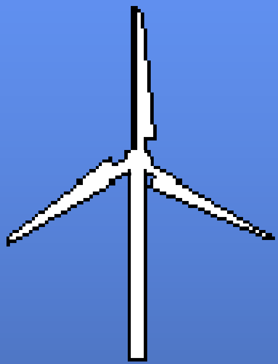
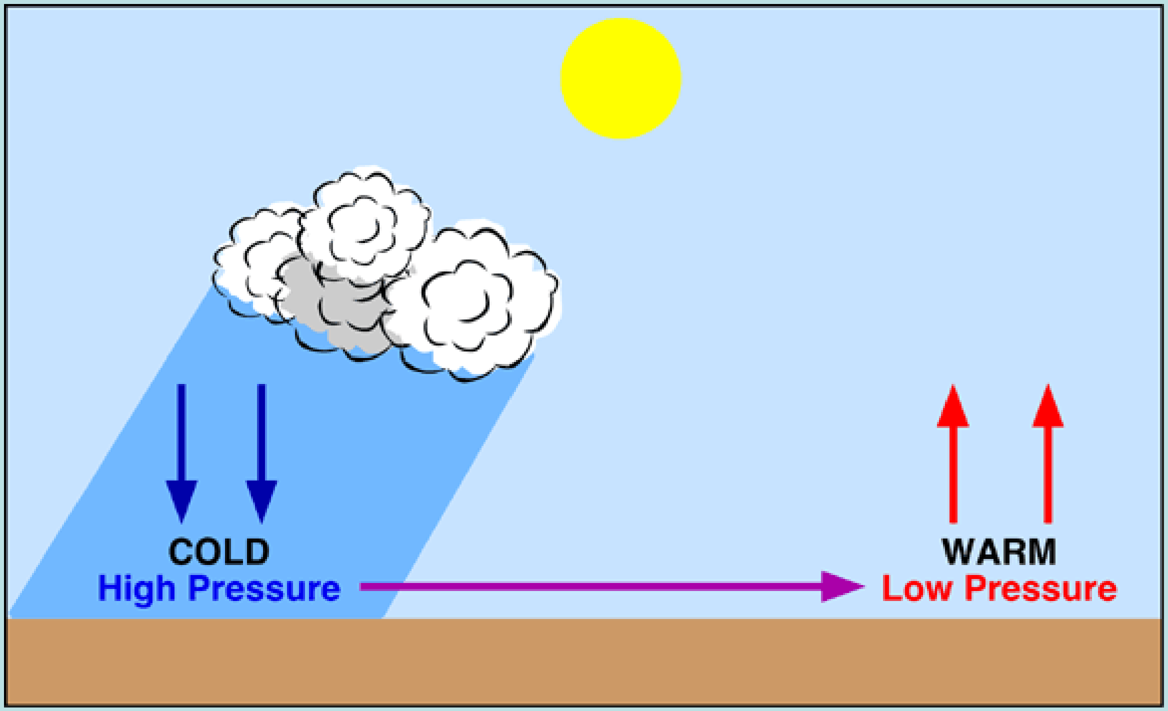


Wind Energy

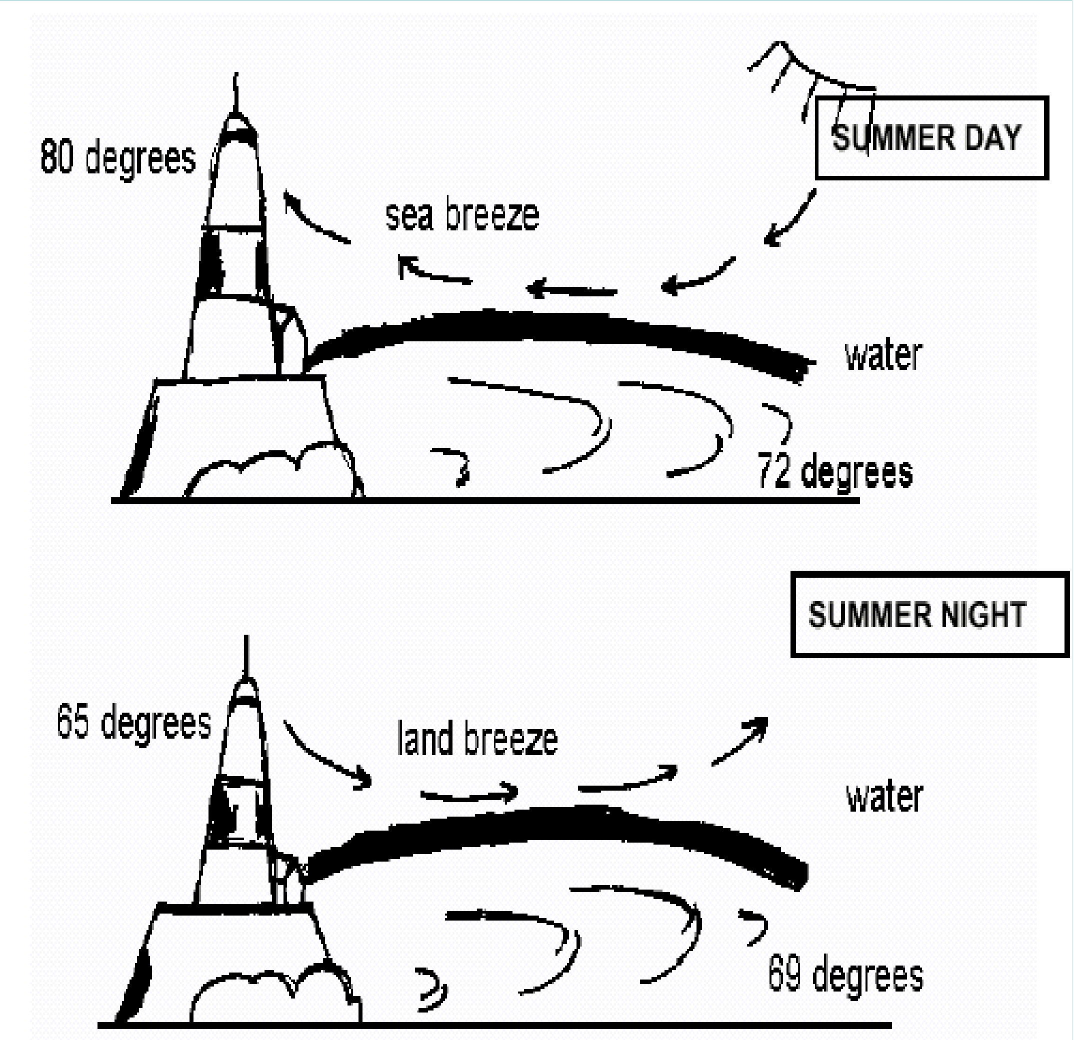
Principles of wind energy

- Wind energy is a converted form of solar energy. The sun's radiation heats different parts of the earth at different rates during the day and night. Also, different surfaces (for example, water and land) absorb or reflect heat at different rates. This in turn causes portions of the atmosphere to heat differently. Hot air rises, reducing the atmospheric pressure at the earth's surface, and cooler air is drawn in to replace it. The result is wind.

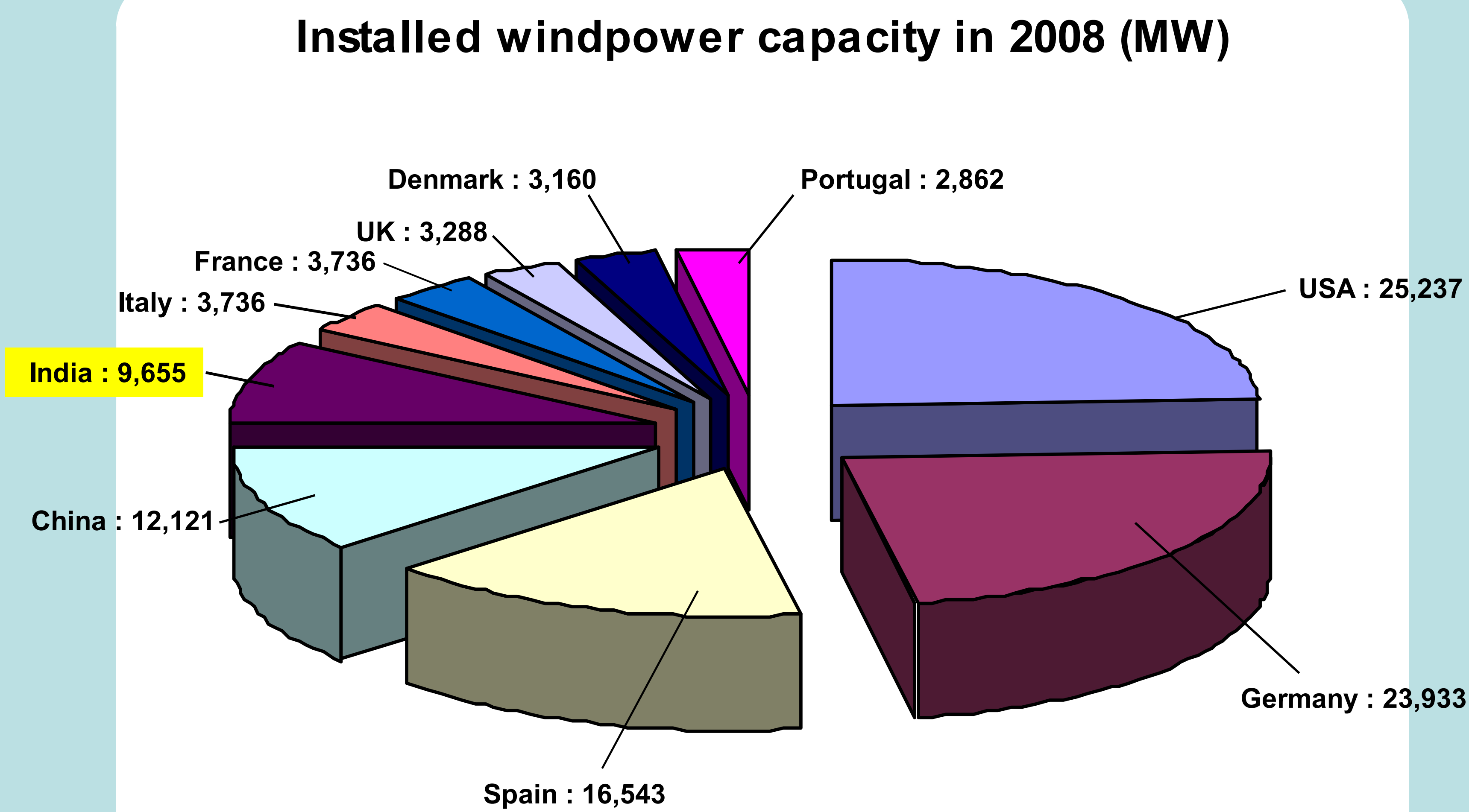


Principles of wind energy

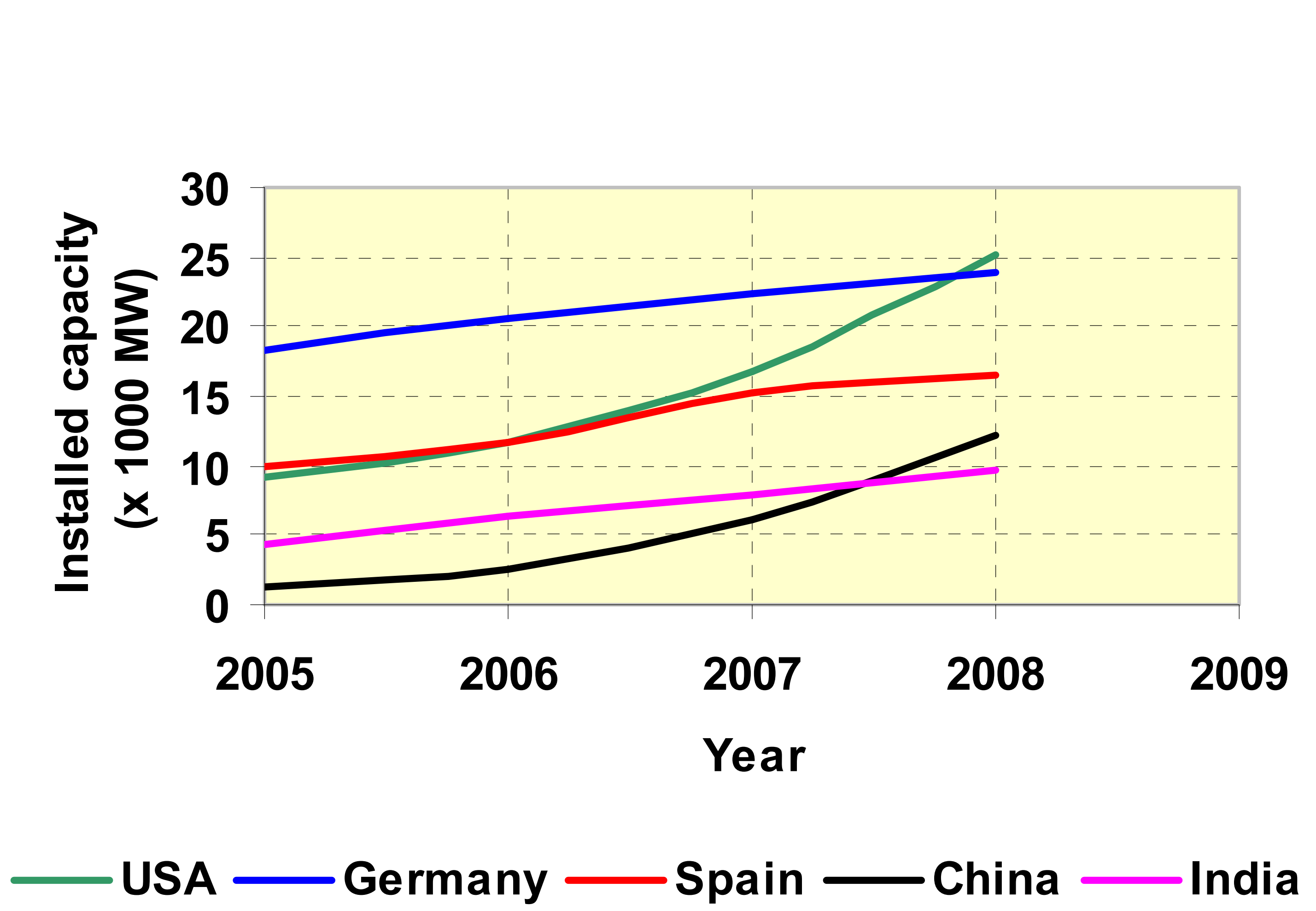
- Land-sea breezes created by temperature differentials
- Winds also stronger near shore because of long unobstructed travel
- Sea breeze typically strongest late in the afternoon



World wind energy scenario, 2008



Growth of wind energy power capacity - Top 5



Principles of wind energy

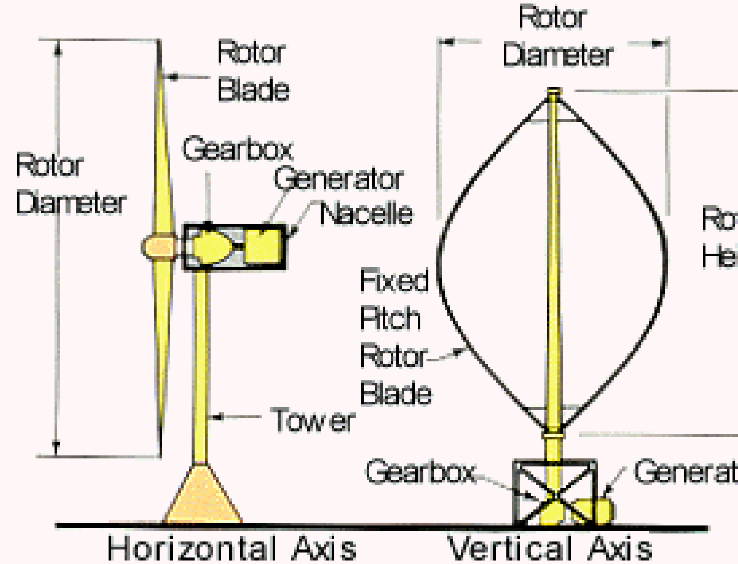
- Air has mass, and when it is in motion, contains kinetic energy. Some portion of that energy can be converted into other forms such as mechanical force or electricity.
- Mechanical energy is most commonly used for pumping water in rural or remote locations- the "farm windmill" can also be used for many other purposes like grinding grain, sawing, pushing a sailboat, etc.
- Wind electric turbines generate electricity for homes and businesses and for sale to electricity grids.

Principles of wind energy

- Today, the most common method of exploiting wing energy is to use wind turbine driven generators to produce electricity.
- Wind plants can range in size from a few megawatts to hundreds of megawatts in capacity. Wind power plants are "modular," which means they consist of small individual modules (the turbines) and can easily be made larger or smaller as needed.
- “Wind power plants” or “Wind farms” are groups of wind electric turbines in groups of large machines (~660 kW and above).

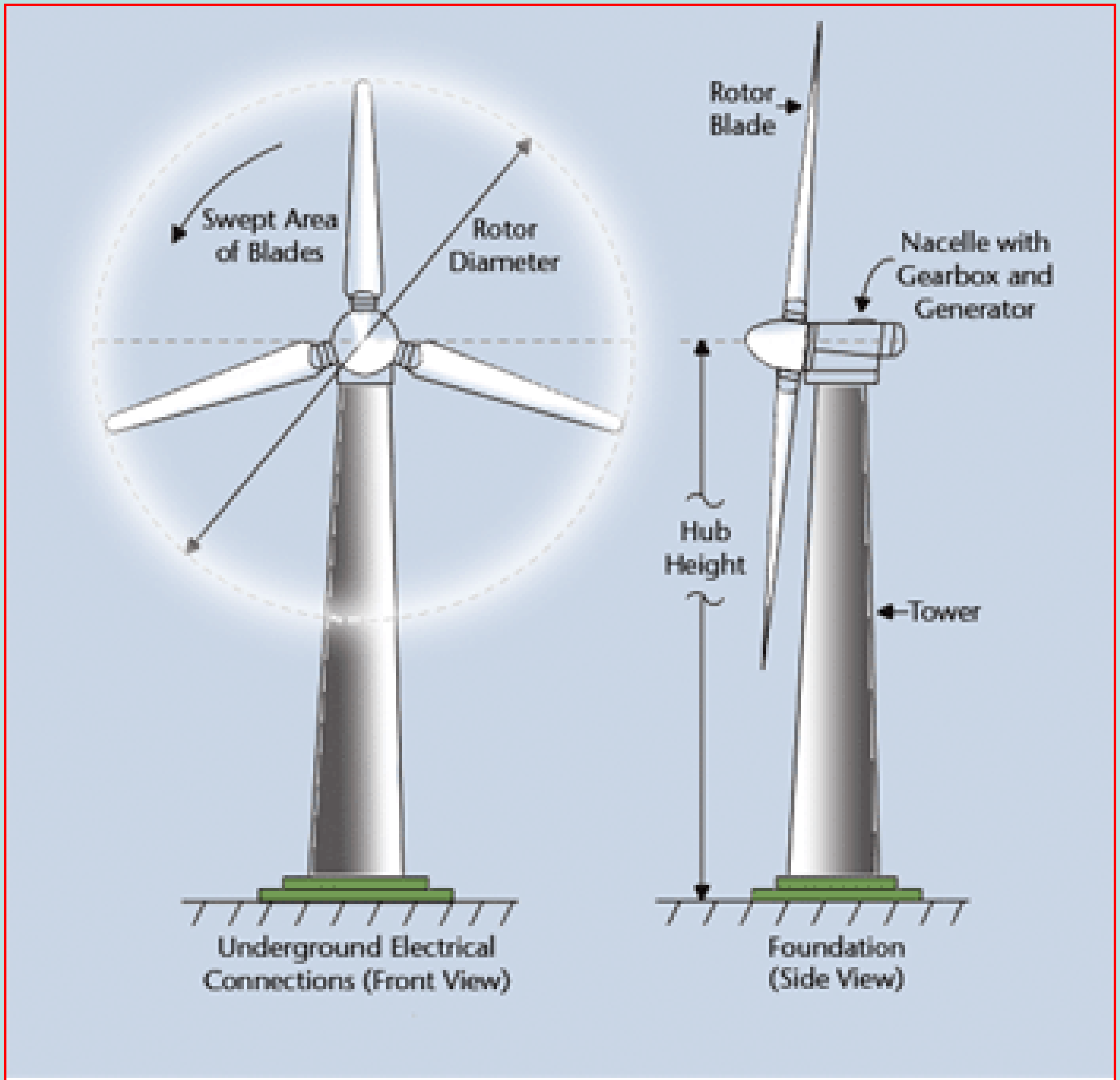
How does a wind turbine work?

- A wind turbine converts the kinetic energy of the wind to rotary motion (or torque) that can do mechanical work.
- There are two basic designs of wind electric turbines: vertical-axis and horizontal-axis machines.
- Horizontal-axis wind turbines are most common today, constituting nearly all of the "utility-scale" (100 kW capacity and larger) turbines in the global market.



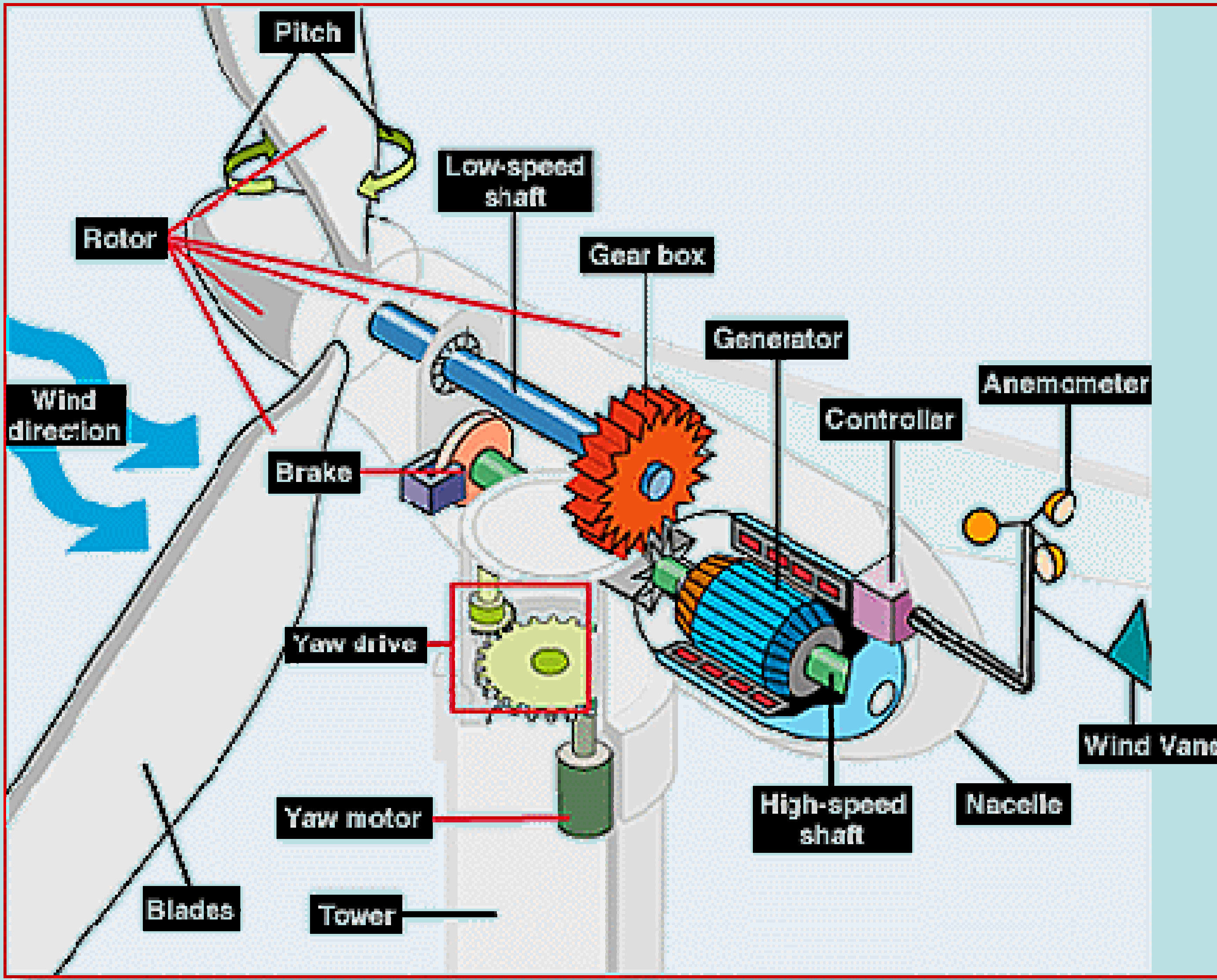
Wind Turbine Configurations

The horizontal wind turbine

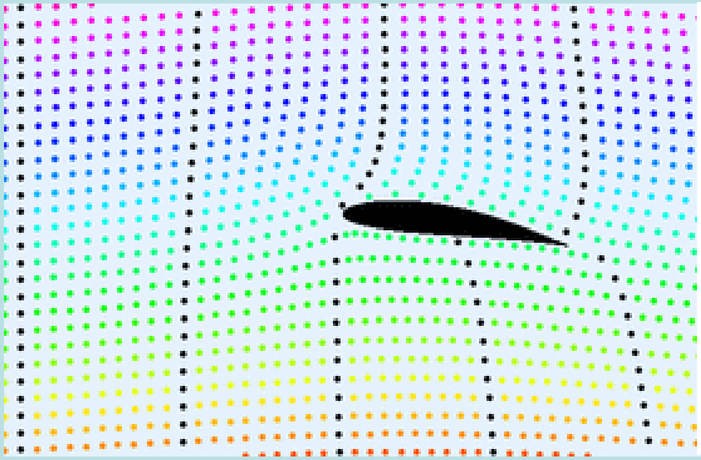


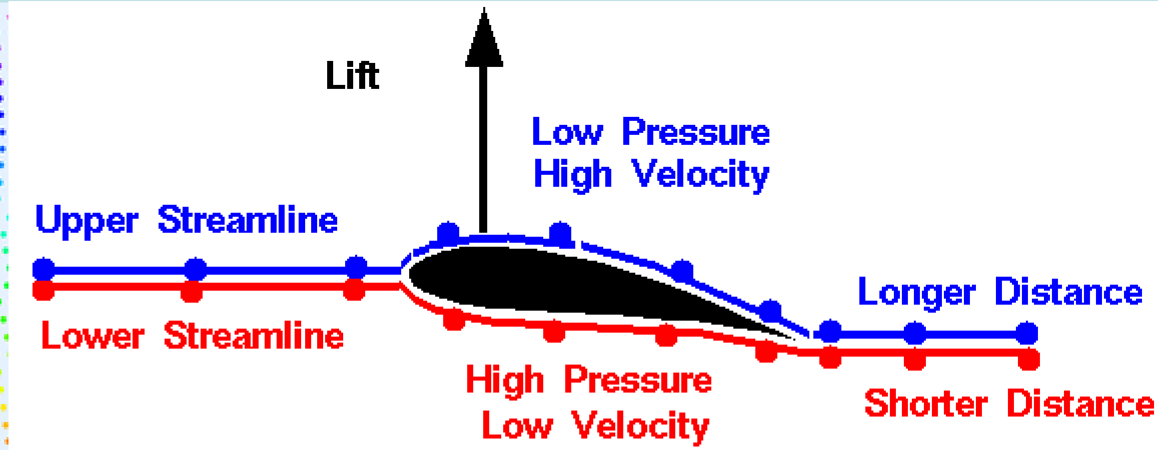
Drawing of the rotor and blades of a wind turbine, courtesy of ESN

The horizontal wind turbine

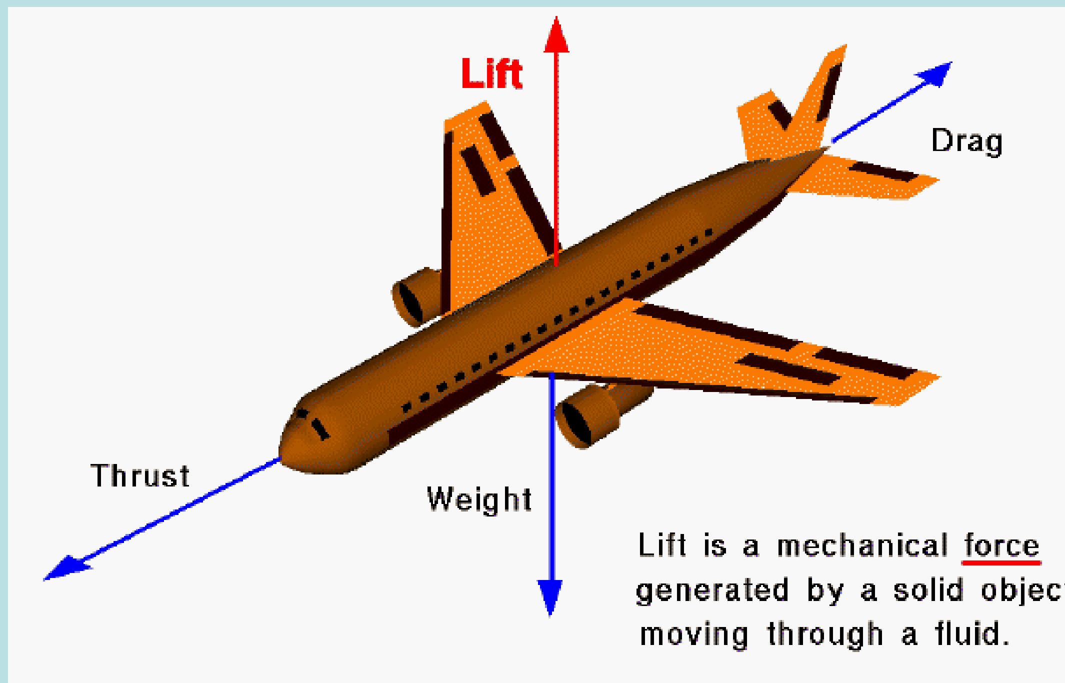


Principles of operation



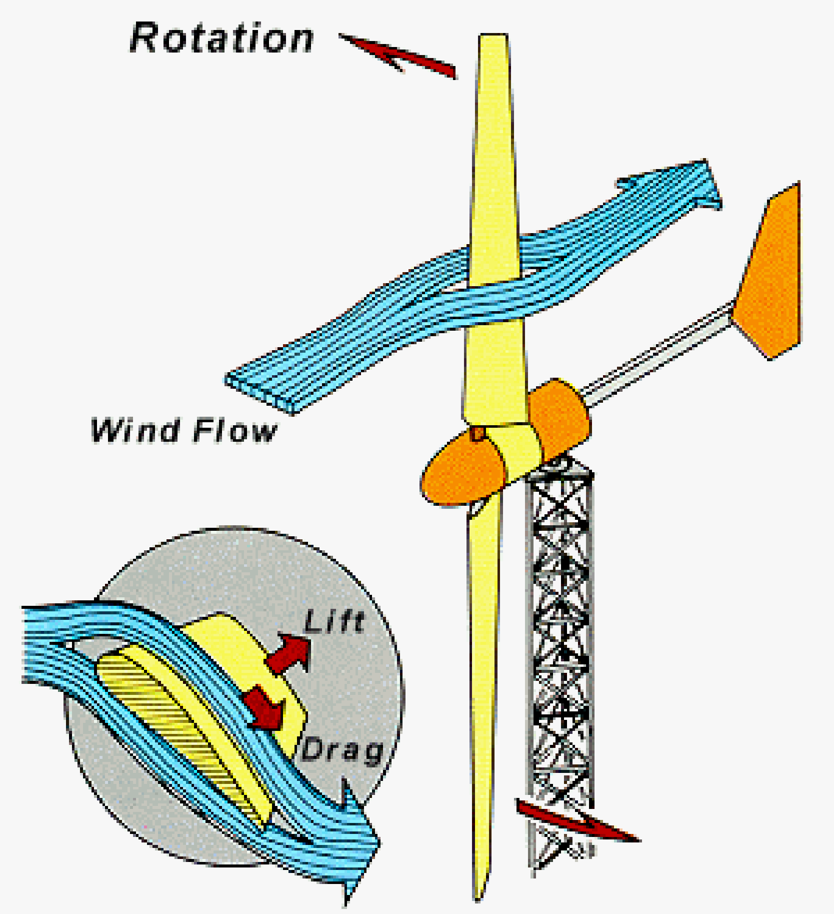


The pressure differential between top and bottom surfaces results in *aerodynamic lift.* In an aircraft wing, this force causes the airfoil to rise, lifting the aircraft off the ground. Since the blades of a wind turbine are constrained to move in a plane with the hub as its center, the lift force causes rotation about the hub.



Principles of operation

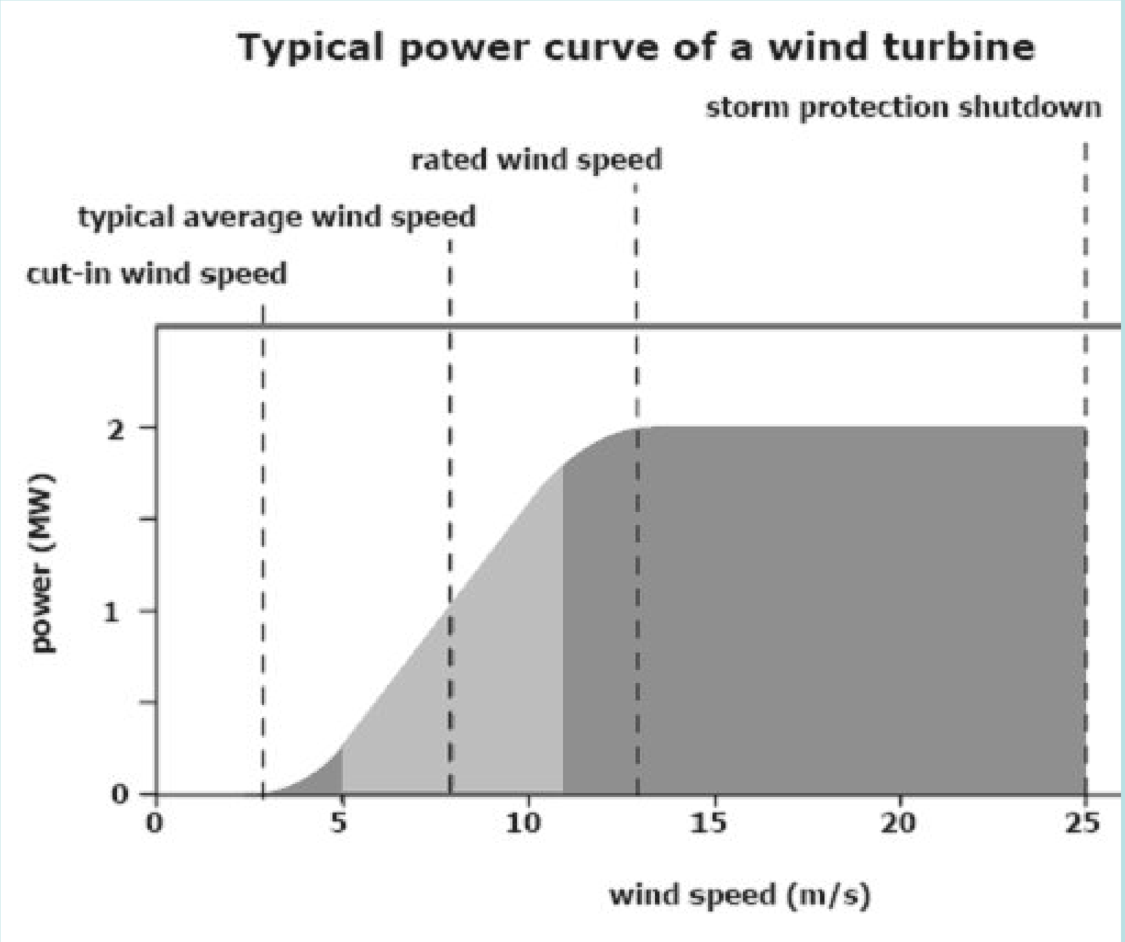
- **The wind passes over both surfaces of the airfoil shaped blade but passes more rapidly over the longer (upper) side of the airfoil, thus creating a lower-pressure area above the airfoil. The pressure differential between top and bottom surfaces results in aerodynamic lift.**
- **In addition to the lift force, a drag force perpendicular to the lift force opposes rotor rotation. A prime objective in wind turbine design is for the blade to have a relatively high lift-to-drag ratio.**
- **Horizontal wind turbines can be of two types:**
  - ***Upward wind turbine* – in which the turbine rotor faces the wind**
  - ***Downward wind turbine* – in which the wind passes the tower before striking the turbine rotor**



Principles of Wind Turbine Aerodynamic Lift

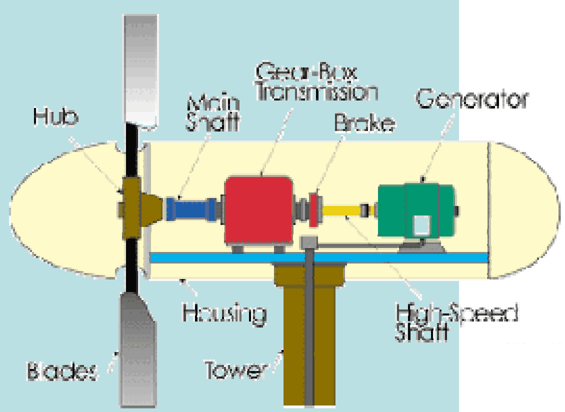
Principles of operation

- Most wind turbines start generating electricity at wind speeds of 3-4 meters per second (about 12 km/h); generate maximum rated power at around 15 m/s (55 km/h); and shut down to prevent storm damage at 25 m/s or above (90km/h).



Wind turbine components

- A rotor with blades of aerofoil section to convert wind energy to shaft power.
- A drive train including a gear box and a generator.
- Tower that supports the rotor and the drive train.
- Controls, electrical cables, ground support equipment and interconnection equipments.
- A “yawing” system to always orient the rotor to head wind.
- Automatic rotor parking (arresting) system to protect against high winds.



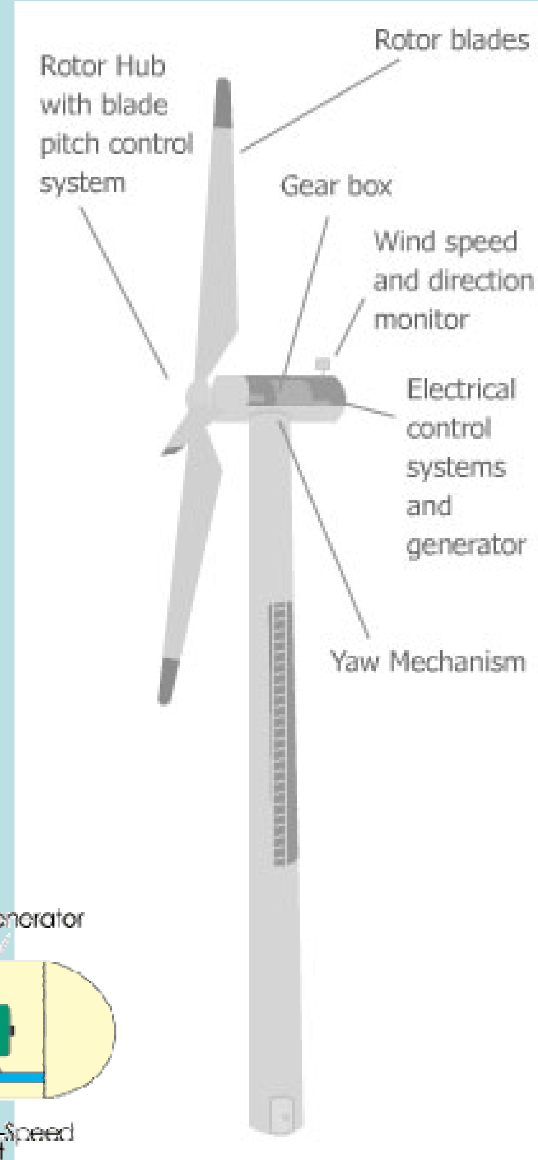
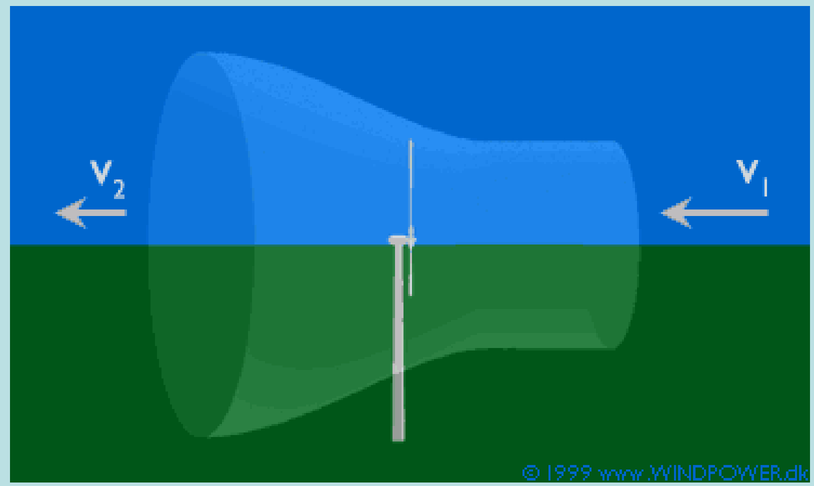


Diagram of a typical wind turbine

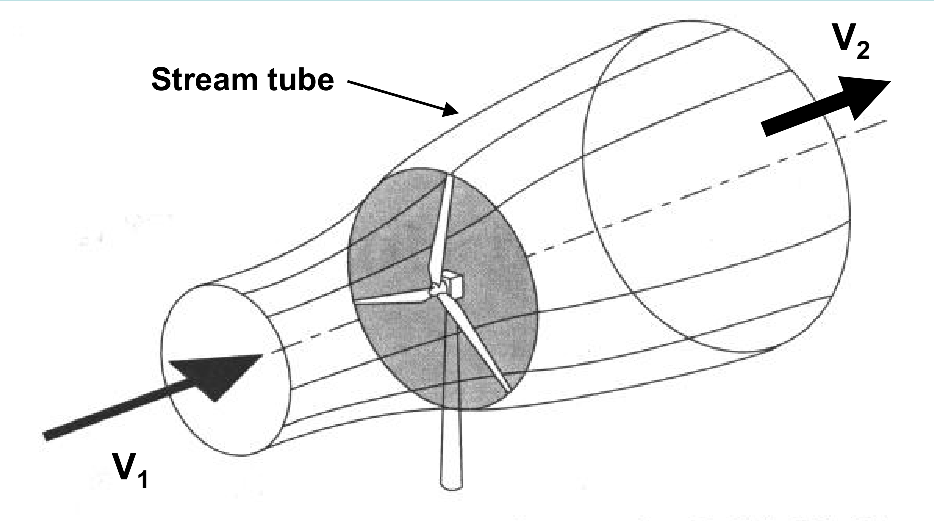
Coefficient of performance and Betz' limit

- Higher the kinetic energy extracted from the wind, lower will be the velocity with which wind leaves the turbine. That is, the wind will be slowed down as it leaves the turbine.
- If we tried to extract all the energy from the wind, the air would move away with zero speed, i.e. the air will not leave the turbine. In that case we would not extract any energy at all, since this condition also prevents wind from entering the rotor of the turbine.
- In the other extreme case, the wind could pass though the turbine without being hindered at all. In this case also we would not have extracted any energy from the wind.



Coefficient of performance and Betz' limit

- Betz' law (formulated by the German physicist Albert Betz in 1919) says that we can only convert less than 16/27 (or 59%) of the kinetic energy in the wind to mechanical energy using a wind turbine.
- To prove Betz' theorem, consider a wind turbine to be placed inside a "stream tube".



- V_1 is the velocity at entry and V_2 is the velocity at exit of the turbine.

The Betz' Law

- Average speed of wind through the rotor = $(V_1 + V_2)/2 = V_a$ ----- (1)
- Mass of air flow through the rotor per second

  m = Area * Density of air * velocity of flow

  $m = A * \rho * V_a$ ----- (2)
- The power extracted from the wind, according to Newton's second law is,

  $P = 0.5 * m * (V_1^2 – V_2^2)$ ----- (3)

  Substituting for m from equation (2), we get

  $P = 0.25 * \rho * A *(V_1 + V_2) (V_1^2 – V_2^2)$ ------ (4)
- Now, let us compare the result with the total power in the undisturbed wind flowing through exactly the same area A, with no rotor to block the wind. Let this power be P_o.

  $P_0 = 0.5 * m * V_1^2 = 0.5 * A\rho V_1 * V_1^2$

  $P_0 = 0.5 * A\rho V_1^3$ ----- (5)

The Betz' Law

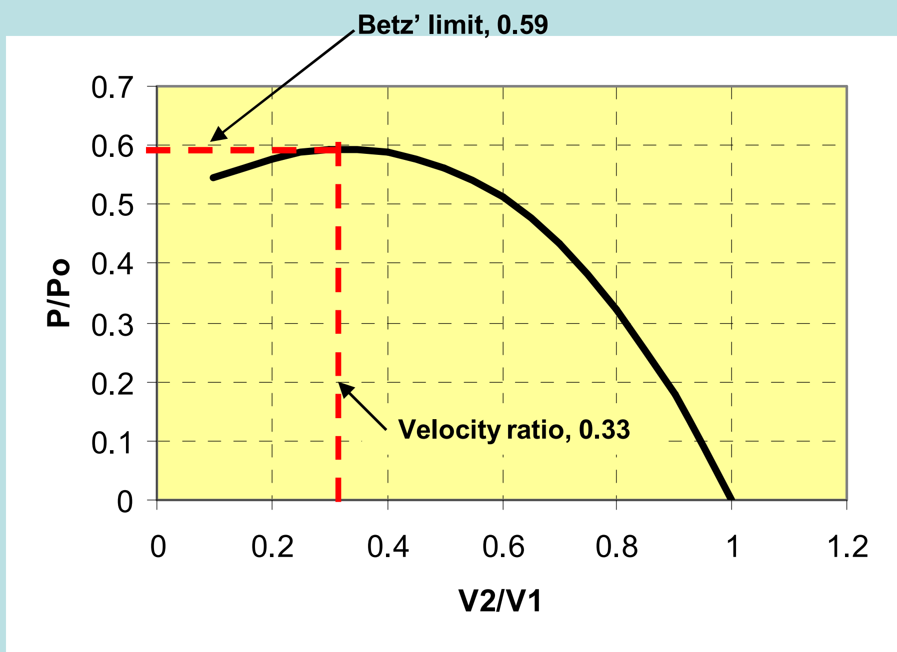
- The ratio of power extracted from the wind to the power in the undisturbed stream is (Equation 4 / Equation 5):

$$(P/P_o) = \{0.25 * \rho * A * (V_1 + V_2) (V_1^2 – V_2^2)\} / \{0.5 * A\rho V_1^3\}$$

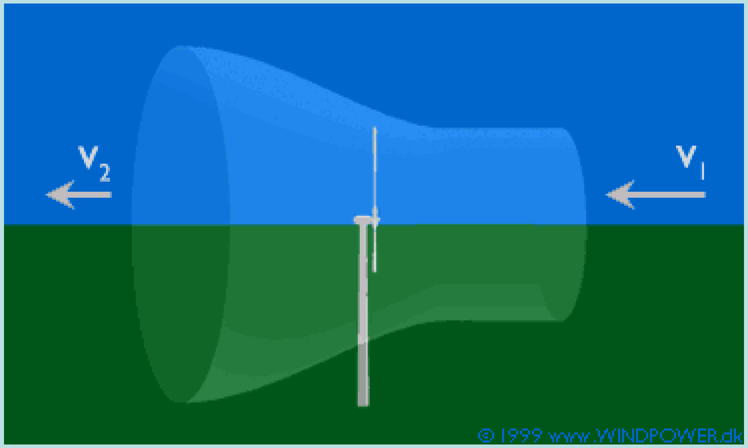
simplifying, we get

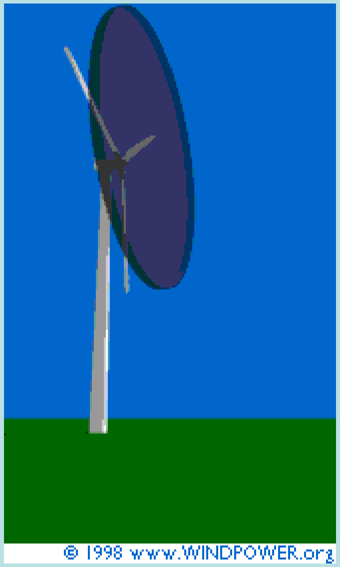
$$\frac{P}{P_0} = \left[\frac{1}{2}\right]\left[1 - \left(\frac{V_2}{V_1}\right)^2\right]\left[1 + \left(\frac{V_2}{V_1}\right)\right]$$

- The ratio (P/P_0) is known as the *coefficient of performance* of a wind turbine.
- We can see that the function reaches its maximum for $v_2/v_1 = 1/3$, and that the maximum value for the power extracted from the wind is 0.59 or 16/27 of the total power in the wind.



Calculation of wind power





- **The power output of a wind generator is proportional to the area swept by the rotor - i.e. if the *swept area* is doubled, the power output will also double.**
- **The power output of a wind generator is proportional to the cube of the wind speed - i.e. if the *wind speed* is doubled, the power output will increase by a factor of eight (2^3).**

Calculation of wind power

- The kinetic energy of wind is = 0.5 * Mass * Velocity ^{2}
- At sea level, air density is ~1.23 kg/m^3. Therefore, the mass of air striking a turbine per second is:

  Mass/sec (kg/s) = Velocity (m/s) x Area (m^2) x Density (kg/m^3)

- The power (energy/second) in the wind striking the turbine with a certain swept area is:

  Power = Mass flow rate of air x Kinetic energy

  = 0.5 x swept area x Air density x Velocity ^{3}

  Where,

  Swept area = πr^2

  r being the outer radius of the turbine rotor

Therefore, the theoretical wind power is,

$P = 0.5\, \pi \rho r^2 v^3$ Watts

ρ = Density of air in kg/m^3

r = Radius of wind turbine in m

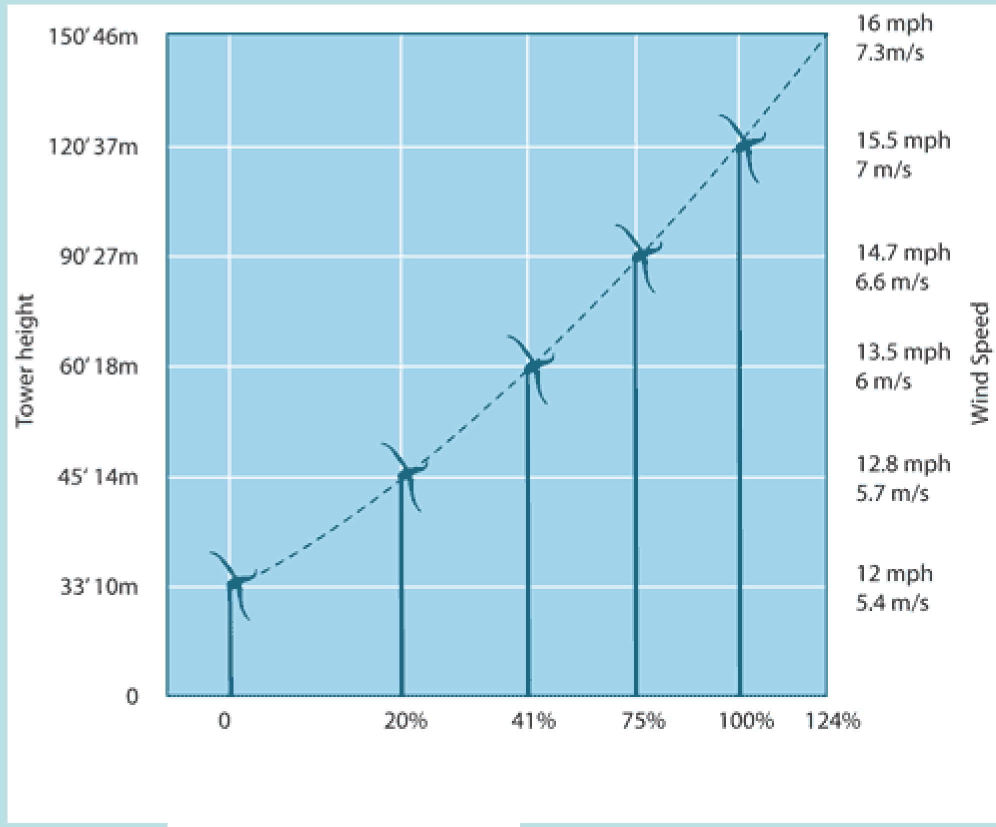
v = Velocity of air in m/s

Wind speed – Effect of height

- Wind speed varies with height. At ground level the speed is low and turbulent and at higher altitudes, it is faster and smoother. This is due to friction as wind passes across the earth's surface.
- While the nature of surface varies, it is common practice to use an empirical relationship between height and wind speed:

$$V = V_{ref}\left[\frac{H}{H_{ref}}\right]^{0.142}$$

- As the power generated is proportional to the velocity cubed, there is an advantage in locating the turbine on some form of tower, typically in the range 30 to 80 metres high.

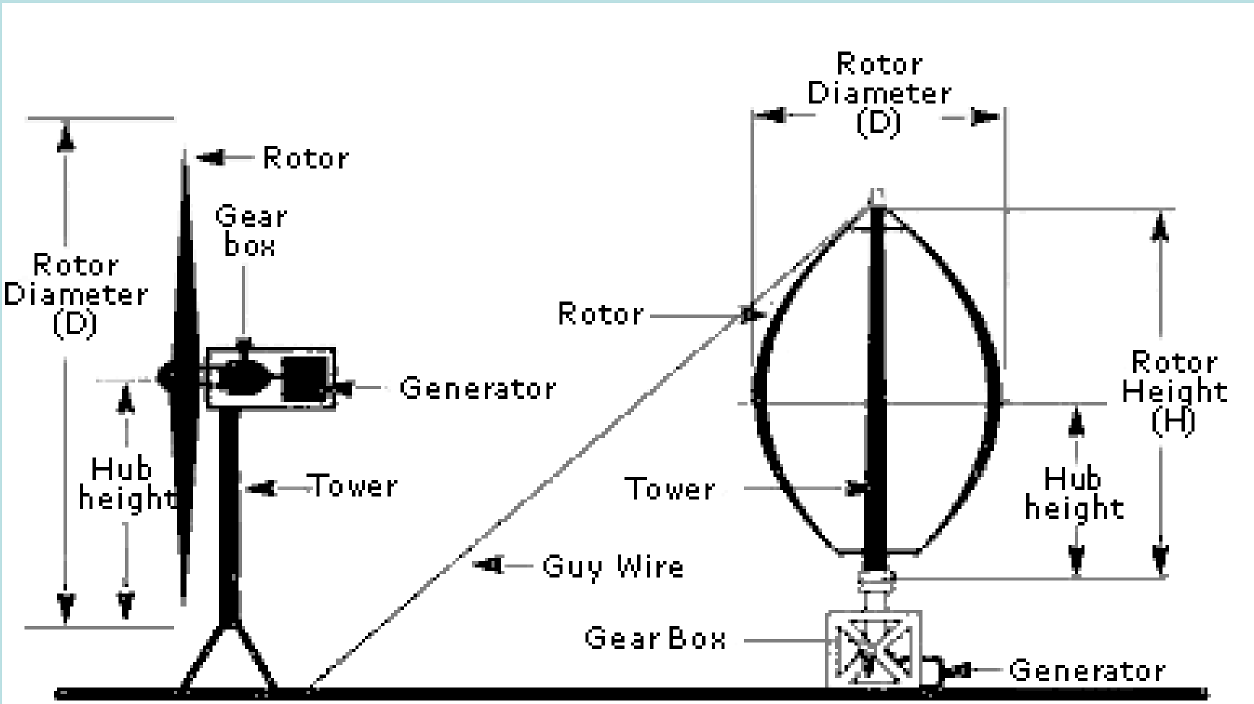


Types of wind turbines

Basically there are two types of wind turbines:

- **Horizontal Axis Wind Turbines**
- **Vertical Axis Wind Turbines**

Depending upon the wind conditions available and ingenuity of design, there are innumerable variants as shown on following slides.



Horizontal Axis Wind Turbine

Vertical Axis Wind Turbine

Horizontal Axis Wind Turbines

Three Blade

Two Blade

Single Blade

Classic modern horizontal axis wind turbines

Horizontal Axis Wind Turbines

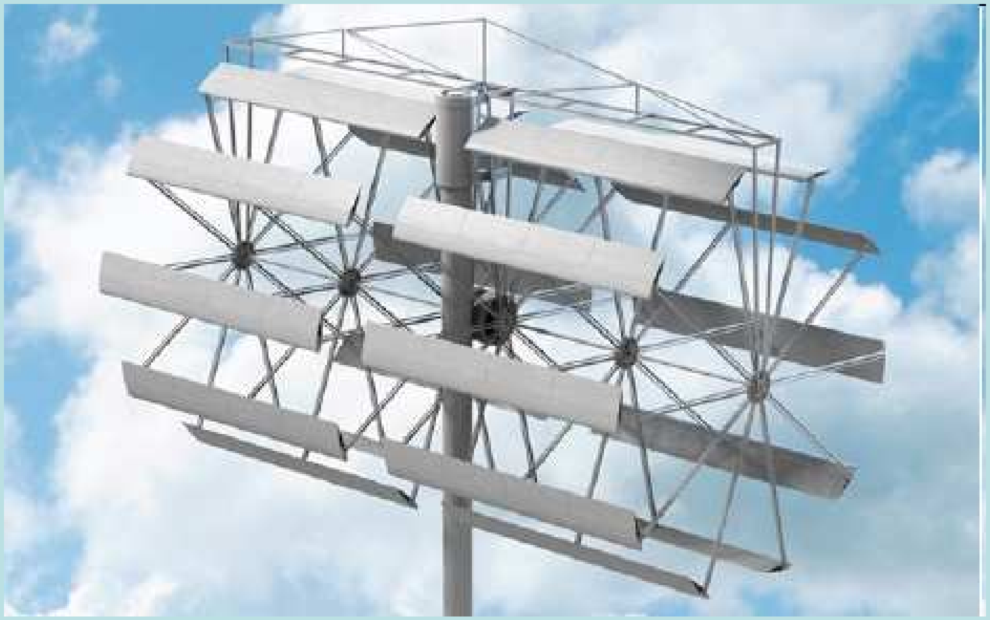
Classic ‘Dutch style’ wind mill

Highway mounted wind turbines, use the turbulence created by passing vehicles

(Concept by University of Arizona)

Examples of Classic and Innovative Designs

Horizontal Axis Wind Turbines

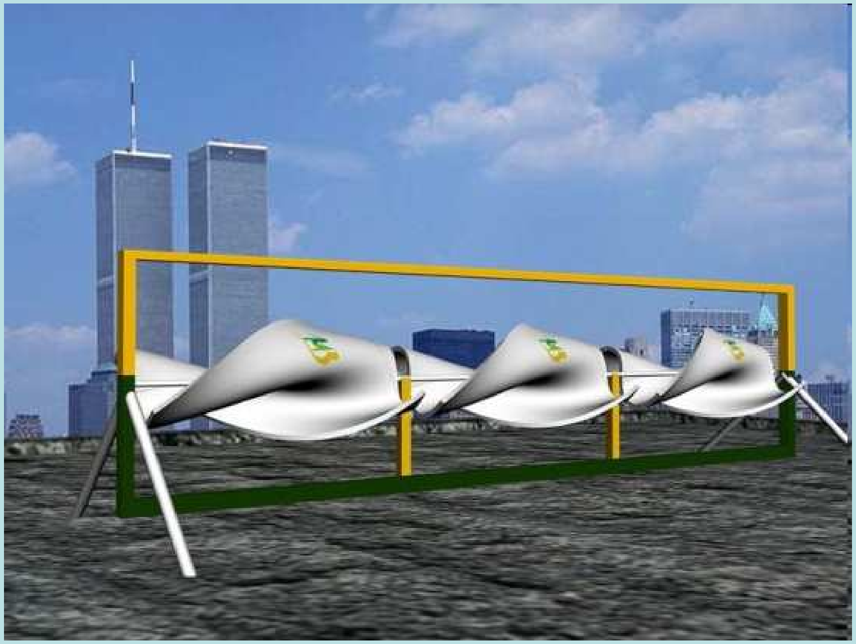


'Broad Star Aerocam' wind turbine

Tethered 'Magenn' wind turbine

Examples of Innovative Designs

Horizontal Axis Wind Turbines



Concept of a helical wind turbine

Sky serpent – an array of small rotors

Examples of Innovative Designs

Horizontal Axis Wind Turbines

Proposed giant turbine on top of 600m sky scraper in Dubai

Wind turbines at the Bahrain World Trade Centre

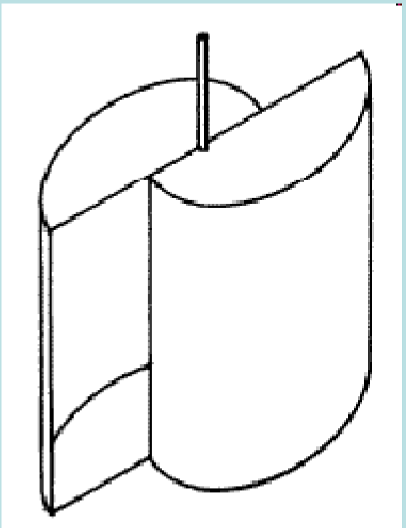
Examples of Innovative Designs

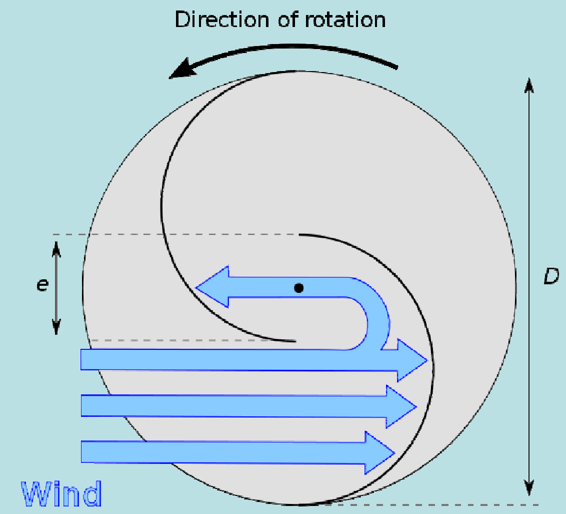
Horizontal Axis Wind Turbines

The 'Energy Ball' small power wind turbine

Examples of Innovative Designs

Vertical Axis Wind Turbines

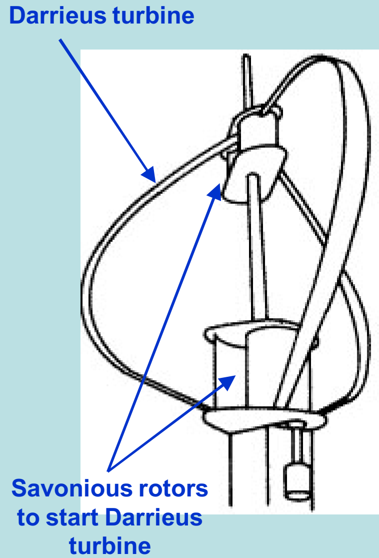


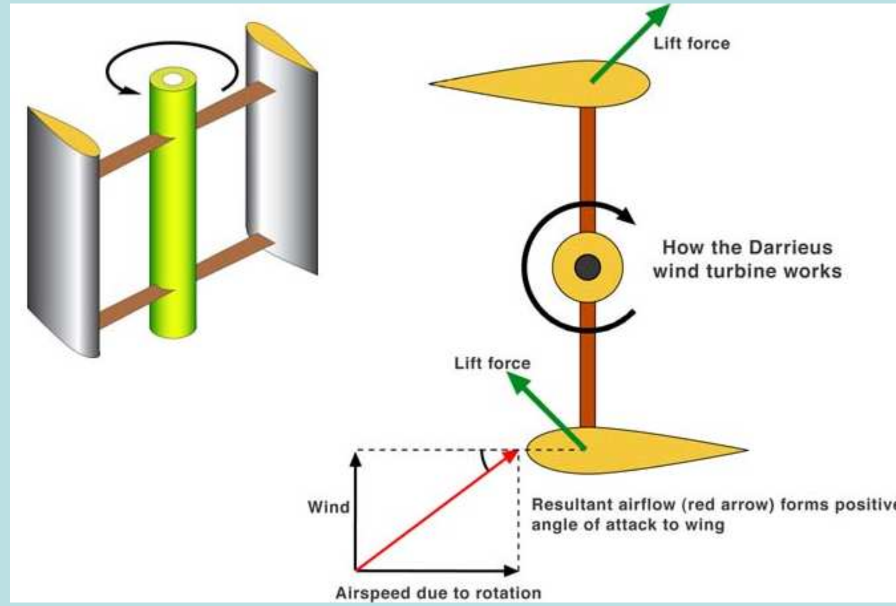


The Savonious wind turbine:

Invented by the Finnish engineer Sigurd J Savonius in 1922. Aerodynamically, they are drag-type devices, consisting of two or three scoops. Looking down on the rotor from above, a two-scoop machine would look like an "S" in cross section. Because of the curvature, the scoops experience less drag when moving against the wind than when moving with the wind. The differential drag causes the turbine to spin. Because they are drag-type devices, Savonius turbines extract much less wind power than other similarly-sized lift-type turbines.

Vertical Axis Wind Turbines





The Darrieus Wind Turbine:

A Darrieus wind turbine can spin at many times the speed of the wind hitting it. Hence it generates less torque than a Savonius but it rotates much faster. This makes Darrieus wind turbines much better suited to electricity generation rather than water pumping and similar activities. The centrifugal forces generated by a Darrieus turbine are very large and act on the turbine blades which therefore have to be very strong. Darrieus wind turbines are not self starting. Therefore a small Savonious rotor is fitted to start the turbine, and then when it has enough speed the wind passing across the aerofoil's starts to generate torque and the rotor is driven around by the wind.

Vertical Axis Wind Turbines

Helical wind turbine

‘Jelly Fish’ micro wind turbine

Examples of Innovative Designs

Vertical Axis Wind Turbines

Variants of Darrieus wind turbine

Examples of Innovative Designs

Vertical Axis Wind Turbines

‘Wind side’ wind turbine

‘Aerofoil’ wind turbine

Examples of Innovative Designs

Vertical Axis Wind Turbines

'Maglev'- magnetically levitated wind turbines – several in operation in China

Examples of Innovative Designs

Advantages of wind energy

- Wind energy is a renewable resource meaning that the Earth will continue to provide this and it's up to people to use it and harness it to best advantage.
- Wind energy is cheap and is largely dependent upon the manufacturing, distribution and building of turbines for the initial costs.
- Wind energy replaces electricity from coal-fired power plants and thus reduces greenhouse gases that produce global warming.
- Wind energy is available worldwide and though some countries may be "windier" than others, the product is not like oil that has to be transported on tankers to the far regions of the earth.
- Wind farms on average have a smaller footprint than coal-fired power plants. Wind turbines can also share space with other interests such as the farming of crops or cattle.
- Wind energy is available in many remote locations where the electrical grid doesn't reach. Farms, mountain areas and third world nations can take advantage of wind energy.
- Wind energy is creating jobs that are far outpacing other sectors of the economy.
- Wind energy doesn't have to be used solely on a commercial scale as residential wind turbines are now gaining ground in many communities.

Disadvantages of wind energy

- Wind is an intermittent source of energy and when connected to the electrical grid provides an uneven power supply. Some places may have too strong winds during hurricane season that may damage wind turbines.
- Some people object to the visual site of wind turbines disrupting the local landscape.
- The wind doesn't blow well at all locations on Earth. Wind maps are needed to identify the optimal locations.
- The initial cost of a wind turbine can be high, though government subsidies, tax breaks and long-term costs may alleviate much of this.
- Even though costs of wind energy have come down dramatically it still has to compete with the ultra low price for fossil fuel power plants.
- Transmission of electricity from remote wind farms can be a major hurdle for utilities since many time turbines are not located around urban centers.
- The storage of excess energy from wind turbines in the form of batteries, or other forms still needs research and development to become commercially viable.
- Depending upon the type of wind turbine, noise pollution may be a factor for those living or working nearby.
- Utility scale wind turbines can interfere with television signals of those living within a mile or two of the installation, which can be frustrating for homeowners.

Availability of wind energy in India

- The development of wind power in India began in the 1990s, and has significantly increased in the last few years.
- A combination of domestic policy support for wind power and the rise of Suzlon (a leading global wind turbine manufacturer) have led India to become the country with the fifth largest installed wind power capacity in the world.
- As of November 2008 the installed capacity of wind power in India was 9587.14 MW, comprising of:
    - Tamil Nadu (4132.72 MW)
    - Maharashtra (1837.85 MW)
    - Karnataka (1184.45 MW)
    - Rajasthan (670.97 MW)
    - Gujarat (1432.71 MW)
    - Andhra Pradesh (122.45 MW)
    - Madhya Pradesh (187.69 MW)
    - Kerala (23.00 MW)
    - West Bengal (1.10 MW)
    - Others (3.20 MW)

Availability of wind energy in India

- The short gestation periods for installing wind turbines, and the increasing reliability and performance of wind energy machines has made wind power a favored choice for capacity addition in India.
- Suzlon, an Indian-owned company, emerged on the global scene in the past decade, and by 2006 had captured almost 8 percent of market share in global wind turbine sales.
- Suzlon is currently the leading manufacturer of wind turbines for the Indian market, holding some 52.4 percent of market share in India. Suzlon's success has made India the developing country leader in advanced wind turbine technology.
- The Ministry of New and Renewable Energy (MNRE) has fixed a target of 10,500 MW between 2007-12, but an additional generation capacity of only about 6,000 MW might be available for commercial use by 2012.
- Wind-Solar and Wind-Diesel Hybrid systems have also been installed at a few places.
- A large number of water pumping windmills and small aero-generators have been installed in the country.