Wind Project Siting and Permitting

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Wind Project Siting and Permitting

- The Energy in Wind
- Resource Assessment (Macro-siting)
- Energy Production Predictions
- Micro-siting
- Permitting

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The Energy in Wind

Wind Energy is kinetic energy

$$\boldsymbol{E = \frac{1}{2}mV^2}$$

Mass of Air is Related to Area of Rotor and Wind Speed

$$m = Volume\ of\ Air\ (m^3) * Air\ Density\ (\rho)\ (g/m^3)$$

$$Volume\ of\ Air = Area\ of Rotor\ (m^2) * Wind\ Speed\ \left(\frac{m}{s}\right) * Time\ (s)$$

$$Volume\ of\ Air = AVt$$

$$\boldsymbol{m = \rho AVt}$$

Energy Formula

$$E = \frac{1}{2}mV^2 = \frac{1}{2}(\rho AVt)V^2 = \boldsymbol{\frac{1}{2}\rho AV^3t}$$

Energy is a function of Wind Speed **CUBED**

- **Doubling Wind Speed increases energy available by 8x!** $(2^3 = 8)$

The Power in Wind

Power is a reference to the potential instantaneous output of a device measured in Kilowatts (kW).

Energy is a reference to the output of a device over time measured in Kilowatt Hours (kWh).

The power in wind can be described using the following equation:

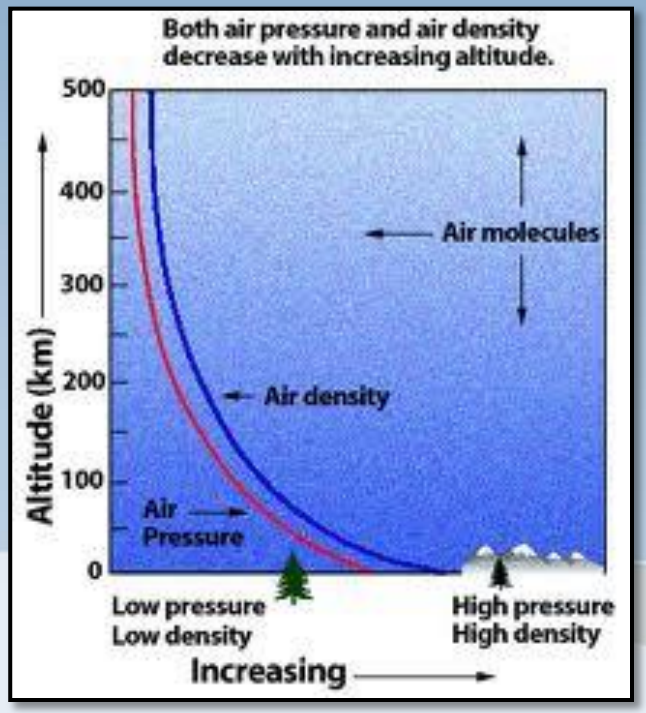
$$P = 1/2\rho A v^3$$

- ρ = Air Density (kg/m^3)
- A = Wind Swept Area (m^2)
- v = Wind Velocity/Speed (m/s)

The Power in Wind

Air Density ρ

- Changes in air temperature
- Changes in pressure
- Density will decrease with increased humidity

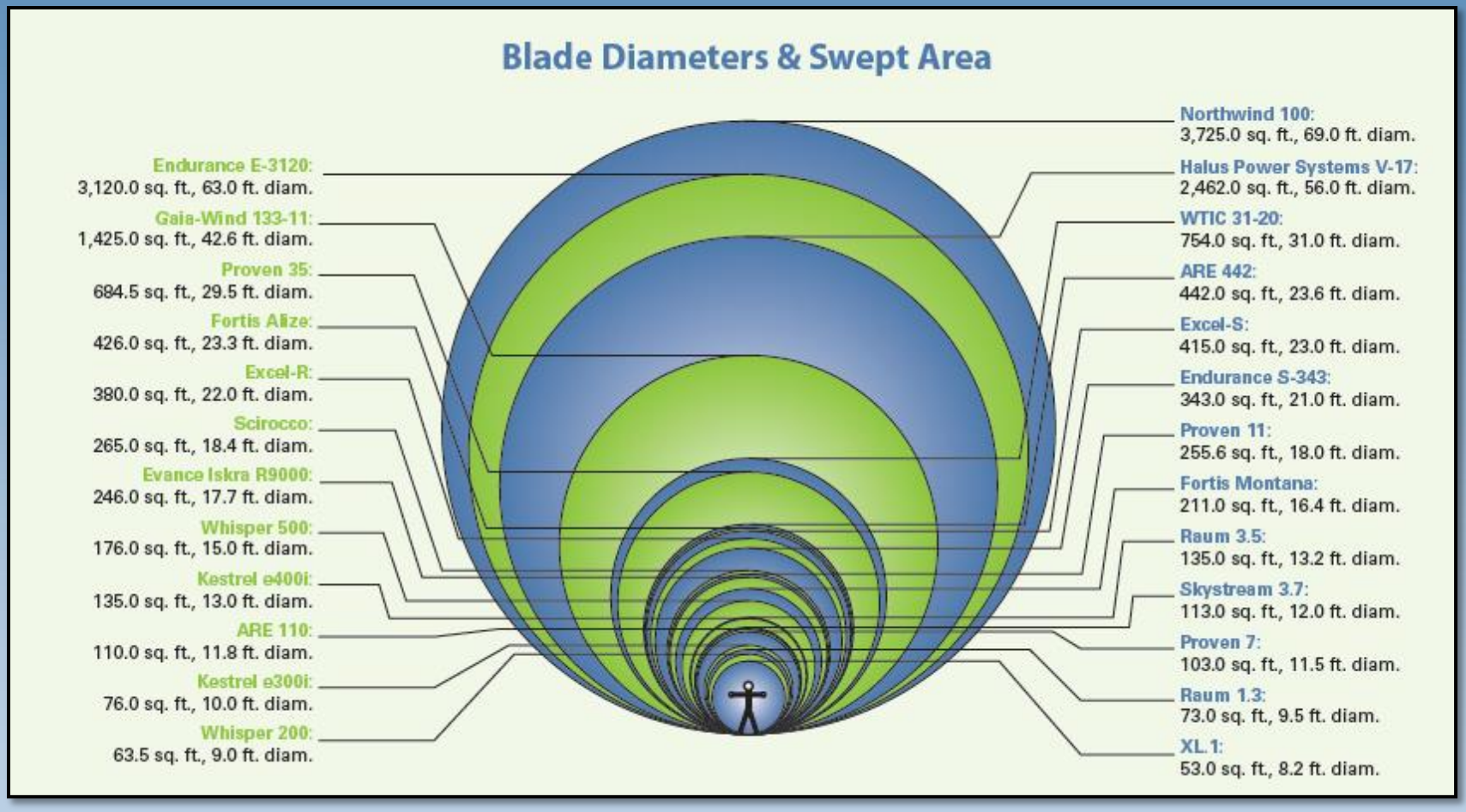


Density of Air at Standard Atmospheric Pressure

Temperature (°C)	Temperature (°F)	Density of Dry Air (kg/m^3)
35	95	1.1455
30	86	1.1644
25	77	1.1839
20	68	1.2041
15	59	1.2250
10	50	1.2466
5	41	1.2690
0	32	1.2920
-5	23	1.3163
-10	14	1.3413
-15	5	1.3673
-20	-4	1.3943
-25	-13	1.4224

Standard Atmospheric Pressure = 101.325 kPa, 14.969 psi

The Power in Wind

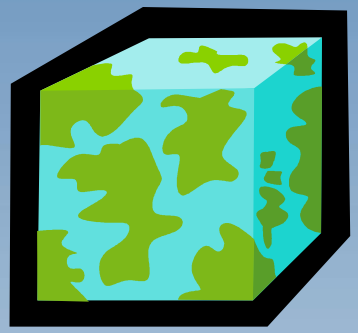


- Area is proportional to the power available in wind.
- **Increasing the area by a factor of 2 will increase the available power by a factor of 2!**

The Power in Wind

Wind Speed: As wind speed increases, power increases by a factor of 3.

$$P = 1/2\rho A\underline{V^3}$$



Example: Consider two sites. One site with a wind speed of 10 mph and another site with a wind speed of 12 mph.

$P_2/P_1=(V_2/V_1)^3$ $\quad$ $P_2 = (12/10)^3P_1$

$P_2 = (V_2/V_1)^3P_1$ $\quad$ $P_2 = 1.73P_1$

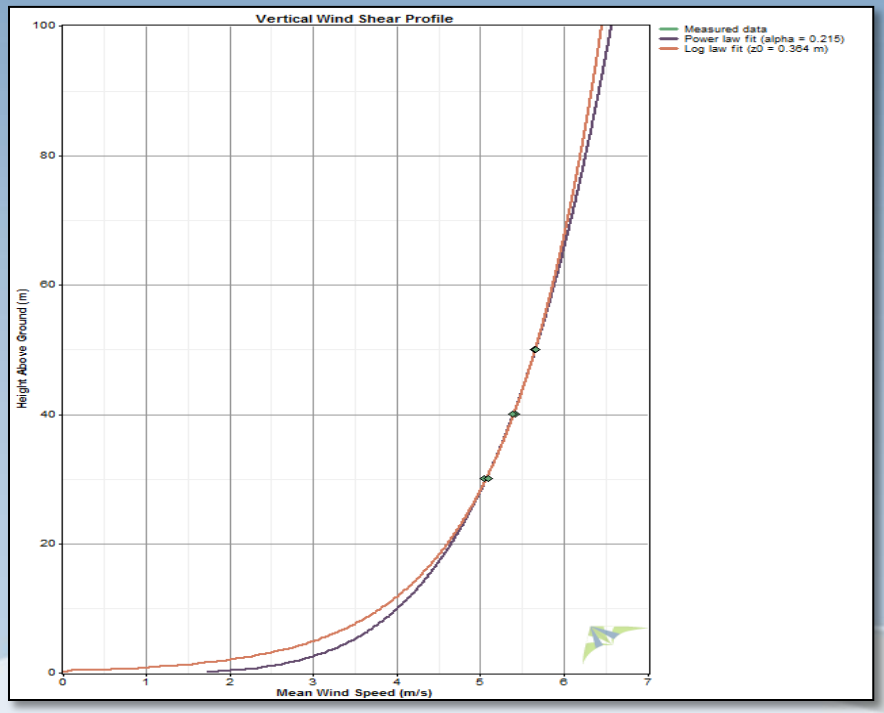
There is only a **20% increase** in **wind speed**, but a **73% increase** in available **power** between the sites.

The Power in Wind

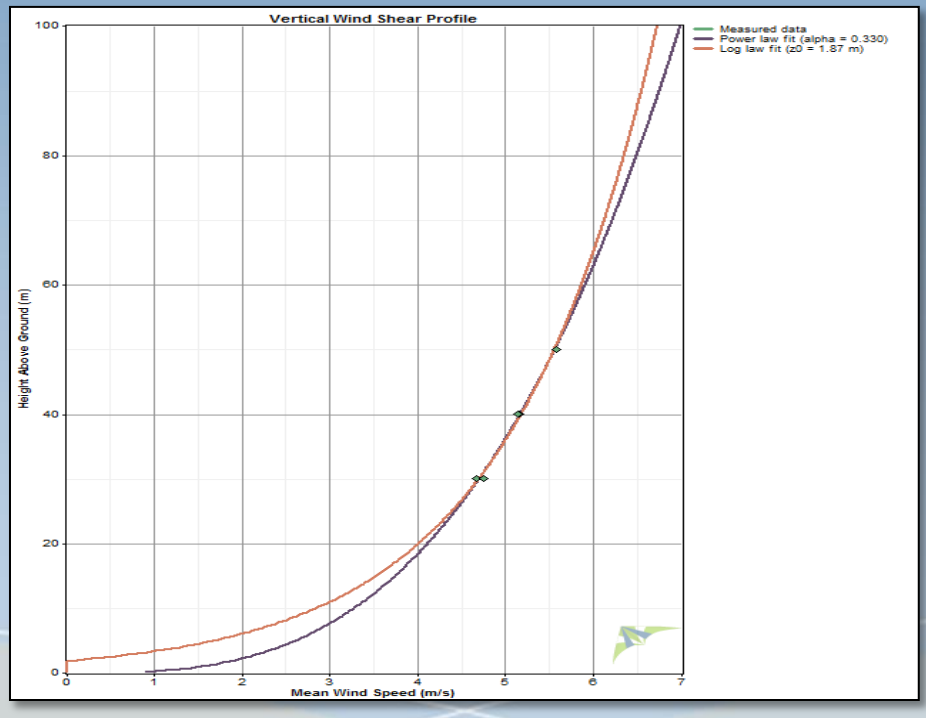
Height: Wind speed, and therefore the power in wind, is affected by height.

$$v_x = v_r(h_x/h_r)^{\alpha}$$

- v_x = wind speed new height
- v_r = original wind speed
- h_x = new height
- h_r = original height
- α = wind shear exponent



$\alpha = 0.215$

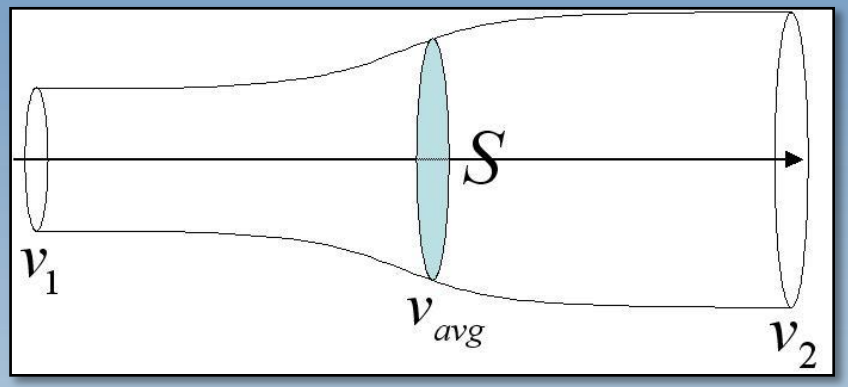


$\alpha = 0.330$

The Power in Wind

Wind Turbines: A wind turbine captures the kinetic energy in wind, converting it to mechanical energy via the spinning rotor and then to usable electrical energy using an alternator.

Betz Limit: The theoretical maximum amount of kinetic energy that can be captured by a wind turbine is 59.3%.



Efficiency: Overall modern small wind turbines can expect to produce electrical energy with 20 – 40% efficiency.

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Resource Assessment

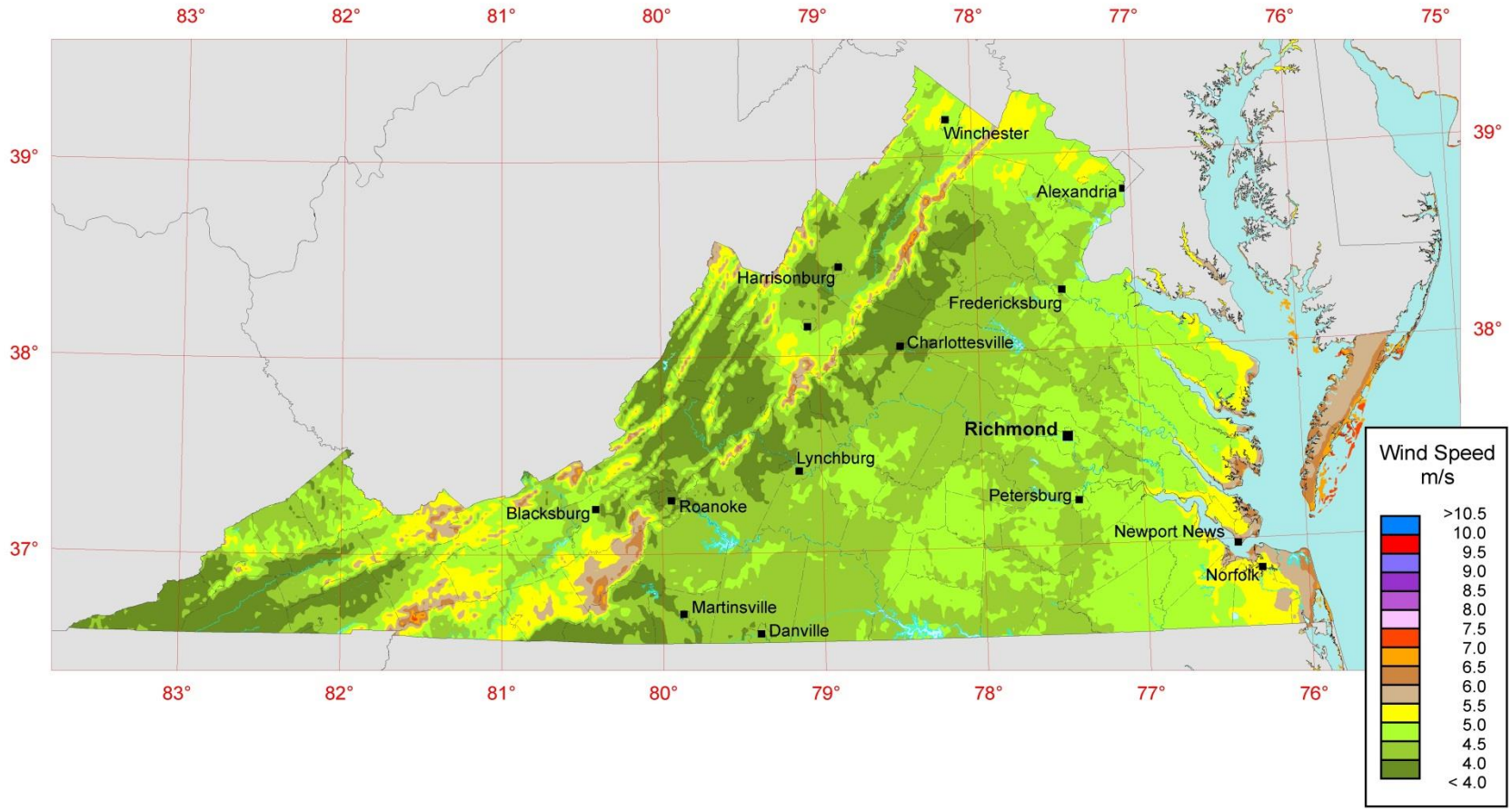
Measuring Wind Speeds

- Meteorological towers
- Airports
- WeatherBug Stations
- Home Weather Stations
- NASA
- NOAA National Weather Service
- Idaho National Laboratories
- Wind Maps
- Home weather stations*
- Griggs-Putnam Index*

Reliable websites for wind data:

- http://wind-for-schools.caesenergy.org/wind-for-schools/Welcome.html
- http://windenergy.cisat.jmu.edu/SBALP/
- http://www.ncdc.noaa.gov/oa/ncdc.html

Virginia - Annual Average Wind Speed at 80 m



Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: UTM Zone 17 WGS84.

50 0 50 100 150 Kilometers

25 0 25 50 75 100 Miles

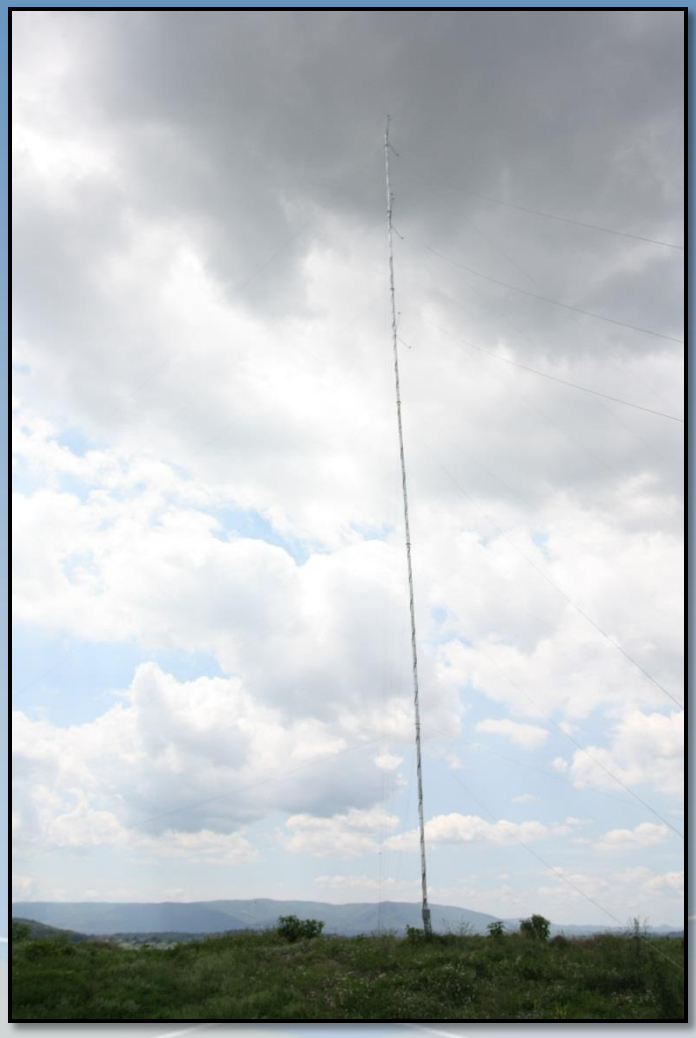
AWS Truepower™
Where science delivers performance.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

26-OCT-2010 1.1.1

Importance of Wind Measurements

- Accurate wind data is crucial for siting turbines of any scale
  - Obstructions, turbulence, etc. affect performance and therefore cost effectiveness
  - 20/250 rule
- On-site data for at least one year is preferred for small scale, three years for commercial scale development
  - Annual cycle – using monthly mean wind speed data
  - Diurnal cycle – using data from one full day
  - Frequency Distribution – using raw data in wind speed bins
- Height of measurements is also important
  - Wind Shear



Measuring the Wind: MET Towers

- Meteorological tower
- Anemometer
- Wind vane or sock
- Data logger
- Data chip

Measuring the Wind: SoDAR

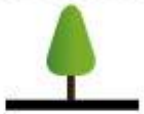
- New remote sensing wind measurement technology
- Uses sound waves to measure the wind up to 200m
  - Generally used for onshore commercial applications
- Can be used to validate MET tower data if there is any question of reliability
- Robust construction can be sited in many environments
- Operate on minimal power requirements – 7 watts

Triton SoDAR installation at Cow Knob in Rockingham County, VA

Measuring the Wind: LiDAR

- Uses lasers to record wind resource
- Larger range capabilities - up to 4km
- LiDAR is an established remote sensing technology, used previously for land and ocean floor mapping
- Allows for measurements in complex and otherwise inaccessible terrains
- Portable and no permitting required (like MET Towers)
- Ideal for offshore applications

The Griggs-Putnam Index of Deformity

Index	Top View of Tree	Side View of Tree	Description	Average Wind Speed
0			No Deformity	No Significant Wind
1			Brushing and Slight Flagging	11-14 kph 7-9 mph 3-4 m/s
2			Slight Flagging	14-18 kph 9-11 mph 4-5 m/s
3			Moderate Flagging	18-21 kph 11-13 mph 5-6 m/s
4			Complete Flagging	21-26 kph 13-16 mph 6-7 m/s
5			Partial Throwing	24-29 kph 15-18 mph 7-8 m/s
6			Complete Throwing	26-34 kph 16-21 mph 8-9 m/s
7			Carpeting	35+ kph 22+ mph 10+ m/s

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Energy Production Predictions

- **Real-World Example**
  - Suffolk, VA

- Bergey Excel 10 kW Wind Turbine
- 50m Tower

Preliminary Assessment

Center for Wind Energy at JMU 540-568-8770 VAcenter4windenergy@jmu.edu windpowerVA.org

Wind Consultation - Nansemond Water Treatment Plant, Suffolk, VA

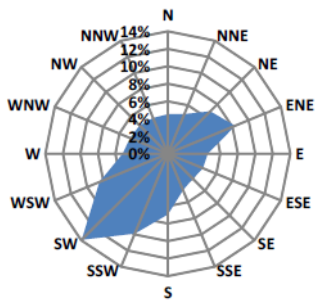
Coordinates: 36°53'38.45"N, 76°25'30.468"W
Elevation: 3 m (~11 ft)
Wind Speed at 20m – 4.38 m/s (9.79 mph)
Wind Speed at 34m – 4.86 m/s (10.86 mph)
Wind Speed at 50m – 5.24 m/s (11.71 mph)
Wind Speed at 80m – 5.76 m/s (12.89 mph)

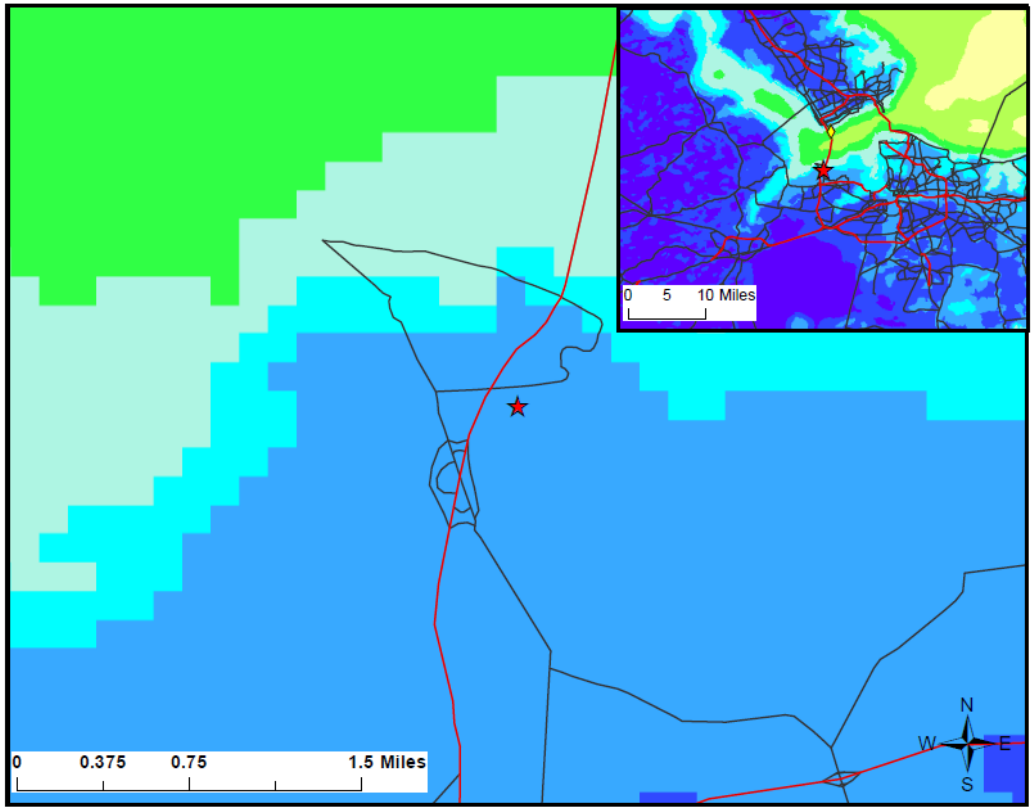
Mean Annual Wind Speed at 34 m (m/s)

< 3.00	6.50 - 6.75
3.00 - 3.25	6.75 - 7.00
3.25 - 3.50	7.00 - 7.25
3.50 - 3.75	7.25 - 7.50
3.75 - 4.00	7.50 - 7.75
4.00 - 4.25	7.75 - 8.00
4.25 - 4.50	8.00 - 8.25
4.50 - 4.75	8.25 - 8.50
4.75 - 5.00	8.50 - 8.75
5.00 - 5.25	8.75 - 9.00
5.25 - 5.50	9.00 - 9.25
5.50 - 5.75	9.25 - 9.50
5.75 - 6.00	9.50 - 9.75
6.00 - 6.25	9.75 - 10.00
6.25 - 6.50	> 10.00

Nearest Data Available
0 miles, HRSD 50m MET Tower

Wind Rose

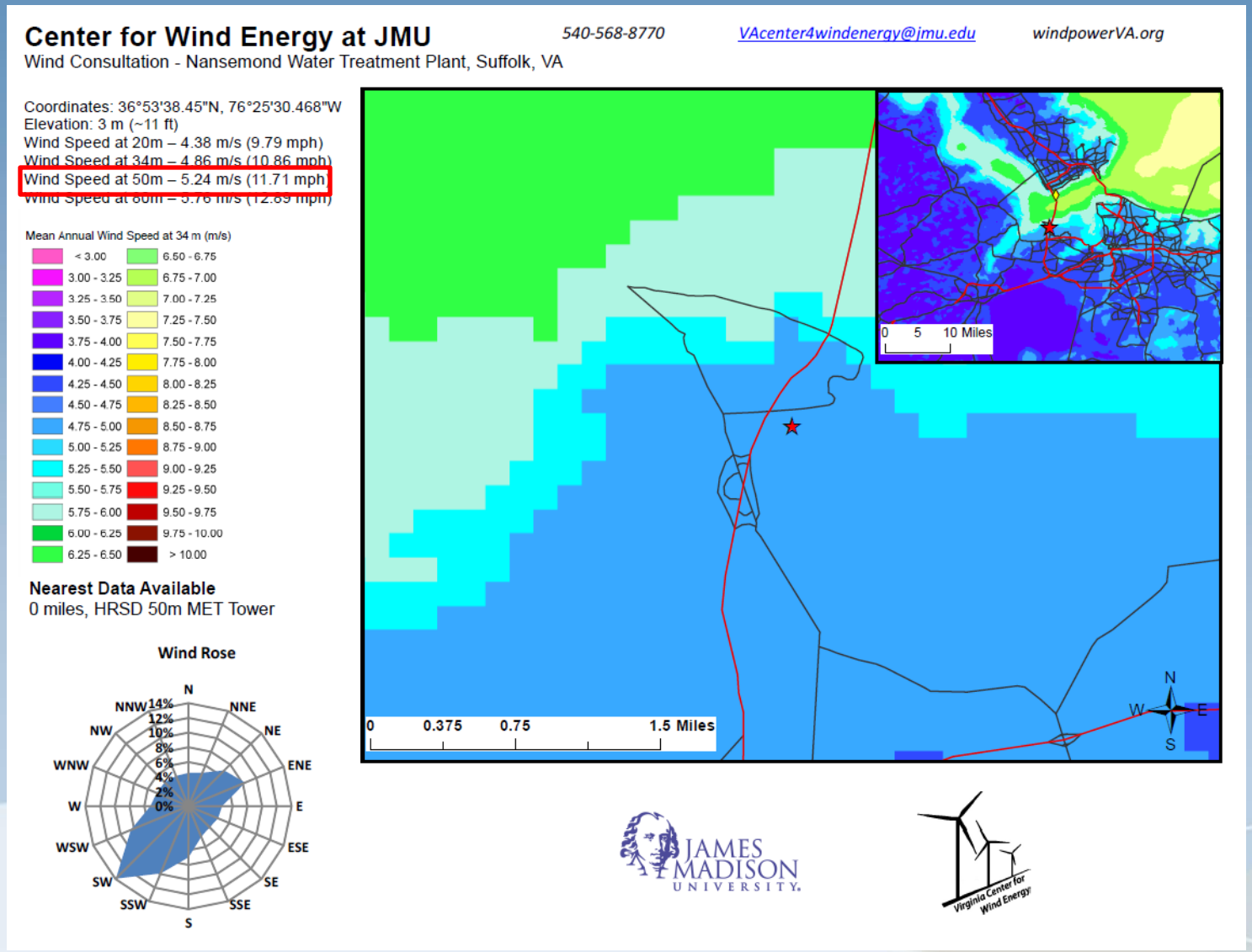




JAMES MADISON UNIVERSITY

Virginia Center for Wind Energy

Preliminary Assessment



Preliminary Assessment

SWCC Summary Report

Manufacturer: **Bergey Windpower Company**

Wind Turbine: **Excel 10** (240 VAC, 1-phase, 60 Hz)

Certification Number: **SWCC-10-12**

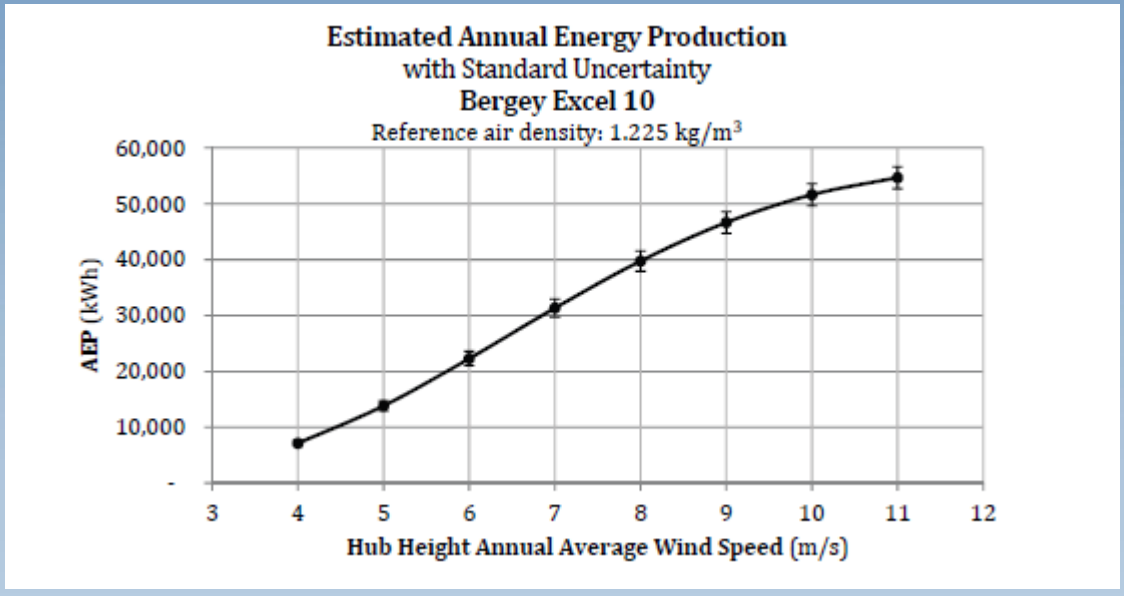
The above-identified Small Wind Turbine is certified by the Small Wind Certification Council to be in conformance with the AWEA *Small Wind Turbine Performance and Safety Standard* (AWEA Standard 9.1 – 2009).

For the SWCC Certificate visit: www.smallwindcertification.org

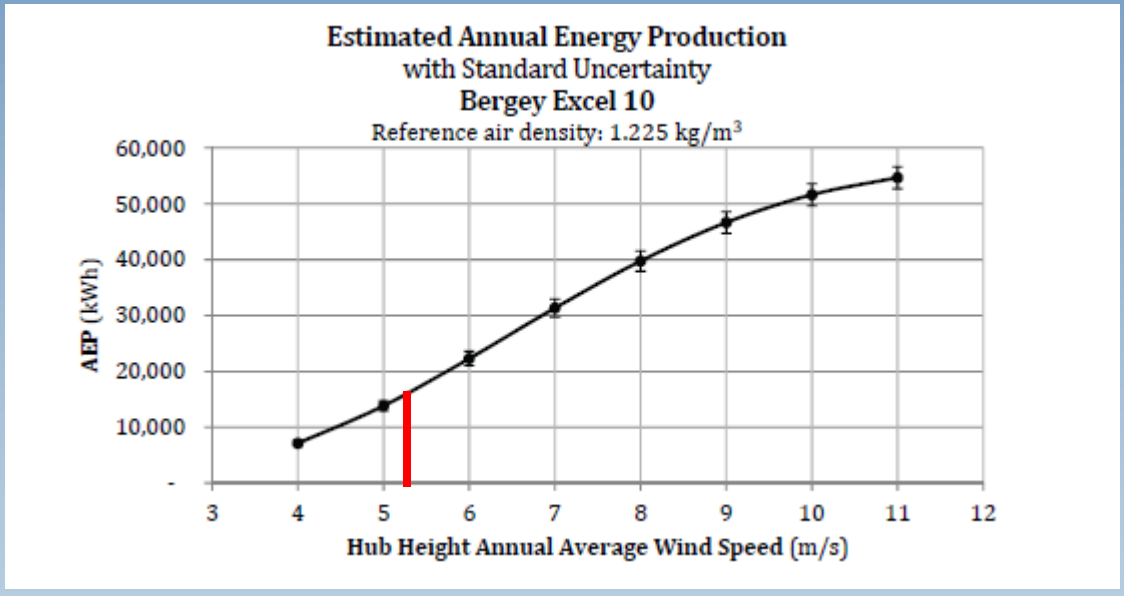
SMALL WIND CERTIFICATION COUNCIL SWCC™

CERTIFIED
SMALL WIND TURBINE

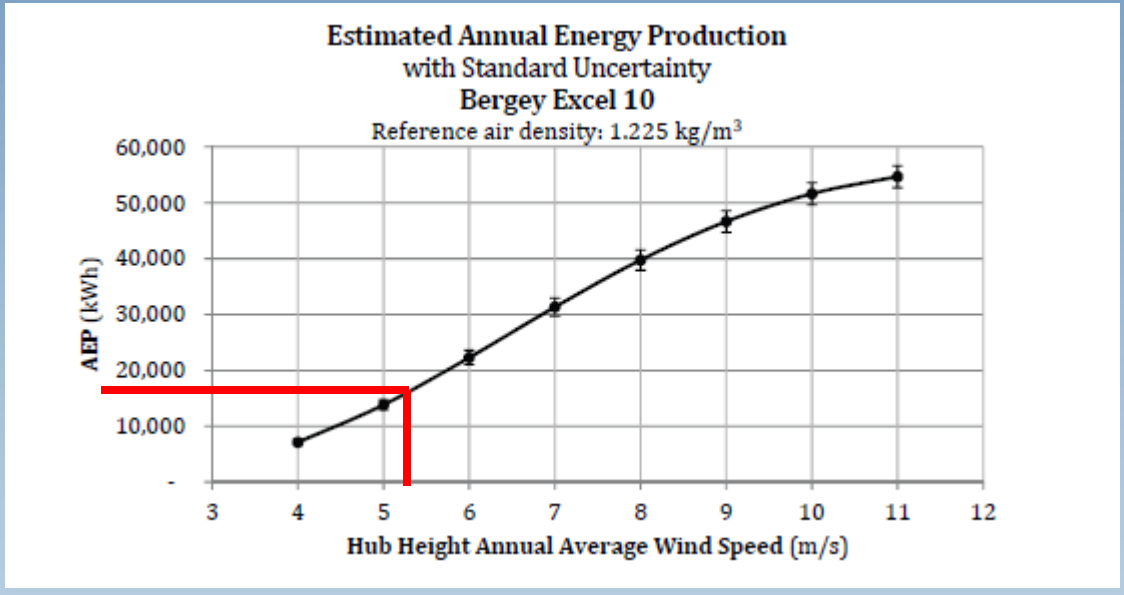
Preliminary Assessment



Preliminary Assessment



Preliminary Assessment

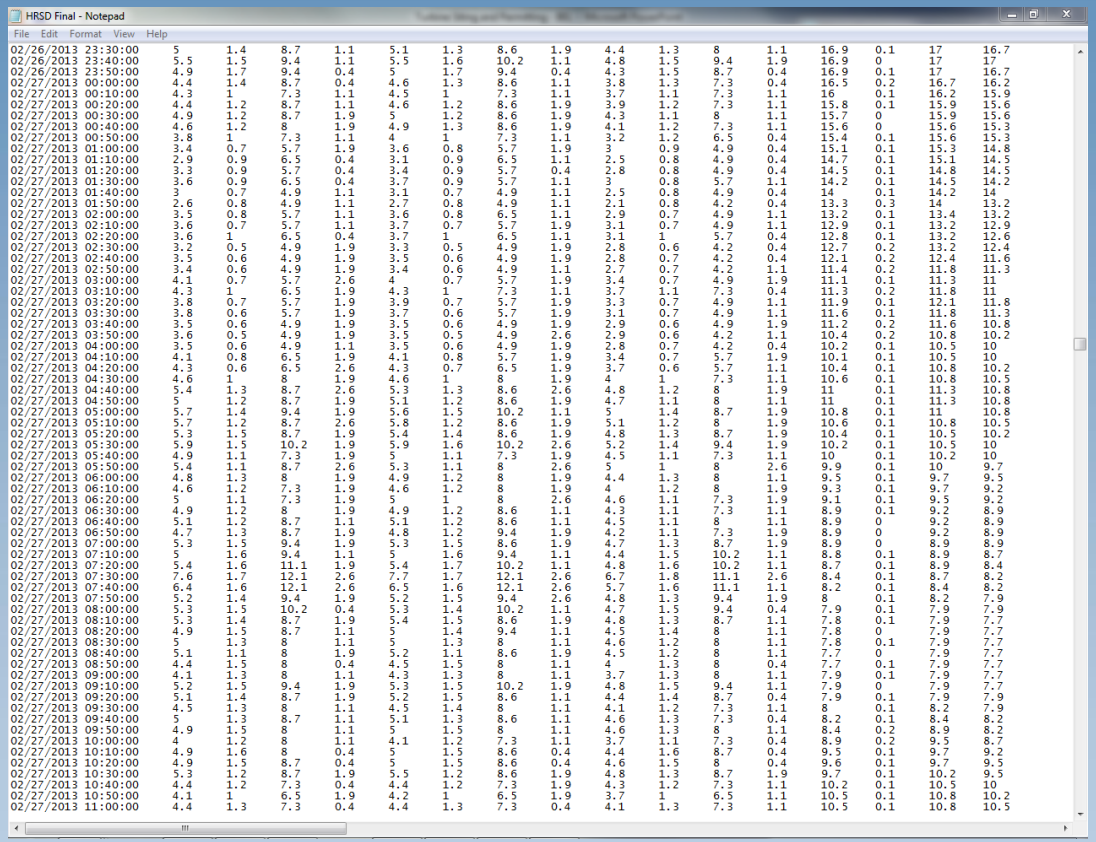


Energy Production Predictions

- **Real-World Example**
  - Suffolk, VA
  - 50m MET Tower
  - March 2012
  - August 2014

Raw Data

- Wind Speed
  - 6 Anemometers
  - 3 Heights
  - Average, Min Max, SD
- Wind Direction
  - 2 Wind Vanes
  - 2 Heights
  - Average, SD
- Temperature
  - Average, Min, Max, SD
- 32 Parameters at 106,097 Data Points -> 3,395,104 Measurements



HRSD Final - Notepad

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02/27/2013 00:10:00	4.3	1	7.3	1.1	4.5	1	7.3	1.1	3.7	1.1	7.3	1.1	16	0.1	16.2	15.9
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02/27/2013 02:00:00	3.5	0.8	5.7	1.1	3.6	0.8	6.5	1.1	2.9	0.7	4.9	1.1	13.2	0.1	13.4	13.2
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02/27/2013 03:30:00	3.8	0.6	5.7	1.9	3.7	0.6	5.7	1.9	3.1	0.7	4.9	1.1	11.6	0.1	11.8	11.3
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02/27/2013 05:40:00	4.9	1.1	7.3	1.9	5	1.1	7.3	1.9	4.5	1.1	7.3	1.1	10	0.1	10.2	10
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02/27/2013 06:20:00	5	1.1	7.3	1.9	5	1	8	2.6	4.6	1.1	7.3	1.9	9.1	0.1	9.5	9.2
02/27/2013 06:30:00	4.9	1.2	8	1.9	4.9	1.2	8.6	1.1	4.3	1.1	7.3	1.1	8.9	0.1	9.2	8.9
02/27/2013 06:40:00	5.1	1.2	8.7	1.1	5.1	1.2	8.6	1.1	4.5	1.1	8	1.1	8.9	0	9.2	8.9
02/27/2013 06:50:00	4.7	1.3	8.7	1.9	4.8	1.2	9.4	1.9	4.2	1.1	7.3	1.9	8.9	0	9.2	8.9
02/27/2013 07:00:00	5.3	1.5	9.4	1.9	5.3	1.5	8.6	1.9	4.7	1.3	8.7	1.9	8.9	0	8.9	8.9
02/27/2013 07:10:00	5	1.6	9.4	1.1	5	1.6	9.4	1.1	4.4	1.5	10.2	1.1	8.8	0.1	8.9	8.7
02/27/2013 07:20:00	5.4	1.6	11.1	1.9	5.4	1.7	10.2	1.1	4.8	1.6	10.2	1.1	8.7	0.1	8.9	8.4
02/27/2013 07:30:00	7.6	1.7	12.1	2.6	7.7	1.7	12.1	2.6	6.7	1.8	11.1	2.6	8.4	0.1	8.7	8.2
02/27/2013 07:40:00	6.4	1.6	12.1	2.6	6.5	1.6	12.1	2.6	5.7	1.6	11.1	1.1	8.2	0.1	8.4	8.2
02/27/2013 07:50:00	5.2	1.4	9.4	1.9	5.2	1.5	9.4	2.6	4.8	1.3	9.4	1.9	8	0.1	8.2	7.9
02/27/2013 08:00:00	5.3	1.5	10.2	0.4	5.3	1.4	10.2	1.1	4.7	1.5	9.4	0.4	7.9	0.1	7.9	7.9
02/27/2013 08:10:00	5.3	1.4	8.7	1.9	5.4	1.5	8.6	1.9	4.8	1.3	8.7	1.1	7.8	0.1	7.9	7.7
02/27/2013 08:20:00	4.9	1.5	8.7	1.1	5	1.4	9.4	1.1	4.5	1.4	8	1.1	7.8	0	7.9	7.7
02/27/2013 08:30:00	5	1.3	8	1.1	5	1.3	8	1.1	4.6	1.2	8	1.1	7.8	0.1	7.9	7.7
02/27/2013 08:40:00	5.1	1.1	8	1.9	5.2	1.1	8.6	1.9	4.5	1.2	8	1.1	7.7	0	7.9	7.7
02/27/2013 08:50:00	4.4	1.5	8	0.4	4.5	1.5	8	1.1	4	1.3	8	0.4	7.7	0.1	7.9	7.7
02/27/2013 09:00:00	4.1	1.3	8	1.1	4.3	1.3	8	1.1	3.7	1.3	8	1.1	7.9	0.1	7.9	7.7
02/27/2013 09:10:00	5.2	1.5	9.4	1.9	5.3	1.5	10.2	1.9	4.8	1.5	9.4	1.1	7.9	0	7.9	7.7
02/27/2013 09:20:00	5.1	1.4	8.7	1.9	5.2	1.5	8.6	1.1	4.4	1.4	8.7	0.4	7.9	0.1	7.9	7.9
02/27/2013 09:30:00	4.5	1.3	8	1.1	4.5	1.4	8	1.1	4.1	1.2	7.3	1.1	8	0.1	8.2	7.9
02/27/2013 09:40:00	5	1.3	8.7	1.1	5.1	1.3	8.6	1.1	4.6	1.3	7.3	0.4	8.2	0.1	8.4	8.2
02/27/2013 09:50:00	4.9	1.5	8	1.1	5	1.5	8	1.1	4.6	1.3	8	1.1	8.4	0.2	8.9	8.2
02/27/2013 10:00:00	4	1.2	8	1.1	4.1	1.2	7.3	1.1	3.7	1.1	7.3	0.4	8.9	0.2	9.5	8.7
02/27/2013 10:10:00	4.9	1.6	8	0.4	5	1.5	8.6	0.4	4.4	1.6	8.7	0.4	9.5	0.1	9.7	9.2
02/27/2013 10:20:00	4.9	1.5	8.7	0.4	5	1.5	8.6	0.4	4.6	1.5	8	0.4	9.6	0.1	9.7	9.5
02/27/2013 10:30:00	5.3	1.2	8.7	1.9	5.5	1.2	8.6	1.9	4.8	1.3	8.7	1.9	9.7	0.1	10.2	9.5
02/27/2013 10:40:00	4.4	1.2	7.3	0.4	4.4	1.2	7.3	1.9	4.3	1.2	7.3	1.1	10.2	0.1	10.5	10
02/27/2013 10:50:00	4.1	1	6.5	1.9	4.2	1	6.5	1.9	3.7	1	6.5	1.1	10.5	0.1	10.8	10.2
02/27/2013 11:00:00	4.4	1.3	7.3	0.4	4.4	1.3	7.3	0.4	4.1	1.3	7.3	1.1	10.5	0.1	10.8	10.5

Manual Calculation

- Calculated using Excel
- Tricky, but accurate
- Free (assuming you own MS Office)

Manual Calculation

HRSD Wind Speed			
Bin Start (m/s)	Bin End (m/s)	Count (50m #1)	Count (50m #2)
0.0	0.5		
0.5	1.0		
1.0	1.5		
1.5	2.0		
2.0	2.5		
2.5	3.0		
3.0	3.5		
3.5	4.0		
4.0	4.5		
4.5	5.0		
5.0	5.5		
5.5	6.0		
6.0	6.5		
6.5	7.0		
7.0	7.5		
7.5	8.0		
8.0	8.5		
8.5	9.0		
9.0	9.5		
9.5	10.0		
10.0	10.5		
10.5	11.0		
11.0	11.5		
11.5	12.0		
12.0	12.5		
12.5	13.0		
13.0	13.5		
13.5	14.0		
14.0	14.5		
14.5	15.0		

Manual Calculation

HRSD Wind Speed			
Bin Start (m/s)	Bin End (m/s)	Count (50m #1)	Count (50m #2)
0.0	0.5	1212	1131
0.5	1.0		
1.0	1.5		
1.5	2.0		
2.0	2.5		
2.5	3.0		
3.0	3.5		
3.5	4.0		
4.0	4.5		
4.5	5.0		
5.0	5.5		
5.5	6.0		
6.0	6.5		
6.5	7.0		
7.0	7.5		
7.5	8.0		
8.0	8.5		
8.5	9.0		
9.0	9.5		
9.5	10.0		
10.0	10.5		
10.5	11.0		
11.0	11.5		
11.5	12.0		
12.0	12.5		
12.5	13.0		
13.0	13.5		
13.5	14.0		
14.0	14.5		
14.5	15.0		

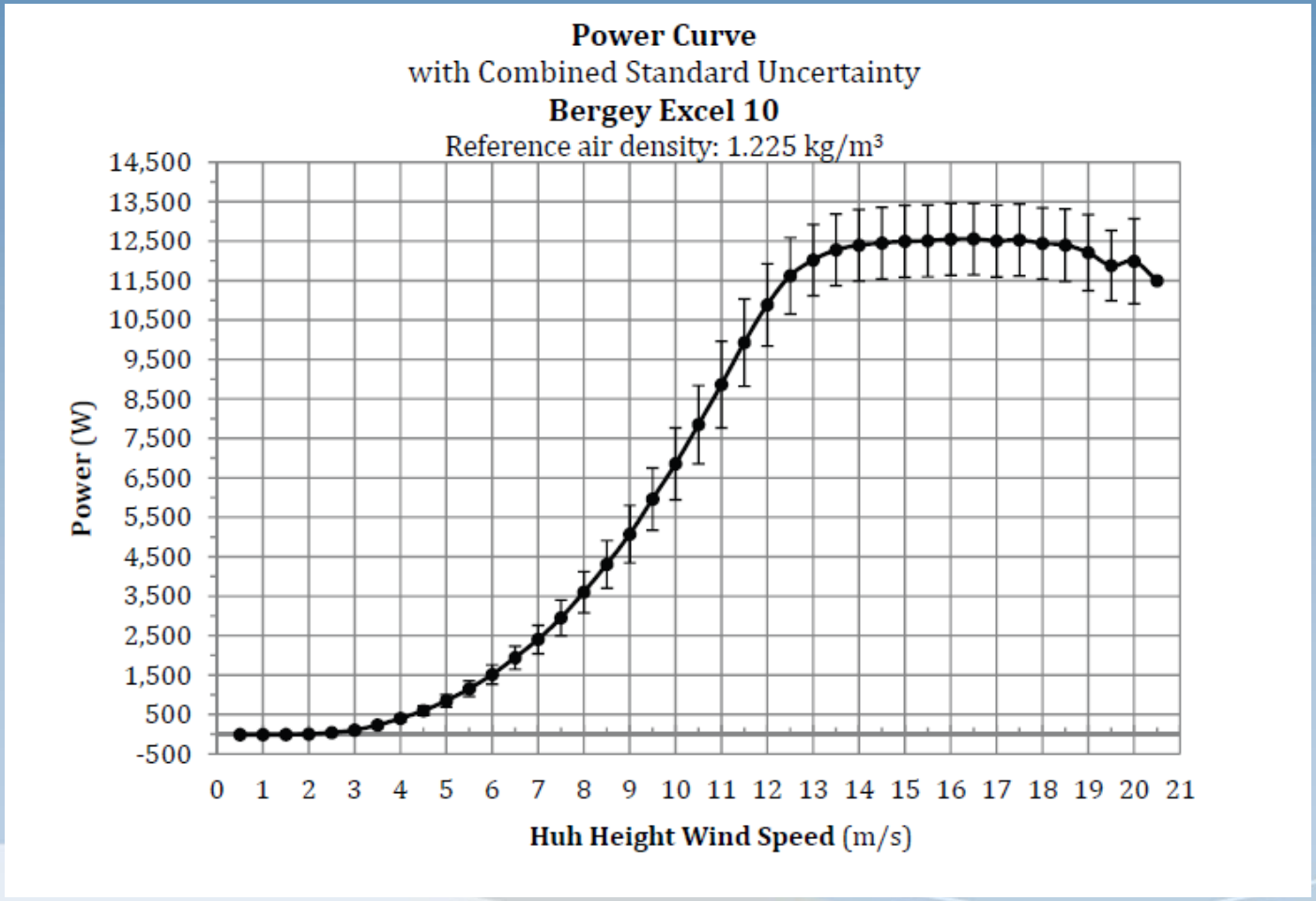
Manual Calculation

HRSD Wind Speed			
Bin Start (m/s)	Bin End (m/s)	Count (50m #1)	Count (50m #2)
0.0	0.5	1212	1131
0.5	1.0	1578	1643
1.0	1.5		
1.5	2.0		
2.0	2.5		
2.5	3.0		
3.0	3.5		
3.5	4.0		
4.0	4.5		
4.5	5.0		
5.0	5.5		
5.5	6.0		
6.0	6.5		
6.5	7.0		
7.0	7.5		
7.5	8.0		
8.0	8.5		
8.5	9.0		
9.0	9.5		
9.5	10.0		
10.0	10.5		
10.5	11.0		
11.0	11.5		
11.5	12.0		
12.0	12.5		
12.5	13.0		
13.0	13.5		
13.5	14.0		
14.0	14.5		
14.5	15.0		

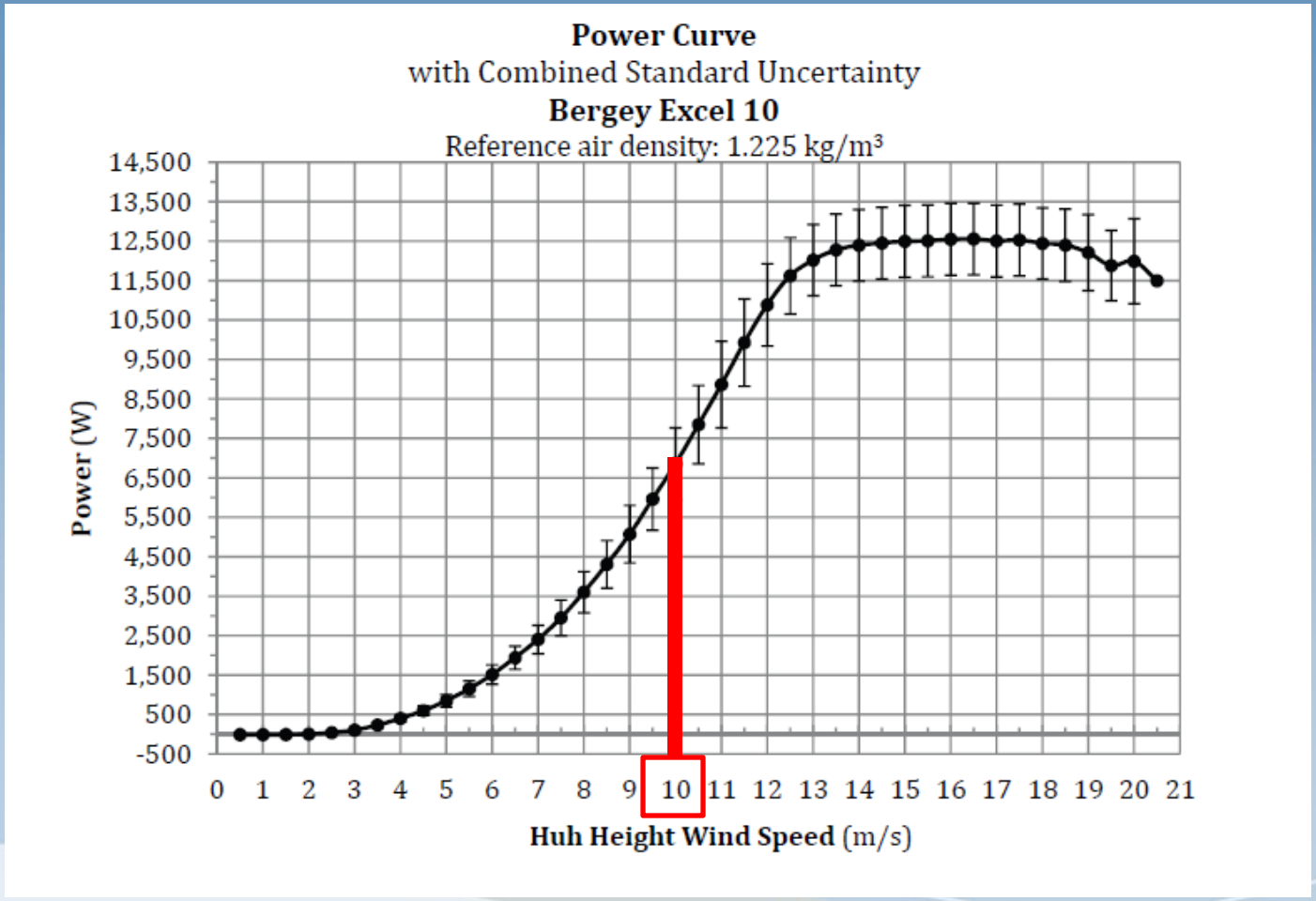
Manual Calculation

HRSD Wind Speed			
Bin Start (m/s)	**Bin End (m/s)**	**Count (50m #1)**	**Count (50m #2)**
0.0	0.5	1212	1131
0.5	1.0	1578	1643
1.0	1.5	2680	2758
1.5	2.0	4450	4677
2.0	2.5	7119	7168
2.5	3.0	9442	9397
3.0	3.5	11397	11648
3.5	4.0	12228	12471
4.0	4.5	11908	12004
4.5	5.0	10618	10572
5.0	5.5	8261	8205
5.5	6.0	6482	6379
6.0	6.5	5117	5140
6.5	7.0	3723	3613
7.0	7.5	2738	2628
7.5	8.0	2058	1990
8.0	8.5	1527	1471
8.5	9.0	1131	1037
9.0	9.5	748	695
9.5	10.0	526	473
10.0	10.5	385	382
10.5	11.0	261	225
11.0	11.5	181	148
11.5	12.0	127	112
12.0	12.5	97	77
12.5	13.0	64	50
13.0	13.5	45	28
13.5	14.0	29	21
14.0	14.5	18	13
14.5	15.0	6	4
Total Count		**106,156**	**106,160**

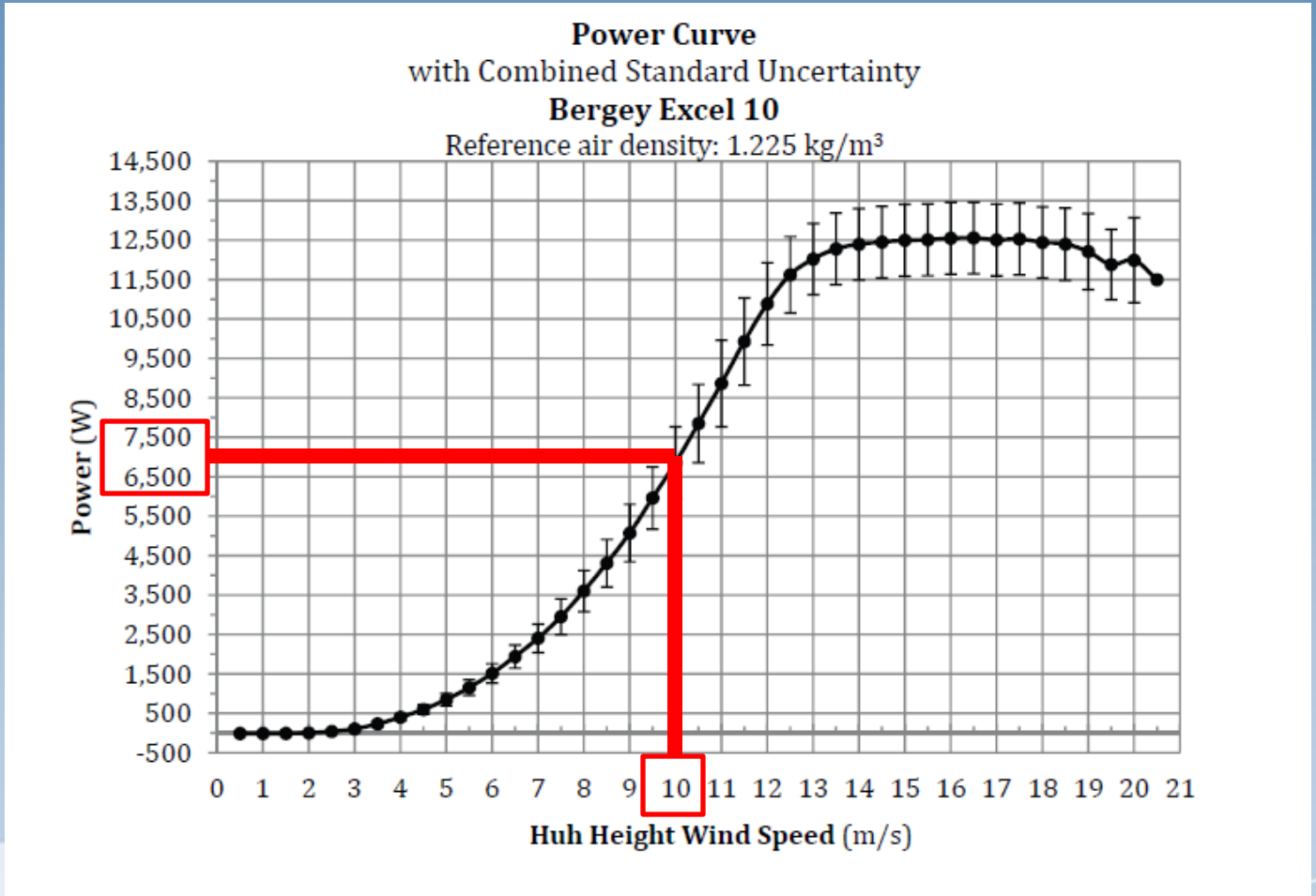
Power Curves



Power Curves



Power Curves



Power Curves

6. Tabulated Power Curve

Corrected to a sea level air density of 1.225 kg/m^3					Category A	Category B	Combined
Bin No.	Hub Height Wind Speed	Power Output	Cp	1-minute samples	Standard Uncertainty, Si	Standard Uncertainty, Ui	Standard Uncertainty, Ci
	m/s	*Watts*			*Watts*	*Watts*	*Watts*
1	0.5	-12		158			
2	1.0	-12		224	0.1	0.9	0.9
3	1.5	-11		309	0.3	0.9	1.0
4	2.0	0		391	0.9	2.9	3.0
5	2.5	39	0.11	375	2.1	10.9	11.1
6	3.0	102	0.16	661	3.0	20.2	20.4
7	3.5	229	0.23	818	3.4	43.8	43.9
8	4.0	399	0.26	1060	3.2	65.4	65.4
9	4.5	596	0.28	1213	3.0	84.5	84.6
10	5.0	848	0.29	1235	3.7	116.9	117.0
11	5.5	1,151	0.29	1279	4.7	152.6	152.6
12	6.0	1,510	0.30	1250	5.4	195.2	195.3
13	6.5	1,938	0.30	1401	6.0	248.5	248.6
14	7.0	2,403	0.30	1355	7.1	293.3	293.4
15	7.5	2,949	0.30	1014	9.9	362.8	362.9
16	8.0	3,602	0.30	885	12.7	452.4	452.6
17	8.5	4,306	0.30	687	16.8	523.1	523.3
18	9.0	5,071	0.30	736	18.0	604.1	604.4
19	9.5	5,960	0.29	668	19.7	725.9	726.1
20	10.0	6,856	0.29	707	21.4	790.8	791.0
21	10.5	7,849	0.29	650	26.2	912.1	912.5
22	11.0	8,863	0.28	599	28.0	994.0	994.4
23	11.5	9,928	0.28	635	24.3	1098.6	1098.9
24	12.0	10,885	0.27	606	24.8	1105.8	1106.1
25	12.5	11,619	0.25	504	21.7	1044.8	1045.0
26	13.0	12,019	0.23	432	15.0	968.6	968.7
27	13.5	12,276	0.21	337	13.3	906.1	906.2
28	14.0	12,395	0.19	333	7.4	906.0	906.1
29	14.5	12,449	0.17	292	7.2	904.5	904.6
30	15.0	12,495	0.16	279	3.3	907.5	907.5
31	15.5	12,508	0.14	231	10.3	907.4	907.4
32	16.0	12,546	0.13	187	5.4	911.0	911.0
33	16.5	12,555	0.12	165	8.5	910.7	910.8
34	17.0	12,503	0.11	125	24.4	908.8	909.1
35	17.5	12,528	0.10	138	17.8	909.2	909.4
36	18.0	12,442	0.09	98	36.2	908.2	908.9
37	18.5	12,396	0.08	94	36.8	901.0	901.7
38	19.0	12,208	0.08	57	65.2	916.2	918.5
39	19.5	11,878	0.07	39	83.4	960.0	963.6
40	20.0	11,989	0.06	18	130.0	882.0	891.5
41	20.5	11,495	0.06	15	124.6	1066.4	1073.7

Power Curves

6. Tabulated Power Curve

Corrected to a sea level air density of 1.225 kg/m^3					Category A	Category B	Combined
Bin No.	Hub Height Wind Speed	Power Output	Cp	1-minute samples	Standard Uncertainty, Si	Standard Uncertainty, Ui	Standard Uncertainty, Ci
	m/s	*Watts*			*Watts*	*Watts*	*Watts*
1	0.5	-12		158			
2	1.0	-12		224	0.1	0.9	0.9
3	1.5	-11		309	0.3	0.9	1.0
4	2.0	0		391	0.9	2.9	3.0
5	2.5	39	0.11	375	2.1	10.9	11.1
6	3.0	102	0.16	661	3.0	20.2	20.4
7	3.5	229	0.23	818	3.4	43.8	43.9
8	4.0	399	0.26	1060	3.2	65.4	65.4
9	4.5	596	0.28	1213	3.0	84.5	84.6
10	5.0	848	0.29	1235	3.7	116.9	117.0
11	5.5	1,151	0.29	1279	4.7	152.6	152.6
12	6.0	1,510	0.30	1250	5.4	195.2	195.3
13	6.5	1,938	0.30	1401	6.0	248.5	248.6
14	7.0	2,403	0.30	1355	7.1	293.3	293.4
15	7.5	2,949	0.30	1014	9.9	362.8	362.9
16	8.0	3,602	0.30	885	12.7	452.4	452.6
17	8.5	4,306	0.30	687	16.8	523.1	523.3
18	9.0	5,071	0.30	736	18.0	604.1	604.4
19	9.5	5,960	0.29	668	19.7	725.9	726.1
20	10.0	6,856	0.29	707	21.4	790.8	791.0
21	10.5	7,849	0.29	650	26.2	912.1	912.5
22	11.0	8,863	0.28	599	28.0	994.0	994.4
23	11.5	9,928	0.28	635	24.3	1098.6	1098.9
24	12.0	10,885	0.27	606	24.8	1105.8	1106.1
25	12.5	11,619	0.25	504	21.7	1044.8	1045.0
26	13.0	12,019	0.23	432	15.0	968.6	968.7
27	13.5	12,276	0.21	337	13.3	906.1	906.2
28	14.0	12,395	0.19	333	7.4	906.0	906.1
29	14.5	12,449	0.17	292	7.2	904.5	904.6
30	15.0	12,495	0.16	279	3.3	907.5	907.5
31	15.5	12,508	0.14	231	10.3	907.4	907.4
32	16.0	12,546	0.13	187	5.4	911.0	911.0
33	16.5	12,555	0.12	165	8.5	910.7	910.8
34	17.0	12,503	0.11	125	24.4	908.8	909.1
35	17.5	12,528	0.10	138	17.8	909.2	909.4
36	18.0	12,442	0.09	98	36.2	908.2	908.9
37	18.5	12,396	0.08	94	36.8	901.0	901.7
38	19.0	12,208	0.08	57	65.2	916.2	918.5
39	19.5	11,878	0.07	39	83.4	960.0	963.6
40	20.0	11,989	0.06	18	130.0	882.0	891.5
41	20.5	11,495	0.06	15	124.6	1066.4	1073.7

Manual Calculation

HRSD Wind Speed					Bergey Excel-S Energy Production		
Bin Start (m/s)	Bin End (m/s)	Count (50m #1)	Count (50m #2)		Power (W)		
0.0	0.5	1212	1131		-12		
0.5	1.0	1578	1643		-12		
1.0	1.5	2680	2758		-11		
1.5	2.0	4450	4677		0		
2.0	2.5	7119	7168		39		
2.5	3.0	9442	9397		102		
3.0	3.5	11397	11648		229		
3.5	4.0	12228	12471		399		
4.0	4.5	11908	12004		596		
4.5	5.0	10618	10572		848		
5.0	5.5	8261	8205		1,151		
5.5	6.0	6482	6379		1,510		
6.0	6.5	5117	5140		1,938		
6.5	7.0	3723	3613		2,403		
7.0	7.5	2738	2628		2,949		
7.5	8.0	2058	1990		3,602		
8.0	8.5	1527	1471		4,306		
8.5	9.0	1131	1037		5,071		
9.0	9.5	748	695		5,960		
9.5	10.0	526	473		6,856		
10.0	10.5	385	382		7,849		
10.5	11.0	261	225		8,863		
11.0	11.5	181	148		9,928		
11.5	12.0	127	112		10,885		
12.0	12.5	97	77		11,619		
12.5	13.0	64	50		12,019		
13.0	13.5	45	28		12,276		
13.5	14.0	29	21		12,395		
14.0	14.5	18	13		12,449		
14.5	15.0	6	4		12,495		
Total Count		**106,156**	**106,160**				

Manual Calculation

HRSD Wind Speed					Bergey Excel-S Energy Production		
Bin Start (m/s)	Bin End (m/s)	Count (50m #1)	Count (50m #2)		Power (W)	Energy 1 (kWh)	Energy 2 (kWh)
0.0	0.5	1212	1131		-12	-2	-2
0.5	1.0	1578	1643		-12		
1.0	1.5	2680	2758		-11		
1.5	2.0	4450	4677		0		
2.0	2.5	7119	7168		39		
2.5	3.0	9442	9397		102		
3.0	3.5	11397	11648		229		
3.5	4.0	12228	12471		399		
4.0	4.5	11908	12004		596		
4.5	5.0	10618	10572		848		
5.0	5.5	8261	8205		1,151		
5.5	6.0	6482	6379		1,510		
6.0	6.5	5117	5140		1,938		
6.5	7.0	3723	3613		2,403		
7.0	7.5	2738	2628		2,949		
7.5	8.0	2058	1990		3,602		
8.0	8.5	1527	1471		4,306		
8.5	9.0	1131	1037		5,071		
9.0	9.5	748	695		5,960		
9.5	10.0	526	473		6,856		
10.0	10.5	385	382		7,849		
10.5	11.0	261	225		8,863		
11.0	11.5	181	148		9,928		
11.5	12.0	127	112		10,885		
12.0	12.5	97	77		11,619		
12.5	13.0	64	50		12,019		
13.0	13.5	45	28		12,276		
13.5	14.0	29	21		12,395		
14.0	14.5	18	13		12,449		
14.5	15.0	6	4		12,495		
Total Count		**106,156**	**106,160**				

Manual Calculation

HRSD Wind Speed					Bergey Excel-S Energy Production		
Bin Start (m/s)	Bin End (m/s)	Count (50m #1)	Count (50m #2)		Power (W)	Energy 1 (kWh)	Energy 2 (kWh)
0.0	0.5	1212	1131		-12	-2	-2
0.5	1.0	1578	1643		-12	-3	-3
1.0	1.5	2680	2758		-11		
1.5	2.0	4450	4677		0		
2.0	2.5	7119	7168		39		
2.5	3.0	9442	9397		102		
3.0	3.5	11397	11648		229		
3.5	4.0	12228	12471		399		
4.0	4.5	11908	12004		596		
4.5	5.0	10618	10572		848		
5.0	5.5	8261	8205		1,151		
5.5	6.0	6482	6379		1,510		
6.0	6.5	5117	5140		1,938		
6.5	7.0	3723	3613		2,403		
7.0	7.5	2738	2628		2,949		
7.5	8.0	2058	1990		3,602		
8.0	8.5	1527	1471		4,306		
8.5	9.0	1131	1037		5,071		
9.0	9.5	748	695		5,960		
9.5	10.0	526	473		6,856		
10.0	10.5	385	382		7,849		
10.5	11.0	261	225		8,863		
11.0	11.5	181	148		9,928		
11.5	12.0	127	112		10,885		
12.0	12.5	97	77		11,619		
12.5	13.0	64	50		12,019		
13.0	13.5	45	28		12,276		
13.5	14.0	29	21		12,395		
14.0	14.5	18	13		12,449		
14.5	15.0	6	4		12,495		
Total Count		**106,156**	**106,160**				

Manual Calculation

HRSD Wind Speed					Bergey Excel-S Energy Production		
Bin Start (m/s)	Bin End (m/s)	Count (50m #1)	Count (50m #2)		Power (W)	Energy 1 (kWh)	Energy 2 (kWh)
0.0	0.5	1212	1131		-12	-2	-2
0.5	1.0	1578	1643		-12	-3	-3
1.0	1.5	2680	2758		-11	-5	-5
1.5	2.0	4450	4677		0	0	0
2.0	2.5	7119	7168		39	46	47
2.5	3.0	9442	9397		102	161	160
3.0	3.5	11397	11648		229	435	445
3.5	4.0	12228	12471		399	813	829
4.0	4.5	11908	12004		596	1,183	1,192
4.5	5.0	10618	10572		848	1,501	1,494
5.0	5.5	8261	8205		1,151	1,585	1,574
5.5	6.0	6482	6379		1,510	1,631	1,605
6.0	6.5	5117	5140		1,938	1,653	1,660
6.5	7.0	3723	3613		2,403	1,491	1,447
7.0	7.5	2738	2628		2,949	1,346	1,292
7.5	8.0	2058	1990		3,602	1,235	1,195
8.0	8.5	1527	1471		4,306	1,096	1,056
8.5	9.0	1131	1037		5,071	956	876
9.0	9.5	748	695		5,960	743	690
9.5	10.0	526	473		6,856	601	540
10.0	10.5	385	382		7,849	504	500
10.5	11.0	261	225		8,863	386	332
11.0	11.5	181	148		9,928	299	245
11.5	12.0	127	112		10,885	230	203
12.0	12.5	97	77		11,619	188	149
12.5	13.0	64	50		12,019	128	100
13.0	13.5	45	28		12,276	92	57
13.5	14.0	29	21		12,395	60	43
14.0	14.5	18	13		12,449	37	27
14.5	15.0	6	4		12,495	12	8
Total Count		**106,156**	**106,160**				

Manual Calculation

HRSD Wind Speed					Bergey Excel-S Energy Production		
Bin Start (m/s)	Bin End (m/s)	Count (50m #1)	Count (50m #2)		Power (W)	Energy 1 (kWh)	Energy 2 (kWh)
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0.5	1.0	1578	1643		-12	-3	-3
1.0	1.5	2680	2758		-11	-5	-5
1.5	2.0	4450	4677		0	0	0
2.0	2.5	7119	7168		39	46	47
2.5	3.0	9442	9397		102	161	160
3.0	3.5	11397	11648		229	435	445
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9.0	9.5	748	695		5,960	743	690
9.5	10.0	526	473		6,856	601	540
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14.0	14.5	18	13		12,449	37	27
14.5	15.0	6	4		12,495	12	8
Total Count		**106,156**	**106,160**		**Total Energy**	**18,402**	**17,757**

Manual Calculation

HRSD Wind Speed					Bergey Excel-S Energy Production		
Bin Start (m/s)	Bin End (m/s)	Count (50m #1)	Count (50m #2)		Power (W)	Energy 1 (kWh)	Energy 2 (kWh)
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0.5	1.0	1578	1643		-12	-3	-3
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1.5	2.0	4450	4677		0	0	0
2.0	2.5	7119	7168		39	46	47
2.5	3.0	9442	9397		102	161	160
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12.5	13.0	64	50		12,019	128	100
13.0	13.5	45	28		12,276	92	57
13.5	14.0	29	21		12,395	60	43
14.0	14.5	18	13		12,449	37	27
14.5	15.0	6	4		12,495	12	8
Total Count		**106,156**	**106,160**		**Total Energy**	**18,402**	**17,757**
					Annual Energy	**7,615**	**7,348**

Manual Calculation

HRSD Wind Speed					Bergey Excel-S Energy Production		
Bin Start (m/s)	Bin End (m/s)	Count (50m #1)	Count (50m #2)		Power (W)	Energy 1 (kWh)	Energy 2 (kWh)
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0.5	1.0	1578	1643		-12	-3	-3
1.0	1.5	2680	2758		-11	-5	-5
1.5	2.0	4450	4677		0	0	0
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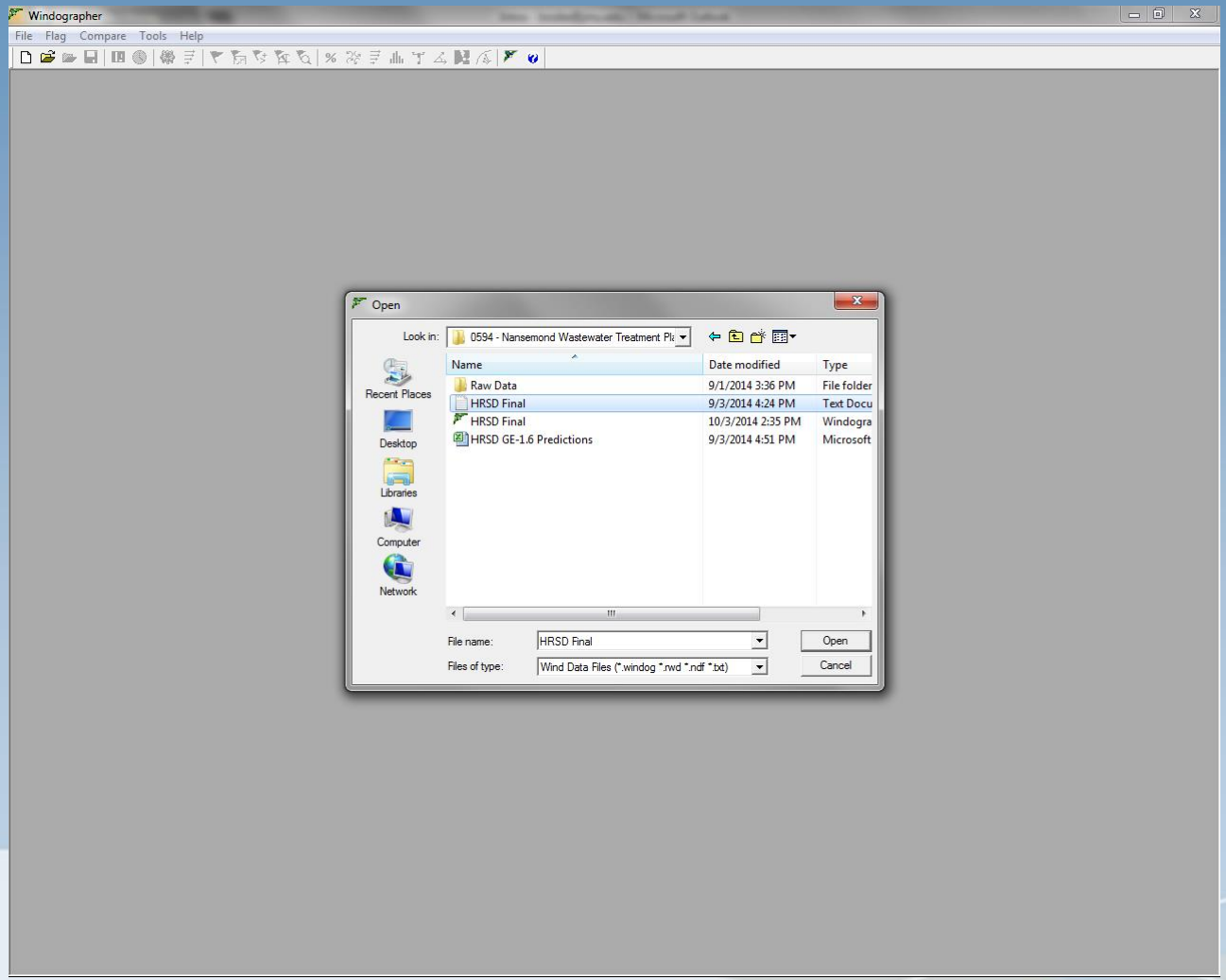
Total Count		**106,156**	**106,160**		**Total Energy**	**18,402**	**17,757**
					Annual Energy	**7,615**	**7,348**

Wind Resource Assessment Software

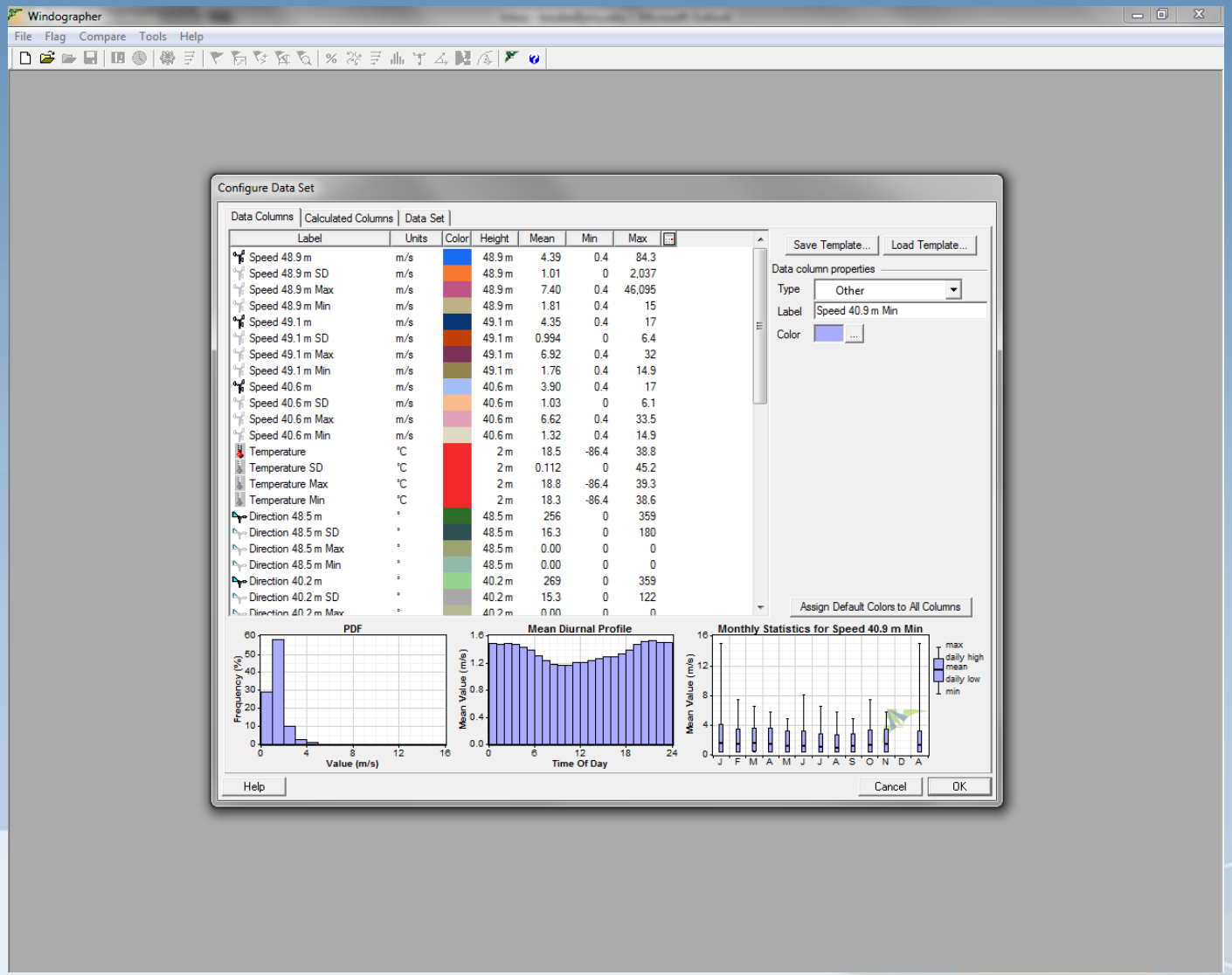
- Windographer
- $1800 per license

Wind Resource Assessment Software

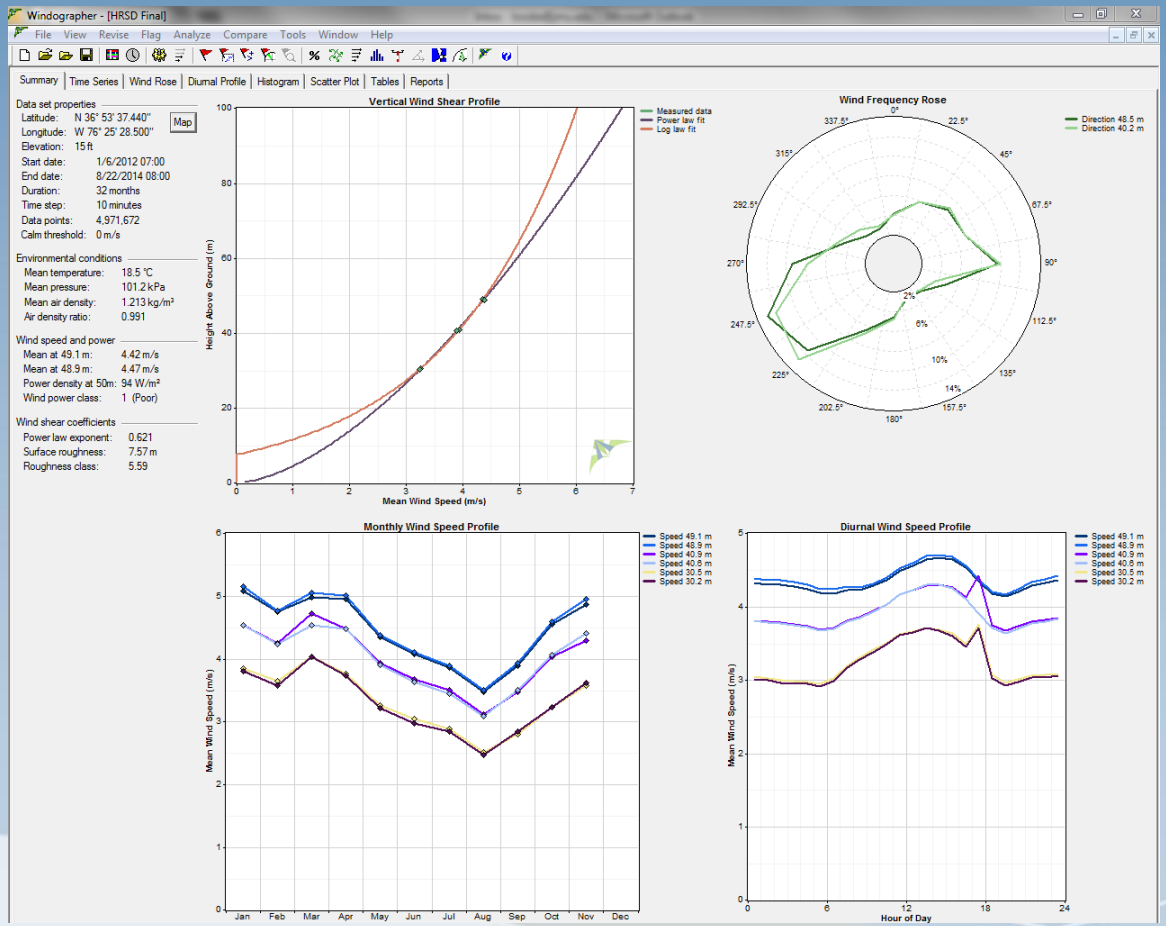


Wind Resource Assessment Software

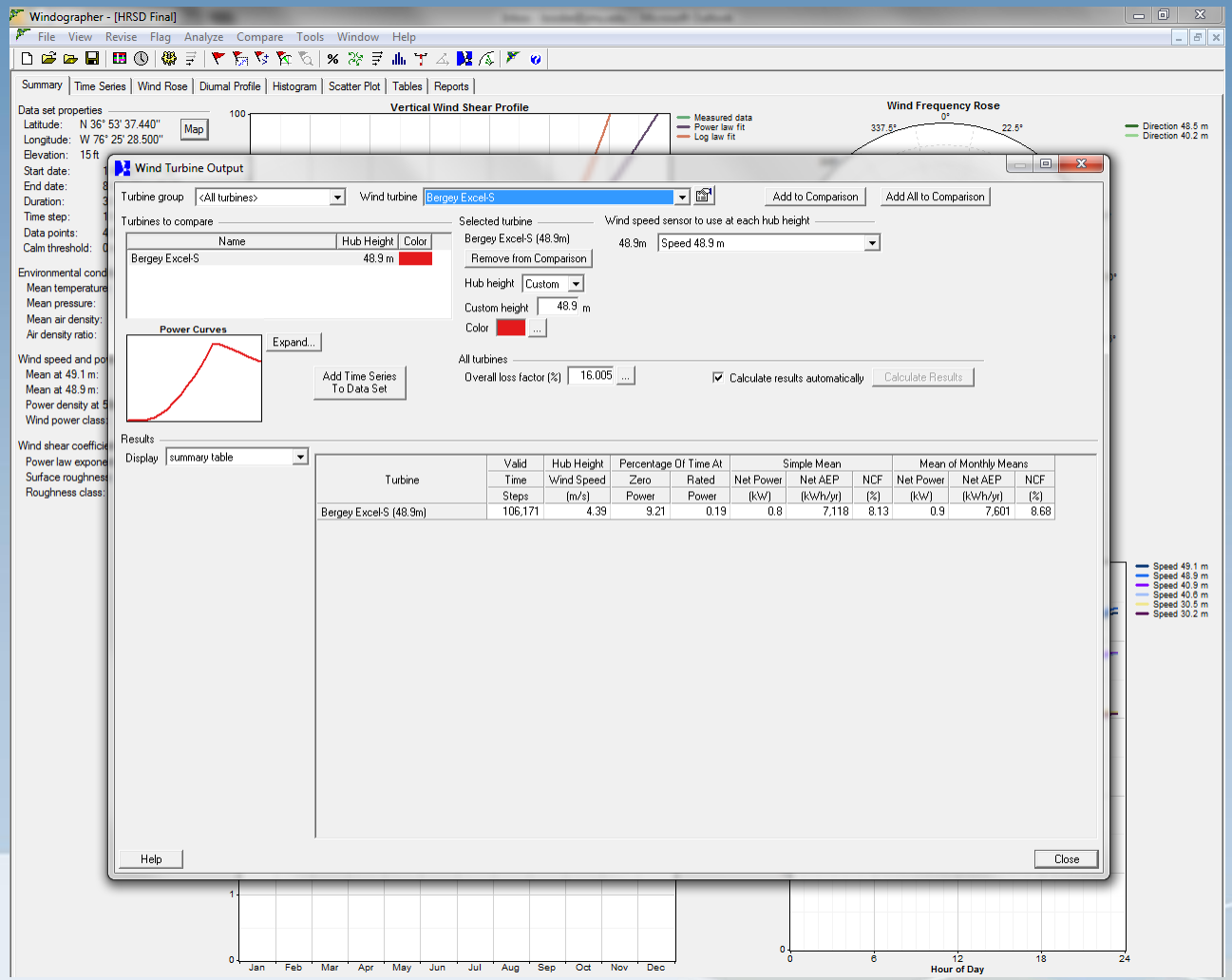
Wind Resource Assessment Software



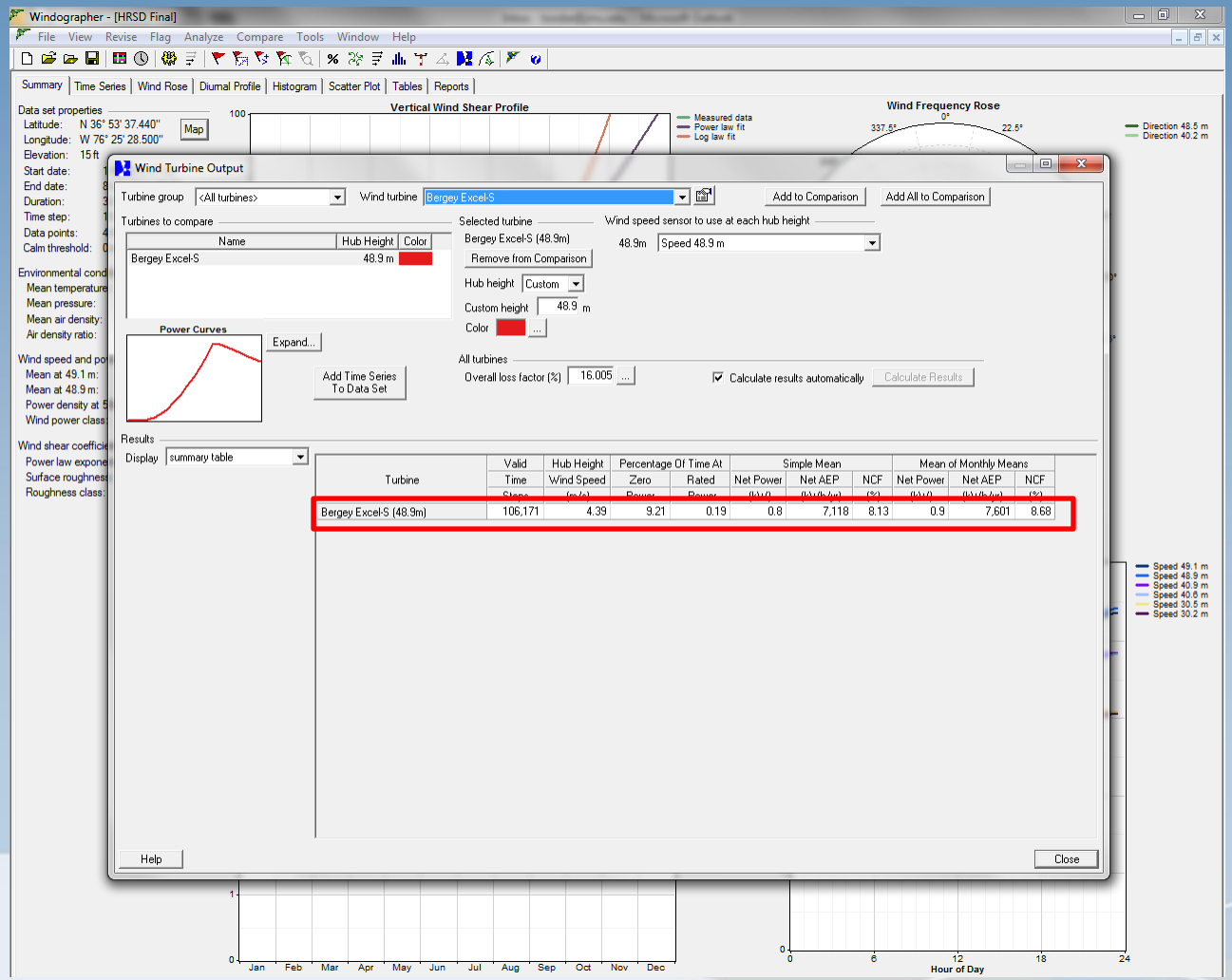
Wind Resource Assessment Software



Wind Resource Assessment Software



Wind Resource Assessment Software



Wind Resource Assessment Software

Turbine	Valid Time Steps	Hub Height Wind Speed (m/s)	Percentage Of Time At Zero Power	Percentage Of Time At Rated Power	Simple Mean Net Power (kW)	Simple Mean Net AEP (kWh/yr)	Simple Mean NCF (%)	Mean of Monthly Means Net Power (kW)	Mean of Monthly Means Net AEP (kWh/yr)	Mean of Monthly Means NCF (%)
Bergey Excel-S (48.9m)	106,171	4.39	9.21	0.19	0.8	7,118	8.13	0.9	7,601	8.68

Wind Resource Assessment

Method	GIS Assessment	MET Tower - Manual	MET Tower - Software
Wind Speed (m/s)	5.24	4.38	4.44
Annual Energy (kWh)	17,500	7,500	7,600
Ease of Use	Easy	Difficult	Easy
Cost	Free	Cost of MET Tower	Cost of MET Tower + $1800
Accuracy	Low	High	Highest

Wind Project Siting and Permitting

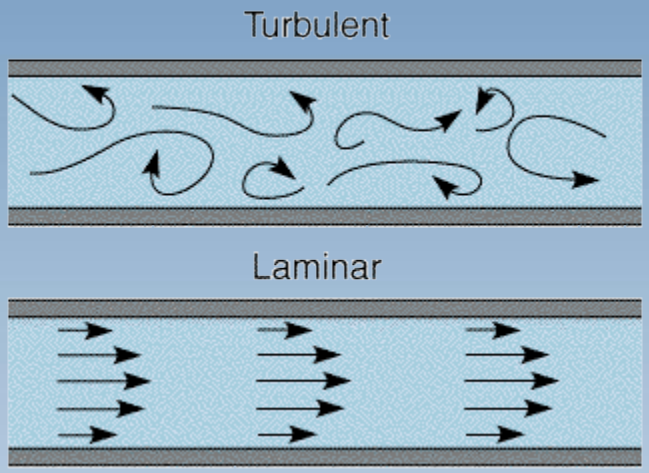
- The Energy in Wind
- Resource Assessment (Macro-siting)
- Energy Production Predictions
- **Micro-siting**
- Permitting

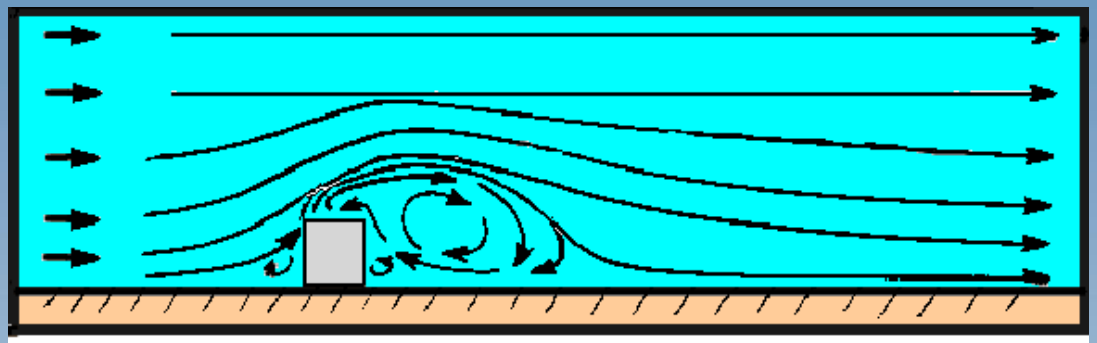
Basic Siting

Selecting the site for a wind turbine is affected wind speed, safety considerations, financial factors, and construction limitations.

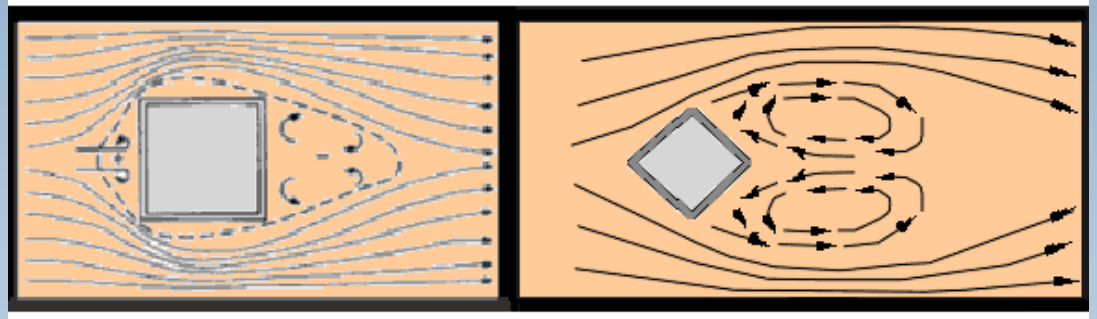
- Is it windy?
- Space and Surroundings
- Avoid Turbulence
- Permits, ordinances, & regulations!

Turbulence & Obstacles





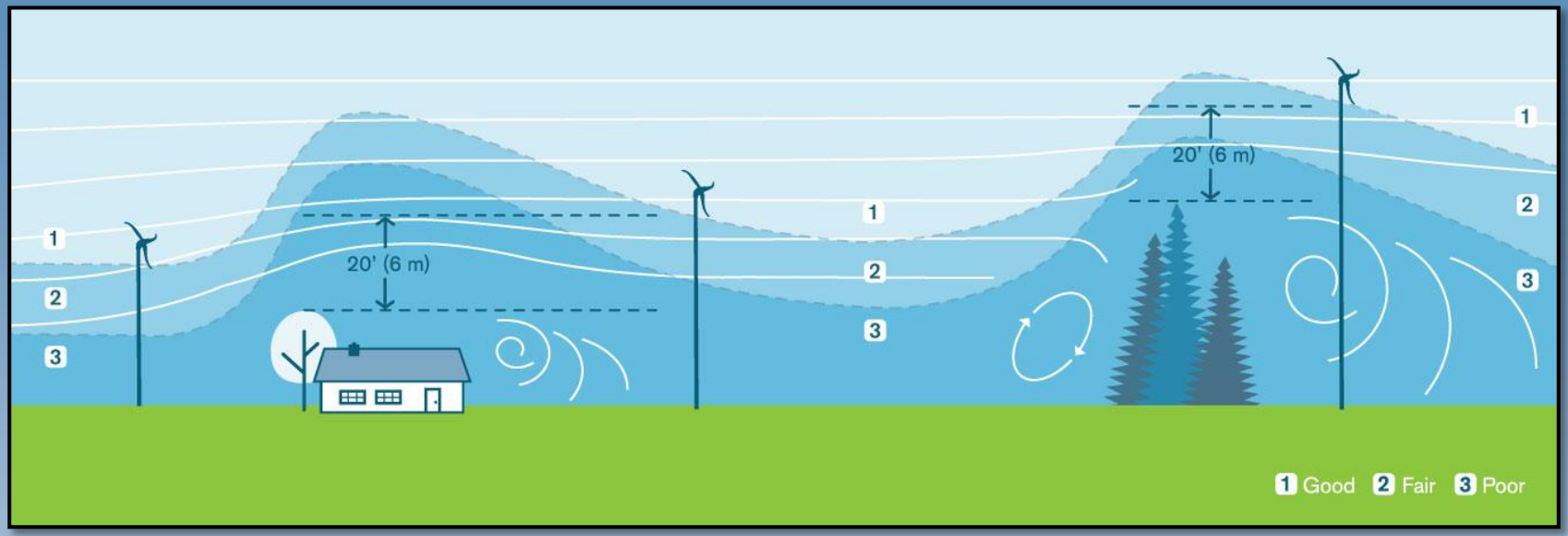
Flow Pattern: Side View Wind Against Face

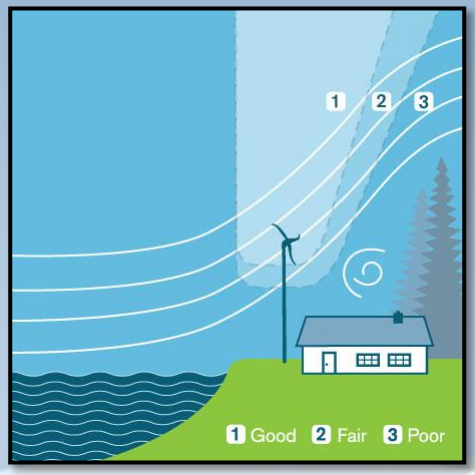


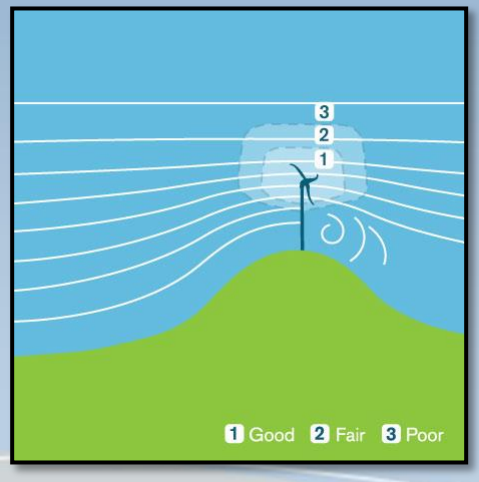
Flow Pattern: Top View
Wind Against Face

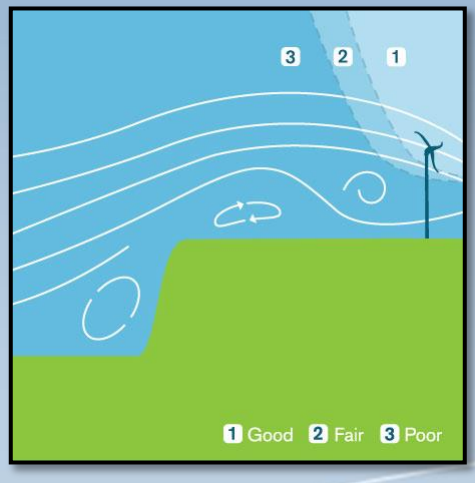
Flow Pattern: Top View
Wind Against Edge

Skystream 3.7 Installation









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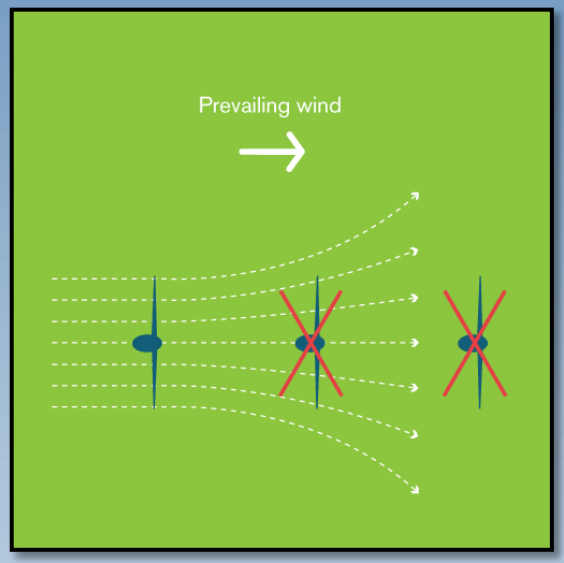
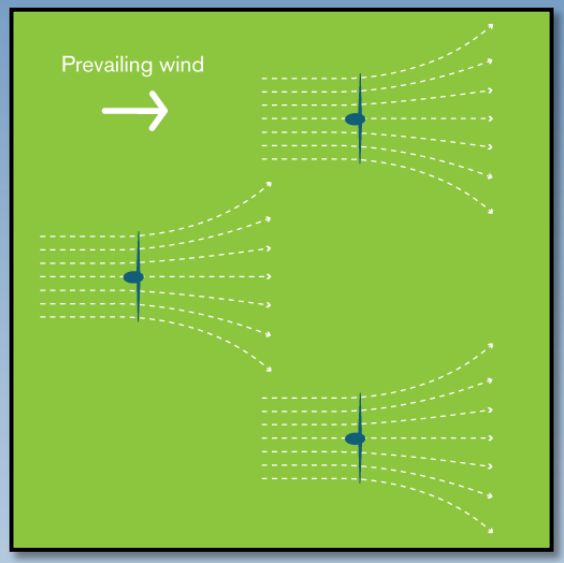
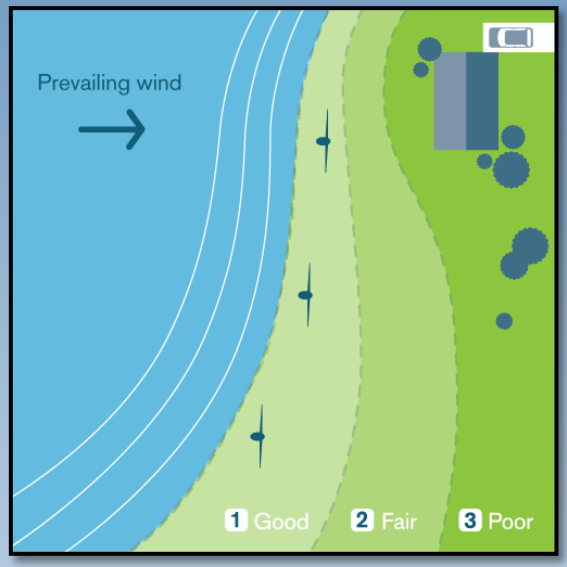
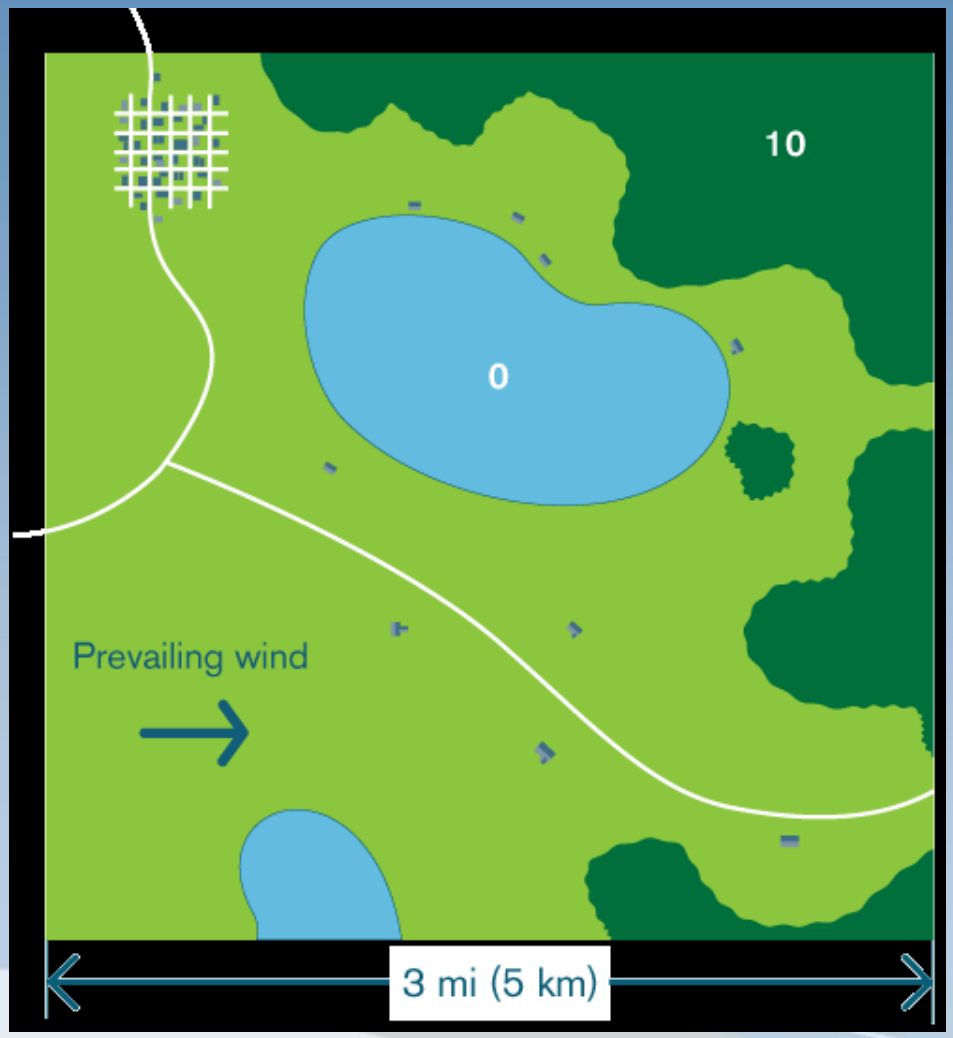




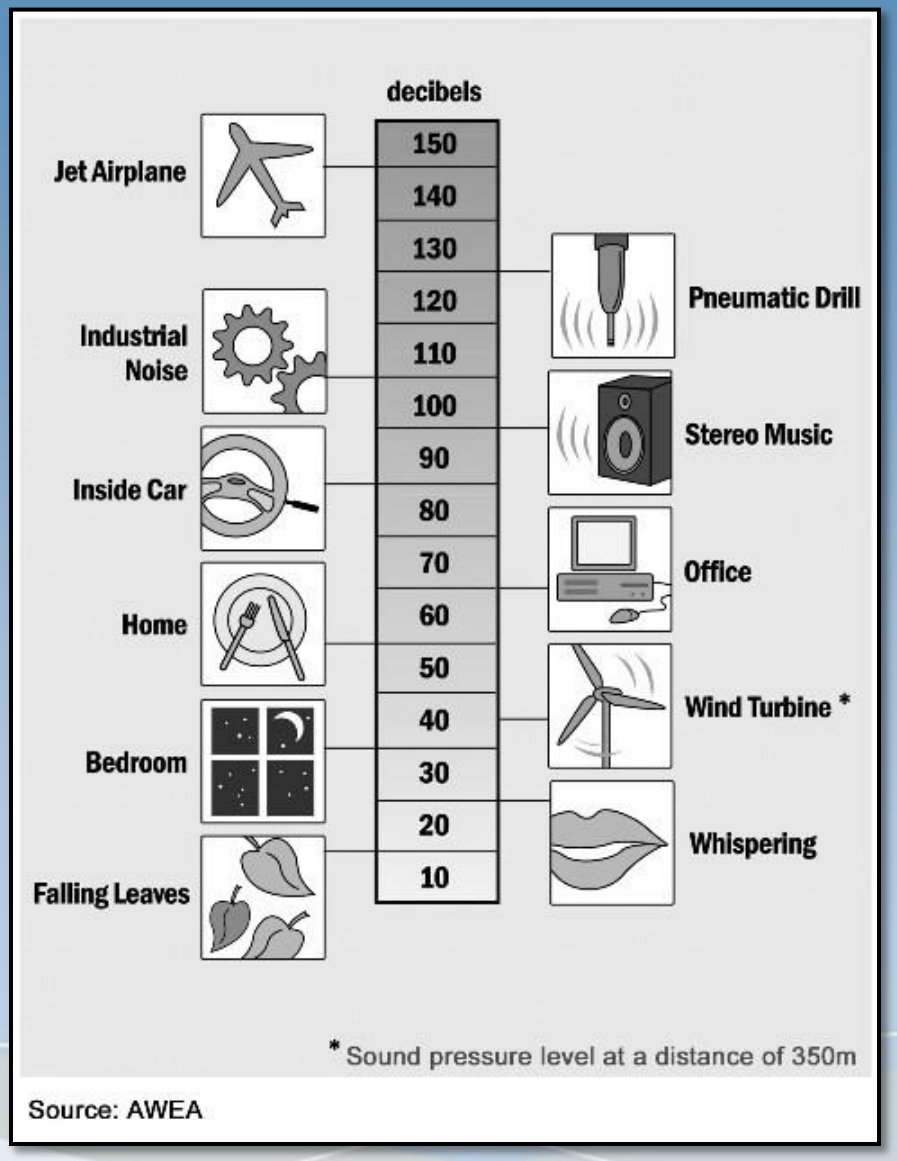


Surface Roughness



Sound Issues

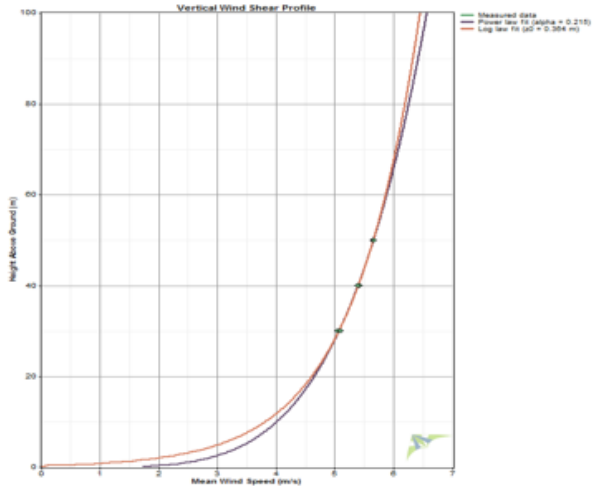
- Local Codes & Ordinances
  - Often expressed as allowable sound level (dB) at property boundary
- Lessens with Distance
- Carried by Wind
- dB Levels of Common Sounds



Siting Activity

Height

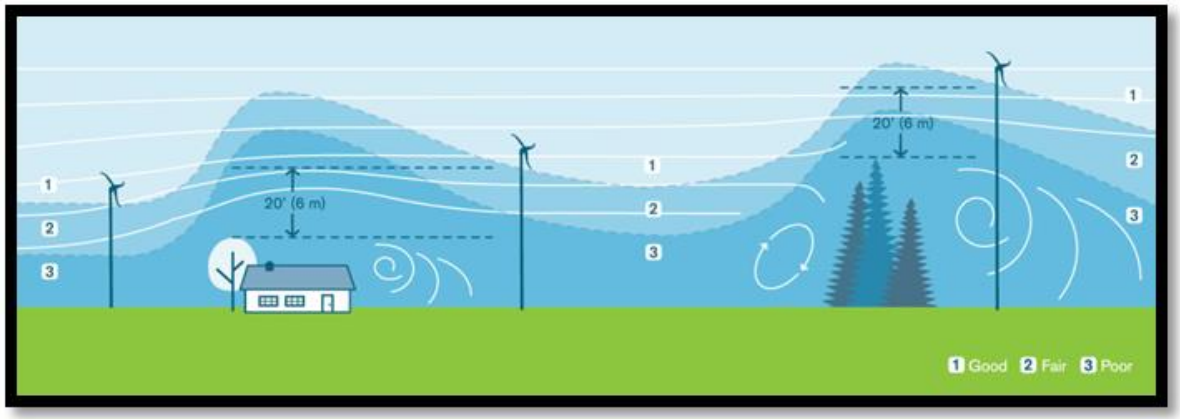
Wind increases in strength as it gets further from the ground, so a taller tower means a turbine will produce more energy. This is mostly due to being above all obstacles that could restrict wind.



Siting Activity

Obstacles

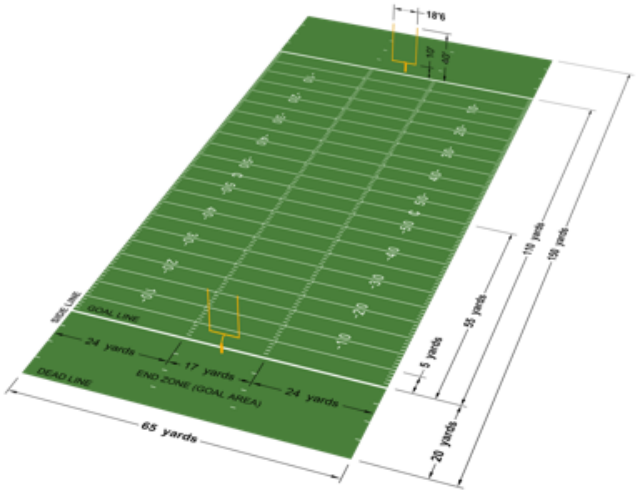
Nearby obstacles (buildings, trees, etc) can cause turbulence that can reduce the amount of energy a wind turbine can produce. The rule-of-thumb is to site the turbine 30 feet higher than anything within 500 feet of its location.



Siting Activity

Land Use

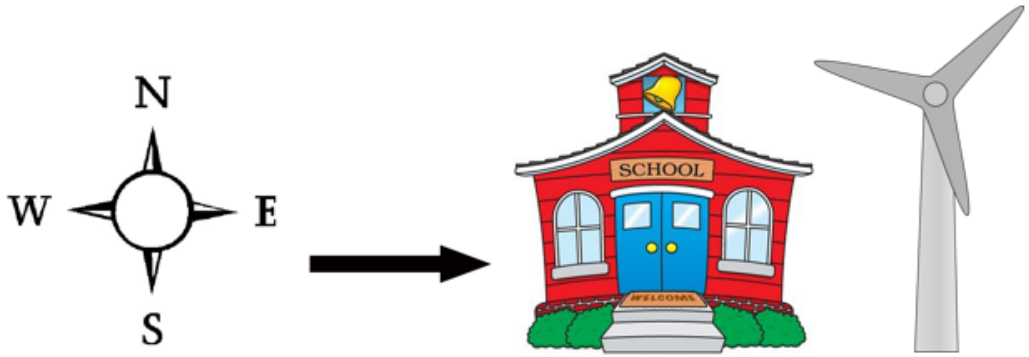
Think about what the land is used for at the school. Is it just open land, or is it used for something like recess or sports? Can you still play football if there is a wind turbine in the middle of the field?



Siting Activity

Prevailing Winds

Winds will come from many directions, but there is usually a prevailing wind direction where the winds come from most of the time. In Virginia that is usually the West – Northwest or Southwest. We need to be sure that nothing is blocking the turbine from the prevailing winds.



Siting Activity

Distance to Building

When installing a turbine, it has to be connected to the building it will power and the cost of cable to do that will get more expensive the further away from the building the turbine is sited. This is because more trenching and work are needed but also larger cable will be needed to make up for any voltage loss with distance.

Siting Activity

Setbacks and Safety

For safety reasons, counties and cities have rules as to how far away from buildings, electric lines, cars, property lines, and other objects a turbine needs to be, to ensure that if the turbine falls over (which it never will) that it will not hit anything. The general rule-of-thumb is to be at least as far from buildings and power lines as the turbine is tall.

Siting Activity

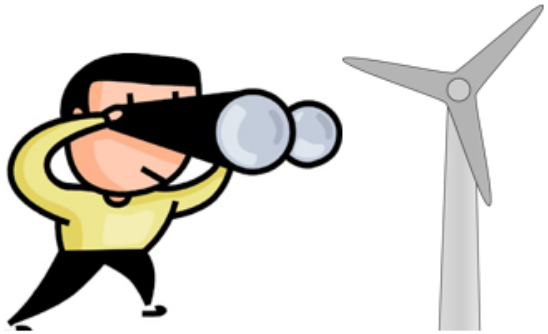
Environmental Issues

Issues such as bird and bat death are not an issue with small (residential) wind turbines, but you will want to be sure to understand if there would be any environmental issues with locating a turbine at the site. Would it displace endangered or threatened animals? Will it be in the way of migrating birds or bats?

Siting Activity

Visibility

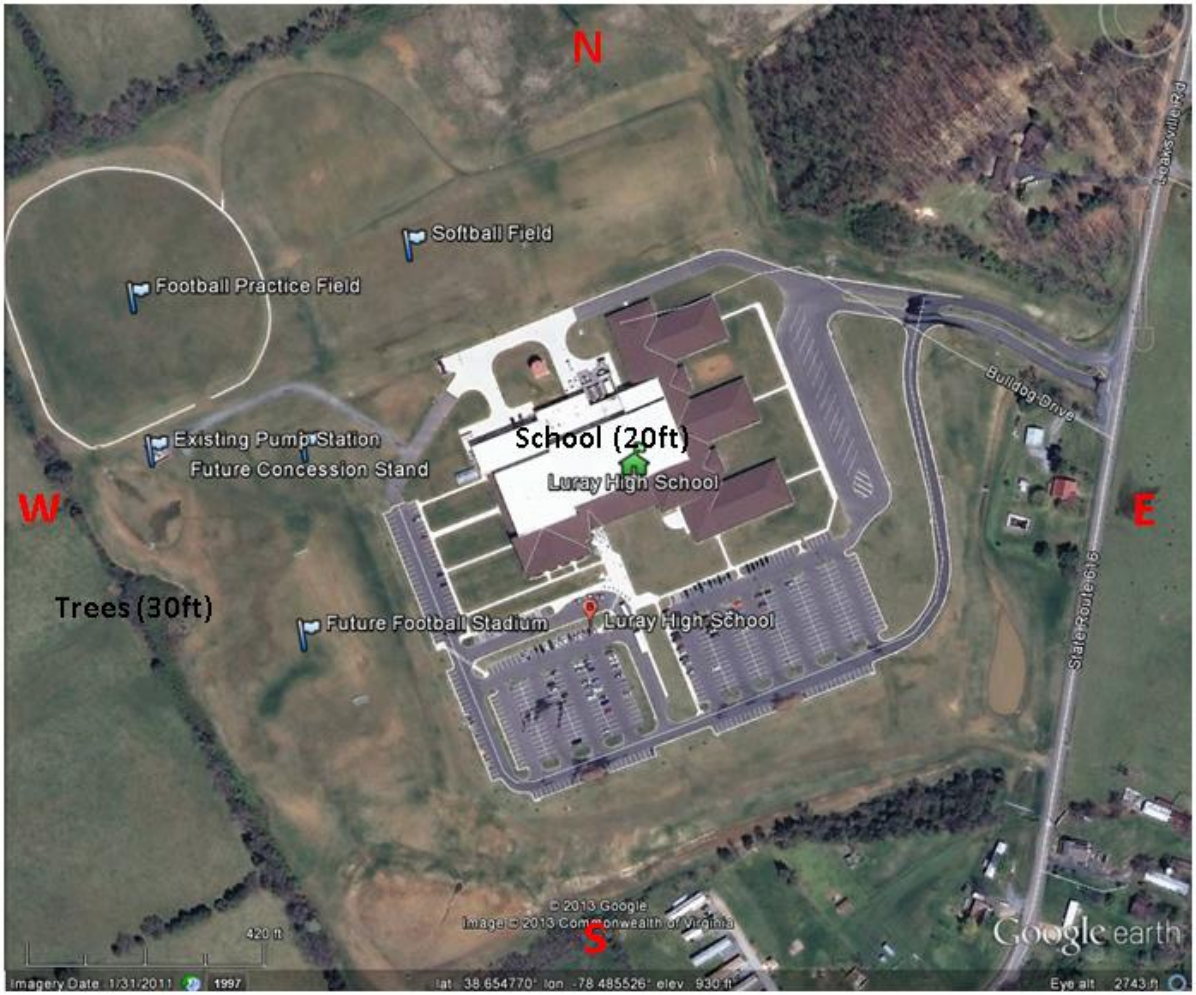
In most cases, people do not want to see a wind turbine and there may be neighbors of a school that will have this concern and you will want to consider that. However, the point of putting a turbine at a school is to teach students and the public about wind energy so it is helpful if the turbine is visible to students and any other school traffic.



List of Considerations

- Plot Plan
- Address
- Survey
- Proposed Tower Location
- Electrical Panel Location
- Longitude & Latitude of the site
- Elevation of the site
- 2 Spare circuit breaker locations in breaker panel for interconnects
- Access for crane/cement truck (if needed)
- Distance from panel to tower/turbine
- Turbine setback, distance to buildings, fences, utility poles
- Proposed tower height
- Town/county zoning
- Pictures of site from all compass directions
- Picture of utility meter, panel box, penetration of wiring into house
- Copy of recent electric bill—account # and utility provider
- 20/250 rule, turbulence, landscape considerations
- Google Earth map of the site

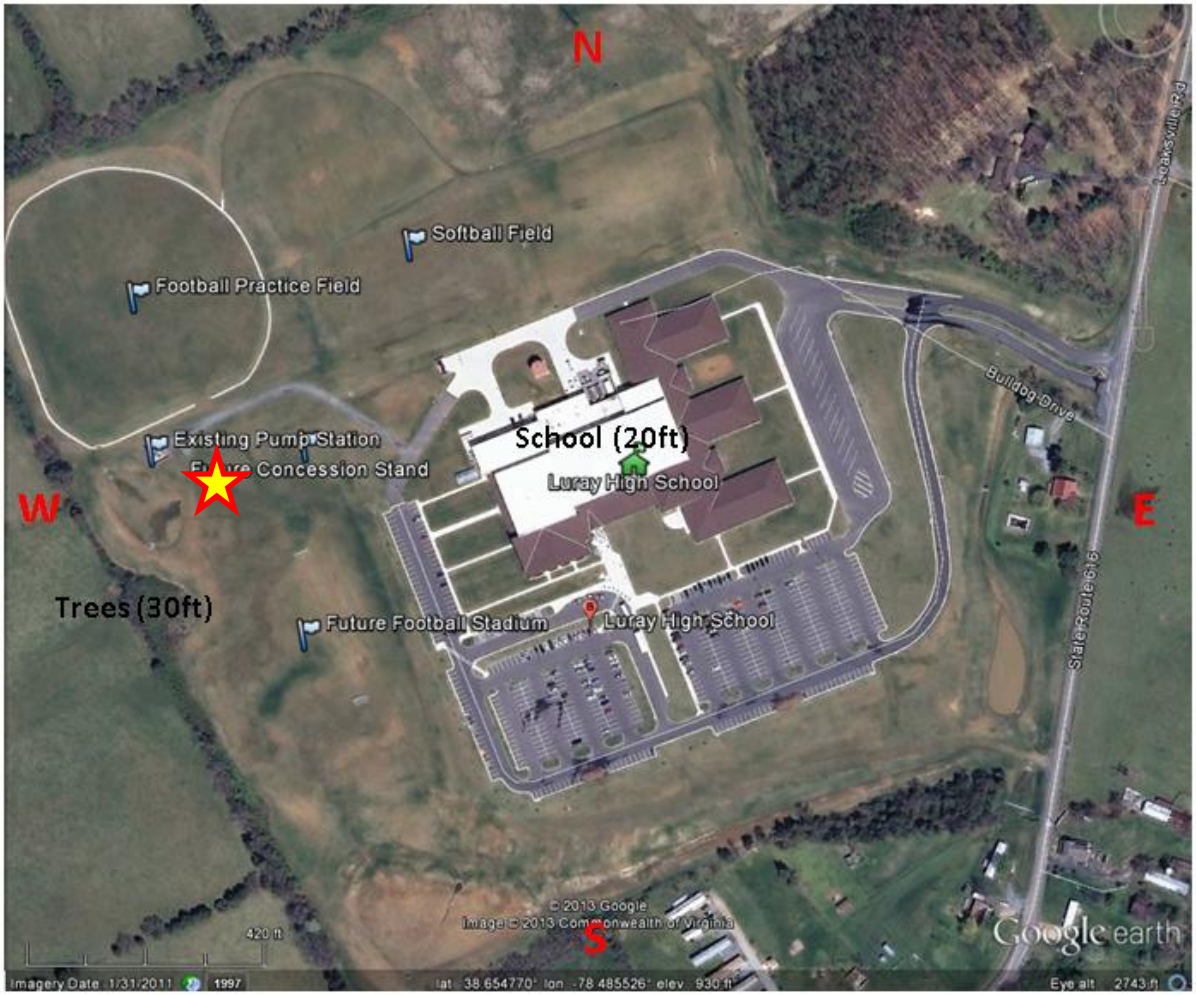
Siting Activity



Luray High School: 55ft Skystream Wind Turbine

Want to power the concession stand at the future football stadium. Assume predominant wind direction is from the west.

Siting Activity



Luray High School: 55ft Skystream Wind Turbine

Want to power the concession stand at the future football stadium. Assume predominant wind direction is from the west.

Siting Activity

Henley Middle School: 45ft Skystream Turbine

Power will be used at the school. Assume predominant wind direction is from the west.

Siting Activity

Henley Middle School: 45ft Skystream Turbine

Power will be used at the school. Assume predominant wind direction is from the west.

Siting Activity

Thomas Harrison Middle School: 55ft Skystream Turbine

Power will be used at the school. Assume predominant wind direction is from the west.

Siting Activity

Thomas Harrison Middle School: 55ft Skystream Turbine

Power will be used at the school. Assume predominant wind direction is from the west.

Siting Activity

Example Installations

Example Installations

Example Installations

Example Installations

Example Installations

Example Installations

Example Installations

Wind Project Siting and Permitting

- The Energy in Wind
- Resource Assessment (Macro-siting)
- Energy Production Predictions
- Micro-siting
- **Permitting**

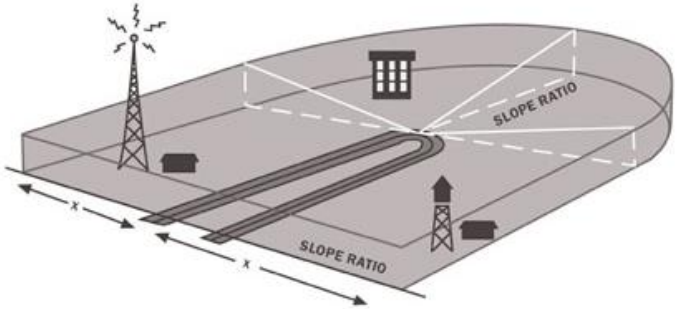
Permitting

- Federal
- State
- Local

- Which permits you need depends on where you live and how big of a project you're considering.

Federal Regulations

- Federal Aviation Administration
  - Height > 200ft
  - Within certain radius of airport (varies)
  - In critical flight paths
- Military
  - Close to military bases
- Fish and Wildlife Service
  - Endangered or sensitive species areas



Criteria for aviation obstructions that trigger FAA notification and permit:

- *Antenna penetrates surface. FAA notice required.*
- *Airports with one runway more than 3,200 ft long, X=20,000 ft. Slope ratio 100:1*
- *Airports with no runway over 3,200 ft. long X = 10,000 ft. Slope ratio 50:1*

Source: Federal Aviation Administration

State Regulations

- Department of Environmental Quality
  - Permit by Rule
  - No action necessary if < 5 MW
- SCC
  - Only for projects > 100 MW

State Regulations

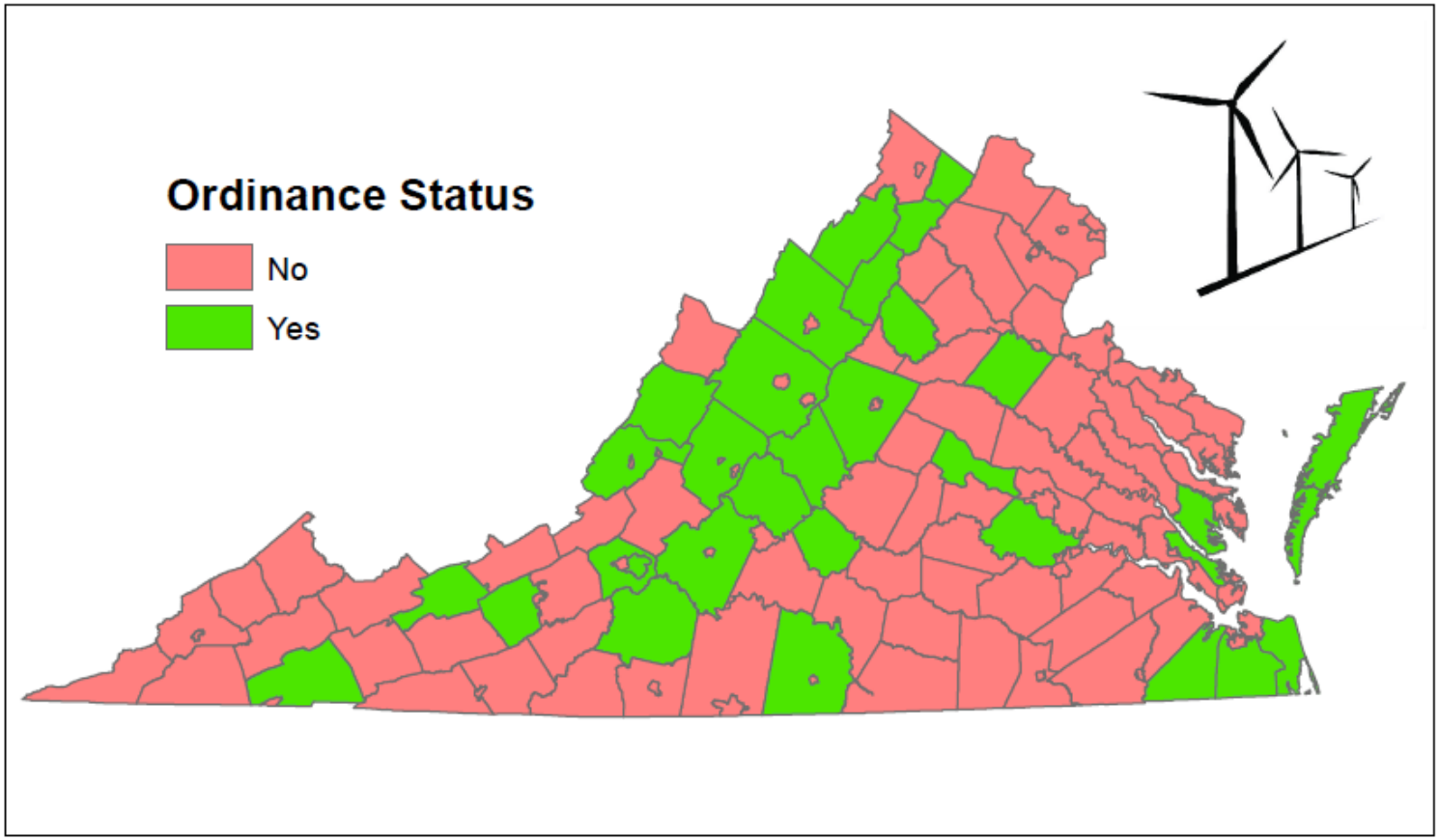
Utility

- Net metering application
- Power purchase agreement application

Local Regulations

- Local Ordinances
  - Very Varied
  - Could be simple or complex
  - Could be inviting or restrictive
  - Could exist or….. not

Local Regulations



Center for Wind Energy at James Madison University

Updated 08/2013

Local Regulations

- Rockingham County

Wind energy systems, small-scale.

(a) The requirements set forth herein shall govern the siting of small wind energy systems used to generate electricity or perform work which may be connected to the utility grid pursuant to Virginia's net metering laws (section 56-594 of the Code of Virginia), serve as an independent source of energy, or serve in a hybrid system.

(b) The requirements for siting and construction of all small wind energy systems regulated by this article shall include the following:

(1) Small wind energy towers shall maintain a galvanized steel finish, unless FAA standards require otherwise, or if the owner is attempting to conform the wind energy tower to the surrounding environment and architecture, in which case it may be painted to reduce visual obtrusiveness. A photo simulation may be required.

(2) Small wind energy systems shall not be artificially lighted unless required by the FAA or appropriate authority.

(3) Small wind energy towers shall not have any signs, writing, or pictures that may be construed as advertising.

(4) Small wind energy systems shall not exceed sixty (60) decibels, as measured at the closest property line; however, the level may be exceeded during short-term events such as severe windstorms.

(5) The applicant shall provide evidence that the proposed height of the small wind energy system tower does not exceed the height recommended by the manufacturer or distributor of the system.

(6) The applicant shall provide evidence that the provider of electric utility service to the site has been informed of the applicant's intent to install an interconnected customer-owned electricity generator, unless the applicant intends, and so states on the application, that the system will not be connected to the electricity grid. This action shall not construe approval for net metering by the electric utility service.

(7) The applicant shall provide information demonstrating that the system will be used primarily to reduce on-site consumption of electricity.

Local Regulations

- Albemarle County

5.1.46 SMALL WIND TURBINES

The purpose of this section 5.1.46 is to authorize small wind turbines as an accessory use in order to promote renewable energy. Each small wind turbine shall be subject to the following, as applicable:

a. *Application for approval.* In conjunction with the submittal of a building permit application for a small wind turbine, the applicant shall submit the following information:

1. A plat of the parcel showing the lot lines, the location of the proposed small wind turbine and the setbacks to the lot lines.

2. Plans that show the total height of the proposed structure, including rotors or turbine blades and that show compliance with the building code.

b. *Requirements.* Each small wind turbine shall be subject to the following:

1. *Primary purpose.* The primary purpose of the small wind turbine shall be to support and provide power for one or more authorized uses of the property; provided that nothing herein shall prohibit the owner from connecting the small wind turbine to a public utility and selling surplus power to the utility.

2. *Location.* Notwithstanding section 4.2.3.1 of this chapter, the small wind turbine may be located in an area on a lot other than a building site. A small wind turbine shall not be located within a historic district or within a ridge area.

3. *Setbacks.* The small wind turbine shall not be located closer in distance to any lot line than one hundred and fifty (150) feet. The agent may authorize a small wind turbine to be located closer to any lot line if the applicant obtains an easement or other recordable document showing agreement between the lot owners that is acceptable to the county attorney and, where applicable, that prohibits development on the portion of the abutting parcel sharing the common lot line that is within the small wind turbine's fall zone. If the right-of-way for a public street is within the fall zone, the Virginia Department of Transportation shall be included in the staff review, in lieu of recording an easement or other document.

4. *Height.* The small wind turbine shall not exceed the maximum height permitted for structures within the applicable zoning district.

5. *Lighting.* The small wind turbine shall have no lighting.

6. *Collocation.* The small wind turbine shall not have personal wireless service facilities collocated upon it.

7. *Removal.* The small wind turbine shall be disassembled and removed from the property within ninety (90) days after the date the use(s) to which it provides power is discontinued or its use to generate power is discontinued. If the agent determines at any time that surety is required to guarantee that the small wind turbine will be removed as required, the agent may require that the owner submit a certified check, a bond with surety, or a letter of credit, in an amount sufficient for, and conditioned upon, the removal of the small wind turbine. The type and form of the surety guarantee shall be to the satisfaction of the agent and the county attorney.

c. *Approval.* The agent is authorized to review and approve small wind turbines. The agent shall act on the application before the building permit application or site plan for the small wind turbine is approved. Notwithstanding subsection 5.1, no requirement of subsection 5.1.46(b) may be waived or modified for a small wind turbine.

d. *Denial.* If the agent denies an application, it shall identify which requirements were not satisfied and inform the applicant of what needs to be done to satisfy each requirement.

Local Regulations

- DEQ Model Ordinances
  - 2012/2013
  - Developed to assist localities
  - Addresses permitting process, appearance, noise, lot size, setbacks, height, decommission, etc.
  - Best option for Counties/Cities

Wind Project Siting and Permitting

- The Energy in Wind
- Resource Assessment (Macro-siting)
- Energy Production Predictions
- Micro-siting
- Permitting

Questions?

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Visit our Facebook Page to ask questions, give feedback, see current events and project photos, and stay up-to-date on what's happening at the Center and with wind energy throughout Virginia!

Join our LinkedIn Group to engage in discussions, participate in polls, read current articles, and ask questions!

Skype us via VACenterforWindEnergy to ask questions or just chat with us!