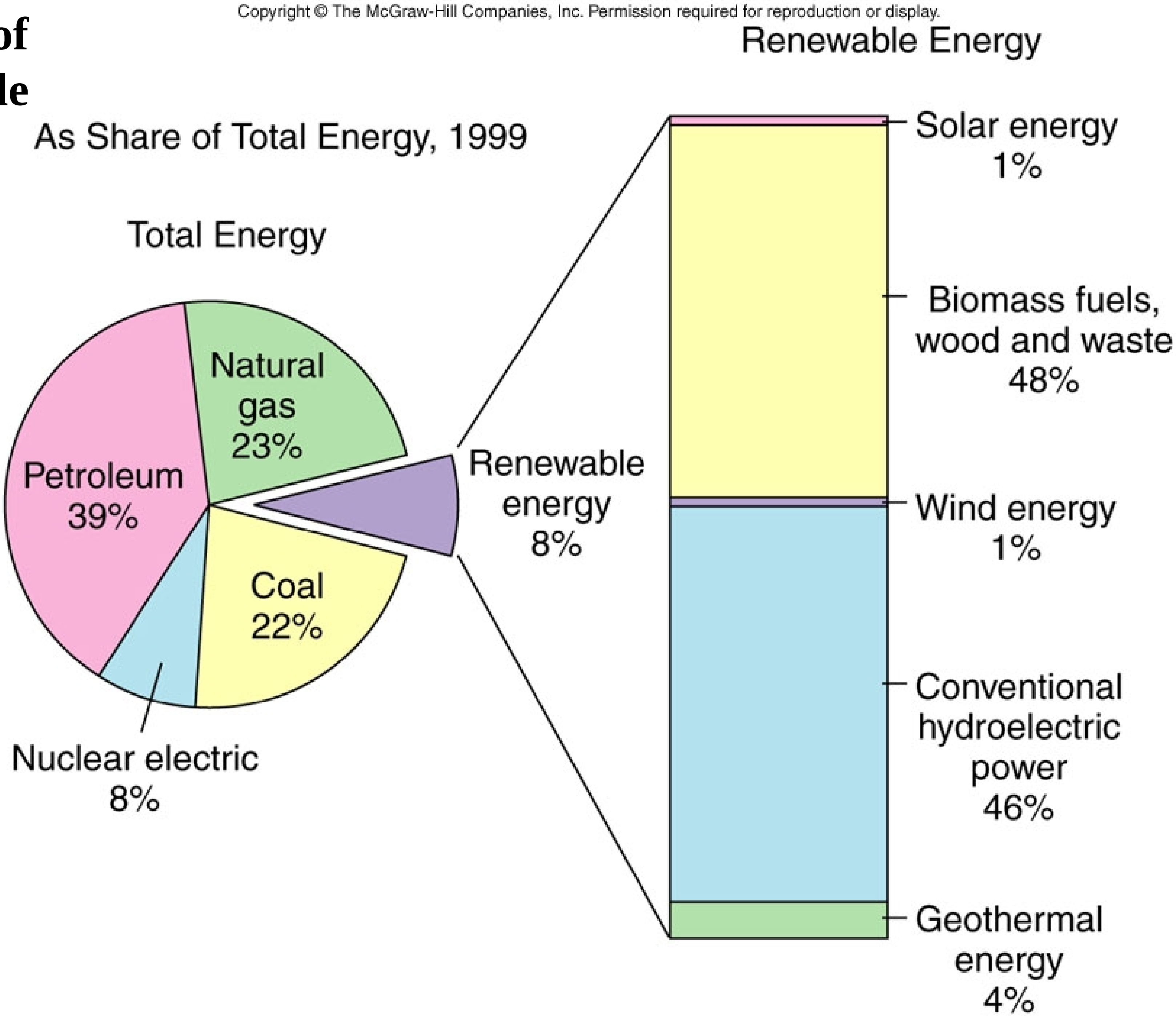
Wind Energy

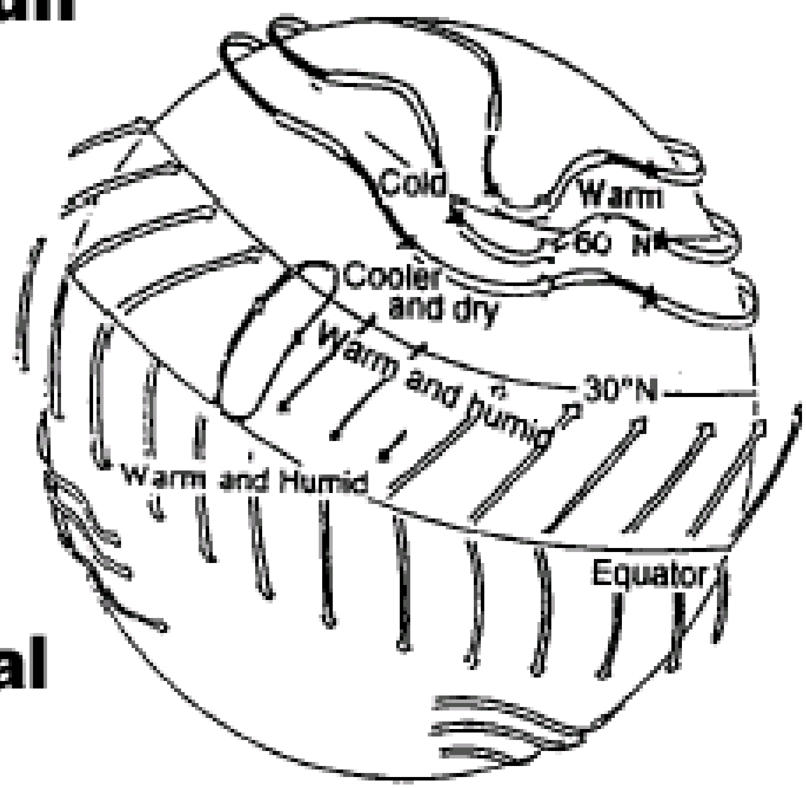
U.S. Use of Renewable Energy



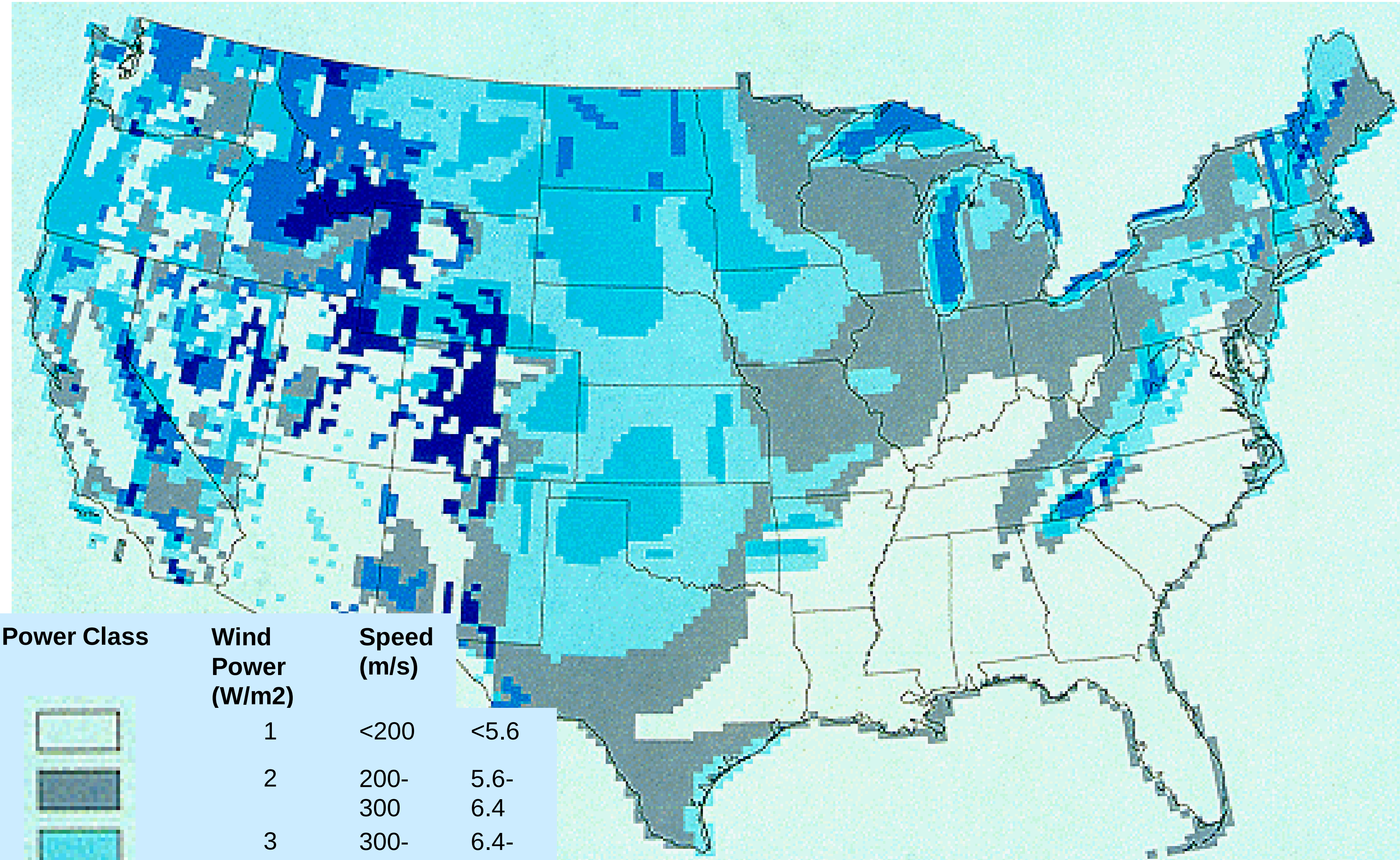
The Wind - from heat to motional energy

- Radiation from Sun
  > heat
  > pressure gradients
  > motion
- coriolis acceleration
  > deflection

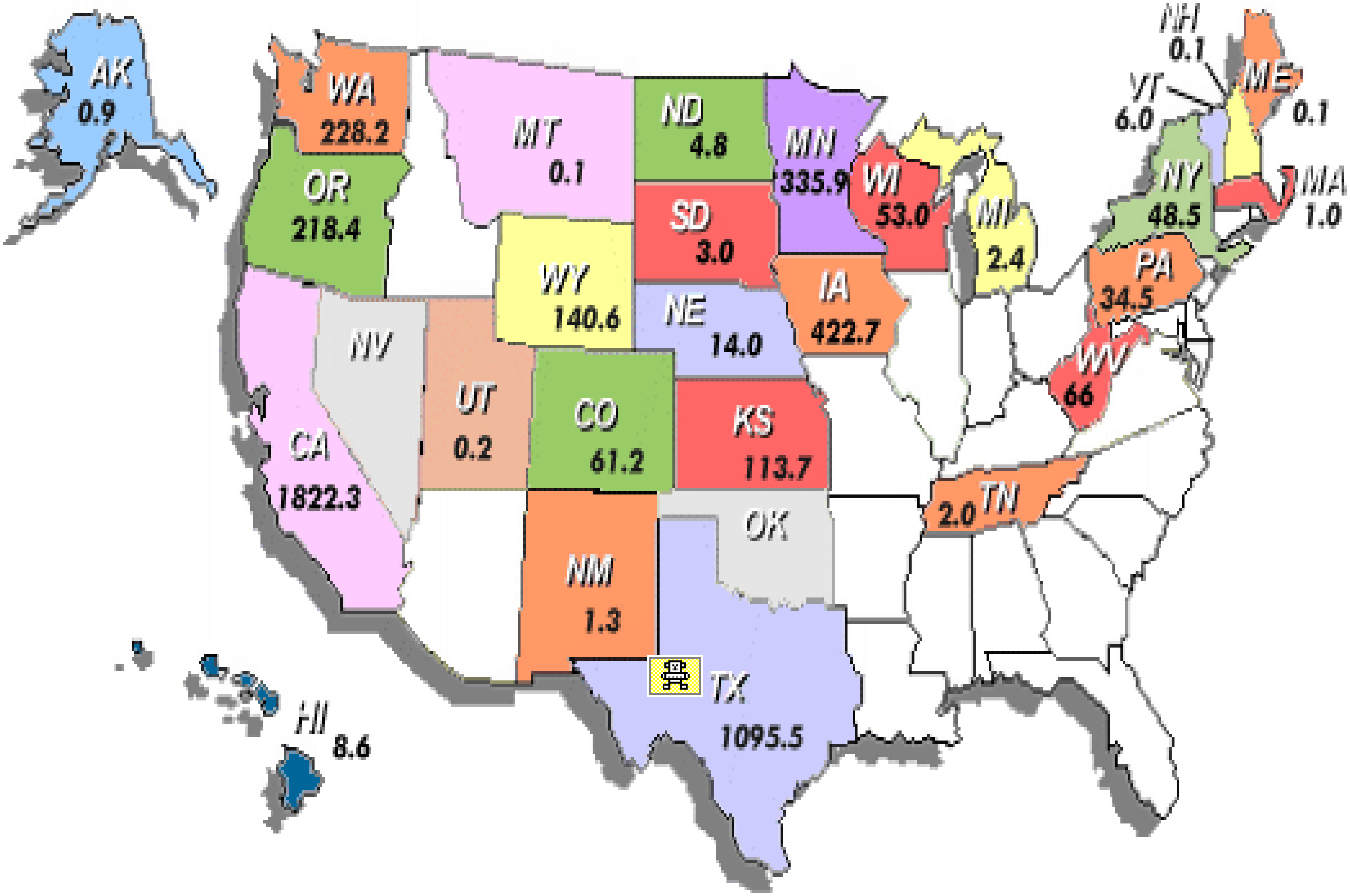
➡ large scale global wind systems



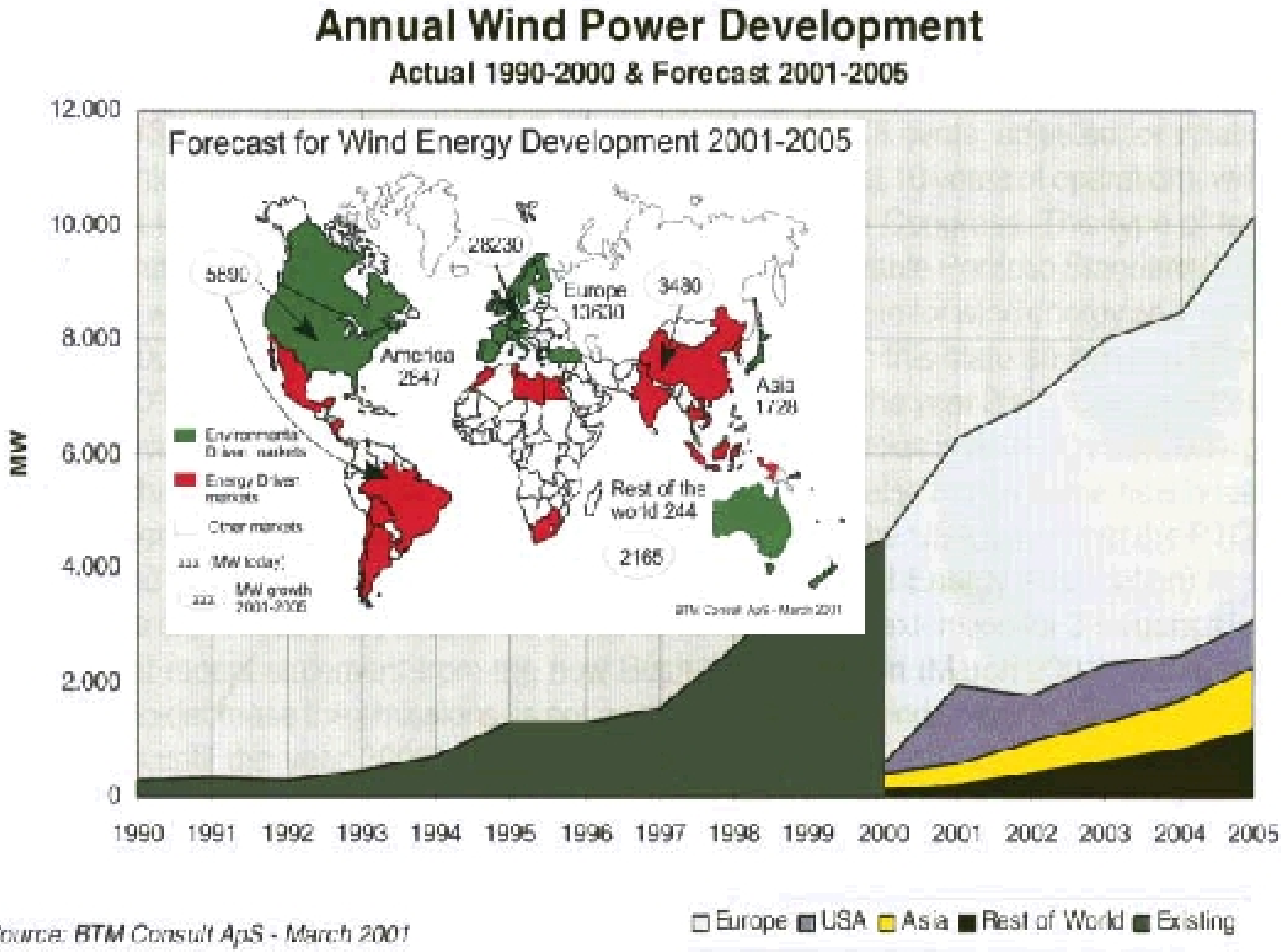
Wind Power Map of the USA



Power Class	Wind Power (W/m2)	Speed (m/s)
1	<200	<5.6
2	200-300	5.6-6.4
3	300-400	6.4-7.0
4	400-500	7.0-7.5
5	500-600	7.5-8.0
6	600-800	8.0-8.8
7	>800	>8.8



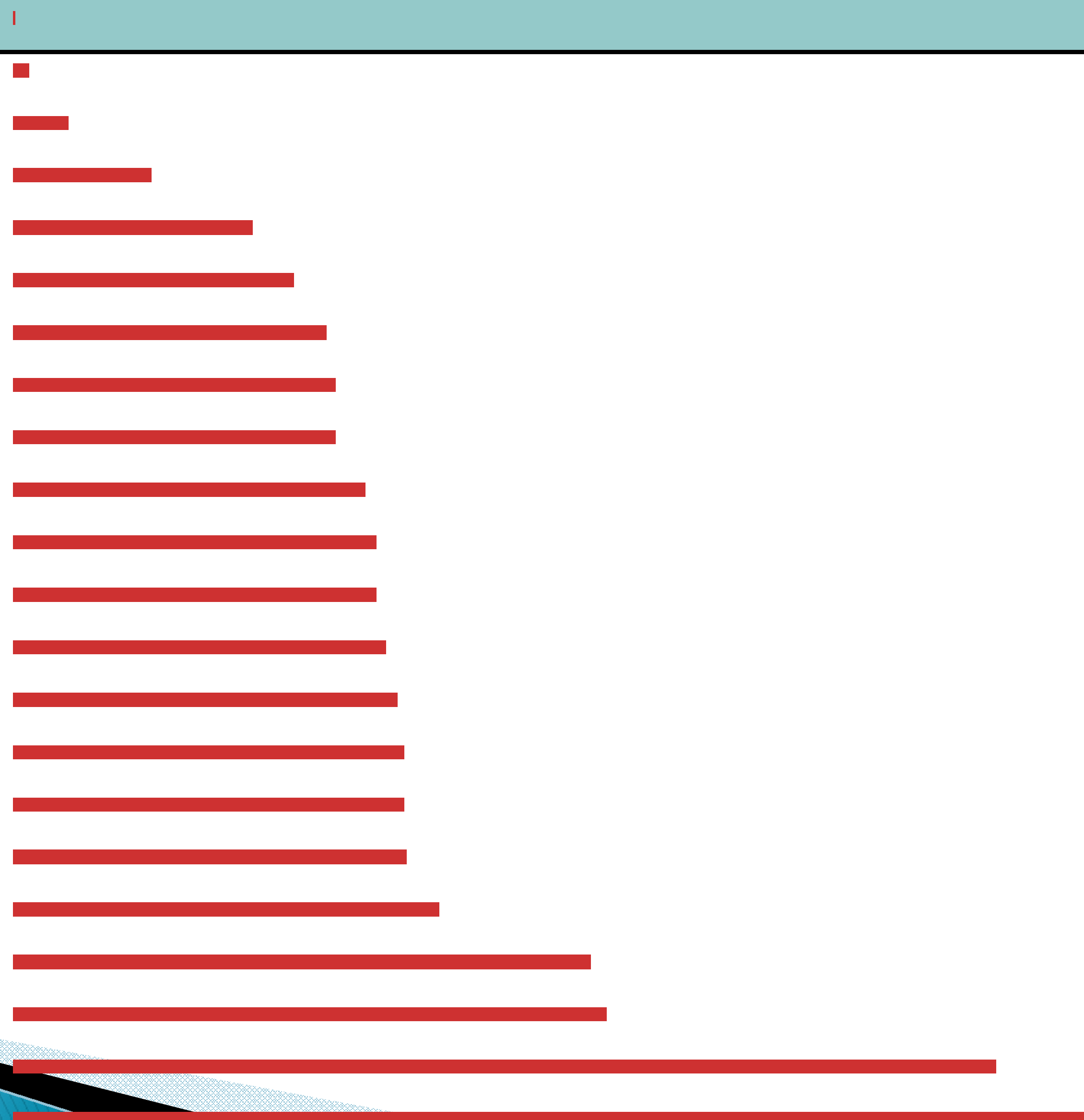
TOTAL INSTALLED WIND ENERGY CAPACITY:
4,685 MW as of Jan 21, 2003



Source: BTM Consult ApS - March 2001

U.S. Installed Capacity (Megawatts) 1981-2002

Year	MW
1981	10
1982	70
1983	240
1984	597
1985	1,039
1986	1,222
1987	1,356
1988	1,396
1989	1,403
1990	1,525
1991	1,575
1992	1,584
1993	1,617
1994	1,656
1995	1,697
1996	1,698
1997	1,706
1998	1,848
1999	2,511
2000	2,578
2001	4,275
2002	*4,685



Wind Power Harnessed

Wind Turbine Power:

$$P = 0.5 \times rho \times A \times Cp \times V^3 \times Ng \times Nb$$

P = power in watts (746 watts = 1 hp)

rho = air density (about 1.225 kg/m^3 at sea level, less higher up)

A = rotor swept area, exposed to the wind (m^2)

Cp = Coefficient of performance (.59 {Betz limit} is the maximum theoretically possible, .35 for a good design)

V = wind speed in meters/sec (20 mph = 9 m/s)

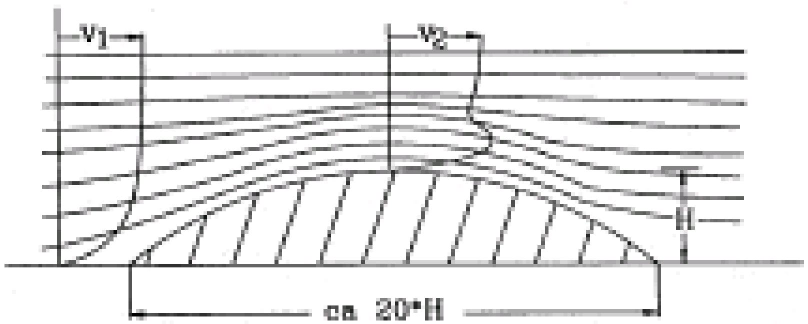
Ng = generator efficiency (50% for car alternator, 80% or possibly more for a permanent magnet generator or grid-connected induction generator)

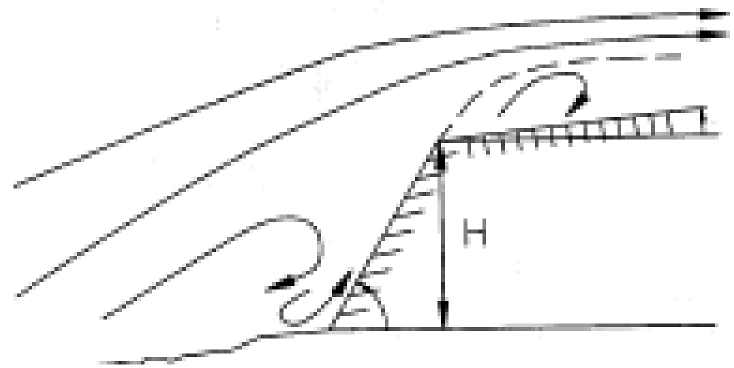
Nb = gearbox/bearings efficiency (depends, could be as high as 95% if good)

Classes of Wind Power Density at 10 m and 50 m[a]

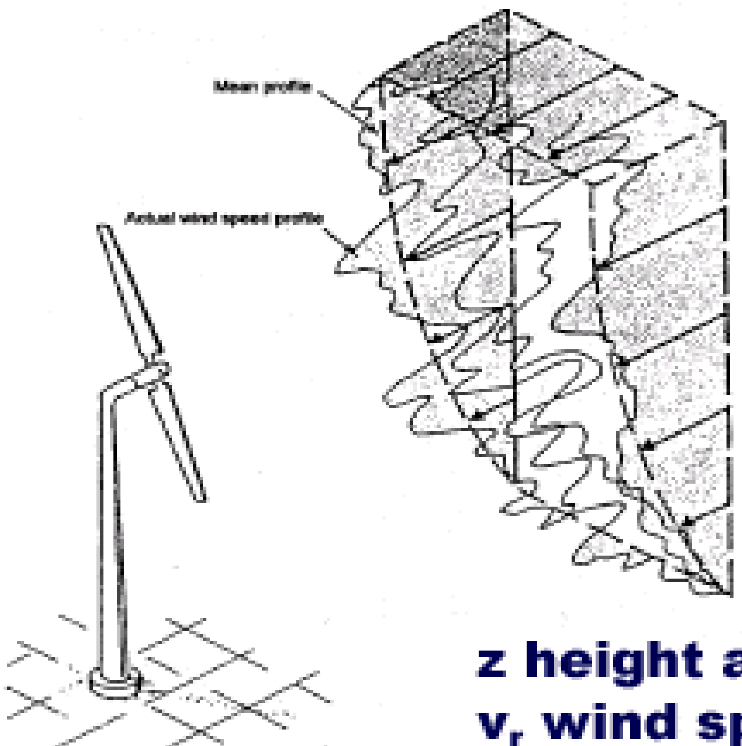
.	10 m (33 ft)		50 m (164 ft)	
Wind Power Class	Wind Power Density (W/m^2)	Speed[b] m/s (mph)	Wind Power Density (W/m^2)	Speed[b] m/s (mph)
1	<100	<4.4 (9.8)	<200	<5.6 (12.5)
2	100 - 150	4.4 (9.8)/5.1 (11.5)	200 - 300	5.6 (12.5)/6.4 (14.3)
3	150 - 200	5.1 (11.5)/5.6 (12.5)	300 - 400	6.4 (14.3)/7.0 (15.7)
4	200 - 250	5.6 (12.5)/6.0 (13.4)	400 - 500	7.0 (15.7)/7.5 (16.8)
5	250 - 300	6.0 (13.4)/6.4 (14.3)	500 - 600	7.5 (16.8)/8.0 (17.9)
6	300 - 400	6.4 (14.3)/7.0 (15.7)	600 - 800	8.0 (17.9)/8.8 (19.7)
7	>400	>7.0 (15.7)	>800	>8.8 (19.7)

Siting
- obstacles & flow over hills





The Wind - vertical profile



- **Amospheric boundary layer**
- **logarithmic profile**

$$v_z = v_r \frac{\ln\left(\frac{z}{z_0}\right)}{\ln\left(\frac{z_r}{z_0}\right)}$$

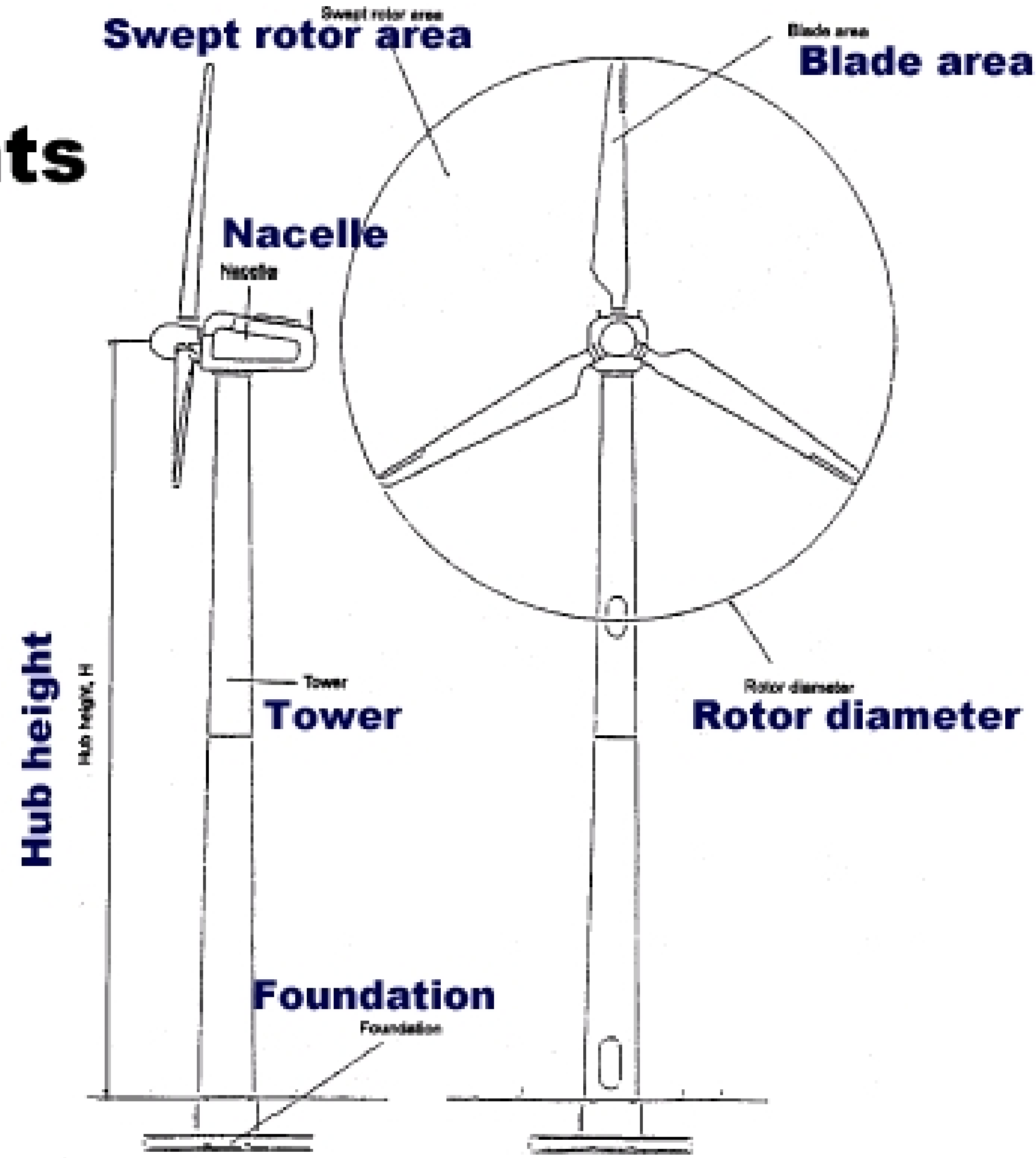
z height above ground level
v_r wind speed at reference height z_r
v_z wind speed at height z
z_0 roughness length

The Wind - logarithmic profile

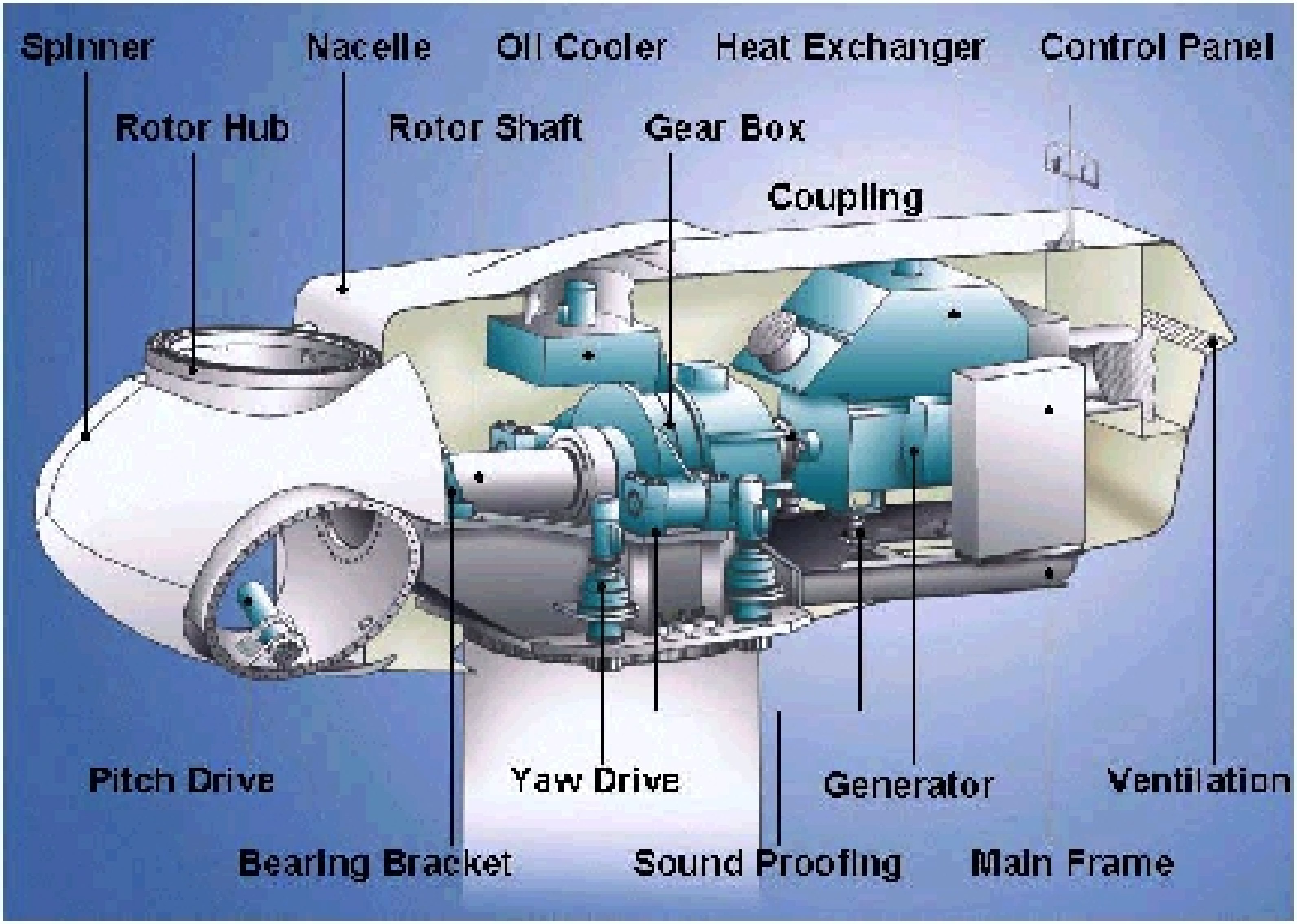
- calculate mean wind speed v_z at height z from known measurement v_r at reference heigth z_r
- roughness length z0

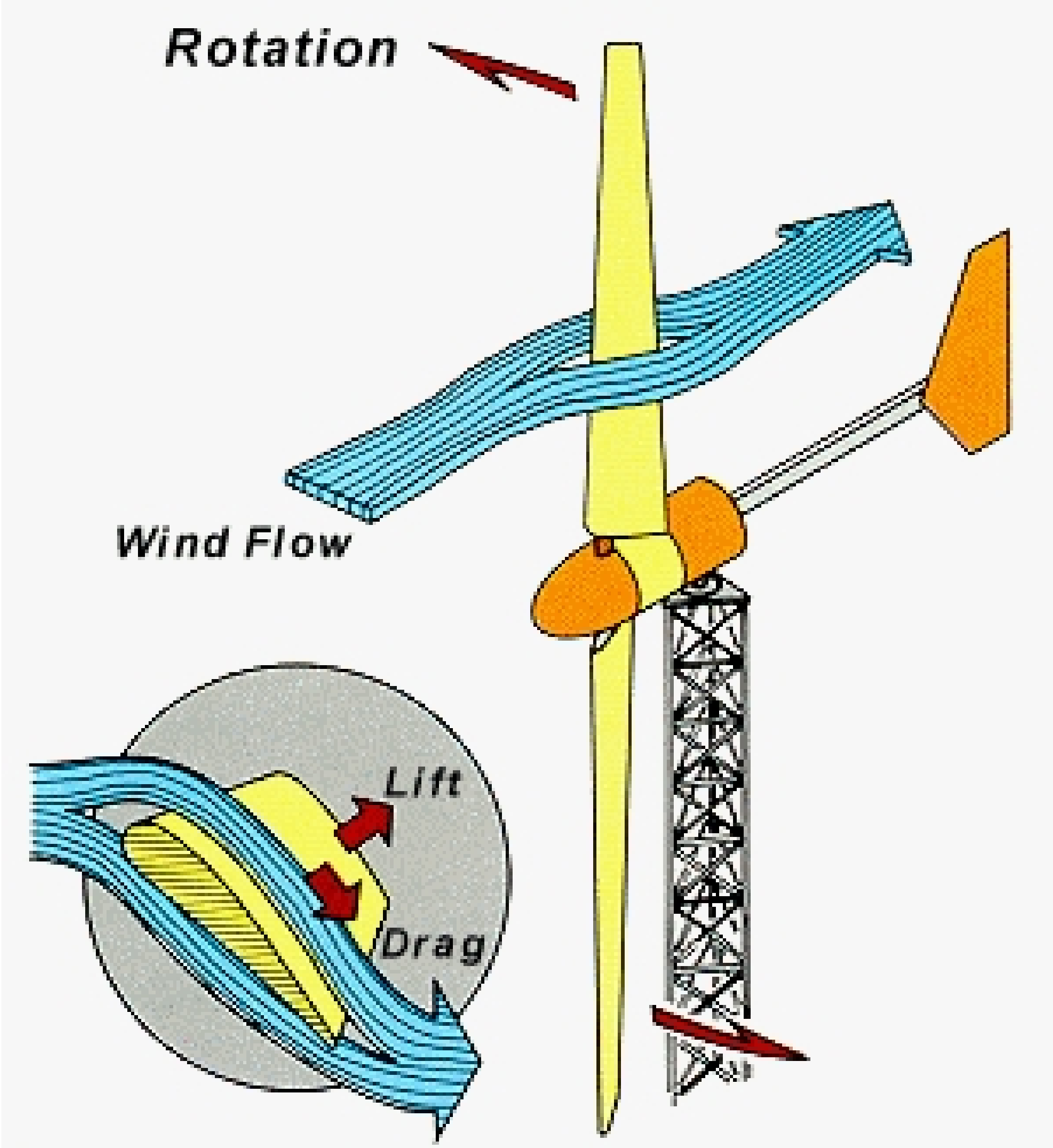
Type of Terrain	Roughnes class	Roughness length z0 [m]
Water areas	0	0.0002
Farmland with very few buildings, trees, etc.; airport areas	1	0.03
Farmland with closed appearance	2	0.1
suburbs	3	0.4

Main Components of a wind turbine

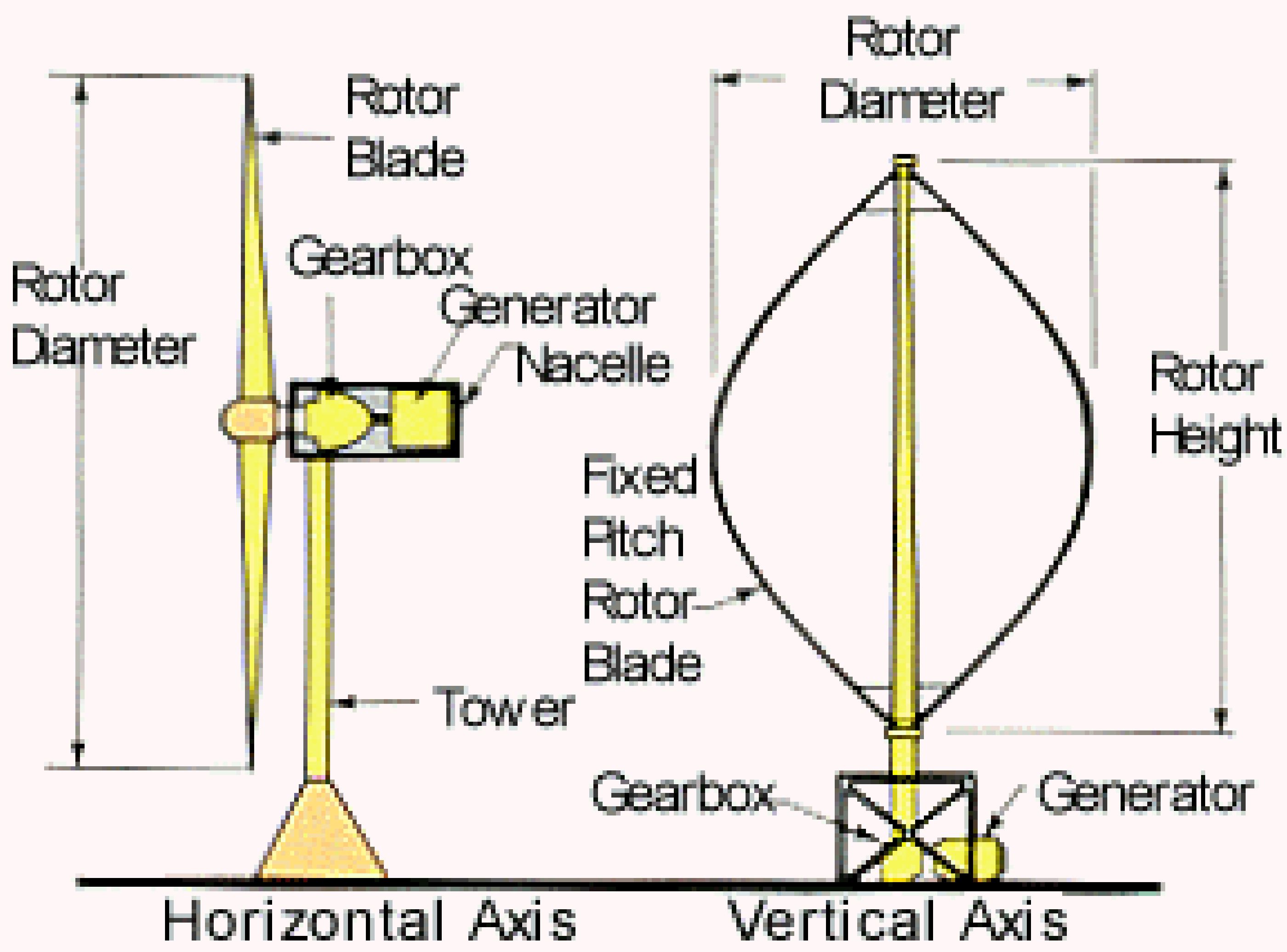


Components - Turbine Layout





Principles of Wind Turbine Aerodynamic Lift



Wind Turbine Configurations

Benefits of Wind Power

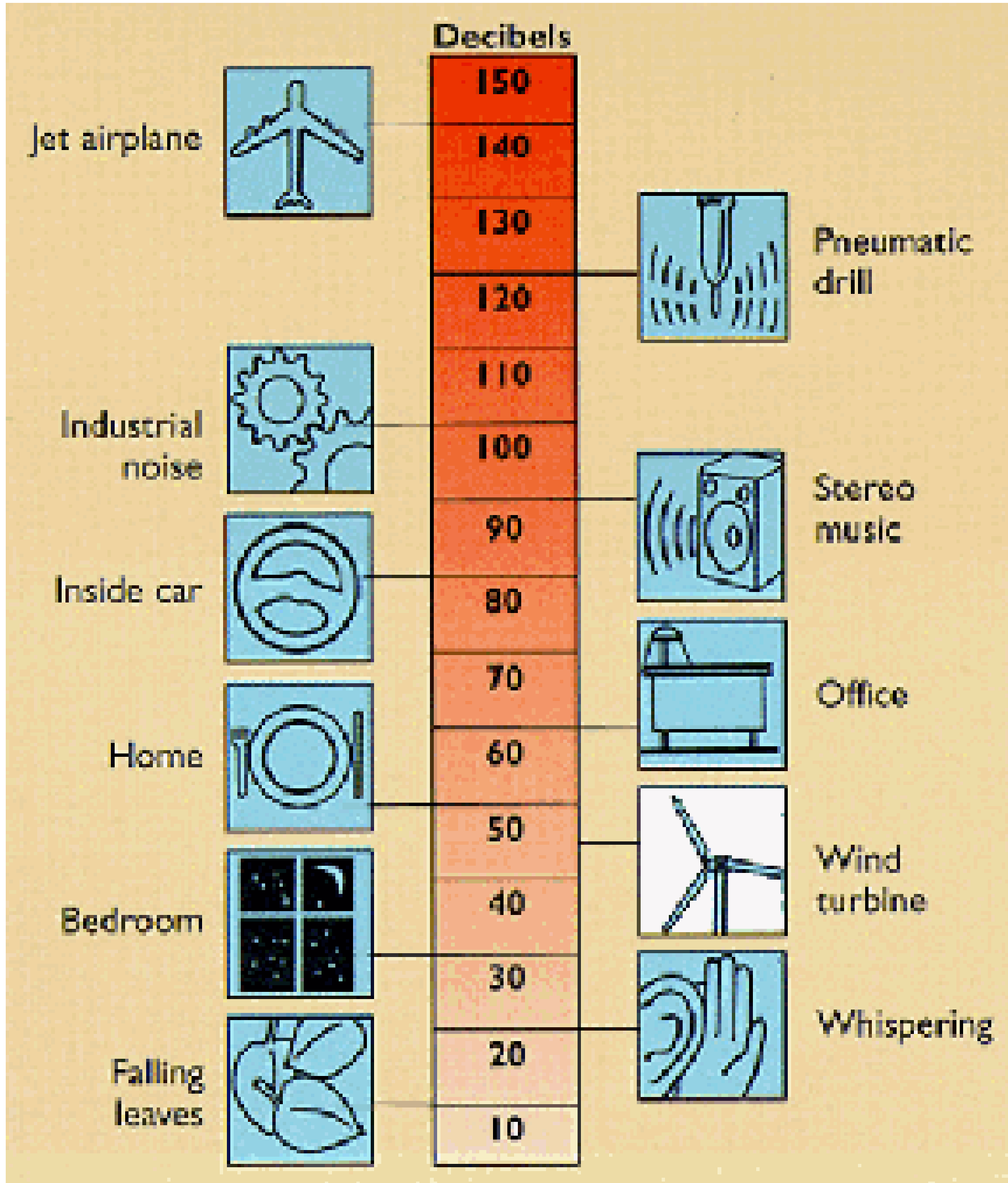
- Environmental benefits
    - No emissions
    - No fuel needed
- Distributed power
- Remote locations

Limitations of Wind Power

- Power density is very low.
  - Needs a very large number of wind mills to produce modest amounts of power.
- Cost.
- Environmental costs.
  - material and maintenance costs.
  - Noise, birds and appearance.
- Cannot meet large scale and transportation energy needs.

Wind Turbine

Noise Levels



The Future of Wind Energy

- Future of wind energy can be bright if government policies subsidize and encourage its use.
- Technology improvements unlikely to have a major impact.
- Can become cost competitive for electricity generation if fossil energy costs skyrocket.