Renewable Energy Research Laboratory, University of Massachusetts at Amherst

Wind Power: Wind Technology Today

Wind Power on the Community Scale

Community Wind Power Fact Sheet # 1

RERL—MTC Community Wind Fact Sheet Series

In collaboration with the Massachusetts Technology Collaborative's Renewable Energy Trust Fund, the Renewable Energy Research Laboratory brings you this series of fact sheets about Wind Power on the community scale:

1. Technology
2. Performance
3. Impacts & Issues
4. Siting
5. Resource Assessment
6. Wind Data
7. Permitting

   Case Studies

Wind Power Technology for Communities

This introduction to wind power technology is meant to help communities begin considering or planning wind power. It focuses on commercial and medium-scale wind turbine technology available in the United States.

We also recommend a visit to a modern wind power installation – it will answer many of your initial questions, including size, noise levels, footprint, and local impact. Some possible field trips are listed on the back page.

Wind Power Today

Wind power is a growing industry, and the technology has changed considerably in recent decades. What would a typical commercial-scale* turbine installed today look like?

Design: - 3 blades
- Tubular tower

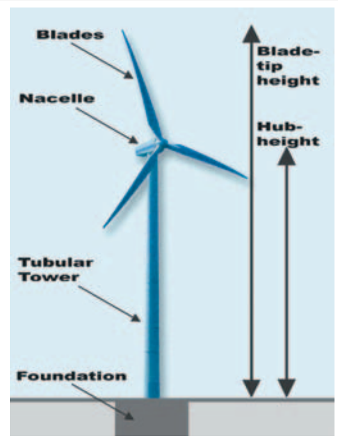
Hub-height: - 164 - 262 ft (50 - 80 m)

Diameter: - 154 - 262 ft (47 - 80 m)

Power ratings available in the US:
- 660 kW - 1.8 MW

** Other scales are discussed below.*

The focus of this series of fact sheets is medium- and commercial-scale wind.



A wind turbine's height is usually described as the height of the center of the rotor, or hub.

Size Ranges

What do we mean here when we say "community-scale wind power"?

Wind power can be divided into three size ranges, which are used for different applications. The focus of this series of fact sheets is medium and commercial-scale wind power. The size is chosen differently depending on the turbine's purpose. Typical sizes in the three ranges available in the US are:

Residential: below 30 kW
- Choose a size based on electrical load
- Diameter: 1 - 13 m (4 - 43 ft)
- Height: 18 - 37 m (60 - 120 ft)
- Example: 20,000 kWh/year

Medium: 30 - 500 kW
- May be sized to a load. Typically used when there is a large electrical load.
- Diameter: 13 - 30 m (43 - 100 ft)
- Height: 35 - 50 m (115 - 164 ft)
- Example: 600,000 kWh/year

Commercial scale: 500 kW - 2 MW
- Usually fed into the grid, not sized to a single load
- Diameter: 47 - 90 m (155 - 300 ft)
- Height: 50 - 80 m (164 - 262 ft)
- Example: 4,000,000 kWh/year

For comparison, an average Massachusetts household uses 7,200 kWh/year

Example annual production is for comparison only. Based on sea-level mean winds of 7m/s (15.6 mph); manufacturer's data for the following turbines: Residential: Bergey XL-S (7.5kW); Medium: Fuhrländer FL 250 (250 kW); Commercial: GE 1.5 SL (1500 kW) .

Inside this Edition: Technology

The Vocabulary of Wind Power

Turbine: a turbine is a device that converts the kinetic energy of a moving fluid into rotational energy (engineers call both liquids and gases "fluids" – i.e. things that flow). A wind turbine's blades use aerodynamic lift and drag to capture some of the wind's energy and turn the generator's shaft.

The main parts of a typical wind turbine are:

- *Rotor:* a wind turbine's blades and the hub to which they attach form the rotor.
- *Nacelle:* the frame and housing at the top of the tower. It protects the gearbox and the generator from weather, and helps control the mechanical noise level.
- *Tower:* a steel structure, typically tubular, with a ladder up the inside for maintenance access.
- *Base or foundation:* made of concrete reinforced with steel bars. Typically either a shallow flat disk or a deeper cylinder.

Other useful terms are:

Yaw: commercial-scale turbines have a motor to yaw, or turn the rotor to face into the wind. At high wind-speeds, they yaw out of the wind to protect themselves.

Up-wind turbines: Modern commercial turbines yaw themselves so the rotor is facing into the wind, i.e. upwind of the tower.

Cut-in speed: the wind speed at which a wind turbine begins to generate electricity. Typically 4 m/s (9 mph) for commercial wind turbines.

Cut-out wind speed: the high wind speed at which the turbine must shut down and turn perpendicular to the wind to protect itself from being overpowered. Typically 25 m/s (56 mph)

Variable-speed turbines: Some turbines incorporate power electronics that allow them to optimize their power output by varying their speed, for instance, from 10 to 20 rpm. Other types vary their speed little or not at all. Variable speed turbines increase their rotation speed in higher winds in order to optimize the aerodynamic efficiency.

Constant speed turbines keep their rotation speed more or less constant while the power and the torque change.

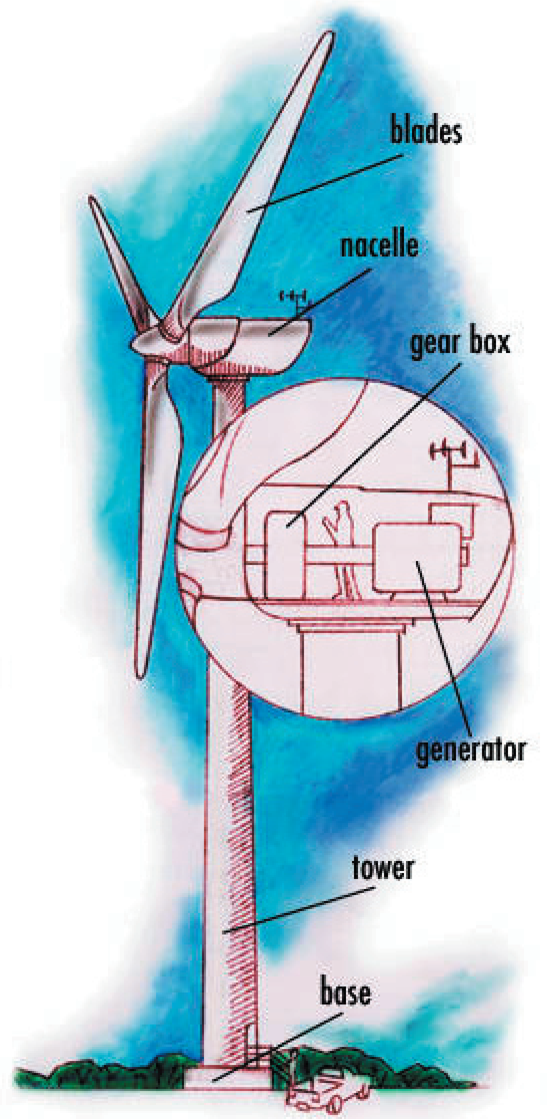


Diagram courtesy of James Rowe

Variable blade pitch: many turbines can change the angle of their blades to optimize performance.

Horizontal axis: All commercial-scale turbines today have the rotor turn around a horizontal axis. Historically, vertical axis turbines have been tested, such as the "Darrieus" egg-beater design, but have not been as efficient or able to survive high winds.

Penetration: The amount of wind energy in a given area of the grid, as a percentage of total production. In the US, wind penetration is under 1%. Northern Germany and parts of Denmark have penetrations of around 20% (2003 figures).

If you come across other unfamiliar terms or ideas, the Danish Wind Industry Association offers clear technical information in their "Guided Tour on Wind Energy": http://www.windpower.org/composite-85.htm.

The Power & Energy in Wind

The Power in Wind

The first law of thermodynamics tells us that energy can neither be created nor destroyed, but it can change forms. Anything that is in motion – such as moving air – contains a form of energy we refer to as kinetic energy. Slowing air down reduces its kinetic energy and that energy has to go somewhere. Wind turbines slow wind down and convert some of the energy to mechanical and electrical energy.

Kinetic energy is:

$$KE = \tfrac{1}{2} mV^2$$

where m stands for mass (in kg) and V stands for velocity (in m/s). This allows us to calculate the amount of power in moving air. The power of the wind passing perpendicularly through a circular area is:

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

Where:

P = the power of the wind (in Watts).

ρ = rho = the density of the air (in kg/m^3) (1.225 kg/m^3 for dry air at sea level)

V = the velocity of the wind measured in m/s

A = πr^2 = the area swept by the circular rotor, in square meters, and

π = pi = 3.1416...

r = the radius (half the diameter) of the rotor (in meters)

Betz's Limit on what we can extract

A wind turbine slows air down, but it cannot remove 100% of the air's kinetic energy – obviously the air cannot stop completely, or else it would pile up behind the turbine. In 1919, German physicist Albert Betz figured out that the upper limit to the amount of energy you can capture from the wind is 16/27 or about 59%. In practice, all real wind turbines extract less than this hypothetical maximum.

The Power from a Wind Turbine

The power a turbine actually gets from the wind is:

$$P = C_p \, \eta \, \tfrac{1}{2} \rho V^3 A$$

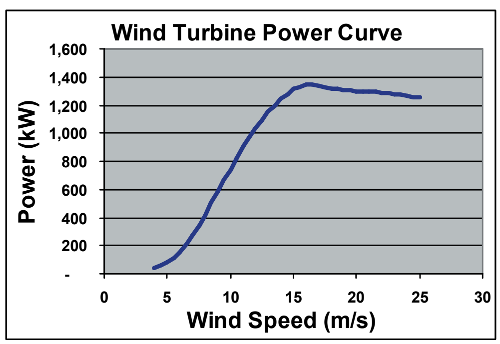
You can see that we have added two things to the original equation of the power in the wind:

C_p = the turbine's power coefficient

η = eta = the turbine's mechanical & electrical efficiencies.

C_p must be less than the Betz limit. In practice, it varies with wind speed, turbulence and operating characteristics; for example it could be around 44% for a commercial-scale turbine, in winds of 10 m/s. A typical overall efficiency, η, would be in the range of 90%.

To estimate the power output of a given commercial turbine, we do not have to use the power equation; rather we use power curves supplied by the manufacturer.



What does the power equation tell us?

Even though we do not use the power equation to calculate power output of a particular turbine, the power equation tells us useful information about significant factors that determine what we can get from a wind turbine:

V^3 : The power available in the wind is proportional to the cube of the wind speed. There is *much* more energy in high-speed winds than in slow winds. Small changes in wind speed make big changes in power.

A : Power is proportional to the swept area, and to the square of the diameter. Doubling the diameter quadruples the available power.

ρ : Air density matters too. The lower density of warmer air, and air at higher altitudes somewhat reduces the power available in the wind.

Energy

is the ability to change oneself or one's surroundings

Power

is a rate of using or producing energy.

Power = energy / time

Units of Measure

A <u>kilowatt-hour</u> (kWh) is a unit of <u>Energy</u>

A <u>kilowatt</u> (kW) is a unit of <u>Power</u>.

So are watts, megawatts, and horsepower.

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Fuhrländer FL 250, 29.5 m diameter, photo courtesy Lorax Energy

Sources for Teachers & Kids

Spirit Lake, Iowa, has 2 wind turbines on their school grounds. The schools use the generators in their curricula: www.spirit-lake.k12.ia.us/dist/wind/index2.htm

The Danish Wind Industry Association includes a section for kids: www.windpower.org/en/kids/index.htm.

www.kidwind.org has curricula and links to other resources. So do www.energyforkeeps.org/ and www.re-energy.ca/t_windenergy.shtml.

GE has curricula, as well as a kids' link page: www.gepower.com/businesses/ge_wind_energy/en/kids_teachers/index.htm

Scholastic books offers wind energy activities for young children in their Magic School Bus series: place.scholastic.com/MAGICSCHOOLBUS/games/teacher/energy/

This website, http://www.horizonwind.com/about/ftkc/, includes introductions to wind energy on various levels.

See RERL's website, www.ceere.org/rerl/rerl_links.html, for a more complete list of teacher resources.

Nearby Wind Installations

A field trip to an installation is one of the best introductions to modern wind power.

▪ Hull, MA, 660 kW turbine at the high school, accessible any time. www.hullwind.org

▪ Searsburg, VT, tours in summer, (802)-244-7522 www.northeastwind.com/

▪ Madison, NY, 11.5 MW, http://www.horizonwind.com/projects/whatwevedone/madison.aspx

▪ Harbec Plastics, Ontario, NY, 250 kW turbine

▪ Fenner project in Madison County, NY, 30 MW, www.fennerwind.com & www.madisontourism.com

For More Information

Wind Energy Explained: Theory, Design and Application, Manwell, McGowan, & Rogers, Wiley, 2002

- RERL's website: www.ceere.org/rerl/ includes this and other fact sheets, www.ceere.org/rerl/about_wind/
- The Danish Wind Industry Association's website has thorough and very accessible technical information: www.windpower.org
- American Wind Energy Association: www.awea.org
- Renewable Energy Policy Project: www.repp.org/articles/static/1/binaries/wind_online_final.pdf
- Case studies of community wind: www.greenpowergovs.org/wind/Case%20Studies.html
- The Database of State Incentives for Renewable Energy (DSIRE) has a thorough list of Massachusetts incentives for wind power: www.dsireusa.org/

Community-owned wind turbine in Spirit Lake, IA