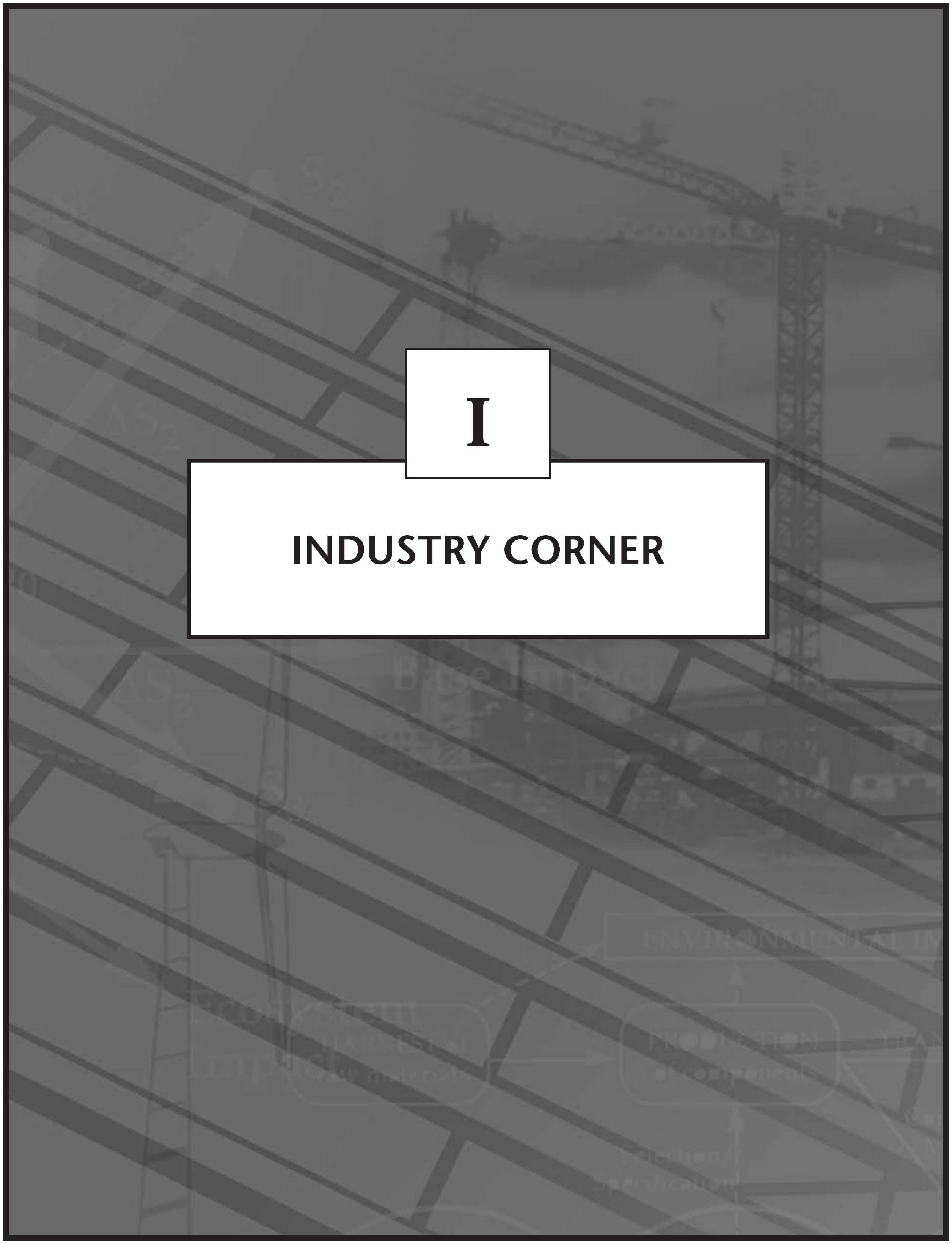

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INDUSTRY CORNER

SMALL WIND POWER CONSIDERATIONS

David Carr[1] and Kenneth Starcher[2]

INTRODUCTION

Wind energy can be a supplemental source of energy to an electric grid or the complete power supply for an isolated source. It produces no waste particulate matter, uses no water for cooling, and contributes no green house gasses to the environment. A short description of the Alternative Energy Institute, at West Texas A&M University, and the basics of wind energy as well as some discussion of home scale wind systems are presented here. The uses of wind energy and many of the basic concerns and considerations of placing wind energy conversion systems on or near primary structures are discussed. The basic plan for a renewable energy system inclusion into a home or building is shown; it is always preferable to reduce the energy load and ensure that the structure will use energy as efficiently as possible before a system is designed. Current federal support for renewables is at a new high, and the source for local and regional description of programs is shown.

ALTERNATIVE ENERGY INSTITUTE

The Alternative Energy Institute (AEI) was created in the fall of 1977 at West Texas State University as an outgrowth of work begun in 1970 by Dr. Vaughn Nelson and Dr. Earl Gilmore. That year, the two conducted computer analysis to quantify the wind regime of the Texas Panhandle. Dr. Robert Barieau joined the group in 1973 adding his extensive knowledge of computers and thermodynamics. The group was asked to present a paper at the First Wind Energy Conversions Systems Workshop held in Washington D.C.

In 1974 a grant from the Governors Energy Advisory Council (GEAC) was awarded to WTSU to expand the study across the State. The resulting report, "Potential for Wind Generated Power in Texas," confirmed that the Panhandle was a prime area for future growth, though it would take 26 years to see the first utility scaled wind farm installed in the area, showing for the first time that AEI was ahead of the times.

A second grant in 1976 to study wind powered irrigation systems led to a long-term cooperative contract with the U.S. Department of Agriculture research facility at the Southwest Great Plains Research Center, Bushland, TX. The first focus of this cooperation was the investigation of wind energy and irrigation studies.

The goal of AEI has been to conduct research and development in the use of alternative energy sources. To accomplish this the focus has been placed to:

- Increase knowledge by data collection, research, and feasibility studies.
- Develop and test alternative energy systems.
- Establish a center for the collection and distribution of information to the general public and state-wide decision makers.
- Educate students and others through research, seminars, and courses.

Within this context, primary emphasis has been placed on wind energy studies. Our abundant resource and available space made this a natural field of concentration. In this field the use of renewables for rural and remote systems has been the constant target, finding application of renewables, primarily wind energy, suitable for home and industry.

Prime focus of AEI has been the dissemination of the collected knowledge and data of the Institute. This has led to long phone calls, correspondence, and e-mails to interested individuals and groups. On the national scene AEI has established itself as a repository of printed information covering the early years of renewable energy studies, a full collection of the Wind Energy Project Office (WEPO) documents is maintained at the AEI offices. These along

[1]West Texas A&M University, Assistant Director of the Alternative Energy Institute MS ET dcarr@wtamu.edu.
[2]West Texas A&M University, Director of the Alternative Energy Institute MS ET kstarcher@wtamu.edu.

with vast collections of periodicals on renewables provide a searchable data base for other researchers looking for obscure references or old articles.

AEI personnel have traveled to sites all over Texas and the surrounding states to make presentations to lay and professional groups. We explain the basics of renewable energy and the impacts that developments could have on the local economy and benefits and possible detractions that renewables could bring.

Nationally, AEI has been active, hosting the AWEA Windpower Conference in Amarillo at the beginning of the industry association run of annual programs. The conference in 1978 had 175 attendees; in 2008, this grew to 13,300 attendees held in Houston, TX, showing the attraction that the Lone Star State has for the wind industry.

Current work and research at AEI includes the performance testing of 6 prototype turbines, wind data collection at more than 20 sites across Texas, and educational presentations to homeowners, landowners, and other interested groups. AEI also teaches two undergraduate courses at West Texas A&M University.

WIND POWER SCIENCE

Wind energy is simply air in motion caused by the uneven heating of the Earth's surface.

The moving molecules of air have kinetic energy, so locally the amount of air molecules moving across some area during some time period determines the power. This area is the area perpendicular to the wind flow.

The mass, m, in the volume of the cylinder which will pass across the area, A, in time, t, can be determined from the density of the air, ρ, and the volume of the cylinder. The power is the kinetic energy of the air molecules divided by the time.

$$\begin{aligned} \text{Power} &= \text{Kinetic Energy / time} \\ &= 0.5 * \text{mass} * \text{velocity}^2 \text{ / time} \qquad (1) \end{aligned}$$

$$\rho = \text{mass / Volume}$$

$$\text{Volume} = \text{area} * \text{length} = A * L$$

$$\text{mass} = \rho * \text{Volume} = \rho * A * L$$

Substitute this value of mass into Equation 1. Only those molecules with a velocity, v = Length / time, will cross the area in that time, and those further to the left will not, so the power is given by

$$\begin{aligned} \text{Power} &= 0.5 * \rho * A * L * \text{velocity}^2 \text{ / time} \\ &= 0.5 * \rho * A * L \text{ / time} * \text{velocity}^2 \\ &= 0.5 * \rho * A * v * v^2 = 0.5\, \rho\, A\, v^3 \end{aligned}$$

The power/area, sometimes referred to as wind power potential or wind power density is

$$\text{Power/Area} = 0.5 * \rho * \text{velocity}^3$$

The wind power per unit area perpendicular to the flow of the wind is proportional to the velocity

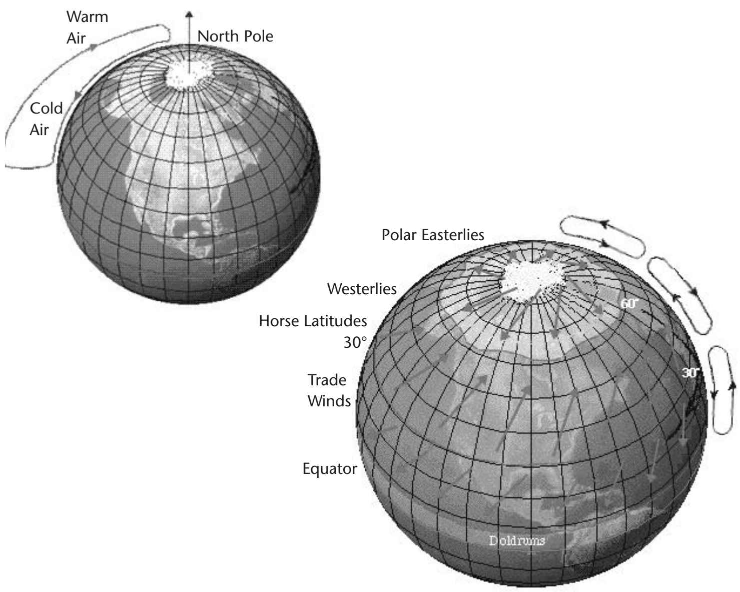


FIGURE 1. General atmospheric circulation, Northern Hemisphere.

FIGURE 2. Flow of wind through a cylinder of area A and length L.

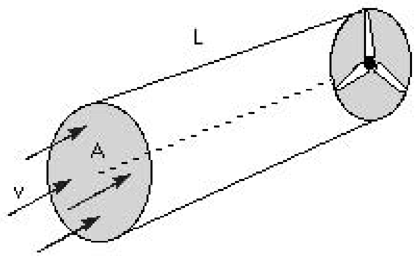
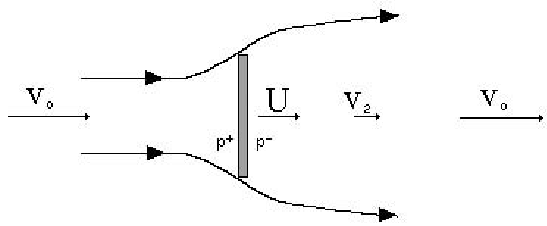


FIGURE 3. The velocity slows down to U at the back side of the turbine rotor, recovers to v_2 and then back to the free stream velocity v_o.



cubed. **Therefore, wind speed is the most important factor in determining wind power and wind energy.**

Siting a system is simply placing it so that it can maximize its operating potential—either by placing it above any obstructions or far enough from obstructions to not be affected by slowing of the free stream wind. An example of siting will be presented later, but to a home owner the costs are always a balancing act. As tower height increases there is increased costs, but a gain of better winds and more hours of operation. If you place a turbine further from obstructions, then there will be higher conductor/cable costs and the need for more land area, but with smoother performance and less turbulence and longer life to the turbine. It is always a tradeoff.

Power comparisons are often made using the coefficient of performance, basically a ratio of the power available to the power delivered by the turbine.

$$Cp = \text{Power Out} / \text{Power Available}$$

For a wind turbine power available is the power in the wind times the area of the turbine

$$Cp = \text{Power Out} / 0.5 * \rho * A * v_o^3$$

There is a maximum theoretical efficiency that a wind turbine can provide. This limit was determined by Dr. Albert Betz. He used the axial interference factor α to find the place where the wind power would be best.

This factor is simply the ratio of how much the wind was slowed compared to the undisturbed wind speed $\alpha = [v_o - U] / v_o$.

Imagine if all the speed of the wind, v_o, were stopped by the rotor of a wind turbine and pulled out as power; the speed after it passed through the turbine would be 0, and it would all "pile up" just behind the turbine. If the wind was not slowed at all, then the rotor did not pull any power from the wind stream. In both cases the wind power would be 0. So the maximum has occured somewhere in between those two extremes. The maximum power can be found by plotting the equation versus α or by using calculus.

$$\text{Power} = 0.5\ \rho * A * v_o^3 * 4 * \alpha * (1 - \alpha)^2$$
$$\text{Power} = 0.5 * \rho * A * v_o^3 * C_P$$

The answer is the maximum occurs when $\alpha = 1/3$. For $\alpha = 1/3$, the maximum power is also the point of maximum power coefficient. The maximum power coefficient is then

$$\begin{aligned} C_P &= 4 * \alpha * (1 - \alpha)^2 \\ &= 4 * 1/3 * (1 - 1/3)^2 \\ &= 4 * 1/3 * (2/3)^2 \\ &= 4/3 * 4/9 \end{aligned}$$

= 16 / 27 or 0.59, this 59% overall efficiency is the limit of what is reasonable to expect from a working turbine, independent of the style or configuration.

Actual rotors will have smaller power coefficients due to drag, tip, and hub losses; losses due to rotation of the wake; and frictional losses. However, measured values of utility scale machines can reach 50% (which includes drive train and generator).

The range of expected output to the potential possible output is the capacity factor, CF. This is a number that compares the performance over time of the unit to the potential it could have made, if it ran at full power during the same time interval. For example, a 5 kilowatt turbine running 100 hours really produced 200 kilowatt-hours. It could have produced 500 kilowatt-hours if it ran full power the whole time. The ratio of what it did versus what it could have done was 200 / 500 = 40%. The annual CF for small wind systems is about 15–18%, maybe 20% in a good wind resource. Modern utility scale machines are often 45–50 % over a year.

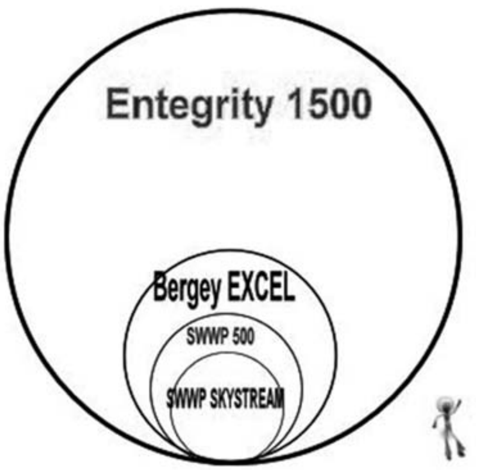
The industry has settled on 200 square meters rotor area, or 100 kilowatt rated power as the limit of "small" wind energy conversion systems. This is comparable to a rotor diameter of 16 meters (52 feet). Turbines larger than this are utility scale and not sized properly for home/small business use.

GENERAL DISCUSSION OF SMALL WIND

Small Wind Defined

Today's small wind is yesterday's large wind and it is all a question of scale. Wind turbines are created commercially around the world anywhere between 5 watts and 7,000,000 watts. The American Wind Energy Association (AWEA) currently defines small wind as any turbine that has a rated capacity under 100 kW. There is a standard for certification and testing being developed that will change this to turbines less than 200 m^2 swept area in the near future. This will eliminate any confusion about what wind speed the rated output is and make it easier to compare turbines.

FIGURE 4. Wind turbine rotor sizes 3 kw to 50 kw compared to a 6 ft person.



Historical Background

The first known electric windmill of any scale is commonly considered to be the one built by Charles F. Brush in 1877 in Cleveland, Ohio. The output of this machine was 12 kW and it had a rotor diameter of 58 feet. It operated for about 20 years, with continuous maintenance, running primarily lighting with use of a battery bank.

The first wave of commonly used wind power devices in the U.S. was energy utilized by the general public and very widespread. In 1899 there were 77 factories in the United States producing water pumping windmills for the expansion of farming and ranching into the Great Plains region. Beginning in 1920 and into 1945, electric windmill or wind turbine use was growing as well. While there were many brands that came and went, the common electric turbine became the "Wincharger" unit. Millions of these units were installed across the country, and appliances and tools were manufactured at the

FIGURE 5. Brush Post Mill 1877. Photo Courtesy of the Charles F. Brush Collection, Kelvin Smith Library, Case Western Reserve University.

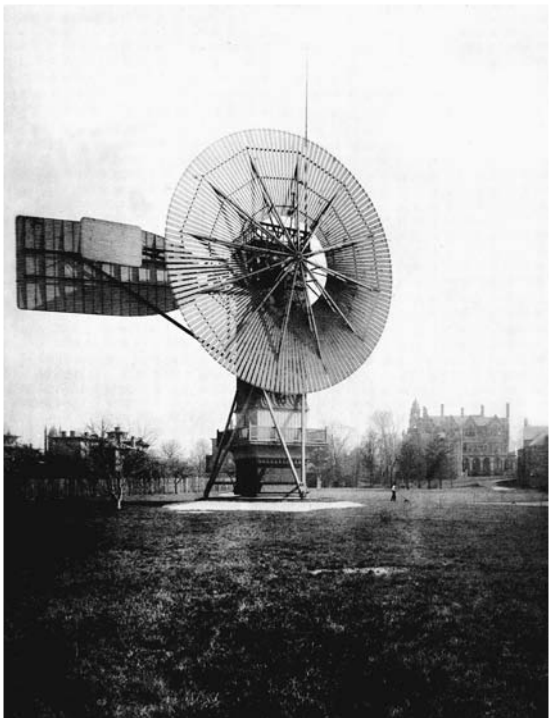


FIGURE 6.

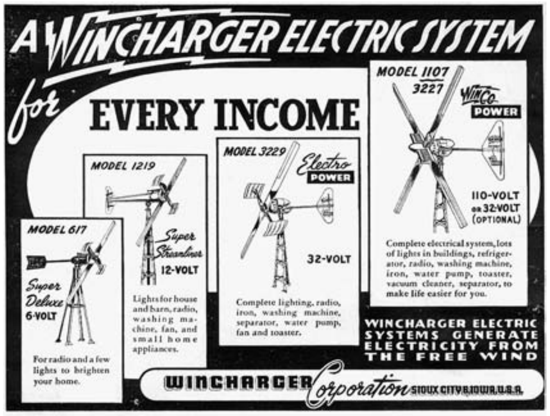


FIGURE 7.

turbines rated voltage, commonly 32 vdc, to work together with the turbines. Also notable in this period was the Jacobs wind turbine, which is still in production today with units to 20 kW.

In 1936 the Roosevelt administration passed the Rural Electrification Act, which spread electric power lines across rural areas. This program was very successful, and electricity from a utility was now inexpensive. Most electric wind systems, now deemed unnecessary, faded out of use and popularity.

The second wind energy boom came about after the 1973 oil embargo. With energy prices rising and an unknown energy future, many people regained interest in renewable energy. Often the old Winchargers and Jacobs units were dusted off, rebuilt, and reinstalled. Many new companies sprung up as well with grid connection being the goal rather than 32vdc systems with special appliances. It was during this period into the mid-1980s that many of the popular turbines of present day were introduced including the Bergey Excel 10 kW, the Entegrity Wind 50 kW (derived from Enertech & Atlantic Orient Corporation), and some models of Southwest Windpower units (derived from World Power Technologies units). There was also much research and design time put into prototype designs such as giromills, savonius, and other vertical axis machines.

Small Wind Certifications and Standards

It is important to know and consider while looking at turbines available on the market that there is currently no real standard or "seal of approval" to ensure that the turbine has any quality whatsoever. A purchaser must be armed with knowledge of the subject, able to distinguish real specifications and ask questions.

Questions to ask:

- Is there a power curve?
- What wind speed is the power rating specification?
- Has there been any third party testing performed?
- Where can I see the test results?

Demand to see real installation photos and case examples. There are other things to consider as well, such as how long the product has been made, and how long the company has been in business. However, with so many start-up and prototype turbines in the market it would be unfair to discount them on the whole just for being new. The best design available for your application may be a new design. By asking and seeing test results, one can at least see the science and data behind their claims and be able to make an educated decision.

Although there is no current testing and production standard, there is work being done branching out from the AWEA for small wind turbine certification. The independent group that is assuming this role is called the Small Wind Certification Council or SWCC (www.smallwindcertification.org).

The goal of the SWCC is to create a standard method of testing that allows them to put their certification upon turbines. These certification labels will feature a rated annual energy output, a rated power, and sound level. With standard testing and standard labeling of these specifications, it will help tremendously in the selection and quality production of turbines.

Tax Credits

State State incentives for renewables vary greatly. There is a very useful web site database that keeps track of U.S. state incentives for renewables. This database project is funded by the U.S. Department of Energy and implemented by Interstate Renewable Energy Council along with the North Carolina Solar Center. Incentives offered in a particular state can be researched at the DSIRE web site in detail. They update their web site every week to keep up with changes (www.dsireusa.org).

Federal The 2009 American Recovery and Reinvestment Act (ARRA) and the Emergency Economic Stabilization Act of 2008 implemented some history making tax incentives for renewable energy. Text of the full ARRA bill is available at www.recovery.gov.

What directly applies to small wind installations and home construction as of this time is the following:

- 30% investment tax credit (ITC) for the purchase and installation of qualifying small wind electric systems rated 100 kW or less. (Through 2016)
- Business taxpayers (as defined in Section 45 and 48 of IRS code) who are eligible for the ITC can opt for a grant in lieu of the tax credit if the project is placed in service in 2009 or 2010 or if placed in service before the credit termination date (Jan 1, 2013) on properties that began construction in 2009 or 2010.
  - The grant does not constitute taxable income.
  - 50% of the grant reduces the property base.
- Workforce training: The ARRA includes $500 million to assist in worker training for renewable energy careers as specified in the Energy Independence and Security Act of 2007.

Incentives can make the difference in an installation being a financial loss or gain. It is important to research what incentives are available before considering a system.

SMALL WIND POWER APPLIED FOR PRACTICAL USE

There are a multitude of choices and possibilities for small wind turbine installations. A homeowner will likely be concerned about energy and monetary savings involved. Often the decision for the installation may be for reasons beyond science and logic. For example, a homeowner may just like the aesthetics, or a neighbor may have installed a system. A homeowner or business may want the visual effect of looking “green” and environmentally friendly. However, it is useful in every case to stand back and look at the science and data involved and see where an installation stands in a practical sense for economics of the system and to avoid surprises once the system is installed and performance is realized.

Simple Method of Assessing a Wind Turbine Location

Over the years there have been many studies of wind characteristics, and as a result there are wind maps available for most locations. Wind maps are useful tools to determine in a general fashion what the wind speed is in an area. However, in cases where the location is unusual topographically from the area, the map may under-predict or over-predict the wind speed.

Wind mapping has been performed extensively by the National Renewable Energy Laboratory for most states, and other states have had maps created either privately or through university programs. An index of state mapping is available at: http://www.windpoweringamerica.gov/wind_maps.asp.

FIGURE 8. From www.dsireusa.org.

DSIRE
Database of State Incentives for Renewables & Efficiency

Financial Incentives for Renewable Energy

State	Personal Tax	Corp. Tax	Sales Tax	Prop. Tax	Rebates	Grants	Loans	Industry Support	Bonds	Production Incentives
Federal	3-F	4-F				3-F	5-F	1-F		1-F
Alabama	1-S				3-U	1-S	1-S 1-U			1-U
Alaska						1-S	2-S			1-U
Arizona	3-S	1-S	1-S	2-S	6-U		2-U			
Arkansas										
California				1-S	6-S 36-U 3-L	1-S 1-L	1-S 1-U 3-L			1-S 2-U
Colorado			1-S 1-L	2-S	7-U 3-L	1-L 1-P	3-U 2-L	1-S		
Connecticut			2-S	1-S	2-S	4-S	2-S	2-S		
Delaware					1-S	2-S				
Florida		2-S	2-S	1-S	1-S 8-U 2-L	1-S	4-U	1-L		2-U
Georgia	1-S	1-S	1-S		6-U		3-U			1-U
Hawaii	1-S	1-S			2-U		1-S 2-U 1-L	1-S		
Idaho	1-S		1-S	1-S	2-U	1-P	1-S		1-S	1-P
Illinois				2-S	1-S 1-U	2-S 1-P				1-P
Indiana				1-S	23-U	1-S	1-U			
Iowa	1-S	1-S	1-S	3-S	15-U	1-S	2-S 1-U			
Kansas				1-S	2-U		1-S			
Kentucky	1-S	2-S	1-S		8-U		3-U 1-P			1-U
Louisiana	1-S	1-S		1-S			1-S			
Maine			1-S		1-S	1-S	1-S			
Maryland	3-S	3-S	2-S	4-S 6-L	3-S 1-L		2-S			
Massachusetts	2-S	3-S	1-S	1-S	2-S 3-U	3-S	1-S 1-U	2-S		1-P
Michigan				2-S	1-U	2-S		3-S		
Minnesota			2-S	1-S	2-S 9-U	1-S 2-U	5-S 1-U			1-S 1-U
Mississippi					4-U		1-S			1-U
Missouri		1-S			6-U		1-S 1-U			
Montana	3-S	1-S		3-S	4-U	1-U	1-S	2-S		1-P
Nebraska			1-S		2-U		1-S			
Nevada			1-S	3-S	1-S					
New Hampshire				1-S	1-S 4-U		1-S			
New Jersey			1-S	1-S	4-S 1-U		1-S 1-U			1-S
New Mexico	3-S	3-S	2-S					1-S	1-S	3-U
New York	3-S	1-S	1-S	2-S 1-L	5-S 4-U 1-L	2-S	2-S	2-S		1-S
North Carolina	1-S	1-S	1-S	2-S	1-U	1-S	1-S			1-U 1-P
North Dakota	1-S	1-S		2-S			2-U			
Ohio		1-S	1-S	1-S 1-L	4-U	6-S	1-L			
Oklahoma		1-S			1-U		3-S 1-U	1-S		
Oregon	1-S	1-S		1-S	7-S 17-U	1-S 1-P	1-S 9-U	1-S		1-U 1-P
Pennsylvania				1-S	1-S	4-S 1-U 3-L	2-S 1-U 5-L	1-S		
Rhode Island	1-S	1-S	1-S	2-S	1-U	1-S	1-S			1-P
South Carolina	1-S	2-S	1-S		1-S 2-U		4-U			1-S 1-P
South Dakota				3-S	4-U		2-U			
Tennessee				1-S		1-S	1-S 1-U			1-U
Texas		1-S		1-S	10-U		1-S	1-S		
Utah	1-S	1-S	1-S		6-U					
Vermont		1-S	1-S	1-S	1-S	1-S 1-U	1-S			2-U
Virginia				1-S				1-S		1-U
Washington			1-S		17-U	1-L 1-P	12-U	1-S		1-S 3-U 1-P
West Virginia		1-S		1-S						
Wisconsin			1-S	1-S	3-S 5-U	1-S 1-U		2-S		4-U
Wyoming			1-S		1-S 3-U					
District of Columbia					1-S	1-S				
Palau										
Guam										
Puerto Rico	2-S	1-S	2-S	1-S				1-S		
Virgin Islands					1-S	1-S				
N. Mariana Islands										
American Samoa										
Totals	35	38	34	61	284	61	115	25	2	42

F = Federal S = State/Territory L = Local U = Utility P = Private

Wind Classes

Wind maps are generally produced using the wind class system. The class system assigns a number, a wind power class, to each range of power available in watts per square meter (W/m^2) at 50 m.

Wind Power Class	Wind Power (W/m^2)	Speed (m/s)	Speed (mph)
1	0–200	0–5.6	0–12.5
2	201–300	5.7–6.4	12.8–14.3
3	301–400	6.5–7.0	14.5–15.7
4	401–500	7.1–7.5	15.9–16.8
5	501–600	7.6–8.0	17.0–17.9
6	601–800	8.1–8.8	18.1–19.7
7	801–2000	8.9–11.9	19.9–26.6

Utilizing a map such as the one in Figure 9, one can find the location and see what type of wind regime the location is predicted to be. In general, if in a Class 2 region or better, there is potential for on-site generation from small wind. If the terrain is flat, and the turbine is inexpensive, this information alone may be enough to justify installing a turbine with no additional information.

Detailed Assessment of a Wind Turbine Location

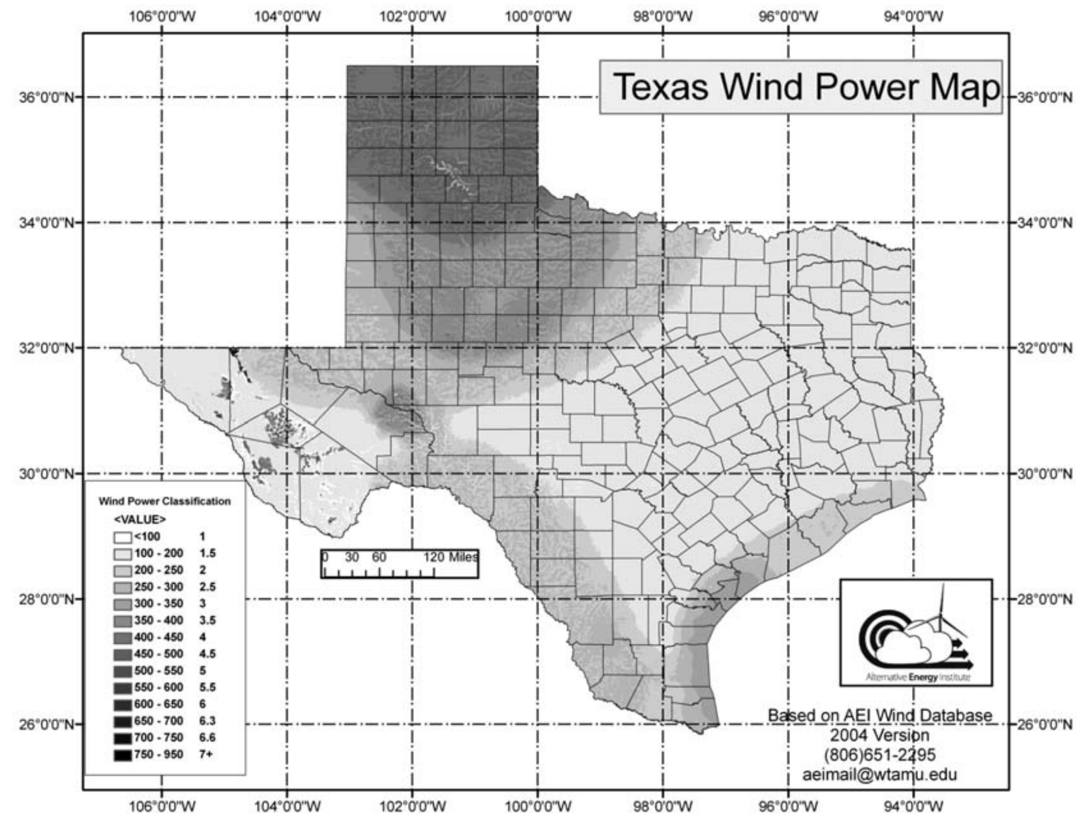
There are many sources of data available to the public that can be used for basic assessment needed to install a wind system. The key ingredients to predict any particular turbine performance are:

A. turbine power curve
B. air density
C. wind speed and direction data

A. Power Curve

A reliable and trustworthy turbine manufacturer should provide a power curve of some type upon re-

FIGURE 9. Texas Wind Class Map.



quest. Often it is included in the product brochure or online documentation. Depending upon the turbine, the data may be found in third party reports documenting tests performed on the units. If it can be obtained, a numerical power curve is desired in table form such as the following:

Example Numerical Power Curve
(Bergey Excel-S at Sea Level)

Wind Speed Bin (m/s)	kW Produced
1	0.00
2	0.00
3	0.03
4	0.26
5	0.56
6	1.00
7	1.62
8	2.51
9	3.49
10	4.59
11	6.00
12	7.46
13	8.78
14	9.74
15	10.20
16	10.03
17	9.83
18	9.15
19	8.70
20	8.30

Note that the windspeed is given in meters per second (m/s) and not in miles per hour (mph). Wind turbines are being sold and installed internationally and often the manufacturer will provide its information in SI units. It is important to give attention to the units and ensure that the units match when you are performing calculations and reading power curves.

B. Air density

Air density affects the potential power that a turbine can extract from the wind. When there is more density in the air, there is more physical matter in the specified area. With more matter in the same area, the wind can physically push the blades slightly harder. The result is that higher density air always will have the best efficiency for similar wind speeds. The simplest way to estimate overall site density is a direct correlation to elevation.

$$\rho = 1.226 - (1.194 \text{ x } 10^{-4})z$$

ρ = density
z = elevation in meters

This formula adjusts the density based upon the standard density at sea level. If the location is near sea level, simply use the standard number 1.226.

C. Wind Speed and Direction Data

Wind data can be obtained in more than one way. A small wind data collection setup can be installed to get exact results, or by using existing historical data. Real data from the location is always more precise; there is no question about that. With real data there is no doubt as to the winds to expect from which turbines expected output can be determined. The decision to be made then is whether the time and expense involved to take data is truly necessary. The size of the system and the time and costs involved must all be weighed in that decision. If you are planning to install a 400 watt turbine in which the installed cost rivals the cost of taking data, it is obvious to forego the data collection. If the decision is whether to install a 50 kW turbine in a marginal wind area, it may be prudent to take data.

When to take your own data on location:

- The location is in a marginal area on the wind maps (bordering class 2).
- The location is in a low class region, but has unique wind siting features such as:
    - Higher elevation than surrounding.
    - A large clearing on high ground.
    - A valley which funnels predominant wind.
    - Close to a lake which provides clearance.

Finding Historical Data

If the location is within 30 miles of another data site, in similar terrain, it can be very useful to utilize existing public data. With just a few minutes of Internet searching, one can often find local airport wind data or personal weather station data.

Some example websites to find historical wind data for multiple locations are:

Weather Underground
www.wunderground.com/history/

Weatherbase
www.weatherbase.com

It should be noted that all data collection sites are not created equal, and there is some risk in trusting outside data. Even an airport location may have shadowing that may not exactly indicate the resource on a particular location. Often there will be multiple data sites near a location, and can be cross compared for data quality assurance. Any data with some quality to estimate the power potential can be extremely useful, rather than relying upon a map or other qualitative indication.

Taking Your Own Data

In certain circumstances it may be needed or wanted to collect data for the small turbine installation. One may not trust, or be able to find nearby existing data. The location may have a unique setting such as an exposed ridge or hilltop that will give it unexpectedly high wind. It could be a very windy area in general, but the particular location is in a protected valley or canyon. These are all valid reasons for collecting independent data.

The data system chosen for collecting data to evaluate a small turbine will likely not be the same system used for monitoring wind data professionally. There are many grades of wind data collection equipment available ranging from $100 to over $100,000. Following are brief examples of systems in different price and quality ranges. These are only systems that are capable of time stamped data logging.

Any one of these units are capable of recording hourly averages, some with even finer detail of wind speed. The Davis unit and the Rainwise are the two listed that can also record wind direction, although the HOBO logger and the Inspeed have that option for additional cost. Wind direction is not as variable as windspeed in most locations so if wind speed data is collected, it may be possible to use wind direction data from another source.

Determining the Power Potential at Your Location

Now that wind data, the power curve, and the density are in hand, how can they be of use?

You should now have at least one of three sets of information to produce your power estimate. These are in order of certainty of your final result:

- Wind class, from a map
- Monthly wind averages
- Hourly wind data

We will continue to use the Bergey Excel 10 kW at 60 ft tall (18.3 m) as an example. Now we will add a location, which will be Amarillo, Texas.

It is important to understand that none of these estimations account for unpredictable maintenance events such as how much downtime there may be in the event of a malfunction or repair of equipment.

Product	Web Site	App. Cost	Description	How to Get Data
Inspeed	www.inspeed.com	$99	Anemometer, cables, and software.	Must be connected to PC for data collection.
APRS World Wind Data Logger Basic	www.aprsworld.com	$335	Stand-alone data logger, Anemometer, 1 GB SD card.	Removable SD data card.
Davis Instruments Wired Vantage Pro2	www.davisnet.com	$335	Anemometer, Wind Vane, temperature, rain gauge, humidity. (Wireless version $65 more)	Must be connected to PC for data collection.
Rainwise Windlog	www.rainwise.com	$350	Anemometer, data logger and software with 1 MB internal memory.	Internal data card. Must download with PC/MAC.
Onset Computer HOBO H21-002	www.onsetcomp.com	$553	Research Grade anemometer, Data Logger, software.	Internal data card. Must download with PC/MAC.

Using Wind Class to Estimate Power Production

If the only information you have is wind class, you can get an easy ballpark estimate of the power production of a turbine. The first thing you must consider in order to do this is the height of the turbine to be installed. Since the typical wind class map shows a 50 meter level of power and windspeed, you have to adjust that down to your turbines level.

Referring back to the wind map, Amarillo, Texas is in a class 4 location. Class 4 translates to 400–500 W/m^2. We will just use the center of that range at 450 W/m^2.

The formula used to perform this adjustment is the following:

$$WindClassPower_{location} = WindClassPower_{map} \times \left(\frac{\text{height}_{location}}{\text{height}_{map}}\right)^{\alpha \times 3}$$

Which gives us:

$$WindClassPower_{location} = 450\frac{W}{m^2} \times \left(\frac{18.3}{50\text{m}}\right)^{0.429} = 292.4\frac{W}{m^2}$$

That number is now power per area at the location and the height of this turbine. A reasonable estimate for α is to use 1/7 unless you have data of the true α at the location.

From many years of testing small turbines, AEI has determined the following simple formula to give a ballpark power number based solely on wind power from a map:

$$CF = \frac{\left(\frac{W}{m^2}\right)}{1450}$$

This is simply stating that the capacity factor is equal to the wind class power number divided by 1450. In Amarillo, the wind class is 4, which as we calculated equals 292.4 W/m^2. The resulting math is:

$$CF = \frac{292.4}{1450} = 0.20 \text{ or } \mathbf{20\%\ CF}$$

Now that you have the capacity factor estimated you can perform a simple calculation to apply that number to any turbine, in this case the 10 kW Bergey Excel. Assuming a Bergey rated maximum capacity is 10 kilowatts, if it were running at full production for 365 days/yr and 24 hrs a day, it would produce the following:

$$\begin{aligned} kWh &= 8760\ hours \times 10\ kW \\ &= 87{,}600\ kWh\ of\ power\ production \end{aligned}$$

By simply applying the capacity factor to the total theoretical production, we should have a close approximation of the production at this location.

$$87600\ kWh \times 0.20\ CF = 17664\ kWh$$

To derate the power according to the average density of the location, you can use the following formula:

$$\frac{\rho_{location}}{\rho_{sealevel}} = Kwh = kWh_{adjusted}$$

which in this particular case, the density is 1.10 producing the following:

$$\frac{(1.10\ kg/m^3)}{(1.225\ kg/m^3)} \times 17664\ kWh = 15862\ kWh$$

So, from this example it can be seen that although this is a good windy location, the density does reduce the amount of energy produced.

Once you have this quantification of the power produced, you can multiply this by the cost or credit received from the utility to perform a Return On Investment (ROI) calculation.

Using Monthly Averages to Estimate Power Production

If you happen to have data reflecting only the monthly averages near a location, this gives you an additional sense of certainty and the information can be calculated in a better method.

Following is a table of monthly averages from a data site in Amarillo, Texas. This data is taken at 25 meters (82 ft). The second column is the windspeed derated to the height of our turbine at 18.3 m using the following calculation:

$$windspeed_{turbine} = \left(\frac{\text{turbine}_{height}}{\text{data}_{height}}\right)^{.14}$$

Month	Measured(m/s)	estimated@18m
Jan	6.5	6.2
Feb	7.6	7.2
Mar	7.2	6.9
Apr	7.4	7.0
May	8.6	8.2
Jun	7.7	7.3
Jul	6.2	5.9
Aug	6.8	6.5
Sep	7.3	6.9
Oct	6.5	6.2
Nov	6.3	6.0
Dec	5.8	5.6

In order to use this with our Bergey power curve, reference the adjusted windspeed to the power output bin at that windspeed (see table below).

To calculate the estimated power per month the following formula was used:

$$\text{Production}_{\text{estimated}} = (\text{hours}_{\text{month}} \times kW_{\text{frompowercurve}}) \times 1.4$$

Since the higher winds in any distribution contain more power, multiplying the power by 1.4 on a monthly average adjusts to a reasonable estimation. This number, 1.4, was determined by calculating ten minute data on multiple sites and then determining the mean mathematical result to use for estimation purposes.

From this method, the average for the year is 16822.8 kWh.

To derate the power according to the average density of the location, you can use the following formula:

$$\frac{\rho_{\text{location}}}{\rho_{\text{sealevel}}} \times Kwh = kWh_{\text{adjusted}}$$

which in this particular case, the density is 1.10 producing the following:

$$\frac{(1.10\ \text{kg/m}^3)}{(1.225\ \text{kg/m}^3)} \times 16822\ kWh = 15106\ kWh$$

$$\text{CF} = (15106\ \text{kWh}/87{,}600\ \text{kWh}) = 0.17\ \text{OR}\ \mathbf{17\%}$$

Using Hourly Averages to Estimate Power Production

If you have a nearby data site from which you can obtain hourly averages, this will give you the most accurate power prediction of the three methods described here.

An example of the hourly data you may obtain is shown below:

Site Number	Date	Time	WS 1 average
406	1/1/2004	0:00:00	7.97
406	1/1/2004	1:00:00	7.91
406	1/1/2004	2:00:00	7.81
406	1/1/2004	3:00:00	6.95
406	1/1/2004	4:00:00	7.04
406	1/1/2004	5:00:00	5.13
406	1/1/2004	6:00:00	5.83

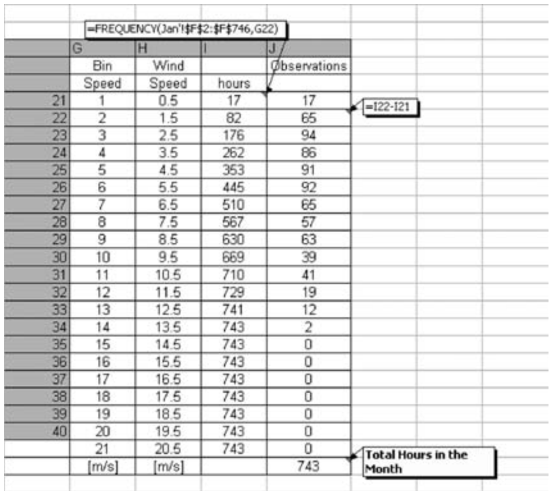
Month	Windspeed	Power Bin	Days in Month	Hours in Month	Estimated power(kWh)
Jan	6.2	1	31	744	1041.6
Feb	7.2	1.62	28	672	1524.1
Mar	6.9	1.62	31	744	1687.4
Apr	7.0	1.62	30	720	1633.0
May	8.2	2.51	30	720	2530.1
Jun	7.3	1.62	30	720	1633.0
Jul	5.9	1	31	744	1041.6
Aug	6.5	1	30	720	1008.0
Sep	6.9	1.62	30	720	1633.0
Oct	6.2	1	31	744	1041.6
Nov	6.0	1	30	720	1008.0
Dec	5.6	1	31	744	1041.6

The first thing to consider, as before, is what height the data is taken compared to the height of the turbine install. The windspeed numbers must again be adjusted as they were in the monthly estimation.

Site Num	Date	Time	WS 1 ave	WS 1 Estimated @18m
406	1/1/2004	0:00:00	7.97	7.60
406	1/1/2004	1:00:00	7.91	7.55
406	1/1/2004	2:00:00	7.81	7.45
406	1/1/2004	3:00:00	6.95	6.63
406	1/1/2004	4:00:00	7.04	6.72
406	1/1/2004	5:00:00	5.13	4.89
406	1/1/2004	6:00:00	5.83	5.56

Using a spreadsheet can organize this large amount of data in such a way that it is useful. The data can be sorted into bins that reflect the same wind speeds as the power curve. The frequency command counts how many times the wind occurs within a bin, and in the observations column, it subtracts all of the relevant data from the total.

FIGURE 10.



=FREQUENCY(Jan'!$F$2:$F$746,G22)

	G	H	I	J
	Bin Speed	Wind Speed	hours	Observations
21	1	0.5	17	17
22	2	1.5	82	65
23	3	2.5	176	94
24	4	3.5	262	86
25	5	4.5	353	91
26	6	5.5	445	92
27	7	6.5	510	65
28	8	7.5	567	57
29	9	8.5	630	63
30	10	9.5	669	39
31	11	10.5	710	41
32	12	11.5	729	19
33	13	12.5	741	12
34	14	13.5	743	2
35	15	14.5	743	0
36	16	15.5	743	0
37	17	16.5	743	0
38	18	17.5	743	0
39	19	18.5	743	0
40	20	19.5	743	0
	21	20.5	743	0
	[m/s]	[m/s]		743

=I22-I21

Total Hours in the Month

By combining your observations with the Bergey Excel, or any wind power curve, you can easily determine the estimated power production.

Bin Speed	Bergey Power(kW)	Observations(Hrs)	kWh
1	0	17	0
2	0	65	0
3	0.03	94	2.82
4	0.26	86	22.36
5	0.56	91	50.96
6	1	92	92
7	1.62	65	105.3
8	2.51	57	143.07
9	3.49	63	219.87
10	4.59	39	179.01
11	6	41	246
12	7.46	19	141.74
13	8.78	12	105.36
14	9.74	2	19.48
15	10.2	0	0
16	10.03	0	0
17	9.83	0	0
18	9.15	0	0
19	8.7	0	0
20	8.3	0	0
		0	1327.97

The above example is only for the month of January, and you can see that the estimated total of 1328 kWh is higher than our previous monthly estimation of 1042 kWh for January. Capacity factor for the month of January compares 18% to 15% between the two. As mentioned before, the finer the resolution of your data produces the higher quality number, so the number to trust in this case is 18%. By binning the data this method results in an accurate presentation of the expected performance.

To achieve the yearly capacity factor, it is simply a case of reproducing the above Excel bin process for the 12 months. Below are the results of that process for this site:

Month	Kwh
Jan	1328
Feb	1713
Mar	1662
Apr	1693
May	2237
Jun	1800
Jul	970
Aug	1200
Sep	1567
Oct	1118
Nov	1303
Dec	1359

The total kWh is 17950 kWh, which equates to 17950/87600 = 0.2049 or **20% CF.**

To derate the power according to the average density of the location, you can use the following formula:

$$\frac{\rho_{\text{location}}}{\rho_{\text{sealevel}}} \times Kwh = kWh_{\text{adjusted}}$$

which in this particular case, the density is 1.10 producing the following:

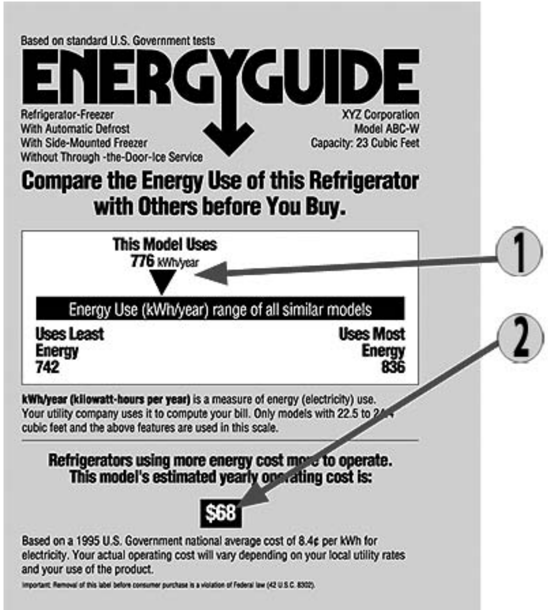
$$\frac{(1.10 \text{ kg/m}^3)}{(1.225 \text{ kg/m}^3)} \times 16822\ kWh = 15106\ kWh$$

CF = (16118 kWh/87,600 kWh) = 0.18 OR **18% CF**

CONSTRUCTION AND RETROFIT GENERAL CONSIDERATIONS

When considering a renewable energy system for a new or retrofit construction project, there are many

FIGURE 11.



practical questions to consider before beginning. The single idea that cannot be stressed enough is this: conservation of energy is *always* the most beneficial in economics and whole house system efficiency. Over the life of a building the addition of extra insulation, efficient appliances, solar design, and proper window placement will benefit the house as a system with overall low cost and negligible maintenance. Putting a wind turbine on a house that is not efficient is like pouring water into a bucket with a hole in it. You must first patch the hole, and then add water.

Earlier it was shown how to determine the amount of kWh that may be produced in a period of time. This is the primary item you need to know to size your wind system. The electric bill from an existing house will give you a record of the kWh consumed. Estimates can be made on new construction by using the major appliances for reference. Reference to the Energyguide labels from the DOE will usually give you an estimate of the kWh that the appliance will use.

1. Estimated energy consumption on a scale showing a range for similar models

2. Estimated yearly operating cost based on the national average cost of electricity.

There is a very useful web site, not affiliated with the DOE, called www.energyguide.com that includes a detailed program that will estimate the energy use of a home based upon several input criteria.

Once you can estimate the kWh consumption for a year, and know the production from a turbine in a year, it is simply a matter of subtracting the production from the consumption to size appropriately on a grid connected system.

Turbine Infrastructure

In many wind turbine designs the install will require an inverter and possibly a separate controller box that will tie into the user's electrical panel. Some grid-tie systems use a small "buffer" battery bank. Off grid, or backup stand-alone systems will require a large area for the battery bank. In new construction this can be planned into the design as a small control room closet, also planning the circuit breaker in the same room. This simplifies the electrical work of the turbine interconnection as well as keeping it in a location where the user can monitor the system periodically.

In such a situation where retrofitting is made to an existing home, the electrical situation will be different in every case. The primary consideration is keeping the inverter in an electrically safe environment—high and dry, and near an existing fuse panel or breaker box. In some locations there may already exist a garage, well house, barn, or outbuilding that can work to this advantage. Each turbine manufacturer will have specific installation instructions and electrical specifications to guide in the initial setup.

One of the popular turbine units today, the Southwest Windpower Skystream, has integrated its inverter into the nacelle of the unit. This eliminates this concern of the inverter location, and the electrician must simply use standard electrical code practices to wire the turbine to the breaker, just as with any appliance.

Safety

A renewable system provides unique challenges especially in an emergency situation. When installing the control panel, cutoffs, and turbine, it is important to label very explicitly where these things are located and make the homeowner aware. For instance, the tower can have a label leading to the closet or building, and the electrical breaker panel or separate disconnect should be labeled to indicate that it disconnects the wind turbine. During a fire or electrical malfunction this simple labeling can easily save lives and prevent further disaster.

Neighborly Concern

It is important to remember that when it comes to visible renewable energy units such as wind turbines, you may risk the chance of offending the neighbor. Opinions on the appearance of a turbine installation have strong currents on both sides of the issue. Be sensitive to the concerns of the neighbors.

As may be imagined, this issue is very unique to the situation. In rural areas, it is less likely to be a concern. However, it is prudent to take some steps to understand the situation in a particular installation.

- Talk with the neighbors. See where their opinion lies.
- Provide photos of the planned unit or examples of another installation.
- If you have data on the noise level, provide a comparison to something familiar. For example, "The turbine will be about the same sound level as an outdoor air conditioning unit."

NIMBY-ism

It is good to be aware of the term NIMBY, which means "Not in My Backyard" as it often applies to wind projects large and small. Basically what this might mean is that although the community and neighbors may generally like the idea of wind energy and renewable energy, they may not want to see it nearby. This may or may not apply to an installation, but it is important to distinguish the difference. Don't assume that because the neighbor works at a wind farm, or has talked proactively about wind energy that he will not have any issues with the installation at your project next door to him.

HOME INSTALLATIONS—RURAL AND SEMI-RURAL

Most restrictions to turbine installation occur in populated areas where height, safety, or aesthetics might be a concern. In rural areas, especially farming and ranching communities, there may be little or no permitting or zoning concerns. In this chapter we will take a look at these ideal types of scenarios where you can use science and data to put the turbine in the best location possible in terms of maximizing power output.

Utility Interconnection and Electrical Safety

The Public Utility Regulatory Policies Act of 1978 (PURPA) requires that public utilities allow connection and will purchase power from small wind energy systems. It is always important and necessary to contact the utility and see what requirements, paperwork, and details you may have to work out in order to get connected properly. Every utility is a little different in their procedures. While some will require 2 meters to show incoming and outgoing power, it is becoming more common to have one "smart" digital meter that can determine the flow in one unit.

It is important to remember that the PURPA law only requires *public* utilities to allow connection and purchasing of the power. If you are in an electric cooperative, it is not considered public; you will need to contact the coop and determine what exactly they require in their rules.

Some utilities have required homeowners to maintain liability insurance on small turbines. While this is relatively rare, it is important to determine if that is a factor in the economics involved in the turbine installation and interconnection.

The technology, efficiency, and reliability of modern grid connected renewable systems have made them one of the safest electrical systems that can be installed. It is important to understand what the safety requirements are in an installation. Any system must meet local and national electrical code. It is also important that the turbine must automatically stop supplying electricity to the grid in the event of a power outage. A grid connected inverter commonly takes care of this task internally. Most utilities will also require a well labeled, separate utility disconnect, to provide them a safety disconnect in the event of an emergency.

Example Scenario of Siting a Turbine Location

Imagine that you are presented with a piece of property of about 3/4 acre that is a candidate for a wind power system.

FIGURE 12. Some example small turbine installations in rural locations.

Southwest Windpower Air403, Colorado

Bergey 10 kW, Vermont

SWWP Skystream, California

FIGURE 13. Example property for turbine installation.

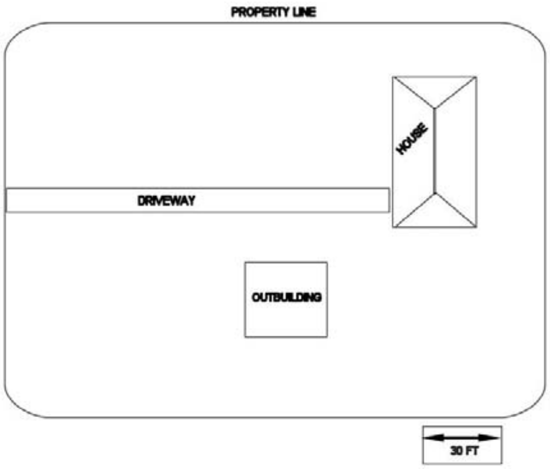
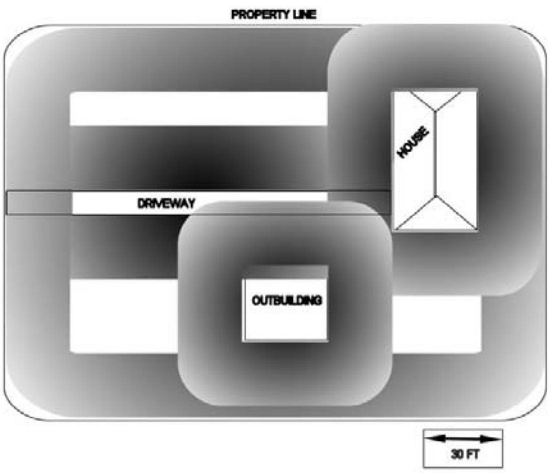
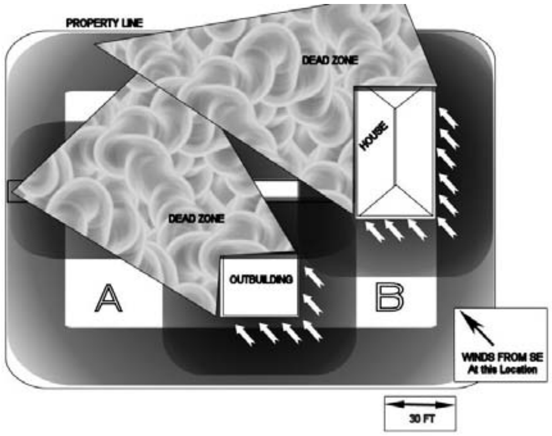


FIGURE 14. Example property for turbine installation with buffer zones in potential fall areas.



At first glance it may appear that there are many options to installing a turbine on this property. Let's begin narrowing it down according to criteria learned in previous sections. First of all, we need to know how tall the tower will be. In this case, let us assume it is a 30 ft tower. Remember, we do not want our tower to be installed in an area where it can potentially fall and affect the house, the property adjacent, the outbuildings, and possibly the road. Now, the road is a judgment call, since it is likely that no one would be on the road at the exact time an incident might occur, but play it safe in this example.

FIGURE 15. Example property for turbine installation with buffer zones in potential fall areas and showing predominant winds.

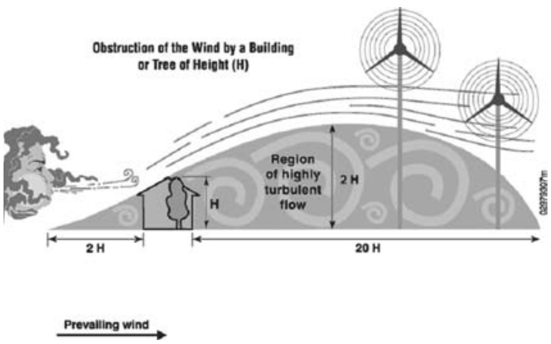


In the above illustration you can see that a 30 ft zone has been marked in grey near all locations that could be in danger should the tower fall. The zones without buildings or road that are left white in the illustration are the areas left with possibility of a turbine installation. In a properly installed small turbine it is very unlikely that an event will occur that will create a tower or turbine mechanical failure catastrophic enough to cause the tower to fall. Most small turbines are designed in their specifications to survive in winds over 100 mph. However, it is always best to plan on the safe side, and should the unlikely failure happen, the property will survive with less damage from the effort.

In our last illustration on this subject, you can see that we have added some wind and what is called "dead zones." The dead zones are areas that will be affected and degraded in some way by the shadowing of the predominant winds. This can have a significant difference in the overall production numbers of a turbine, and these zones should be avoided if at all possible.

You may ask, "How do I know what the predominant winds are in the area?" This is one place that the data research noted earlier comes to work for you. By observing the wind direction data over the year you can determine which direction the wind comes from most. If you have a fairly even tie between two directions, you may have to analyze a

FIGURE 16. U.S. Department of Energy Illustration.



little further and see which one of the tied directions then has the highest wind averages. The winds that blow most of the time with the hardest force contain the most power, therefore they are the ones you want to try and capture.

In the resultant illustration, the choice has been narrowed down to the blank areas east and west of the outbuilding, labeled A and B. Now the decision comes down to other considerations such as where electrical panels are located. If you have a good electrical source existing in the outbuilding, that may be a good choice. You must also consider what is on the property to the south. If there are buildings, trees, or other wind blockage to the southeast from either location, that may easily eliminate A or B. The illustration above depicts how the height of a structure affects the winds as it passes over.

Every case is unique and this simplified example covers most of the wind science involved. By avoiding the turbulent air flow, dead zones, and safety areas as much as possible, you can ensure a safe, low maintenance, and productive installation.

URBAN TURBINE

Using the energy at the point that it is delivered has always made sense. Thomas Edison preferred having lots of generator plants distributed throughout a city to a central site. But he was working with DC electricity, and when the AC became predominate the method of power transport moved from the locally produced and delivered to the central power plants and major transmission and distribution lines. Placing a renewable system on a structure then makes sense to use all its energy on-site and minimize the delivery to or purchase from the normal grid. To do this the use of parallel connection of the system to the grid calls for a synchronized inverter. This allows for the power to be in step with and same style and quality as that delivered by the utility, and the appliances inside the building will be able to use power from both sources. When the internal production is less that the total required from the structure, the utility supplies the rest. When there is excess energy the leftover is fed back to the grid. This can then be used by the next load on down the line and makes it imperative that the quality and form of the energy be as an exact match as possible to the utility provided power.

The worries that the typical home owner has to consider are the interconnection requirements of the utility system and the regulations regarding adding systems to the home or zoning requirements for the area. Many municipalities have limits on heights and noise so that the neighbors are protected from new structures affecting the enjoyment of their lands. Many cities have created ordinances for wind systems, to provide guidelines for land owners to meet so that the growth of these systems is allowed where they are suitable. In the Texas Panhandle the results have gone from city ordinances that allow wind systems on a case-by-case basis to allowing them only in certain zoning districts to outright rejection of any wind systems within the city limits.

For larger buildings the potential for rooftop installations increases with size; the higher winds with increased height means that a system will have greater performance if the mounting can expose the turbine to the better winds and not exceed the structural limits of the building. AeroVironment has been a leader in this type of building add on, the image in Figure 17 shows a typical rooftop installation for multiple small systems. They hope that the light weight (about 130 pounds each) and the sleek design leads to greater general acceptance as these types of installations are considered in more and more locations. They also stress that this style of multiple installations along the rooftop line can be done without penetrations into the roof, reducing the chance for leaks and weather intrusions into the building envelope. The disadvantage is from having multiple turbines to get the performance of one

FIGURE 17. AeroVironment installation on building at Logan Airport, this style is called Architectural Wind™ by the company.

larger turbine. The site at Logan Airport in Boston, MA takes 20 turbines of the type shown above to make the estimated 100,000 kilowatt-hours of energy for the facility to use on-site. A single turbine of 60 kilowatt rated power would be able to do this amount too but would need a 100 foot tower and would have a wingspan of 15 meters (49 feet).

RECS

Renewable energy from wind can be practical in rural areas and semi-rural. While it is possible to install turbines in urban areas, the practicality from a scientific viewpoint decreases as you install within an increasingly urban area.

The extreme example of such a situation would be an apartment in a large metropolitan city. How could such a dwelling benefit from green energy with little physical footprint available to allow any turbine installation?

This is where the concept of Renewable Energy Certificates (RECS) can be an option. These are also known as green tags, or green certificates. One REC represents 1000 kWh of produced energy. The certificates are bought from wind farms as a commodity and sold to businesses, the government, and can be purchased retail as well.

By purchasing RECS you can offset the power, or some percentage of power, used in a home or business. The power being produced for the RECS will be from a windfarm with multi-megawatt turbine arrays with possibly 45–50% CF. A rural home sized turbine may be producing power at a maximum of 20–25% CF. A roof mounted system in a modestly urban area may have a CF of 12–15%. Using RECS provides the benefit of a more efficient turbine without taking any of your land area.

The chart on the next page lists many retailers of RECS.

CLOSING SUMMARY

The Alternative Energy Institute has been researching and educating about wind energy since 1976. AEI reinforces the fact that conservation and using existing energy wisely is always the first and best option to be "green." After efficiency is taken care of, installing a wind turbine is one of the most cost effective ways to produce on-site energy in many places. By using national, state, and regional mapping and data, you can determine an area's potential. Every situation is unique and a method of narrowing down a location on a property is given, as well as how to estimate a turbine's production on this property. Often installing turbines within an urban area will prove to be impractical. In these situations there are other options such as purchasing Renewable Energy Certificates (RECS) to offset on-site energy with green energy produced elsewhere.

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Photos of example wind systems came from the NREL PIX public database.

National Retail REC Products (last updated May 2008).

Certificate Marketer	Product Name	Renewable Resources	Location of Renewable Resources	Residential Price Premiums*	Certification
3Degrees	Renewable Energy Certificates	100% new wind	Nationwide	1.5¢/kWh	Green-e
NativeEnergy	CoolWatts	100% new wind	Nationwide	0.8¢/kWh	Green-e
Ameren Energy Marketing (AEM)	AEM 5% Renewable Energy	various	Nationwide	2.0¢/kWh	—
Bonneville Environmental Foundation	Wind & Solar Green Tags Blend	50% new wind, 50% new solar	Nationwide	2.4¢/kWh	Green-e
Bonneville Environmental Foundation	Wind Green Tags	100% wind	Nationwide	2.0¢/kWh	Green-e
Bonneville Environmental Foundation	Denali Green Tags (Alaska only)	100% new wind	10% Alaska, 90% Nationwide	2.0¢/kWh	Green-e
Carbonfund.org	MyGreenFuture	99% new wind, 1% new solar	Nationwide	0.5¢/kWh	Green-e
Choose Renewables	CleanWatts	100% new wind	Nationwide	1.7¢/kWh	Green-e
Clean and Green	Clean and Green Membership	100% new wind	Nationwide	1.6¢/kWh-3.0¢/kWh	—
Community Energy	NewWind Energy	100% new wind	Nationwide	2.5¢/kWh	Green-e
Enpalo	US CleanGen	100% new wind	Nationwide	1.0¢/kWh	Green-e
Good Energy	Good Green RECs	various	Nationwide	0.4¢/kWh-1.5¢/kWh	Green-e
Green Mountain Energy	BeGreen RECs	wind, solar, biomass	Nationwide	1.4¢/kWh	—
Juice Energy	Positive Juice - Wind	100% wind	Nationwide	1.1¢/kWh	Green-e
Maine Renewable Energy/Maine Interfaith Power & Light	Maine WindWatts	100% new wind	Maine	2.0¢/kWh	Green-e
Mass Energy Consumers Alliance	New England Wind Fund	100% new wind	New England	~5.0¢/kWh (donation)	—
Premier Energy Marketing	Premier 100% Wind REC	100% wind	Nationwide	0.95¢/kWh-2.0¢/kWh	Green-e
Renewable Choice Energy	American Wind	100% new wind	Nationwide	0.5¢/kWh	Green-e
SKY energy, Inc.	Wind-e Renewable Energy	100% new wind	Nationwide	2.4¢/kWh	Green-e
Sky Blue Electric	Sky Blue 40	100% wind	Nationwide	4.2¢/kWh	Green-e
Sterling Planet	Sterling Wind	100% new wind	Nationwide	1.85¢/kWh	Green-e
Village Green Energy	Village Green Power	solar, wind, biogas	California, Nationwide	2.0¢/kWh-2.5¢/kWh	Green-e
Waverly Light & Power	Iowa Energy Tags	100% wind	Iowa	2.0¢/kWh	—
WindCurrent	Chesapeake Windcurrent	100% new wind	Mid-Atlantic States	2.5¢/kWh	Green-e
WindStreet Energy	Renewable Energy Credit Program	wind	Nationwide	~1.2¢/kWh	—

Notes:
* Product prices are updated as of May 2008. Premium may also apply to small commercial customers. Large users may be able to negotiate price premiums.
** Product is sourced from Green-e and ERT-certified RECs. ERT also certifies the entire product portfolio.
*** The Climate Neutral Network certifies the methodology used to calculate the CO_2 emissions offset.
NA = Not applicable.
Source: National Renewable Energy Laboratory.