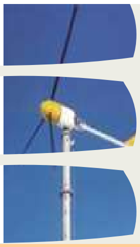


REV 1 | 2009

Small Wind

Terms & Definitions

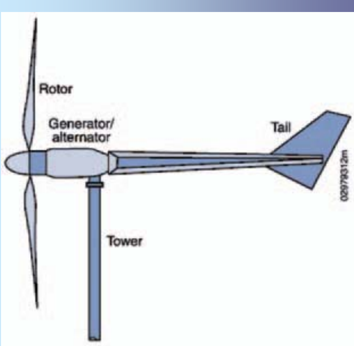
Blades: Most turbines have 2-3 blades. Wind blowing over the blades causes the blades to "lift" and rotate.

BOS: Balance of System—typically denoting all components other than the turbine, tower, inverters and batteries as applicable.

Brake: A disc brake which can be applied mechanically, electrically or hydraulically to stop the rotor in emergencies.

Controller: The controller starts up the machine at "cut-in" wind speeds (minimum forces for turbine operation) and shuts off the machine at "cut-out" wind speeds (to prevent damage).

Conversion Efficiency: The ratio of output power to input power (e.g. generator)



Gear Box: Gears connect the low-speed shaft to the high speed shaft and increase the rotational speed to the generator to produce electricity.

Generator/Alternator: Typically induction generator to produce 60-cycle AC electricity.

High-Speed Shaft: Drives the generator.

Inverter: Converts DC power from wind system to AC power for on-site use or net metering.

kW: kilowatt. Unit of turbine capacity.

kWh: kilowatt-hour. Unit of energy.

Low-Speed Shaft: The rotor turns the low-speed shaft

Met Tower: A meteorological tower, with instrumentation, erected to verify the wind resource found within an area.

MW: megawatt. Unit of turbine capacity.

MWh: Megawatt-hour. Unit of energy.

Pitch: Blades are turned, or pitched, out of the wind to control the rotor speed and keep the rotor from turning in winds that are too high or too low to produce electricity.

Rotor: The blades and the hub together are called the rotor.

Net Metering: Feeding of produced energy into the utility grid and selling to utility (runs meter backwards). Net bill to customer is the difference between energy used and energy produced.

Terms & Definitions (cont.)

Swept Area: Of the rotor is the area of the circle "swept" by the blades in square meters or square feet.

SWCC: Small Wind Certification Council is an independent 3rd-party organization that will begin "certifying" wind turbines in 2009 to a performance, reliability & safety standard.

Tail: Acts like a wind vane on turbines, allowing the wind to position the rotor into the wind.

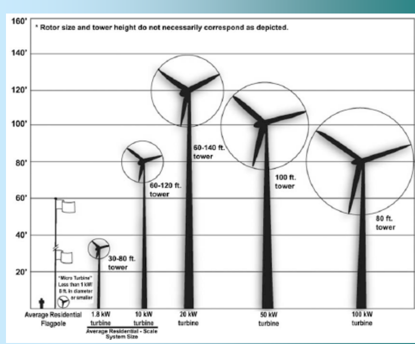
Tower: Towers are made of tubular steel, concrete, or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

Turbine Capacity Factor (CF)—Capacity factor is the energy conversion efficiency of the turbine. It is dependent upon wind speed vs. the optimum performance characteristics of the turbine (shown on a turbine's performance curve).

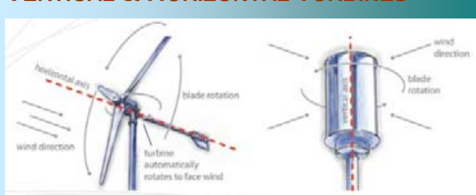
Wind Power Density (W/m^2): The amount of power available from wind at a given speed. With area (m^2) denoting the swepted area of the rotor.

Wind Shear: The change in wind velocity with elevation above ground (see the 1/7th Rule in Calculations).

Rotor Size & Heights



Vertical & Horizontal Turbines

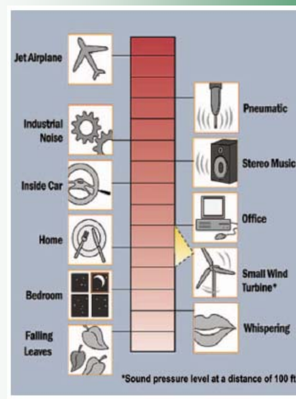


Turbine Market Segments

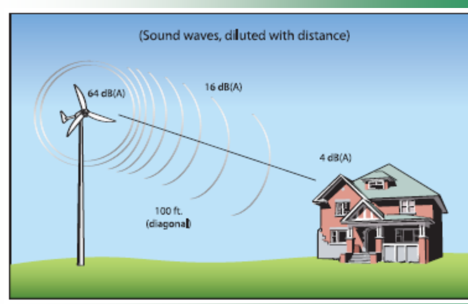
Wind Turbine Market Segmentation		
Turbine Size Range	**Applications**	**Barriers**
Small (<10 kW)	Residential, off-grid	Zoning
Intermediate (10 kW - 500 kW)	Wind/diesel, industrial	Zoning
Large (500 kW - 5 MW)	Grid interconnect	Transmission and access; operational impacts
Very Large (>5 MW)	Offshore grid interconnect	Cables to shore, viewshed, new regulatory

Turbine Noise Levels

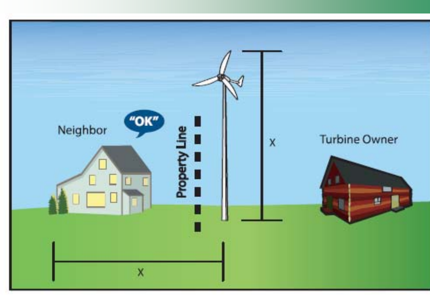
Sound decreases 4-fold with every doubling of distance from the turbine hub to the listener (direct diagonal distance).



Sound Level Comparison



Wind Turbine Location for Noise



Is your rural property suitable?

There are some relatively simple things you can do to assess whether your property is suitable for a small wind turbine.

Consider the terrain

Turbines generally operate best on:

- areas with smooth, steady wind flows, as opposed to irregular, turbulent ones
- gaps, passes, gorges and valleys extending down from mountain ranges
- high elevation plains and hilltops, ideally with gentle surrounding contours
- exposed ridges and mountain summits
- coastlines and inland strips with minimum wind barriers and vegetation.

Calculations, Production Variables & Wind Power Classifications

Energy Production Variables

Wiring Losses: Roughly 3-5% loss in system performance.

Battery-Based Systems: 10% loss due to need for small trickle charge to maintain float voltage. DO NOT MIX BATTERY TYPES.

Inverter Efficiency: Approximately 85% for battery-based systems; 90% for batteryless systems.

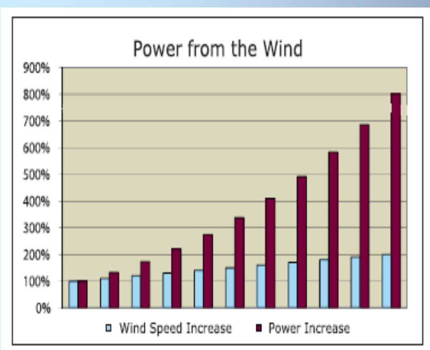
Capacity Factor (CF)—Should choose turbine for a CF range of 15-35% in the given wind regime. Higher CF values used in application calculations are suspect and should be checked with manufacturer.

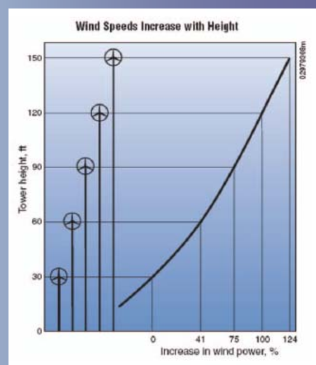
Wind Velocity vs. Power—Power density varies as a cube of the wind velocity:

$P_w = \rho\, v^3/2$ watts per m^2 where; ρ = density of wind

Because not all wind power density is available for useful work; the ***maximum power*** that can be extracted from a wind stream is:

$0.593\, P_w$ = the Betz limit





Wind Shear—The 1/7th Rule (Wind Velocity vs. Elevation Above Ground)—Turbine height is the most important factor in the economic viability of a small wind turbine The increase of wind velocity with elevation (wind shear) is a function of surface roughness, wind speed, and atmospheric stability. It can be approximated by:

$v(h_2) = v(h_1) \times (h_2/h_1)^{1/7}$

For more precise calculations:

$v(h_2) = v(h_1) \times (h_2/h_1)^{\alpha}$ where α= wind shear coefficient

Wind-Shear Coefficients

α	Description
0.1	Perfectly smooth (calm water)
0.2	Flat grassland or low shrubs
0.3	Trees or hills, buildings in area
0.4	Close to trees or buildings
0.5	Very close to trees or buildings
0.6	Surrounded by tall trees or buildings

Calculating Wind Speed from Known Data

Assume a Midwestern farm site, which is mostly flat grassland, has a wind-shear coefficient of 0.2 (α = 0.2) and your 50-foot-high anemometer (H1) has recorded an annual average wind speed of 15.6 mph (V1).

What annual average wind speed (V2) can you expect at turbine hub height on a 75-foot tower (H2)?

$$\frac{V_2}{V_1} = \left(\frac{H_2}{H_1}\right)^{\alpha};\ V_2 = V_1\left(\frac{H_2}{H_1}\right)^{\alpha};\ V_2 = 15.6\text{ mph}\left(\frac{75\text{ ft.}}{50\text{ ft.}}\right)^{0.2}$$

V_2 = 16.9 mph

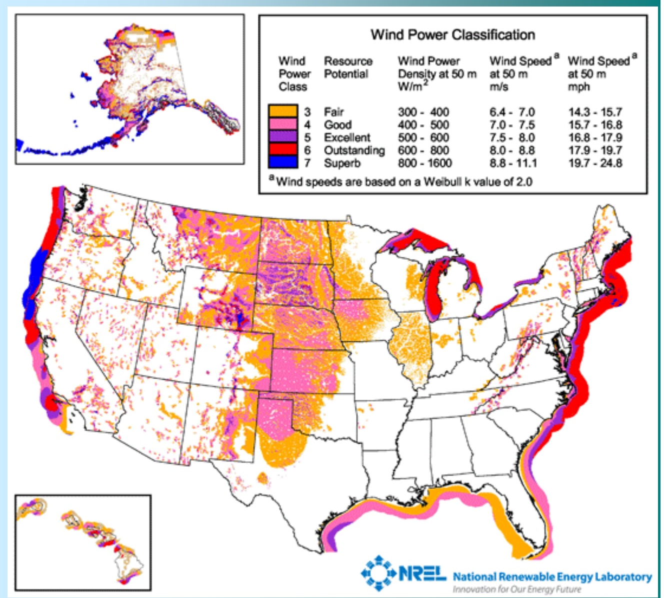
Energy Calculations

Annual Energy Output (AEO)

AEO	=	Power Density	X	Swept Area	X	CF	X	8760 h/yr
	=	253 W/m^2	X	38.5 m^2	X	20%	X	8760 h/yr
	=	17,000 kWh/yr						

Wind Power Classification

Wind resources are designated in groups called "classes" of wind ranging from Class 1 – 7. Each class denotes an annual average wind speed range (m/s or mph) and wind power density (Watt/m^2) for rotor swept area at different hub heights for given locations.



Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

[a] Wind speeds are based on a Weibull k value of 2.0

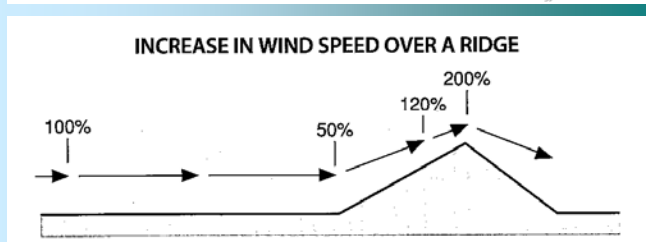
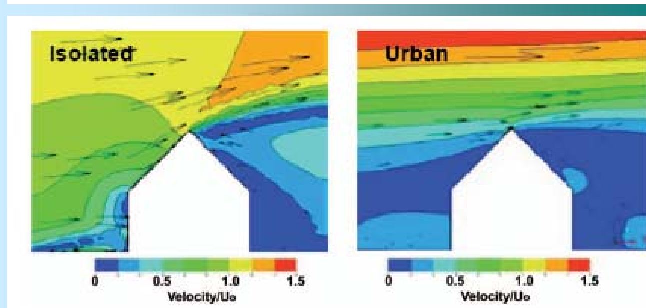


Figure 3-2. Variation in wind speed over a ridge. Wind speed increases near the summit of a long ridge lying across the wind's path. (Battelle PNL)



Other

Critical Factors

- Having good wind resource data—measured at site or local meteorological data (e.g. airport, neighbors small turbine)
- Turbine selection, size, height & location for local wind regime
- Siting and height of turbine for the least impact to flow & lowest turbulence
- Verification of energy calculations.
- Soil studies for adequate foundation/installation design.

Environmental Issues

- Visual Impacts—siting critical to mitigate
- Noise—location of turbines key
- Bird/Bat Impacts—minimal concern with small wind turbines

Market Status

- Commercially available turbines and BOS.

Calculations/Engineering Review

Wind Flow Disturbance Area

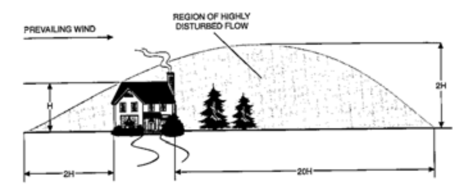
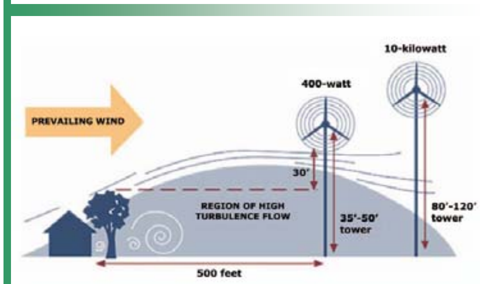
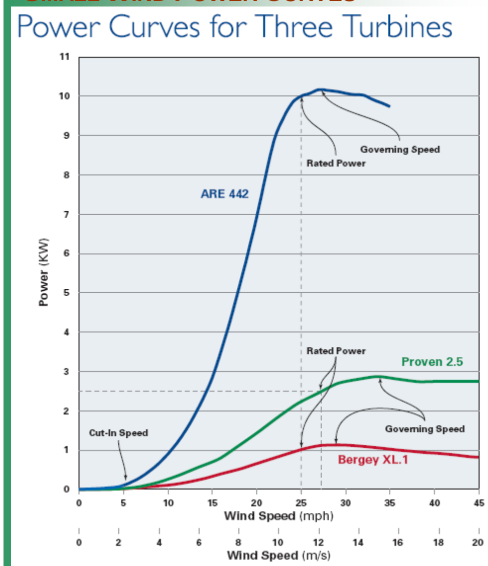


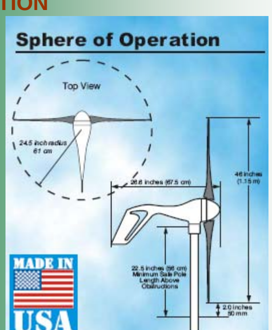
Figure 13-2 Zone of disturbed flow. Wind speeds decrease and turbulence increases in the vicinity of obstructions. The effects are most pronounced downwind but also occur upwind as the air piles up in front of the obstruction. The flow over a hedgerow or group of trees in a shelter belt is disturbed in a similar manner.

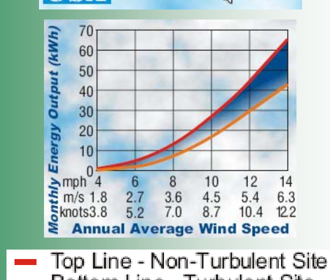


Small Wind Power Curves



Example Small Turbine Spec Sheet Information





Rules of Thumb

Wind Resource Date—Energy output is very sensitive to average wind speeds at the site. A 10% reduction in wind speed can mean a 30% drop in energy output.

Turbine Height—The bottom of the turbine rotor should clear the highest wind obstacle (e.g. roof, tree) within a 500 ft radius by 30 feet minimum.

Independent Structural Analysis— Independent analysis of the tower and it's foundation are available from the manufacturer. Requiring additional studies is unnecessary and cost prohibitive for the owner. Turbines are engineered to withstand hurricane force winds (110-120 mph).

Aesthetics—Aesthetic impacts of turbines may be unacceptable in historically significant areas. Zoning laws must be checked.

Utility Outages—Turbines and/or inverters are designed to shut down automatically during utility outages and will not energize a dead power line.

Over-Speed Protection—Turbines are equipped with manual and automatic over-speed protection devices to keep the turbine operating within a controlled range of speeds.

Electrical Safety/Permitting—The applicant must submit a line diagram of the electrical components, with sufficient detail, to the local zoning board for determination of whether the proposed installation method conforms to code requirements.

Maintenance Requirements

- Tighten bolts to specific tightness on hub, generator suspension and nacelle.
- Inspect airfoils for cracks & report any immediately, noting type & severity.
- Check brake pads, replace if necessary.
- Change oil filters, lubricate hub axle, yawing mechanism, generator & transmission.
- Check oil level in transmission, take oil sample and send for analysis.
- Check starting current of generator.
- Check overspeed safeguards (aerodynamic brakes & mechanical breaks).
- Check cables, sensors, generator cooling fan.
- Clean area thoroughly.

Applicable Electrical Codes

- IEEE 1547
- UL 1741

Engineering Review

Review Steps

- Check commercial availability of key system components (vendor specification sheets must be supplied)
- Verify total system generation capacity (Watts)
- Confirm wind resource measurements & analysis, average annual wind speed and power density. Use NREL data. Actual site measurements and analysis for 12 months ideal.
- Confirm turbine/inverter sizing. Check the inverter manufacturer specification sheet.
- Verify the system design contains all key components and that they are adequately sized for the generation capacity (turbine, conductors (w/ sizing), overcurrent protection, charge controllers, disconnects, batteries, inverters, grounding, safety signage)
- Verify energy production calculations and derating factors.
- Review system installation and mounting methods.
- Confirm adequacy of O&M and decommissioning procedures.
- Confirm system installed cost ($/kW) is within a reasonable range.
- Calculate simple payback using stated utility rate, system costs minus any stated incentives/tax rebates, and calculated energy production.
- Confirm zoning allows for turbine of height specified with indicated setbacks & noise restrictions.
- Confirm turbine meets FAA requirements for height & lighting if near airports or air strips.
- Check that the installer confirmed local soil conditions meet the minimum requirements of the turbine/tower manufacturer for the foundation design specified. For turbines >20 kW, require a soil analysis & engineers stamp.

Non-Issues/"Red Herrings"

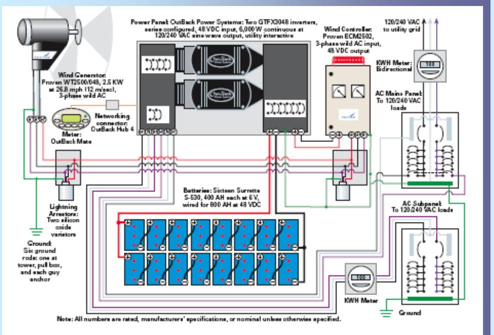
The following are common misconceptions about small wind:

- Shadow "flicker"
- Fences/attractive nuisance
- Birds/bats
- "Icing"
- Electrical signal interference
- Lightning strikes
- Stray voltage

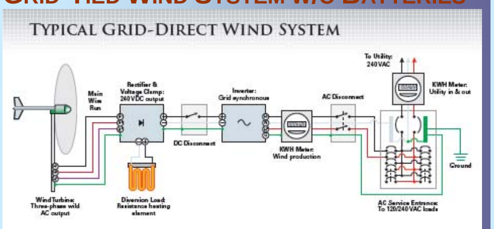
Installation

Calculations/Engineering Review

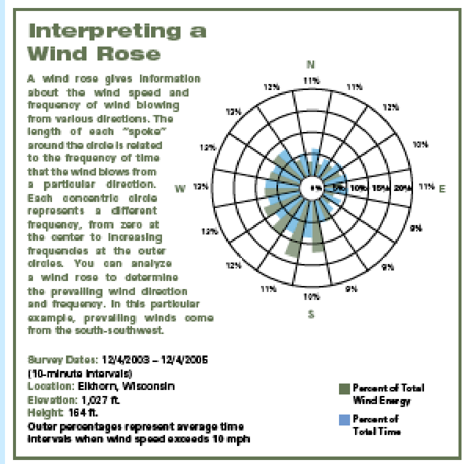
Grid-Tied Wind System w/ Batteries



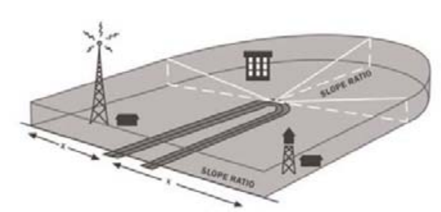
Grid-Tied Wind System w/o Batteries



Wind Resource Assessment



FAA Siting Requirements

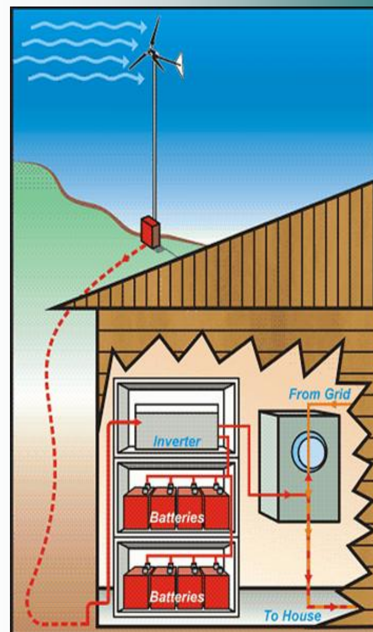


Criteria for aviation obstructions that trigger FAA notification and permit:

- *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

Pictorial Examples of Small Wind Systems



Other

System Design Review Calculations

Wind Farmers Discussion Forums

The Wind Farmers Network is a discussion forum for those interested in wind power to exchange ideas and information about wind power resources, economics, technology, and how to develop a wind project.
http://www.windustry.com/networks/wind-farmers-network/wind-farmers-network

NREL GIS Data

Data for GIS software for wind, solar, biomass and transmission line resource assessments.
http://www.nrel.gov/gis/data_analysis.html

State Wind Activities

Information on state activities for wind development.
http://www.nrel.gov/gis/data_analysis.html

NREL Atlas of Renewable Energy

Wind resource data mapping.
http://mapserve2.nrel.gov/website/Resource_Atlas/viewer.htm

AWS Truewind Interactive Map

Wind resource data mapping.
http://navigator.awstruewind.com/

State Anemometer Loan Programs

Wind Powering America supports state and Native American anemometer loan programs. Anemometer data can help businesses, developers, farmers, ranchers, and homeowners determine if there is enough wind energy at their site to invest in a wind turbine.
http://www.windpoweringamerica.gov/anemometer_loans.asp
http://www.windpoweringamerica.gov/na_anemometer_loan.asp

Wire Sizing

Minimum wire sizing calculator
http://www.elec-toolbox.com/calculators/voltdrop.htm

AWEA Expert Advice

www.awea.org/faq/sagrillo

Costs/Financials

CostBreakdown (Rough Ratios)

Installation	=	?% of cost
Turbine	=	?% of cost
Tower	=	50% of cost
Engineering	=	5% of cost
O&M	=	\$15 - \$30/MWh/yr
Total Installed Cost	=	\$1,000 -- \$2,500/kWatt (Community Scale)
	=	\$2,500 – \$10,000/kWatt (Small Scale)

Life Cycle

10-15 years (last much longer)

Simple Payback

$$\frac{\text{(Total Installed System cost) + (Annual O\&M X Equip Life)}}{\text{(Annual System kWh generation) X (Utility Rate \$/kWh)}}$$

For a 10kW residential-scale turbine

Tower height (feet)	Wind speed (mph)	kWh/year	System cost	Incremental cost from 60′	Incremental energy output from 60′	Incremental energy ÷ incremental cost = ROI*
60	7.3	2,709	$48,665	—	—	—
80	9.3	6,136	$49,841	$1176 or 2.4%	226%	226% ÷ 2.4% = 94 to 1 ROI
100	10.7	9,338	$51,346	$2681 or 5.5%	344%	344% ÷ 5.5% = 63 to 1 ROI

* = Return on Investment   Mick Sagrillo, AWEA Windletter, January 2006