UNIVERSITY OF ANBAR

College of Applied Sciences-Hit

Dept. of Environmental Sciences

Renewable Energy Course

Wind Energy

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Early days

3000 B.C wind energy used for the first time in the form of sail boats in Egypt

2000 B.C The earliest windmills, used to grind grain, in ancient Babylon

1888 first wind turbine for electricity was built by Charles F. Brush in Cleveland, Ohio

1930s an estimated 600,000 wind turbines supplied rural areas with electricity and water-pumping services in the US

1931: Installation of a 100 kW generator on a 30 m (100 ft) tower in USSR

Pitstone Windmill, the oldest windmill in the British Isles

Modern history

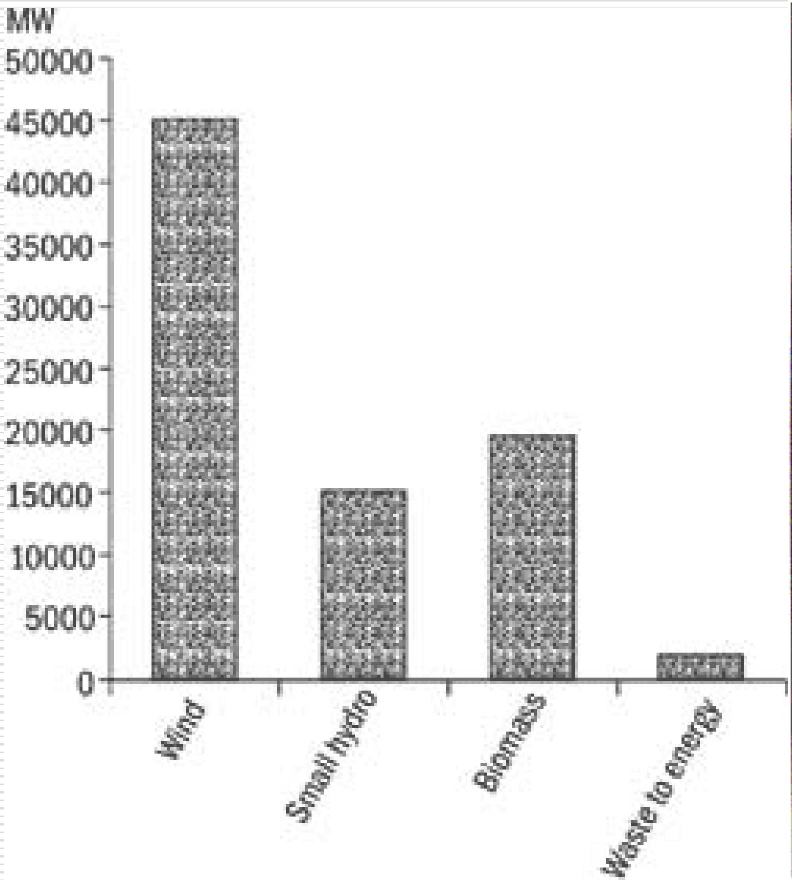
- 1981 : The world's first private sector installations in California
- Indian Wind Power Programme commenced in 1986
- First private windfarm in the country installed at Muppandal
- In 1931 the Darrieus wind turbine was invented
- 2008: Rock Port,becomes the first city in the United States to receive 100 percent of its power from wind in a project developed by Wind Capital Group

THE PRINCIPLE OF A WIND TURBINE

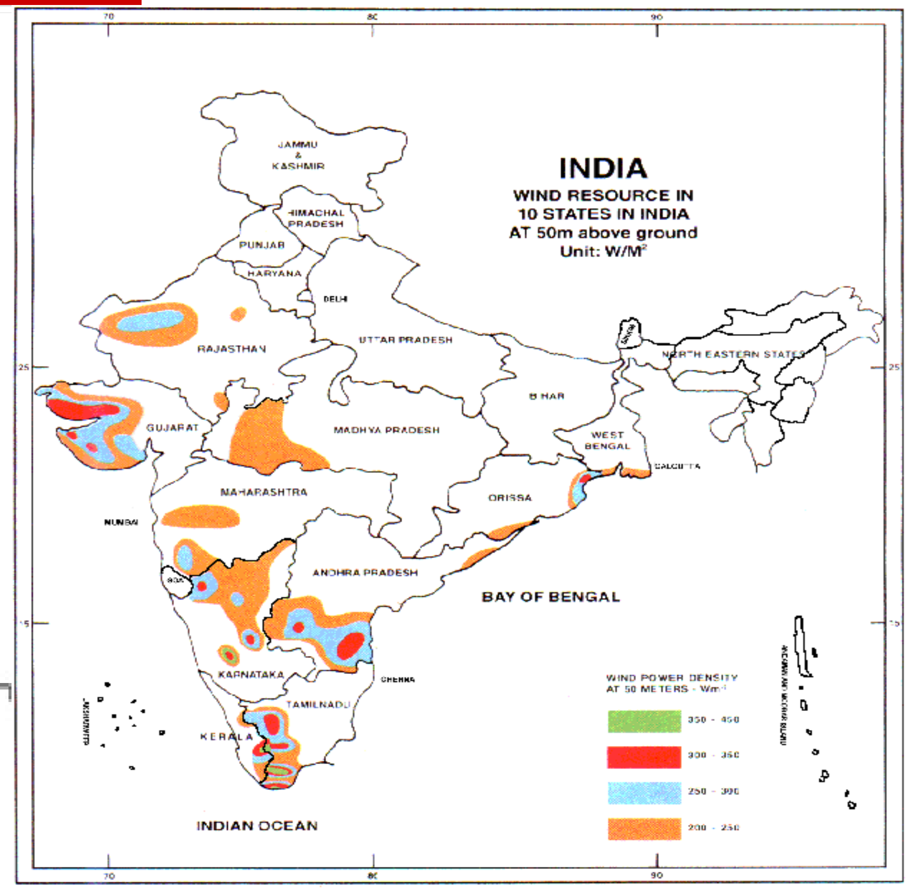
The wind power can be gained by making it blow past the blades that will cause the rotor to twist. The amount of power transferred is directly proportional to the density of the air, the area swept out by the rotor, and the cube of the wind speed. It can be found out by the following equation:

$$P = \frac{1}{2}\rho\pi R^2 v^3$$

Example: Indian Scenario



Available potential



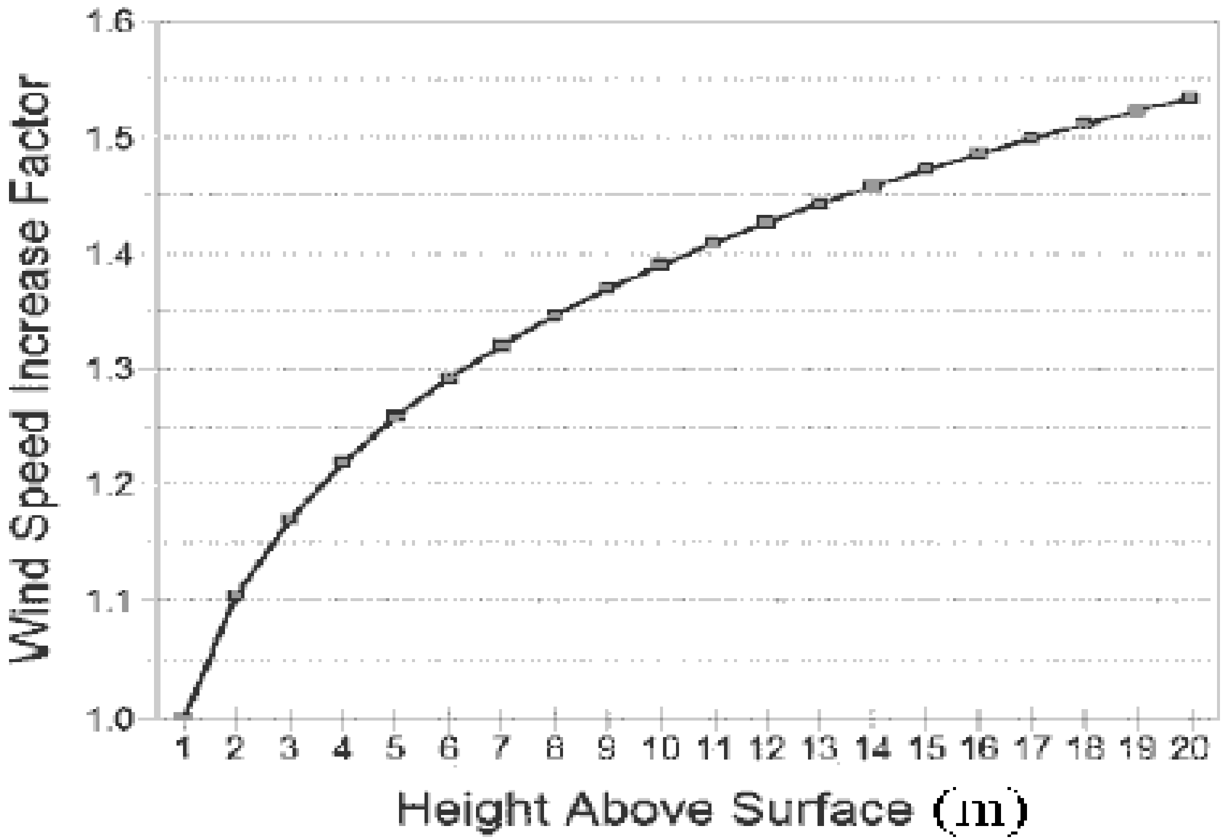
Map not strictly according to scale

Wind power density

Wind…

Force	Strength	km/h	Effect
0	Calm	0-1	Smoke rises vertically
1	Light air	1-5	Smoke drifts slowly
2	Light breeze	6-11	Wind felt on face; leaves rustle
3	Gentle breeze	12-19	Twigs move; light flag unfurls
4	Moderate breeze	20-29	Dust and paper blown about; small branches move
5	Fresh breeze	30-39	Wavelets on inland water; small trees move
6	Strong breeze	40-50	Large branches sway; umbrellas turn inside out
7	Near gale	51-61	Whole trees sway; difficult to walk against wind
8	Gale	62-74	Twigs break off trees; walking very hard
9	Strong gale	75-87	Chimney pots, roof tiles and branches blown down
10	Storm	88-101	Widespread damage to buildings
11	Violent Storm	102-117	Widespread damage to buildings
12	Hurricane	Over 119	Devastation

Wind velocity with Height



Wind Farms

- Normally, it makes sense to install a large number of wind turbines in a wind farm or a wind park

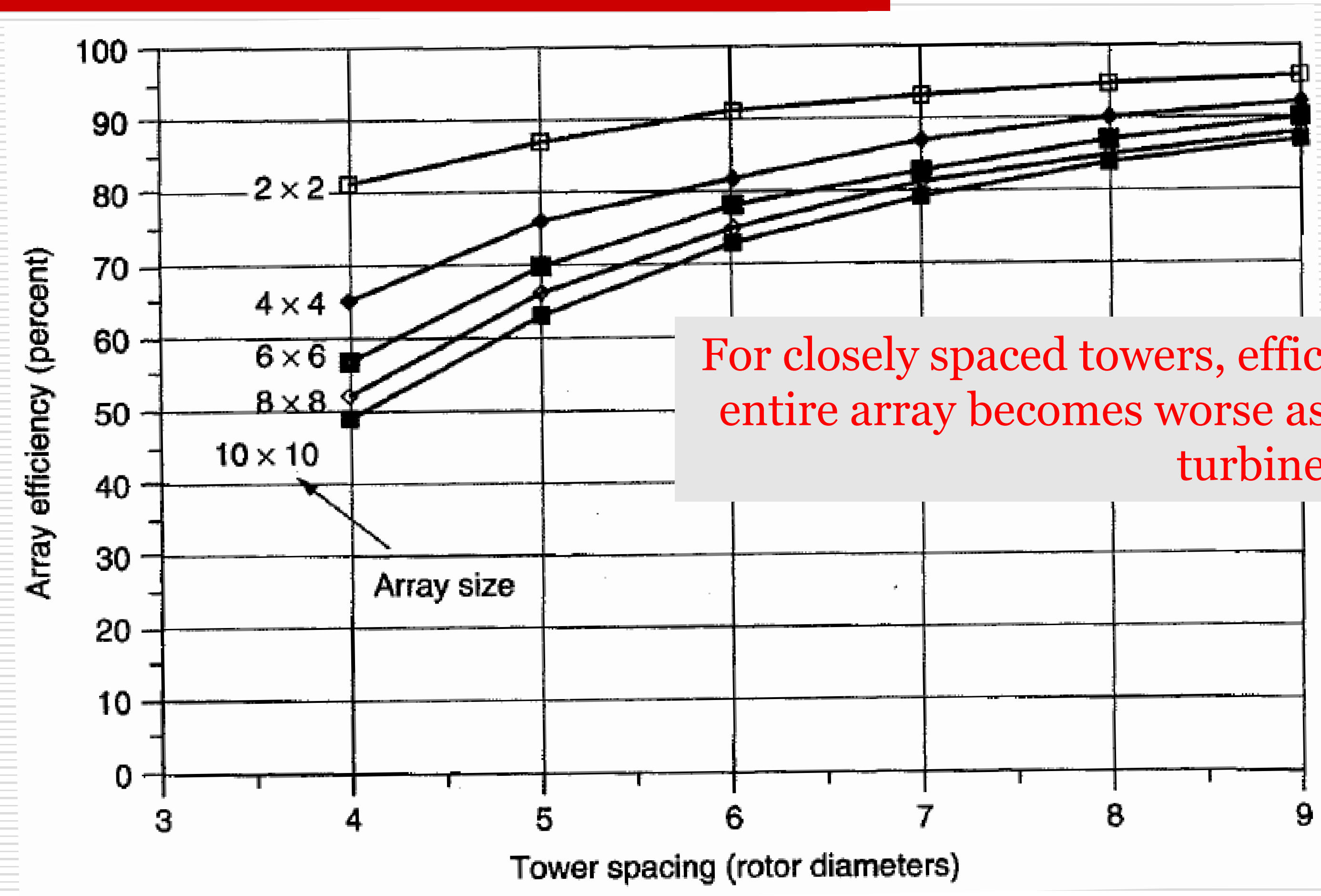
Benefits

- Able to get the most use out of a good wind site
- Reduced development costs
- Simplified connections to the transmission system
- Centralized access for operations and maintenance
- How many turbines to install?

- We know that wind slows down as it passes through the blades. The power extracted by the blades:

$$P_b = \frac{1}{2}\dot{m}\left(v^2 - v_d{}^2\right)$$

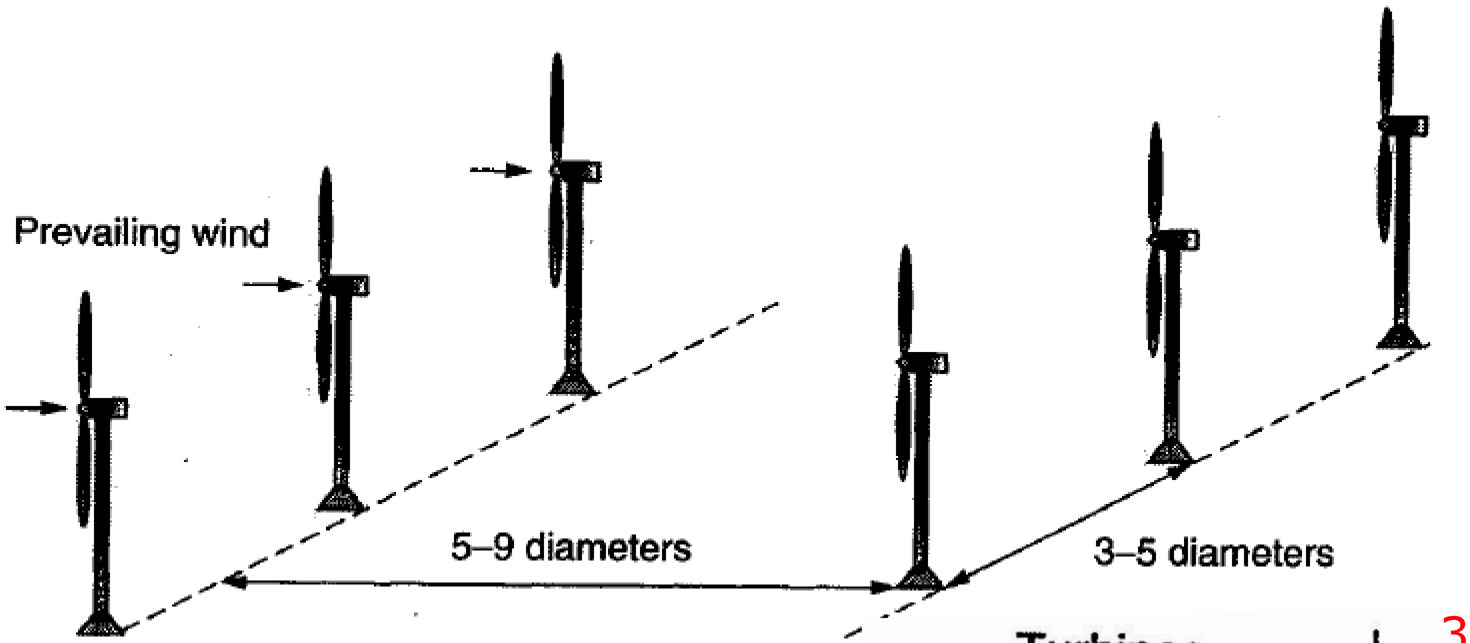
- Extracting power with the blades reduces the available power to downwind machines
- What is a sufficient distance between wind turbines so that wind speed has recovered enough before it reaches the next turbine?



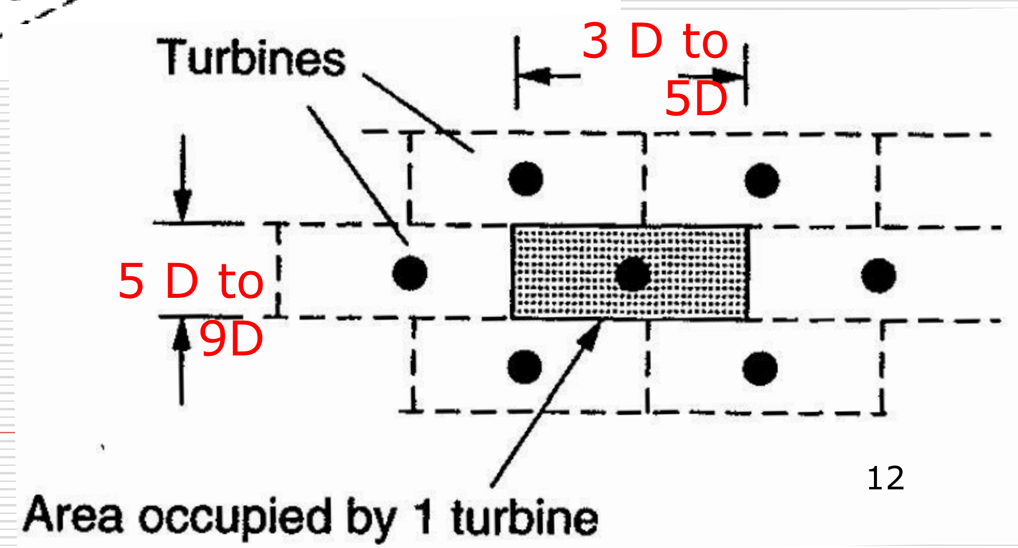
For closely spaced towers, efficiency of the entire array becomes worse as more wind turbines are added

- The study in Figure considered square arrays, but square arrays don't make much sense
- Rectangular arrays with only a few long rows are better
- Recommended spacing is 3-5 rotor diameters between towers in a row and 5-9 diameters between rows

Wind Farms – Optimum Spacing



Optimum spacing is estimated to be 3-5 rotor diameters between towers and 5-9 between rows

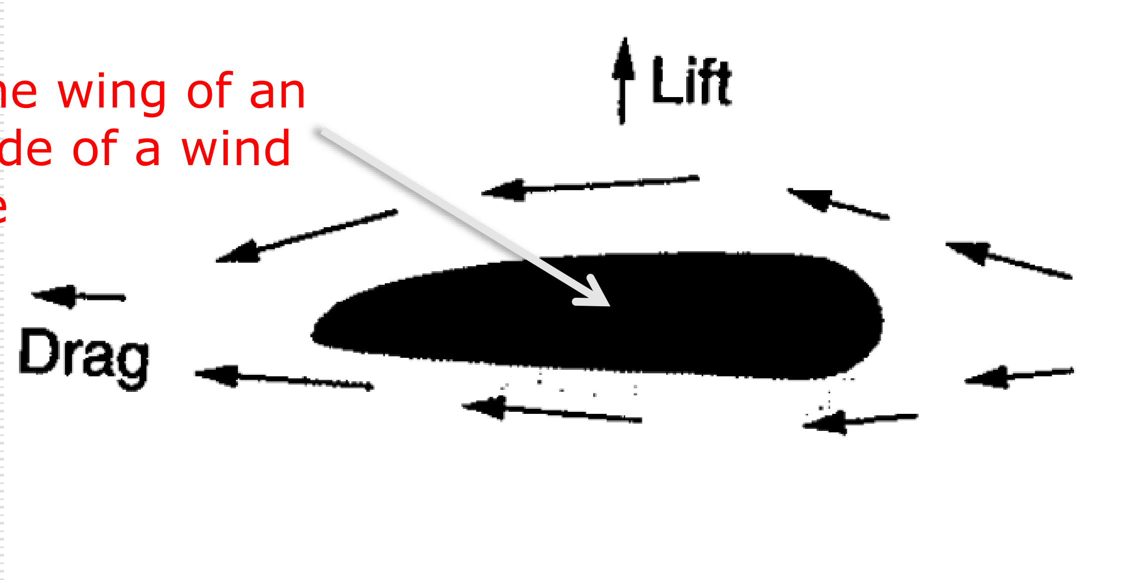


Variation of Wind

- We need to not just consider how often the wind blows but also when it blows with respect to the electric load.
- Wind patterns vary quite a bit with geography, with coastal and mountain regions having more steady winds.

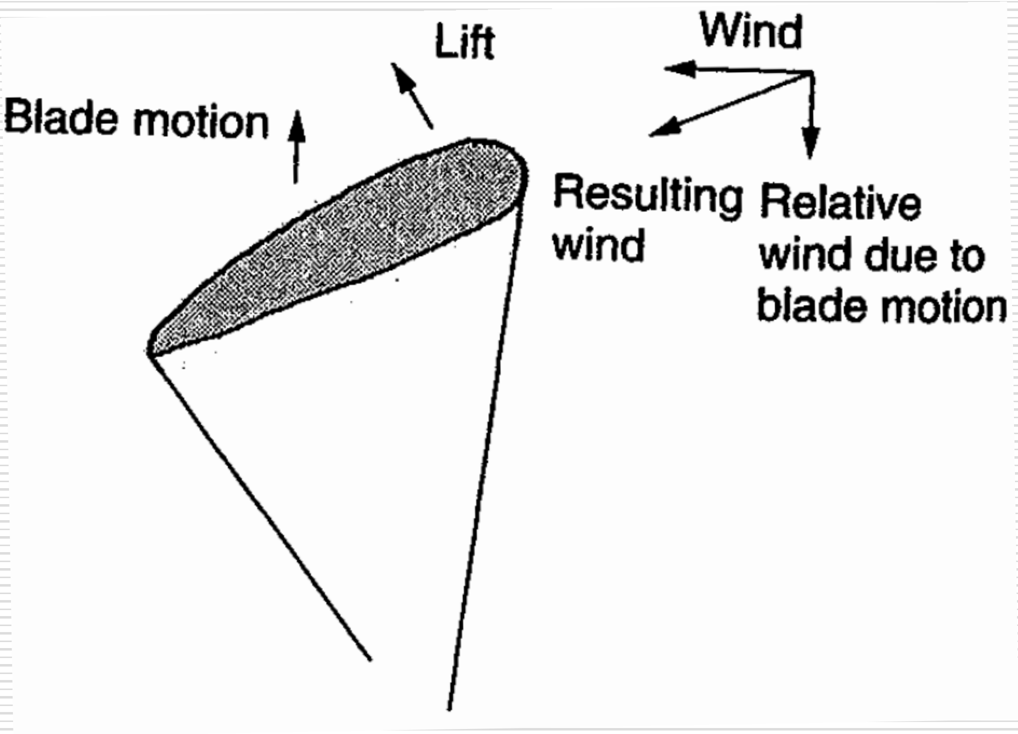
How Rotor Blades Extract Energy from the Wind?

Airfoil – could be the wing of an airplane or the blade of a wind turbine



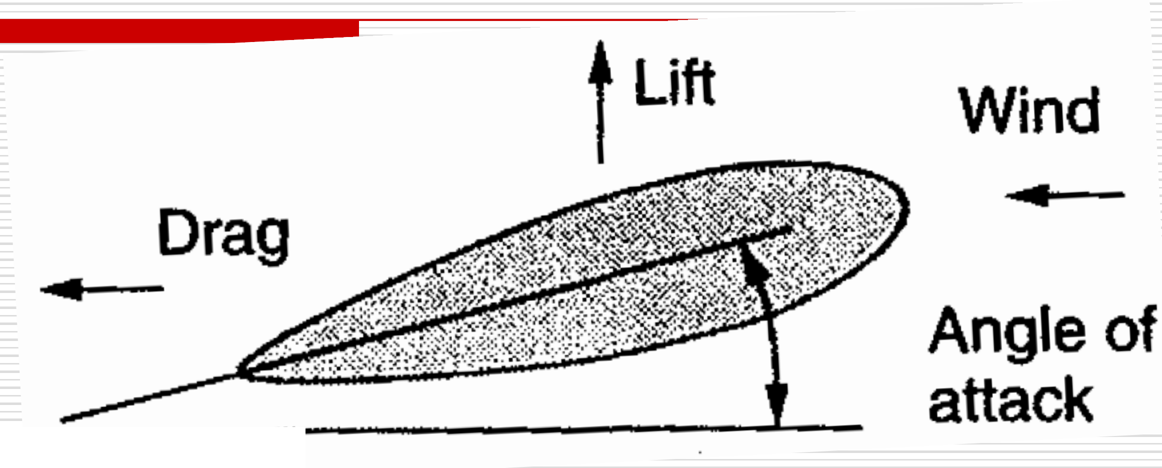
Bernoulli's Principle - air pressure on top is lower than air pressure on bottom because it has further to travel, creates lift

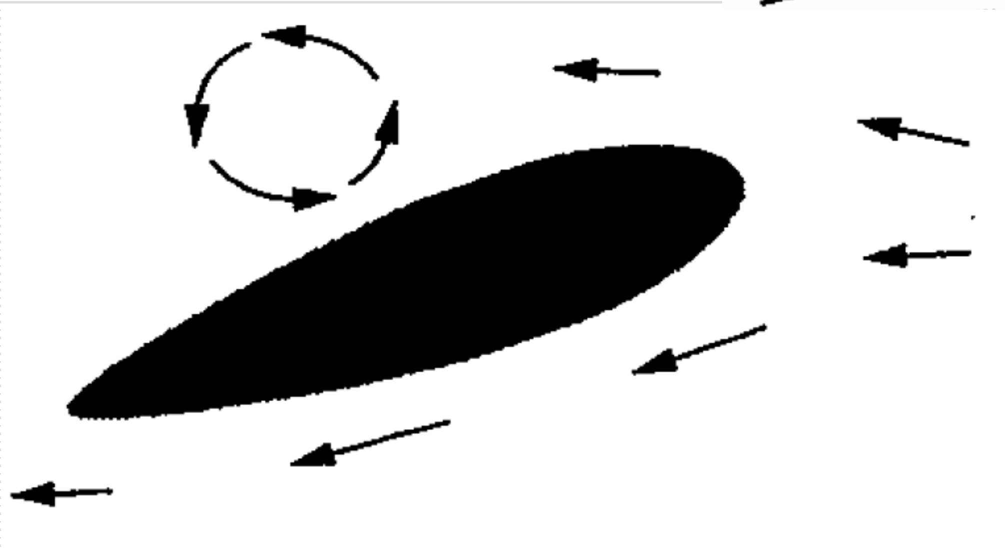
- Air is moving towards the wind turbine blade from the wind but also from the relative blade motion
- The blade is much faster at the tip than at the hub, so the blade is twisted to keep the angles correct



Angle of Attack, Lift, and Drag

- Increasing angle of attack increases lift, but it also increases drag

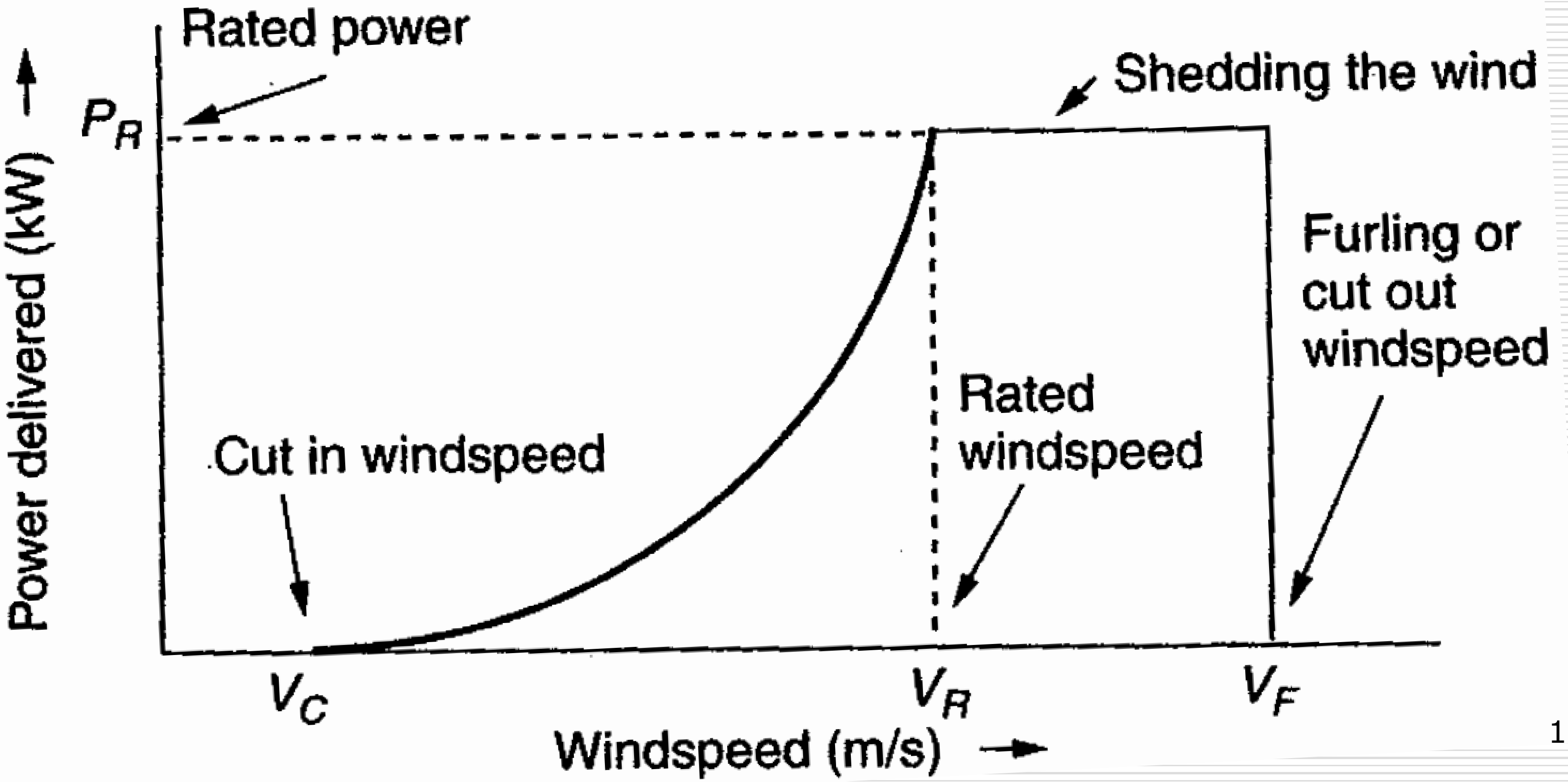




- If the angle of attack is too great, “stall” occurs where turbulence destroys the lift

Idealized Power Curve

Cut –in wind speed, rated wind speed, cut-out wind speed

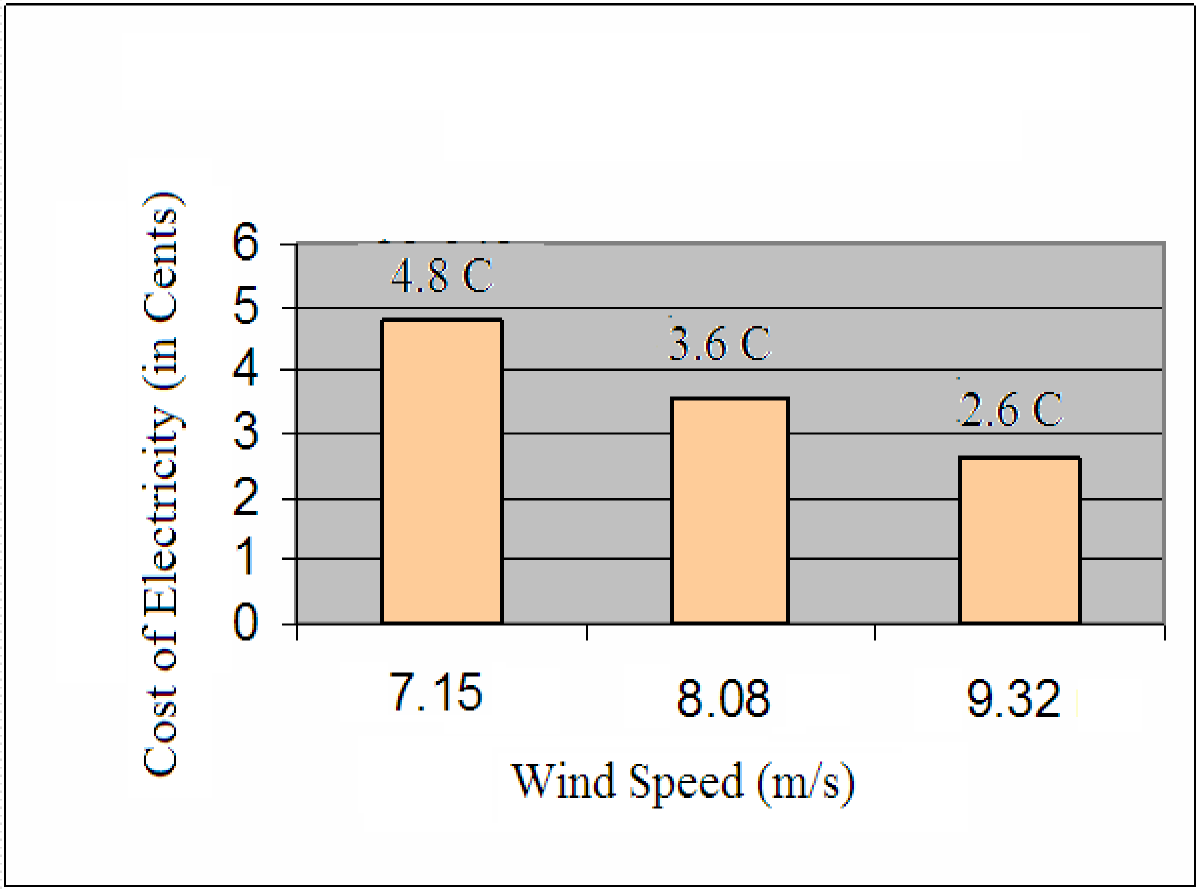


- Before the cut-in wind-speed (about 14 km/h), no net power is generated
- Then, power rises like the cube of wind-speed
- After the rated wind-speed is reached, the wind turbine operates at rated power
- Pitch-angle (angle between blade and plane of the axis of rotation) is controlled to maintain the constant rated power above the rated wind speed
- Above cut-out (about 90 km/h) wind-speed, the wind is too strong to operate the turbine safely, machine is shut down, output power is zero

Economies of Scale

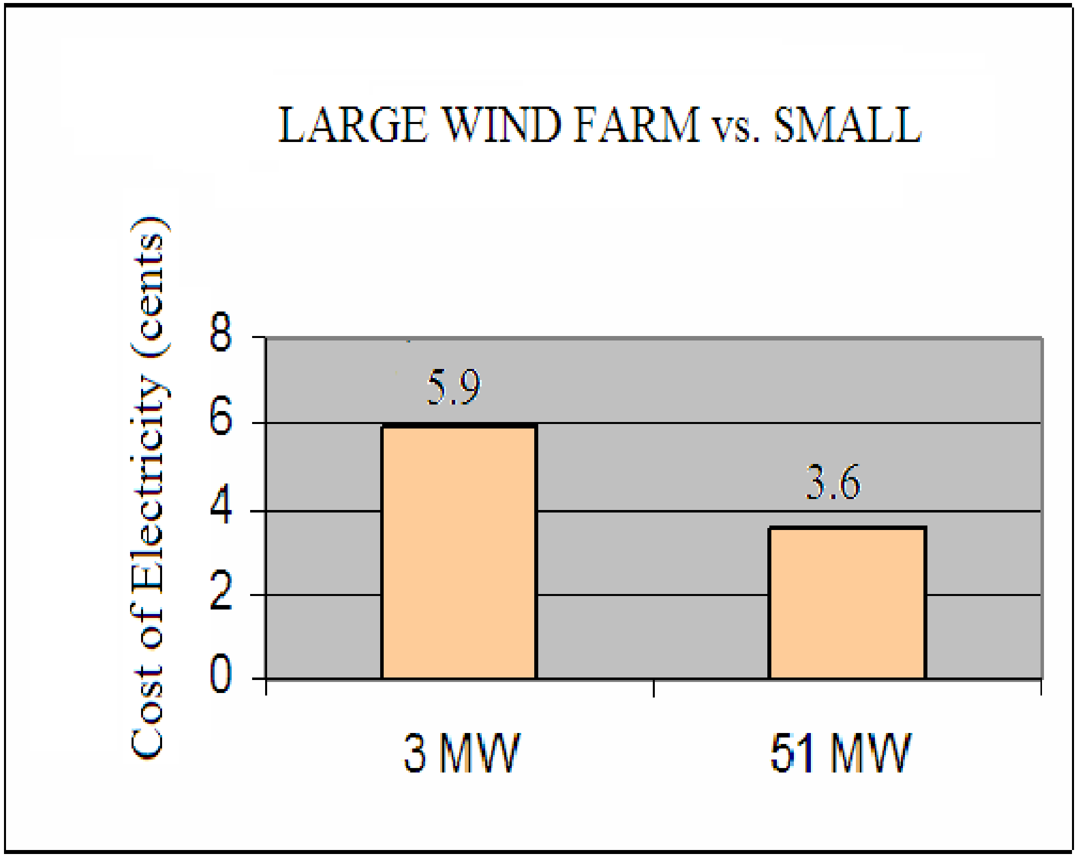
- Large wind farms produce electricity more economically than small operations
- Factors that contribute to lower costs are
  - Wind power is proportional to the area covered by the blade (square of diameter) while tower costs vary with a value less than the square of the diameter
  - Larger blades are higher, permitting access to faster winds
  - Fixed costs associated with construction (permitting, management) are spread over more MWs of capacity
  - Efficiencies in managing larger wind farms typically result in lower O&M costs (on-site staff reduces travel costs)

Wind Speed Matters

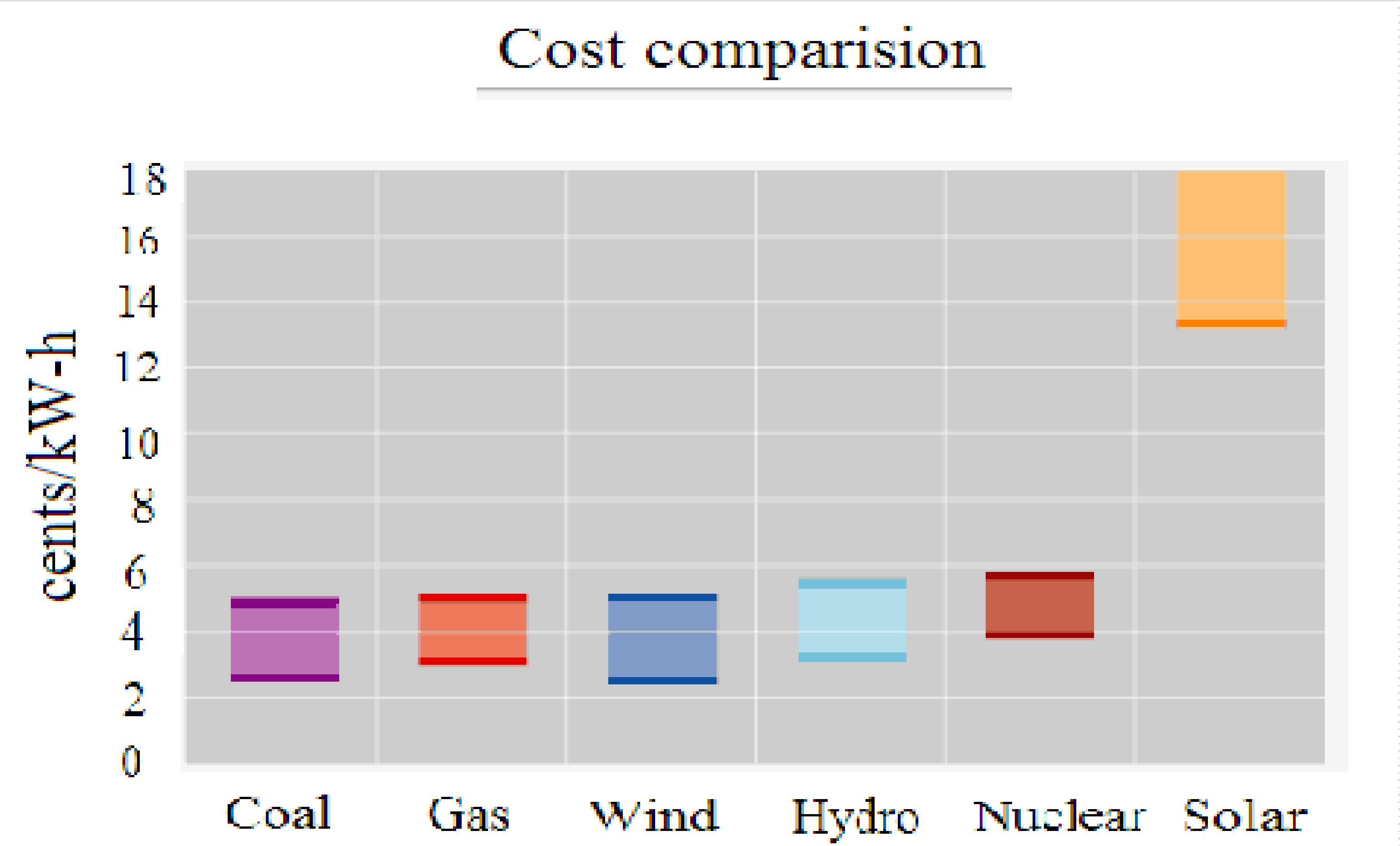


Assuming the same size project, the better the wind resource, the lower the cost.

Size Matters



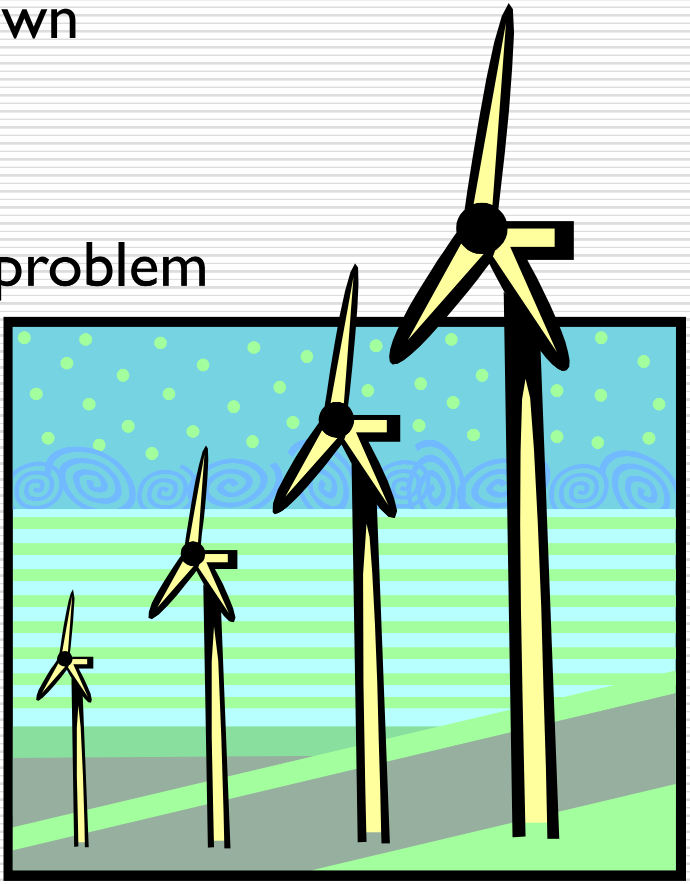
Assuming the same wind speed of 8.08 m/s, a large wind farm is more economical



Cost comparision
cents/kW-h
18
16
14
12
10
8
6
4
2
0
Coal
Gas
Wind
Hydro
Nuclear
Solar

So…..?

- Price of wind power is coming down
- There is enormous capacity
- Energy storage, however, is still a problem



Types Of Wınd Turbınes Farms (Based On Location)

Onshore
Onshore wind turbines are placed in hilly and mountainous places and are at least three kilometers away from the nearest shore.

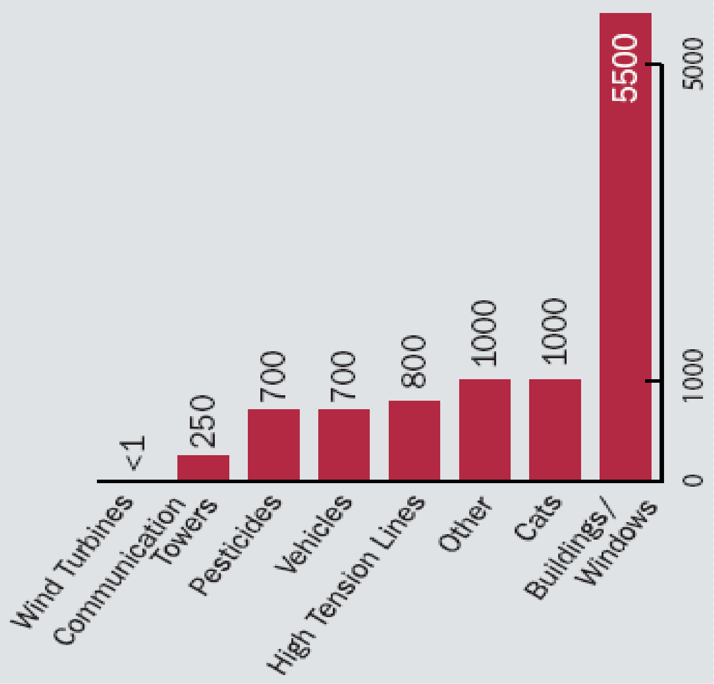
Near-shore
Near-shore wind turbines are installed within three kilometers from the nearest shore or on water within ten kilometers from land.

Offshore
Offshore wind turbines’ developement zones are at least ten kilometers away from land.

Environmental Aspects of Wind Energy

- Wind system emit no air pollution and no carbon dioxide; they also have essentially no water requirements
- Wind energy serves to displace the production of energy from other sources (usually fossil fuels) resulting in a net decrease in pollution
- Other impacts of wind energy are on animals, primarily birds and bats, and on humans

- Wind turbines certainly kill birds and bats, but so do lots of other things; windows kill between 100 and 900 million birds per year
- Turbine design and location has a large impact on mortality



Estimated Causes of Bird Fatalities, per 10,000

- Wind turbines often enhance the well-being of many people, but some living nearby may be affected by noise and shadow flicker
- Noise comes from 1) the gearbox/generator and 2) the aerodynamic interaction of the blades with the wind
- Shadow flicker is more of an issue in high latitude countries since a lower sun casts longer shadows

Power Grid Integration of Wind Power

- Currently wind power represents a minority of the generation in power system interconnects, so its impact of grid operations is small
- But as wind power grows, in the not too distant future it will have a much larger, and perhaps dominant impact of grid operations
- Wind power has impacts on power system operations ranging from that of transient stability (seconds) out to steady-state (power flow)
  - Voltage and frequency impacts are key concerns

Wind Power, Reserves and Regulation

- A key constraint associated with power system operations is pretty much instantaneously the total power system generation must match the total load plus losses
  - Excessive generation increases the system frequency,
  - Excessive load decreases the system frequency
- Generation shortfalls can suddenly occur because of the loss of a generator; utilities plan for this occurrence by maintaining sufficient reserves (generation that is on-line but not fully used) to account for the loss of the largest single generator in a region (e.g., a state)

- A fundamental issue associated with "free fuel" systems like wind is that operating with a reserve margin requires leaving free energy "on the table."
  - A similar issue has existed with nuclear energy, with the fossil fueled units usually providing the reserve margin
- Because wind turbine output can vary with the cube of the wind speed, under certain conditions a modest drop in the wind speed over a region could result in a major loss of generation
  - Lack of other fossil-fuel reserves could aggravate the situation

TYPES OF WIND TURBINE

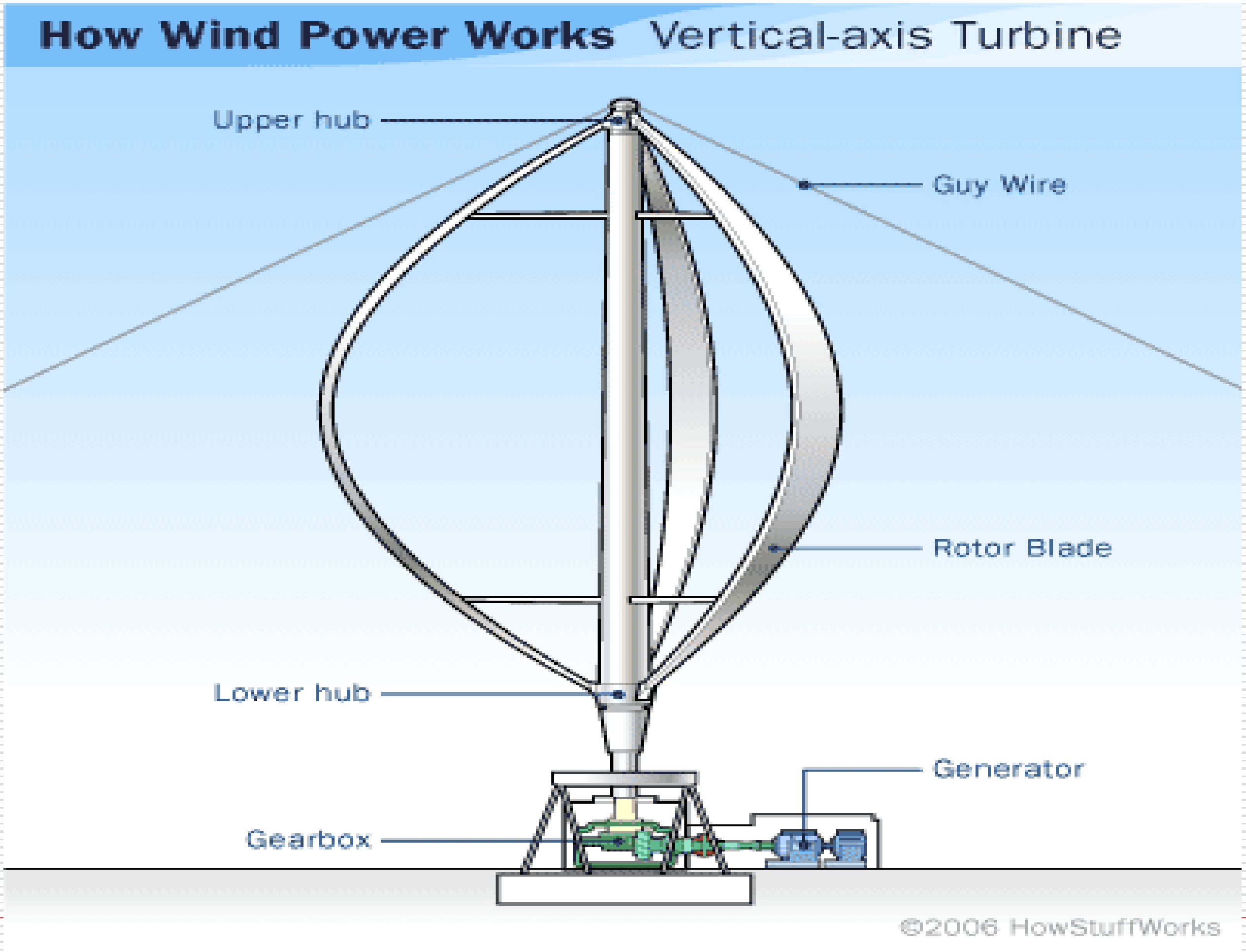
WIND TURBINE TYPES

Modern wind turbines fall into two basic groups

- The vertical-axis design,
- The horizontal-axis design typically
  - Two blades
  - Three blades

Horizontal axis turbines are the most common type used nowadays.

Vertical-axis Turbine



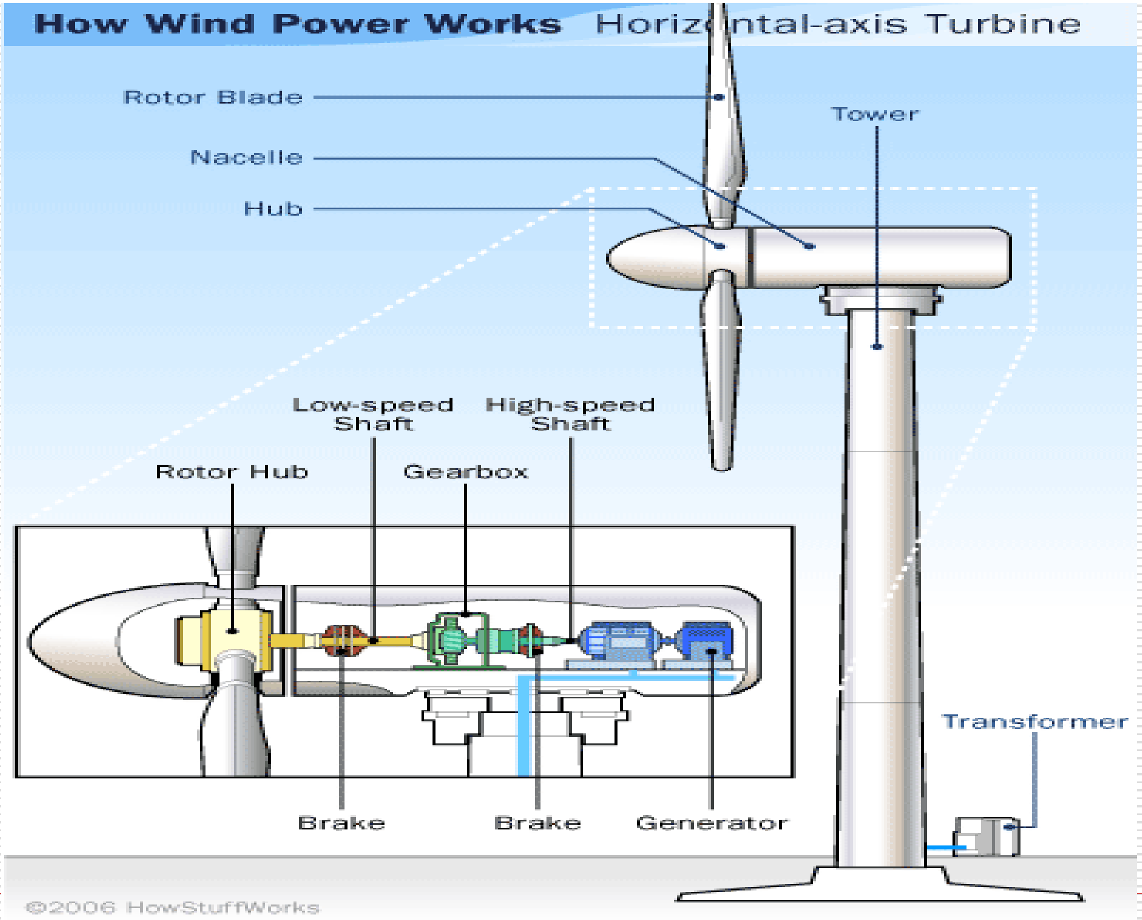
The Darrieus Vertical axis wind turbine

• Convenient as the generator is at ground level

•No yaw operation needed

• Non self-starting, needs a power source

Horizontal-axis Turbine



Horizontal axis wind turbine with three blades

•The most widely used.

• Lightweight construction, high dependability and proven ability to generate electricity efficiently.

• The generator needs to be on top of the support

• Slip rings required for power cable connection

Classification of Wind Turbines

Scale	Rotor Diameter	Power Rating
Micro	Less than 3m	50 W to 2 kW
Small	3m to 12m	2 kW to 40 kW
Medium	12m to 45m	40 kW to 999 kW
Large	46m and larger	1 MW and more

Rotor Size and Maximum Power Output

Rotor Diameter (meters)	Power Output (kW)
10	25
17	100
27	225
33	300
40	500
44	600
48	750
54	1000
64	1500
72	2000
80	2500

TURBINES(WITH/WITHOUT GEAR)

- Gear connects low-speed shaft to high-speed shaft to increase the rotational speeds from about 15 to 50 rpm to about 1100 to 1550 rpm, the speed required by most generators to produce electricity. The gear box is a costly and heavy part of the wind turbine
- “Direct Drive” wind turbines operate at lower rotational speeds and don't need gear boxes

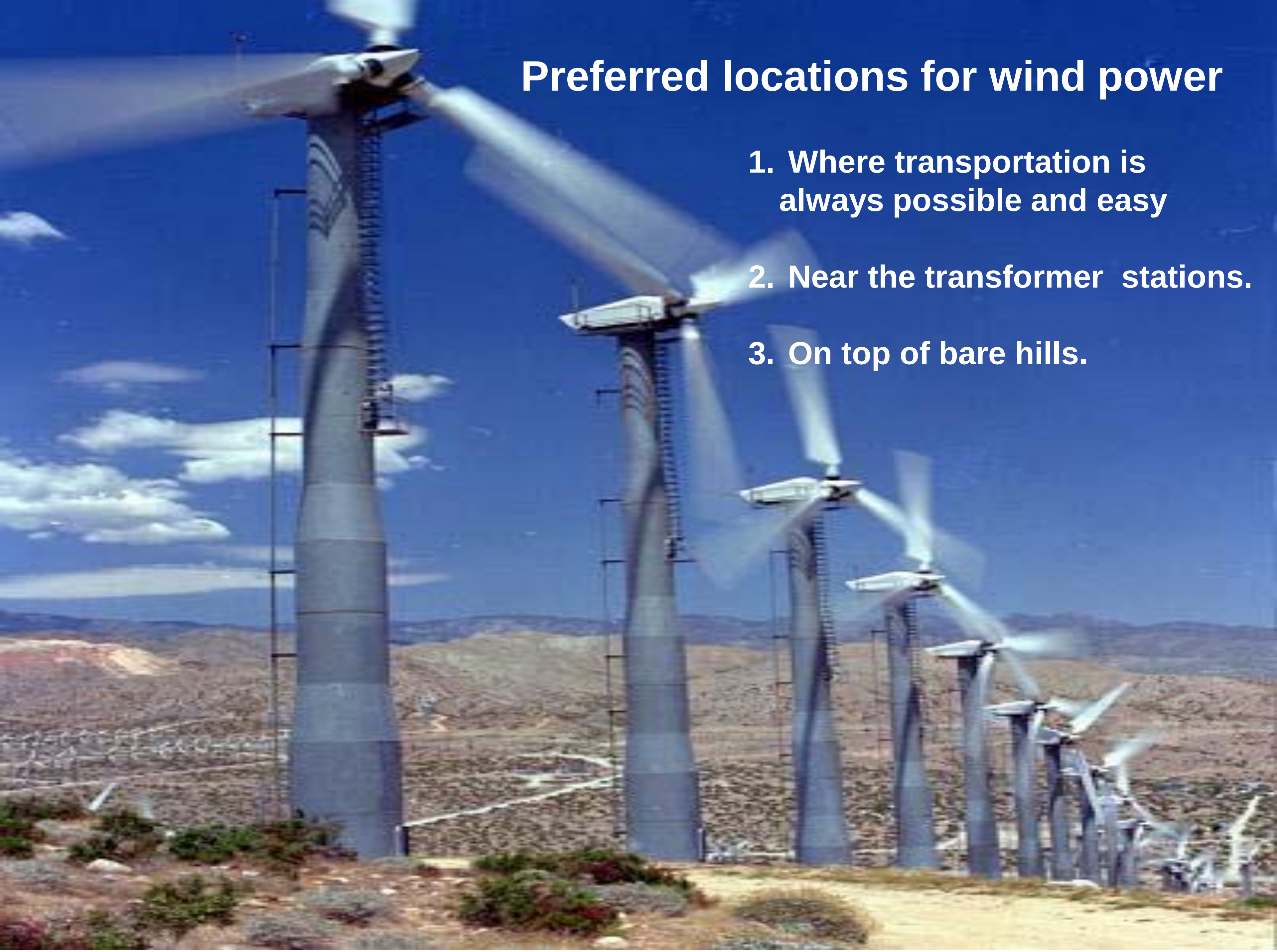
Mega Watt-size wind turbine

Wind Turbine used for pumping water

1941 The world's first megawatt-size wind turbine, Castleton, Vermont ,USA . The 1.25 MW Smith-Putnam turbine operated for 1100 hours

Wind Energy Centre in Texas (generating capacity of 1600 MW)

Area 47,000 acres



Preferred locations for wind power

1. Where transportation is always possible and easy

2. Near the transformer stations.

3. On top of bare hills.

Components Of Wind Turbine

1. **Rotor blades** - convert wind's energy it to rotational energy of shaft
2. **Shaft** - transfers rotational energy into generator
3. **Nacelle** - casing that holds **gearbox, generator, electronic control unit, yaw controller, brakes**
4. **Tower** - supports rotor and nacelle and entire setup at higher elevation where blades can safely clear the ground
5. **Electrical equipment** - carries electricity from generator down through tower and controls many safety elements of turbine

Components Of The Nacelle

1. **gearbox** - increases speed of shaft between rotor hub and generator
2. **generator** - rotational energy is converted to electricity using electromagnetism
3. **electronic control unit** - monitors system, shuts down turbine in case of malfunction and controls yaw mechanism
4. **yaw controller** - moves rotor to align with direction of wind
5. **brakes** - stop rotation of shaft in case of power overload or system failure

World's largest turbines

- The *Enercon E112* delivers up to 6 MW , has an overall height of 186 m (610 ft) a diameter of 114 m (374 ft). Blade length 57m

- The *REpower 5M* delivers up to 5 MW , has an overall height of 183 m (600 ft) a diameter of 126 m (413 ft). Blade length 63m

Large Wind Turbine

Horizontal-axis wind turbine,
 the Enercon model E-66
 wind energy converter,
in Germany. The tower is
 98 meters high, with
a rotor diameter of 70 meters.

Large Blade being transported

Large Wind Turbine Blades

Modern rotor blades (up to 126 m diameter) are made of lightweight glass-reinforced plastic (GRP) with an epoxy or polyester resin matrix.

Large Horizontal axis wind turbine

Man on the Nacelle

THE USE OF BIG-ROTOR TURBINES

- Electricity produced by big rotors get transferred to centeral electricity network. Some of the electricity that’s needed in industrial fields is provided from wind power.

THE USE OF SMALL-ROTOR TURBINES

- Small turbines are generally used in the fields where centeral electricity network has problems providing energy or there is no way to reach it.

- The electricity produced by these turbines get stored in generators.

New designs

‘Wind Wandler’
Helical Turbine

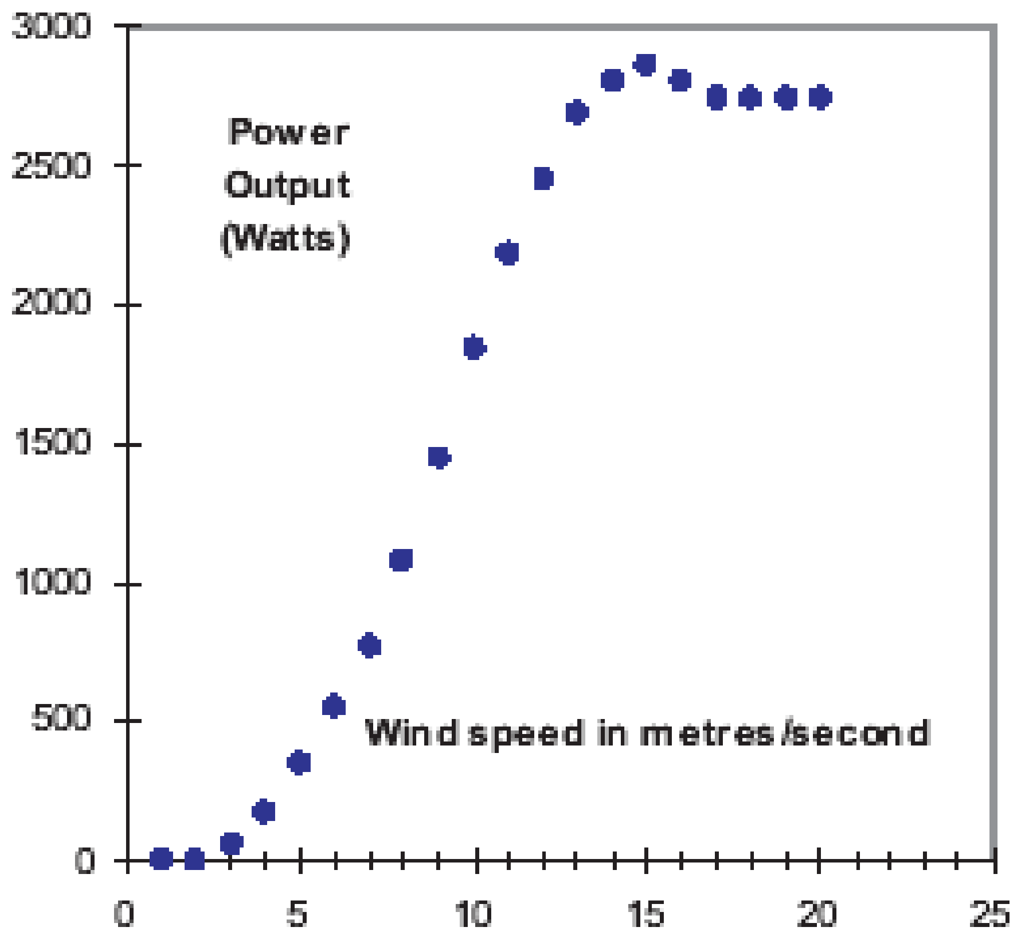
53% efficient, as opposed to 46% for conventional bladed turbines

New designs

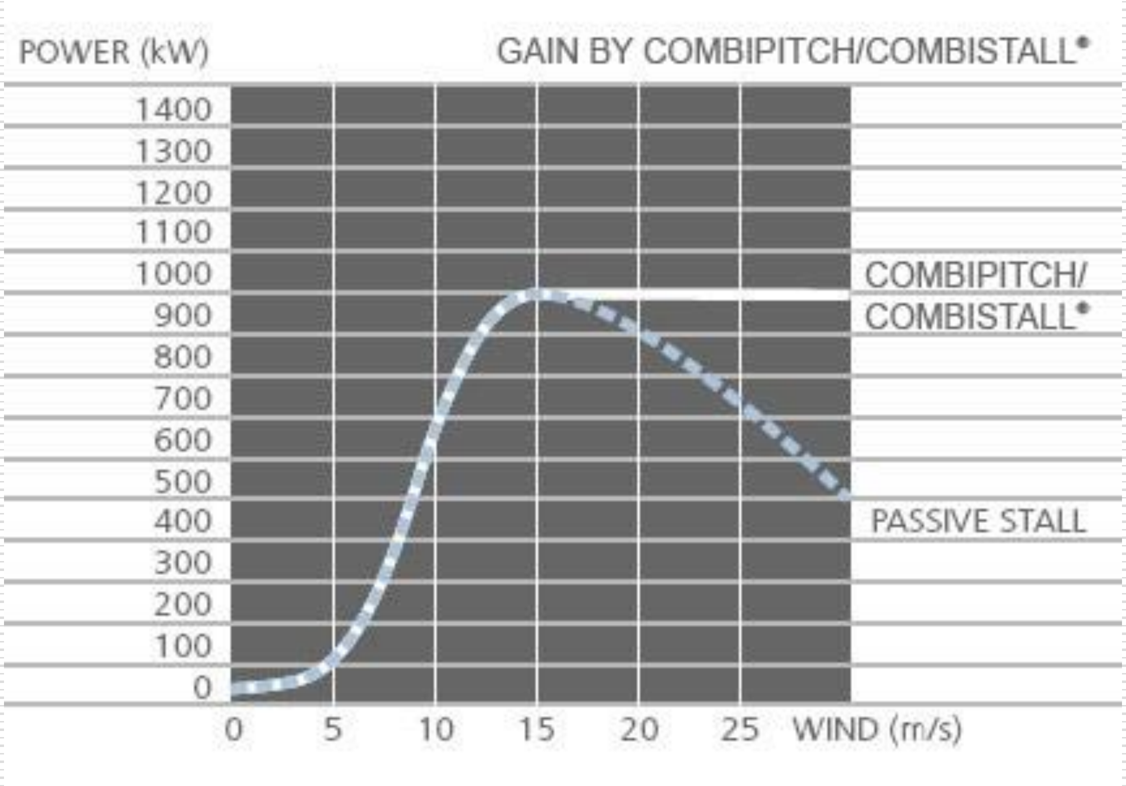
Carbon Concepts, UK

A near silent vertical axis turbine for domestic and industrial use

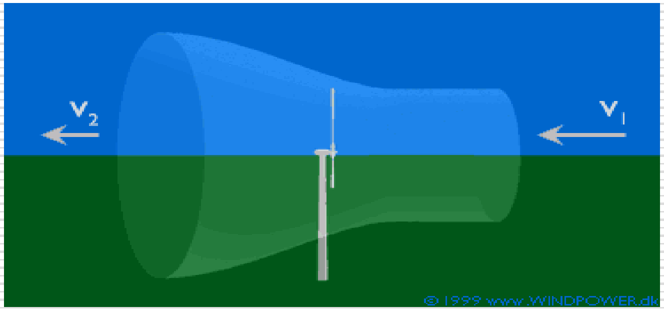
Small Turbine Characteristics



Large Turbine Characteristics



Betz' Law



Betz' law says that you can only convert less than 16/27 (or 59%) of the kinetic energy of the wind to mechanical energy using a wind turbine.

$$P_{\max} = 0.59 \frac{1}{2} \dot{m} V^2 \quad = 0.59 \frac{1}{2} \rho A V^3$$

Variation of Air Density with elevation

Elevation m	Air Density %
0 - 150	100
150 - 300	97
300 - 600	94
600 - 900	91
900 - 1200	88
1200 - 1500	85
1500 - 1800	82
1800 - 2100	79
2100 - 2400	76
2400 - 3000	73

Projections Example - India

Power requirement by the year 2012 :
2,40,000 MW

Contribution required from RE sector :
24,000MW

Wind power share :
12,000MW