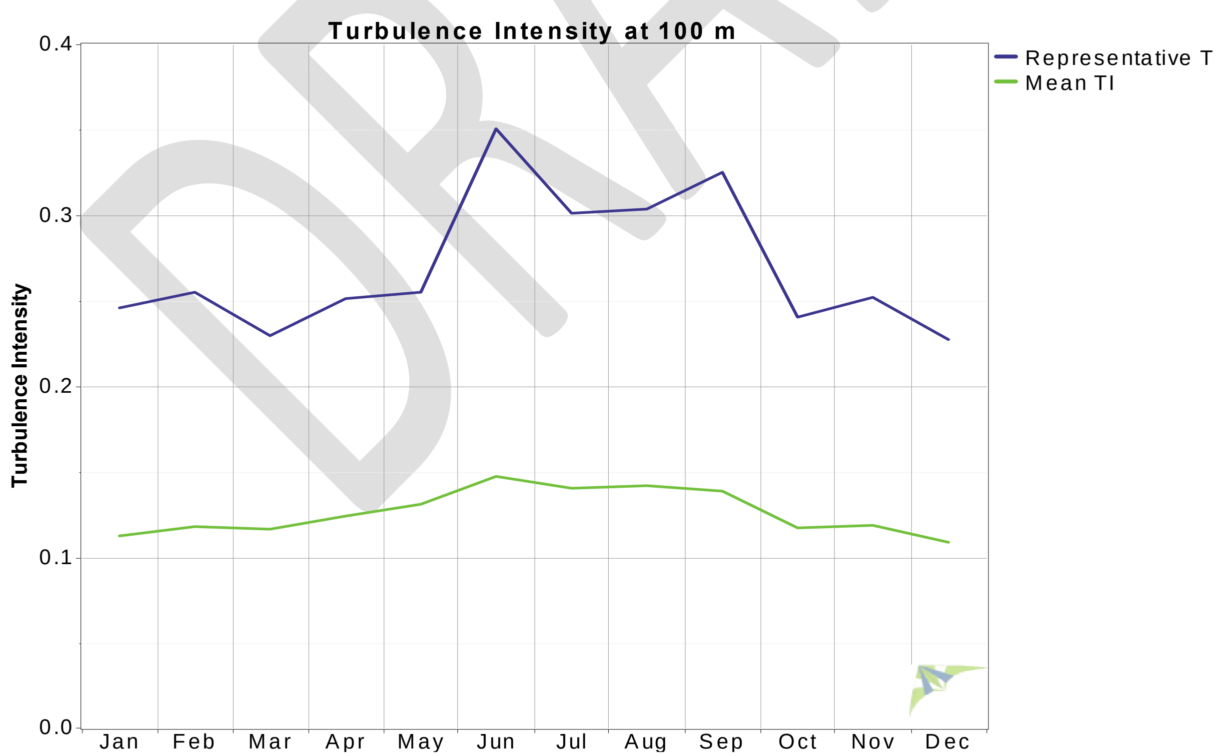


Figure 16 Turbulence Intensity by Month at 100 m at Washburn Tower Site #152 for 9/2003 – 12/2009

The turbulence intensity rose below illustrates that the representative turbulence comes from essentially all directions while the mean turbulence comes typically comes from the north, east and southwest directions.

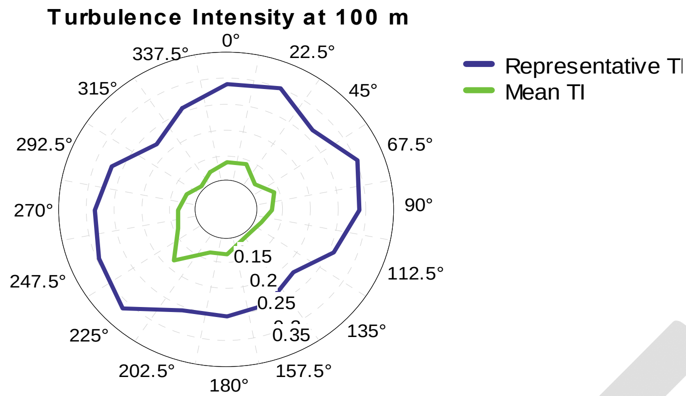


Figure 17 Turbulence Intensity Rose at 100 m at Washburn Tower Site #152 for 9/2003 – 12/2009

Long Term Reference for Washburn Tower Anemometer Data

It is important to consider if the monitoring period data reflects a high, low or average year in terms of wind resource. Overall, for the purposes of this study at this particular site with 6.3 years of quality wind data collected, the mean of the collected data will be considered to be reasonably representative of the long term data.

Estimated Electric Load at PANTEX

Electric load data was shared by Fred Johnson on PANTEX with NREL in 2008. This data was used for the economic analyses to follow. The electricity usage was given in kW every 15 minutes. Those values were summed and divided by four to given an approximate energy usage for the year of 71,567,000 kWh/yr. The annual electric bill of $3,982,844 was divided the energy usage to determine an approximate cost per kWh ($/kWh) as shown in the table below.

Table 12 Energy and Cost Calculations for PANTEX in 2008

Annual Electric Load		Total Electric Bill 2008	Estimated Cost/kWh
(kWh)	(MWh)	($/yr)	($/kWh)
71,567,000	71,567	$3,982,844	$0.0557

Estimated Wind Turbine Performance

The collected data was used to estimate the performance of a number of representative utility-scale wind turbines. Some of the key outputs are shown in the table below. Note the rated power for the turbines varies from 2-3 MW, so the output should likewise vary. The hub heights modeled were all assumed to be 80m (~262 ft) for consistency in comparison, though it is somewhat negated by the different rotor sizes and power ratings. Due to the high wind speeds at the site, generally smaller rotors were chosen from among the available models.

Table 13 Comparison of Wind Turbine Sizes and Output at 80 m Hub Height

Turbine	Hub Height	Hub Height Wind Speed	Rated Power	Time at Zero Output	Time at Rated Output	Mean Net Power Output	Mean Net Energy Ouptut	Net Cap. Factor
	(m)	(m/s)	(MW)	(%)	(%)	(kW)	(kWh/yr)	(%)
Clipper Liberty C89	80	8.35	2.5	6.45	4.07	877.3	7,685,484	35.1
DeWind D8.2	80	8.35	2.0	6.49	2.4	582.2	5,099,789	29.1
GE 3.0s	80	8.35	3.0	9.92	1.86	816.8	7,155,341	27.2
Mistubishi MWT92/2.4	80	8.35	2.4	6.44	8.88	917.8	8,039,812	38.2
Siemens SWT-2.3-82 VS	80	8.35	2.3	6.44	0.68	779.5	6,828,101	33.9
Vestas V112 - 3.0 MW	80	8.35	3.0	4.44	14.32	1,303.70	11,420,250	43.5

Economic Analysis of Wind Turbine Performance

The economics of any particular wind turbine depend upon a number of factors and costs – not all of which can be known accurately a priori. Items such as the: wind turbine cost, geotechnical requirements and excavation costs, installation costs, tower height, shipping/freight costs, permitting, etc. are all important cost components that determining specific costs may not be publically available. Average installed costs per kW, taken from DOE's 2009 WIND TECHNOLOGIES MARKET REPORT[8]. These costs were applied generically to the turbines based on size and the turbine outputs estimated using publicly available power curves stored within the Windographer database.

Commercial electricity rates from the DOE's Energy Information Agency[9] were used in addition to the calculated rate at PANTEX calculated above to determine the expected annual value of the electricity produced and the estimated years to payback. The average retail rate for electricity in the commercial sector was $0.0885 /kWh in November, 2010 vs. $0.1007/kWh in the US as a whole. The EIA data indicated that Texas electricity rates decreased by ~9.0% from November 2009 to November 2010 vs. an overall increase of 2.2% across the country. As electricity prices are subject to change, rather than analyze with a single static price, a range of prices were used to provide greater insight to the effect of price on Simple Payback in Years.

The calculated rate of $0.0557/kWh was used as the low price, the November 2010 EIA price for Texas of $0.0885 was used as the high price. The average of these two prices were used as a third price to provide information on the impact of the electricity price being offset on the simple payback. These results are shown in Table 14 below.

Table 14 Representative Turbine Annual Output, Cost Savings and Simple Payback

	$2,100 $/kW Installed Cost				Value of Annual Energy ($/yr)			Simple Payback (yrs)		
Turbine	Estimated Installed	# of Turbines	Cash Investment	Annual Energy	($/kWh)	($/kWh)	($/kWh)	($/kWh)	($/kWh)	($/kWh)
	($/turbine)	(#)	($)	(kWh/yr)	$0.056	$0.072	$0.089	$0.056	$0.072	$0.089
Clipper Liberty C89	$5,250,000	5	$26,250,000	38,427,420	$2,138,561	$2,769,694	$3,400,827	12.3	9.5	7.7
DeWind D8.2	$4,200,000	6	$25,200,000	30,598,734	$1,702,880	$2,205,434	$2,707,988	14.8	11.4	9.3
GE 3.0s	$6,300,000	4	$25,200,000	28,621,364	$1,592,835	$2,062,913	$2,532,991	15.8	12.2	9.9
Mistubishi MWT92/2.4	$5,040,000	5	$25,200,000	40,199,060	$2,237,157	$2,897,387	$3,557,617	11.3	8.7	7.1
Siemens SWT-2.3-82 VS	$4,830,000	5	$24,150,000	34,140,505	$1,899,986	$2,460,710	$3,021,435	12.7	9.8	8.0
Vestas V112 - 3.0 MW	$6,300,000	4	$25,200,000	45,681,000	$2,542,237	$3,292,503	$4,042,769	9.9	7.7	6.2

[8] Wiser, R., Bolinger, M, 2009 WIND TECHNOLOGIES MARKET REPORT, Energy Efficiency & Renewable Energy, Department of Energy, 2009.

[9] Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, Hhttp://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html

As the simple payback column shows, there are reasonable economics associated with any of these wind turbines. These figures shown should be treated as preliminary results and should not be used as a basis for selecting a wind turbine for this project. If there is site specific wind data, or representative data closer to PANTEX than the Washburn met tower, then that data should be carefully analyzed to determine the full extent of the wind resource at PANTEX.

It must be noted that these simple calculations assumed a cash purchase for the wind turbines by DOE. This means there are no finance fees (which increase project costs), but also the US Treasury grants, the Production Tax Credit (PTC) and potential accelerated depreciation of the wind turbine assets are not included and these tend to lower overall project costs in the commercial wind sector.

To do an appropriate cost analysis, an RFP should be issued citing the appropriate class of wind turbine and the best available wind data for the site. The proposals in response to the RFP should be analyzed with factors such as installed cost, constructability, timeframe, O&M, track record of bidder, etc. taken into consideration. NREL would be happy to participate in the development of the RFP, the analysis of the submitted proposals or any other technical assistance that may be needed to get this project in the ground.

Next Steps

If PANTEX wants to go forward with the Cash Purchase scenario, there are steps that can be taken now to enhance the RFP when it is released. It is assumed that many of these steps are already completed or underway, but they are included here as a reference of the wind project development process.

The RFP could be written so the selected contractor does all of these tasks, but this increases the uncertainty of a successful project and a more variable timeline. Contractors/developers prefer to know that PANTEX is fully committed to this project(s) and is willing to take care of the necessary groundwork. Contractor/developers do not want to have National Environmental Policy Act (NEPA) responsibilities. In some instances, it can take of lot of money and an indeterminate amount of time. It is the uncertainty that will keep developers from bidding on the RFP.

It would greatly enhance the pool of respondents to an RFP if GSA were to work through the following items:

- NEPA – begin the process, identify the relevant issues and which type of approval will be required (Categorical Exclusion, Environmental Assessment, or full Environmental Impact Statement). Try to determine the timeline for completion.

- Identify endangered species of animals or plants at the U.S. Fish & Wildlife's Environmental Conservation Online System at: http://ecos.fws.gov/ecos/indexPublic.do

- Federal Aviation Administration (FAA) – determine the height restrictions of a wind turbine based on on-site operations and the Amarillo Airport, then apply for permission to construct with FAA, Department of Defense (DoD) and the NEXRAD weather services. Apply on-line at with the coordinates at: https://oeaaa.faa.gov/oeaaa/external/gisTools/gisAction.jsp?action=showLongRangeRadarToolForm

- Geotechnical study – it will need to be done before starting the design of the wind turbine foundation. It is one more piece to help simplify the RFP. The selected contractor could also do this without a problem.

- Find a private or government entity with experience in wind project development to assist in the development of the RFP and review of the submitted proposals. An RFP developed by contracting officers, with the best of intentions but lacking in wind specific experience, risks omissions or mis-statements that can result in higher costs, unsatisfactory performance or re-issue of the RFP.

- Make plans to send several people from the PANTEX Project Development and Community Relations departments to "Wind Siting Workshops" sponsored by the American Wind Energy Association (AWEA). They offer 2-3 day courses and workshops throughout the year. PANTEX people need to learn from industry experts how to inform the public of its intent to pursue a wind turbine project. Web site: http://www.awea.org/

With these pieces in place, PANTEX will be able to attract a reasonable pool of RFP respondents and move forward on a successful wind turbine project at the PANTEX facility.

Summary and Conclusions

The wind resource assessment for the 100 m met tower at the Washburn site has been completed using collected wind data at the site over a period of 6.3 years and within ~14-16 km of the PANTEX facility.

The overall wind resource is very good with a Mean Annual Wind Speed of 8.8 m/s at 100 m. The site has a Wind Power Density of 468 W/m^2 at 50 m and 672 W/m^2 at 100 m. The site is considered a Class 4 wind resource at 50 m.

Table 15 Mean Annual Wind Speed and Wind Power Densities at Washburn Tower Site #152 in TX

Variable	Units	WS 5 ave 100m	WS 6 ave 100m	WS 3 ave 75m	WS 4 ave 75m	WS 1 ave 50m	WS 2 ave 50m
Measurement height (m)	(m)	100	100	75	75	50	50
Mean wind speed (m/s)	(m/s)	8.8	9.0	8.5	8.6	7.8	8.1
Weibull k		2.448	2.33	2.558	2.536	2.55	2.583
Weibull c (m/s)	(m/s)	9.889	10.097	9.603	9.692	8.806	9.152
Mean power density (W/m^2)	(W/m2)	642	701	574	592	444	494

It is expected that the resource at PANTEX is very similar with the on-site buildings being the primary potential source of interference or ground clutter that may negatively impact the wind resource.

Potential wind turbine output was modeled using the existing wind data from the Washburn met tower. Simple paybacks ranged between 6 – 16 years, assuming a cash purchase for the wind turbines and the foregoing of PTC, accelerated depreciation and US Treasury grants.

There are other factors to consider for a wind turbine project beyond wind resource and economics. The wind resource assessment provides the framework for the subsequent economic analysis. Consideration of factors such as base operations, visual impacts, environmental impacts, etc. are necessary in scoping a wind turbine project, but are beyond the scope of this wind resource assessment.

To do an appropriate cost analysis, an RFP should be issued citing the appropriate class of wind turbine and the best available wind data for the site. The proposals in response to the RFP should be analyzed with factors such as installed cost, constructability, timeframe, O&M, track record of bidder, etc. taken into consideration. NREL would be happy to participate in the development of the RFP, the analysis of the submitted proposals or any other technical assistance that may be needed to get this project in the ground.

Appendix A – Other Wind Data from Washburn Met Tower

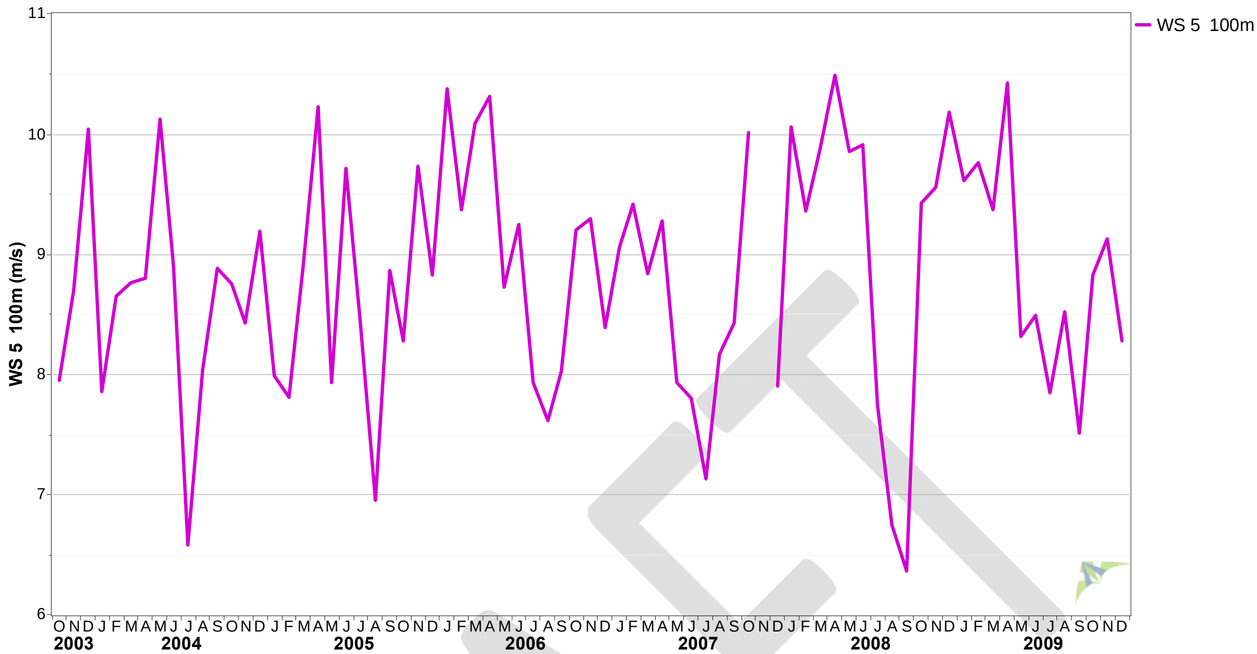


Figure 18 Long Term Mean Monthly Wind Speeds at Washburn Met Tower at 100 m

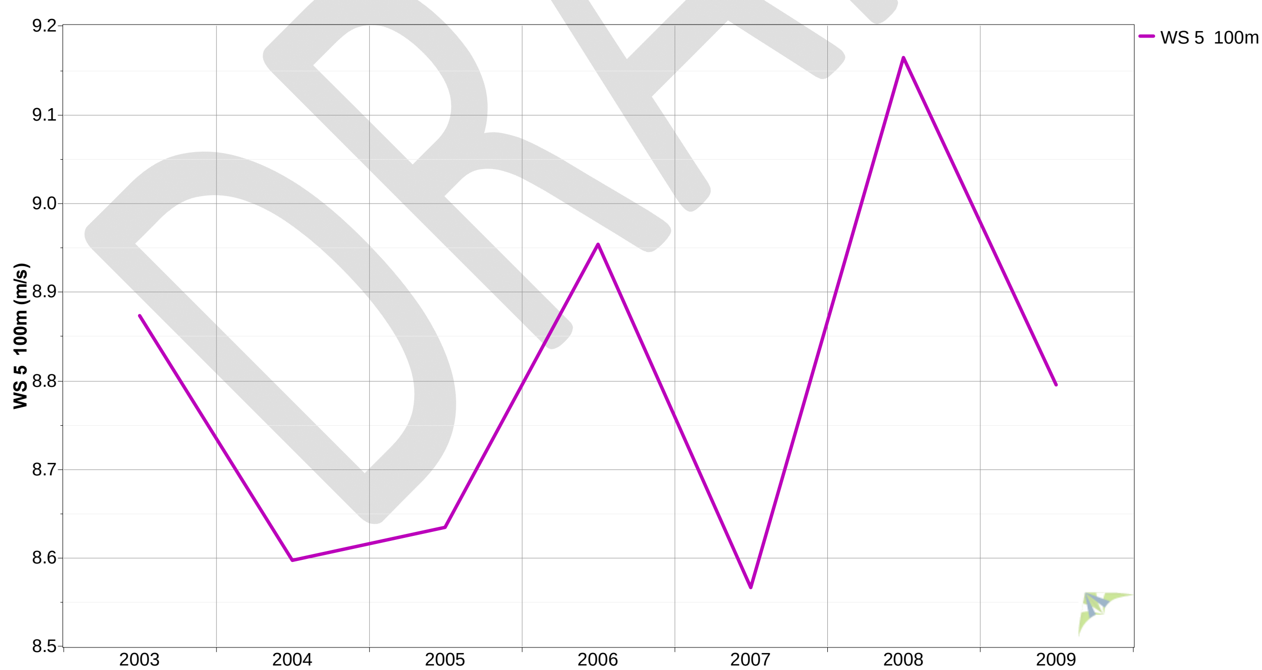
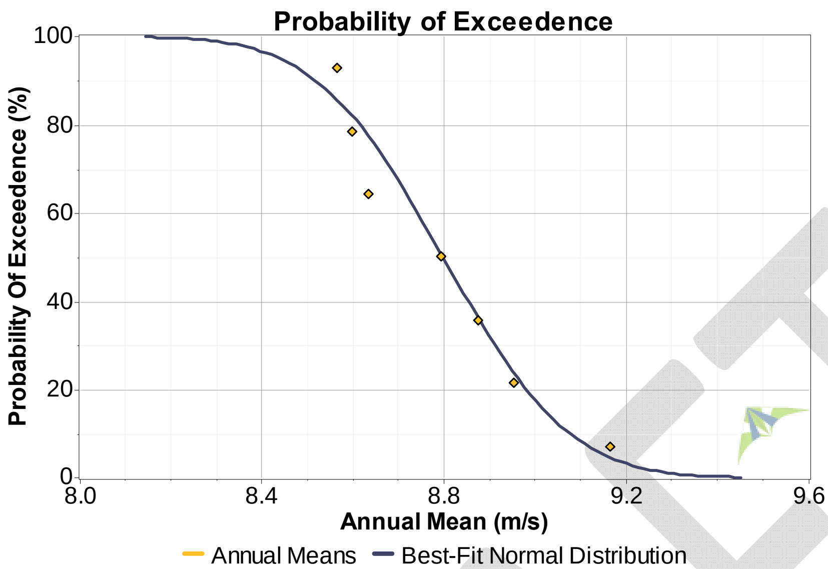


Figure 19 Long Term Mean Annual Wind Speeds at Washburn Met Tower at 100 m



Percentile	Actual Distribution m/s	Normal Distribution m/s
P99		8.291
P95		8.439
P90	8.573	8.518
P75	8.607	8.651
P50	8.795	8.798
P25	8.933	8.945
P10	9.122	9.077
P5		9.156
P1		9.305

Figure 20 Probability of Exceedence Graph and Table

Appendix B – Nearby Wind Data Stations

WHITE DEER # 14

SITE INFORMATION SUMMARY

AEI-GLO DATA TEMPLATE VERSION 4.1

Enter the name, elevation, and levels of sensors. Data within spreadsheet will be based on this info.

Site name:	WhiteDeer 0614			
Elevation in m:	1045	Year:	2010	
Levels of sensors	3			
WS LEVEL 1	50	meters	WS1	
WS LEVEL 1	50	meters	WS2	
WS LEVEL 2	40	meters	WS3	
WS LEVEL 2	40	meters	WS4	
WS LEVEL 3	25	meters	WS5	
WS LEVEL 3	10	meters	WS6	
WS LEVEL 4		meters	WS7	
WS LEVEL 4		meters	WS8	

The number below will be calculated, do not enter the number.

ρ for this site	1.10	
WD 1	50	meters
WD 2	40	meters
WD 3	25	meters
Latitude	N 35°00'00"	
Longitude	W 101°00'00"	

Calculate feet to meters here:

Feet	100
Meters	30.5

Calculate meters to feet here:

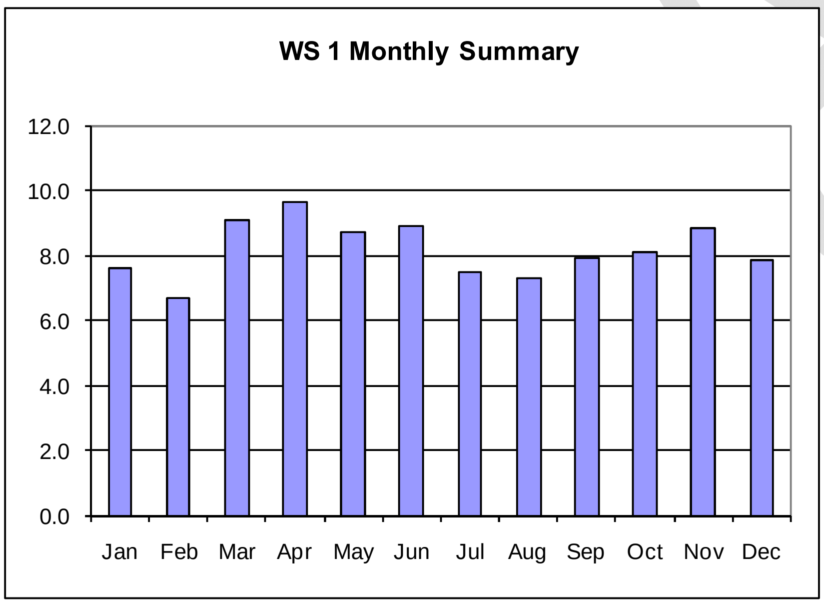
Meters	30.5
Feet	100.0

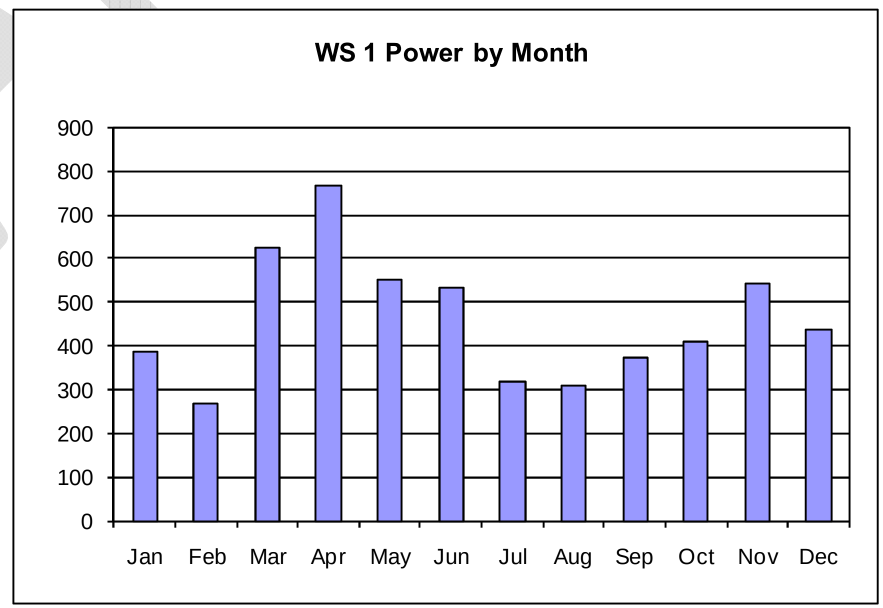
Expected Windspeed Max:	15
(15 if unknown)	

ALL DATA IN ORANGE MUST BE ENTERED.
IT WILL BE UTILIZED THROUGHOUT THE TEMPLATE IN LABELS AND CALCULATIONS
All DATA IN GREEN IS CALCULATED, DO NOT ENTER A NUMBER.

White Deer - Site #14
2010 Wind Data

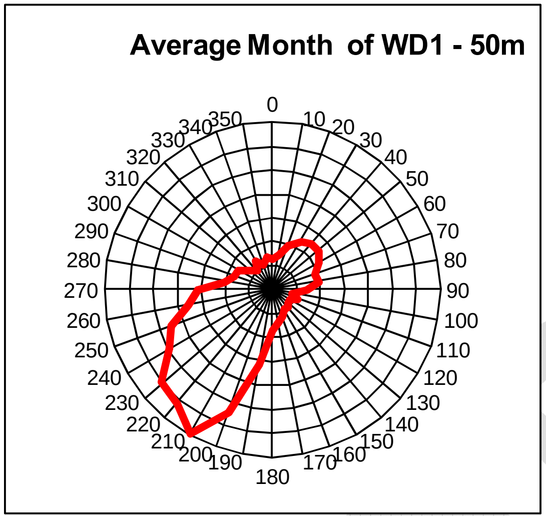
	# data pts	WS 1	WS 1 Pwr	# data pts	WS 2	WS 2 Pwr	# data pts	WS 3	WS 3 Pwr	# data pts	WS 4	WS 4 Pwr	# data pts	WS 5	WS 5 Pwr	# data pts	WS 6	WS 6 Pwr
	50 m	50 m	50 m	50 m	50 m	50 m	40 m	40 m	40 m	40 m	40 m	40 m	25 m	25 m	25 m	10 m	10 m	10 m
Jan	666	7.6	389	660	7.4	360	665	7.2	325	670	7.0	305	671	6.3	233	669	5.0	120
Feb	582	6.7	269	580	6.6	249	611	6.3	218	595	6.3	221	634	5.9	177	653	4.8	99
Mar	744	9.1	626	744	9.0	604	744	8.7	537	744	8.7	542	744	8.0	436	744	6.5	253
Apr	720	9.7	767	720	9.4	695	720	9.3	685	720	9.1	635	720	8.6	566	720	7.3	357
May	744	8.7	552	744	8.7	537	744	8.3	474	744	8.4	492	742	7.7	401	744	6.6	266
Jun	720	8.9	535	720	8.7	495	720	8.5	460	720	8.5	456	720	7.9	384	720	6.8	252
Jul	744	7.5	321	744	7.3	293	743	7.2	277	743	7.0	265	743	6.6	224	743	5.6	152
Aug	744	7.3	310	744	7.1	278	744	6.9	254	744	6.8	244	744	6.3	192	744	5.1	111
Sep	720	7.9	372	720	7.8	349	720	7.5	314	720	7.5	313	720	7.0	250	720	5.8	150
Oct	744	8.1	409	744	7.9	379	744	7.5	326	744	7.6	325	744	6.9	248	744	5.3	130
Nov	720	8.9	542	720	8.6	494	720	8.3	441	720	8.2	426	720	7.5	326	720	5.8	168
Dec	744	7.8	437	744	7.7	416	744	7.4	362	744	7.4	358	744	6.6	273	743	5.0	135
TOTAL	716	8.2	461	715	8.0	429	718.3	7.7	389	717	7.7	382	721	7.1	309	722	5.8	183

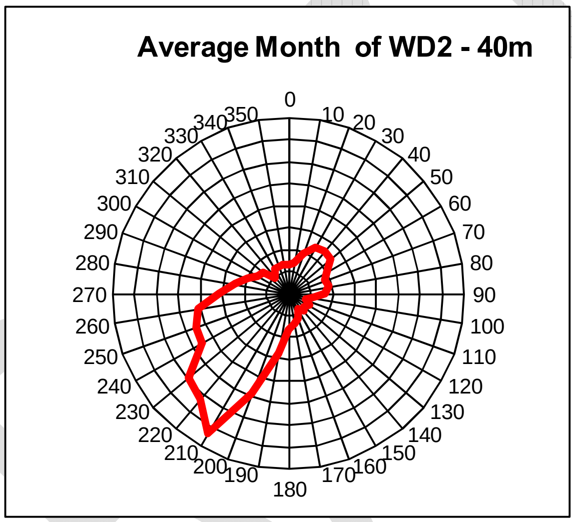


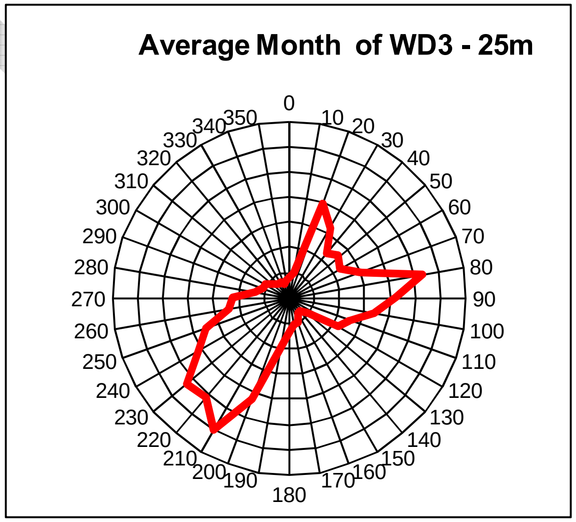


White Deer – Site # 14 for 2010

Average Wind Direction by Month







AMARILLO Site # 6

40 m Met Tower

Cumulative Monthly Mean Wind Speed from 1994 – 2004

Month	10M (1) WS (m/s)	10M (2) WS (m/s)	10M (x) WD (m/s)	25M (3) WS (m/s)	25M (4) WS (m/s)	25M (x) WD (m/s)	40M (5) WS (m/s)	40M (6) WS (m/s)	40M (7) WD (deg)
Jan	5.5	5.6	215	6.0	6.5	214	6.9	7.1	227
Feb	6.2	6.3	189	6.9	7.2	186	7.8	7.6	187
Mar	6.9	6.9	173	7.9	7.9	176	8.5	7.5	184
Apr	7.2	7.2	174	8.2	8.1	177	8.3	6.1	178
May	6.9	7.2	155	8.1	8.0	159	8.8	6.4	155
Jun	6.7	7.0	164	7.8	7.8	175	5.0	5.8	137
Jul	6.1	6.2	160	7.0	7.0	169	3.7	5.5	166
Aug	5.6	5.9	158	6.8	6.7	166	4.4	5.3	152
Sep	5.4	6.0	155	6.9	6.8	162	5.3	5.5	163
Oct	6.0	6.3	171	7.2	7.1	174	5.0	6.1	175
Nov	5.7	5.9	203	6.8	6.8	201	5.0	5.8	213
Dec	5.5	5.6	218	6.5	6.6	222	5.1	5.8	223
AVG	6.1	6.3	174	7.1	7.2	170	6.4	6.2	172

AMARILLO Site # 6

40 m Met Tower

Cumulative Monthly Mean Wind Speed from 1994 – 2004