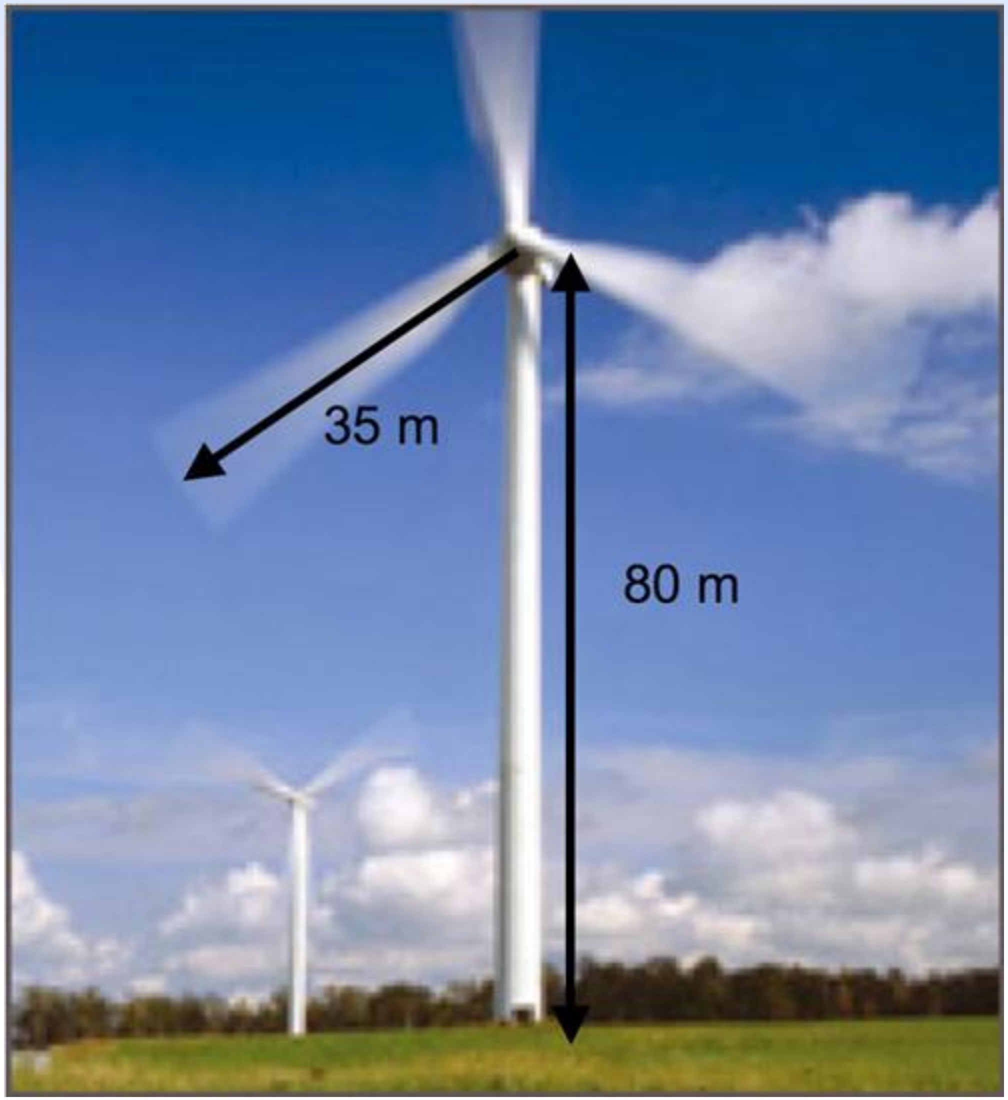


# Wind Energy

PHYS 4400, Principles and Varieties of Solar Energy

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The University of Toledo

February 18, 2014

# What is wind energy?

Wind is the movement of air resulting from pressure differentials in the atmosphere. I.e., wind is the motion of air as it rushes from a high pressure region toward lower pressure regions.

Wind, which has a typical density (standard temperature and pressure) of 1.275 $kg/m^3$, embodies the kinetic energy of air.

Air at rest (velocity equal to zero) creates no wind, and based on a simple consideration that kinetic energy depends on the square of a mass's velocity, the kinetic energy will be zero.

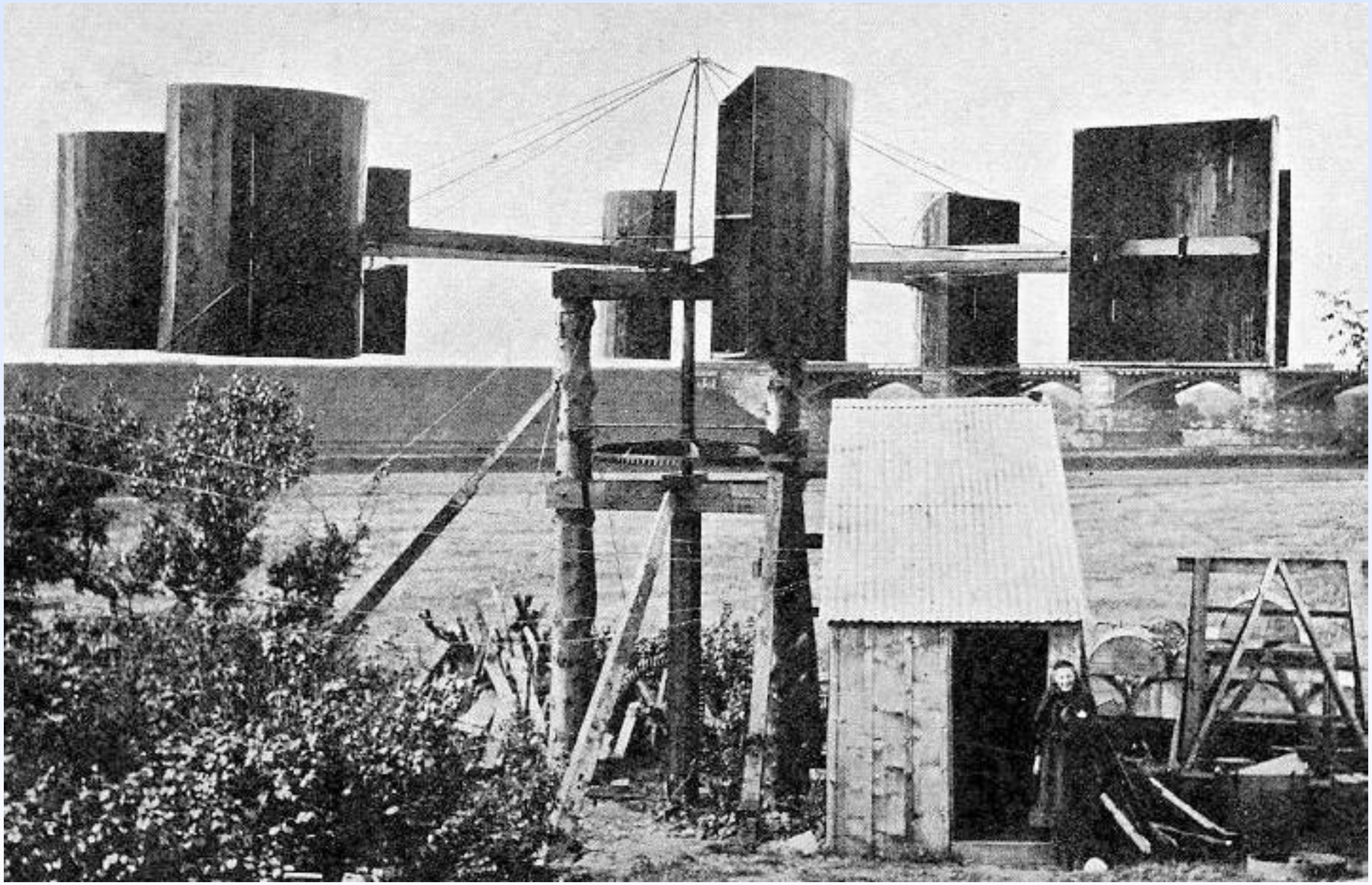
A very basic introduction to wind energy can be found here:
http://www.ftexploring.com/energy/wind-enrgy.html

http://en.wikipedia.org/wiki/Density_of_air

# How does wind energy relate to solar energy?

*"Globally, the two major driving factors of large-scale winds (the atmospheric circulation) are the differential heating between the equator and the poles (difference in absorption of solar energy leading to buoyancy forces) and the rotation of the planet."*

# Wind energy (electricity) in use in the 1800's



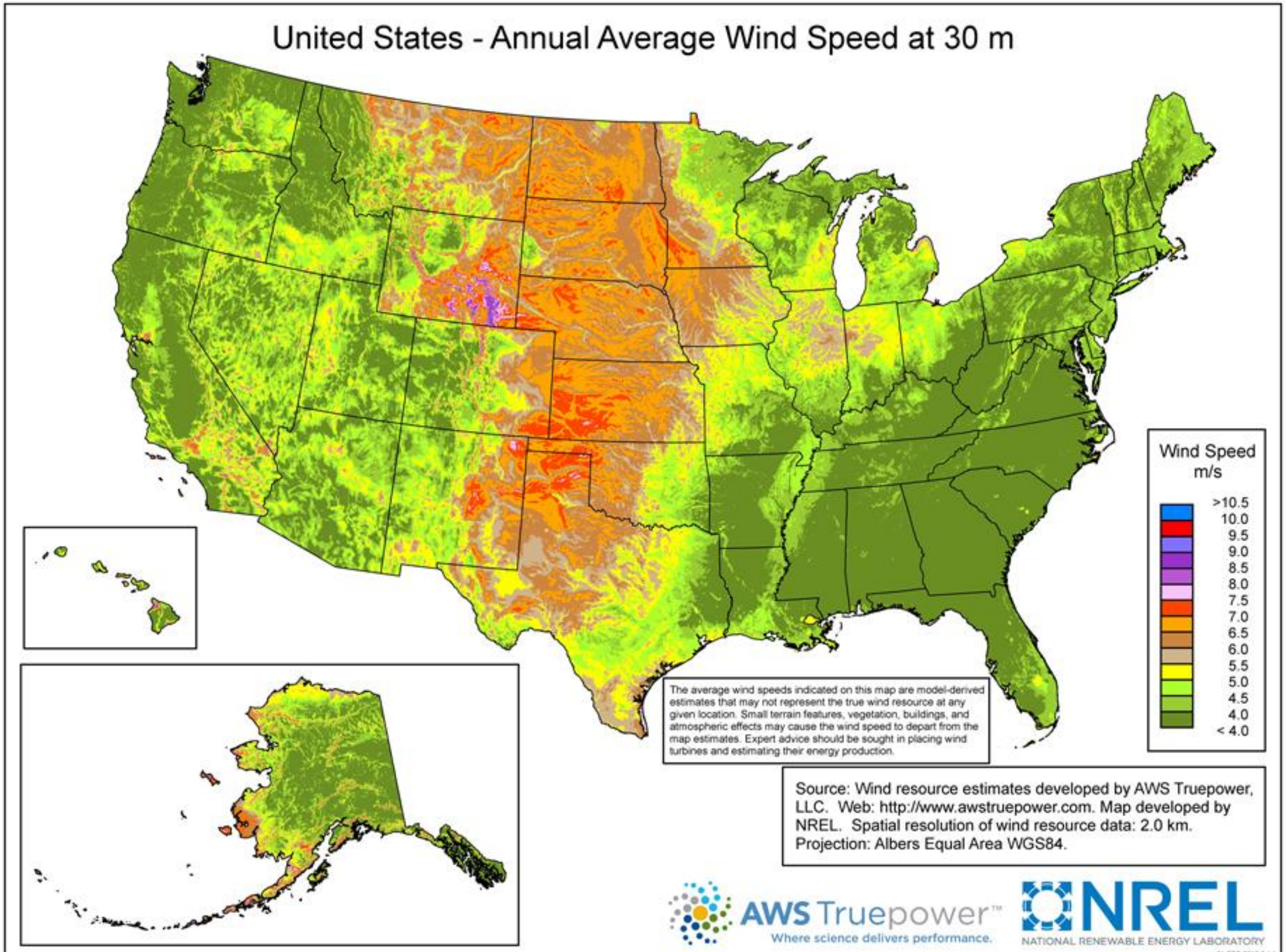
First electricity-generating wind turbine : a battery charging machine installed in 1887 by Scottish academic James Blyth to light his holiday home in Marykirk, Scotland. Later in 1887, American inventor Charles F Brush built the first automatically operated wind turbine for electricity production in Cleveland, Ohio.

# Wind power density

**Wind power density**

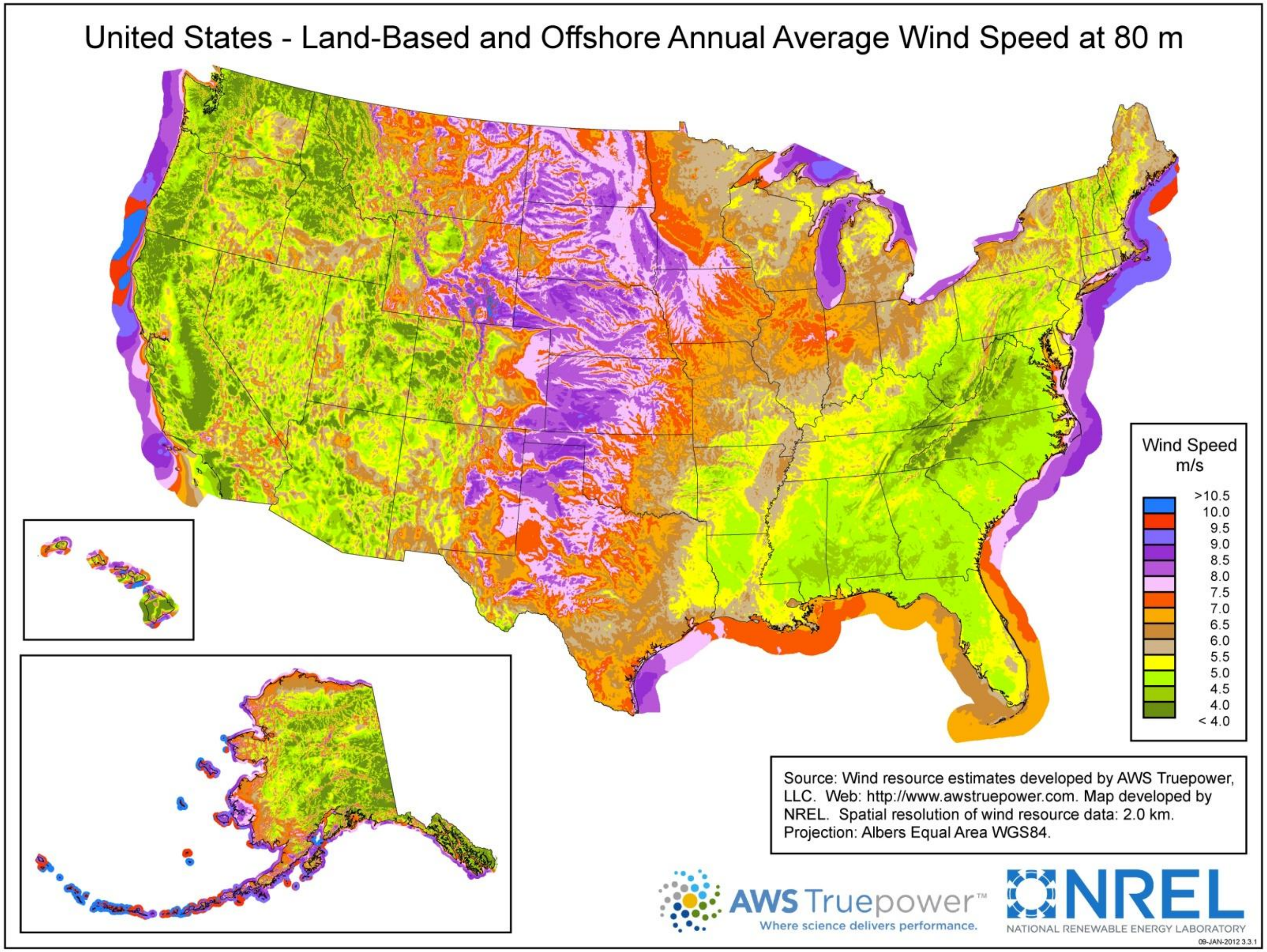
*Nowadays, a yardstick used to determine the best locations for wind energy development is referred to as wind power density (WPD). It is a calculation relating to the effective force of the wind at a particular location, frequently expressed in terms of the elevation above ground level over a period of time.*

# Wind speeds at 30 m height




http://www.nrel.gov/gis/wind.html

# Wind speeds at 80 m height

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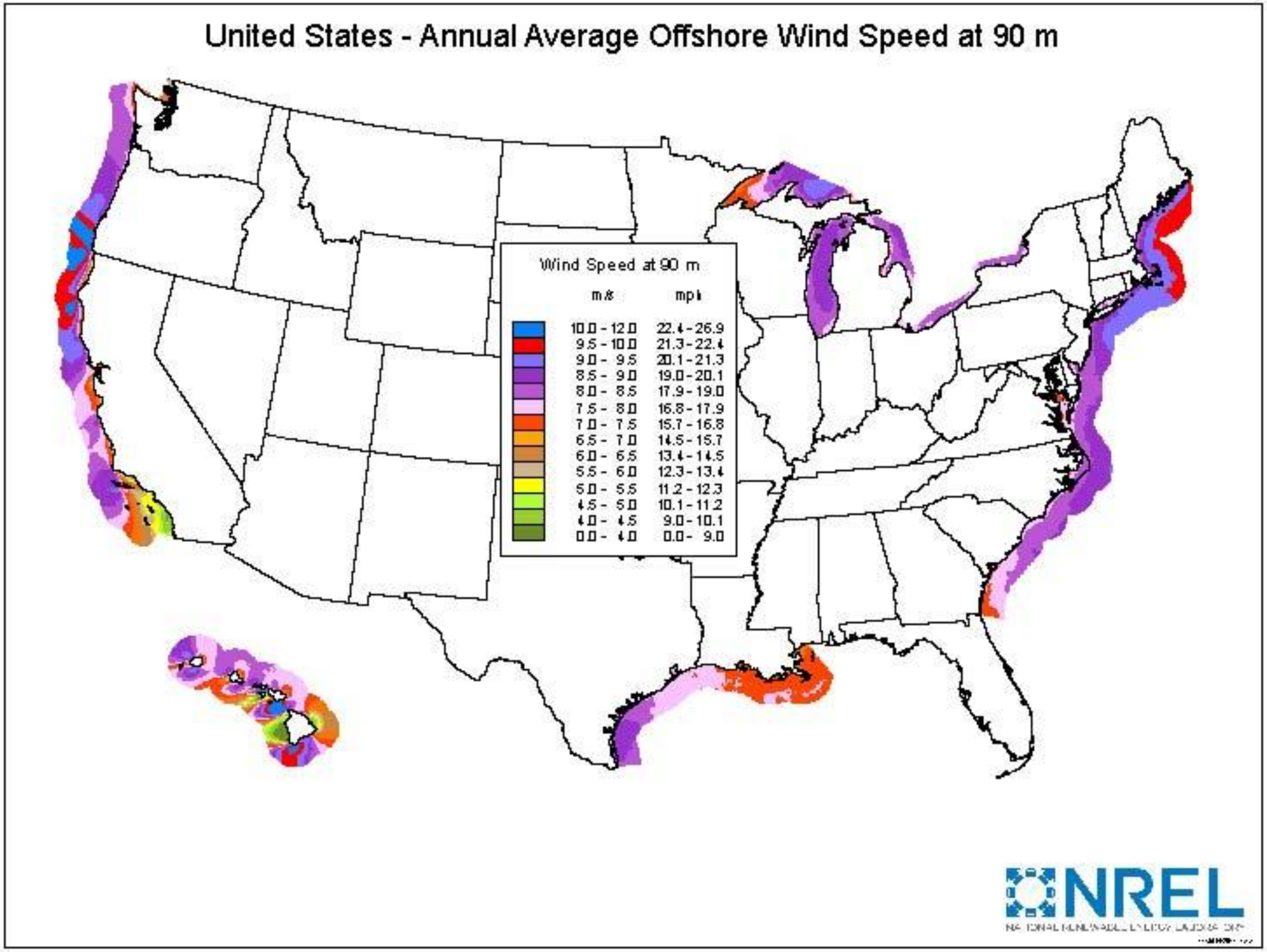
# Offshore wind speeds

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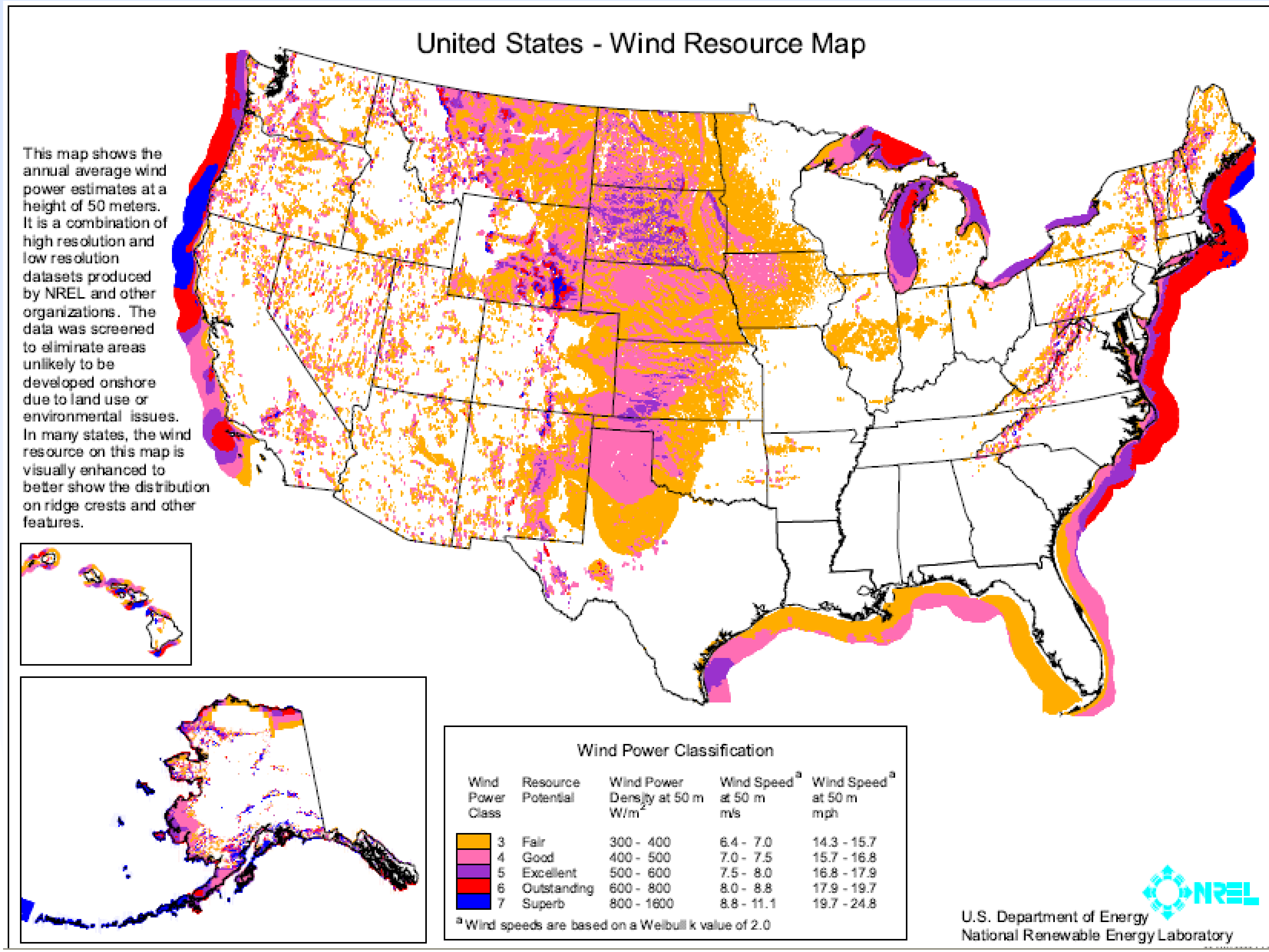
# US Wind Resource Map



# Wind power density

$$E = \frac{1}{2}mv^2 = \frac{1}{2}(Atv\rho)v^2 = \frac{1}{2}At\rho v^3$$

$$P = \frac{E}{t} = \frac{1}{2}A\rho v^3$$

These equations show the rate of wind energy flow through an area *A* normal to the wind direction, and the power incident on the area *A*.

# Maximum wind → mechanical energy conversion

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# Looking at Betz's Law

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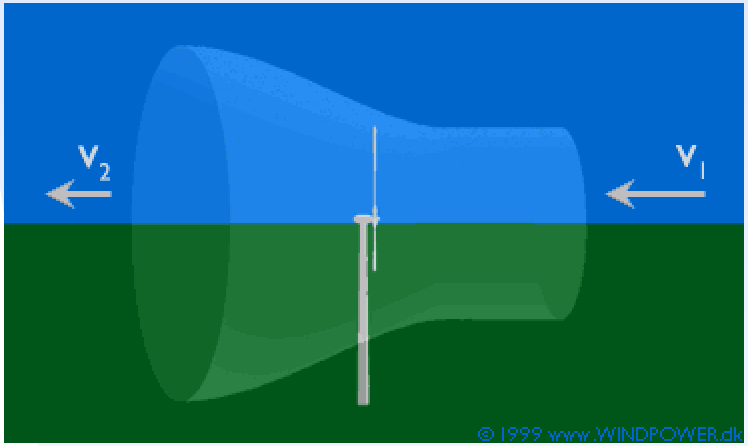


Note that if you consider air moving into the tube and then slowing at the rotor, in order to carry enough air away from the rotor, the tube must expand it's diameter to accommodate the slower-moving air.

The rate at which air mass moves through the tube per second can be calculated using the density of air times the volume per unit time:
$m_{air} = \rho A(v_1 + v_2)/2$, where $\rho$ is the density of air, A is the area intersected by the rotor, and $(v_1 + v_2)/2$ is the average velocity of the air and in fact is the velocity of the air at the plane of the rotor.

The power transferred from the wind to the rotor is given by taking the difference between the wind's power before and after the rotor: $P_{\rightarrow rotor} = (1/2)\ m_{air}\ (v_1^2 - v_2^2)$

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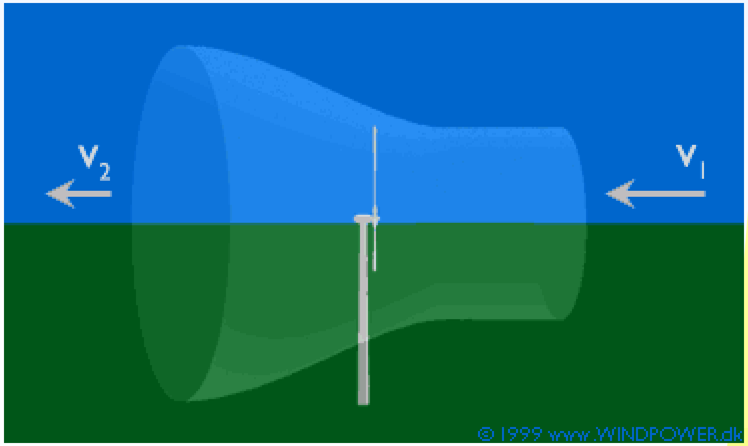
Substituting for $m_{air}$ we find:

$P_{\rightarrow rotor} = (1/2)(\rho A(v_1 + v_2)/2)(v_1^2 - v_2^2)$

Next look at the initial wind power flow (without a turbine): $P_{initial} = (1/2)\, \rho A v_1^3$

The ratio then:

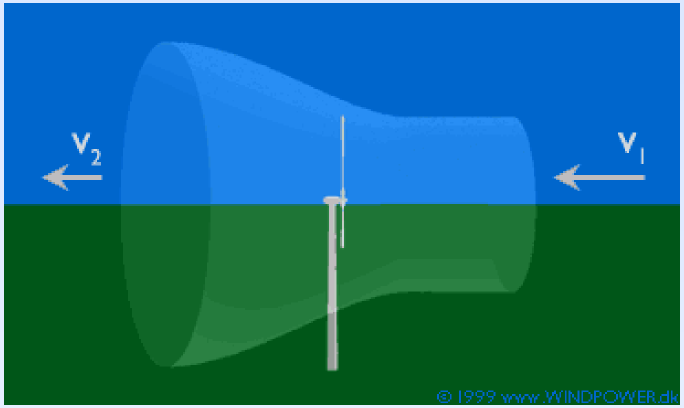
$P_{\rightarrow rotor}/P_{initial} = (1/2)(v_1 + v_2)(v_1^2 - v_2^2)/v_1^3 =$
$(1/2)(1+v_2/v_1)(1-(v_2/v_1)^2)$.

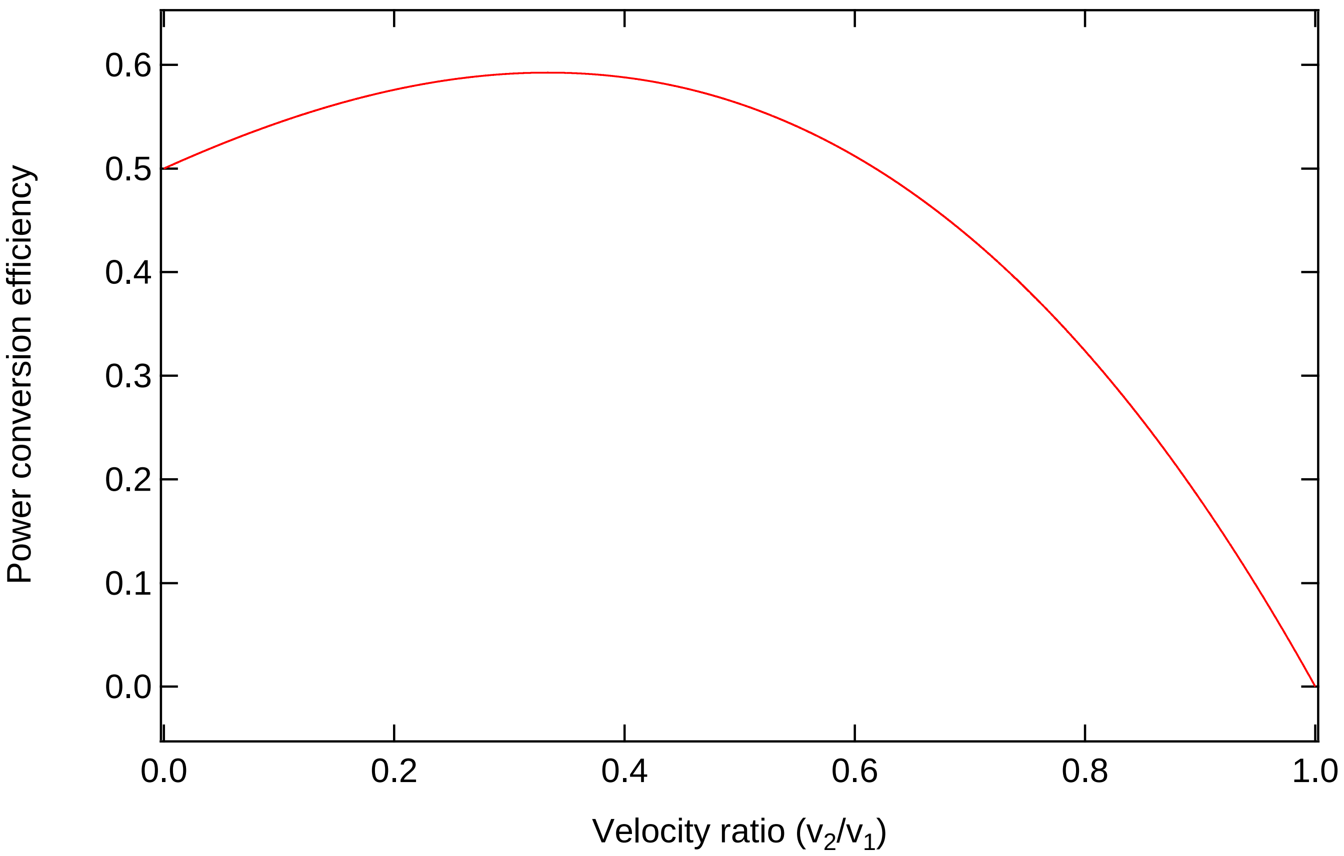


# Plotting the ratio $P_{\rightarrow rotor}/P_0$

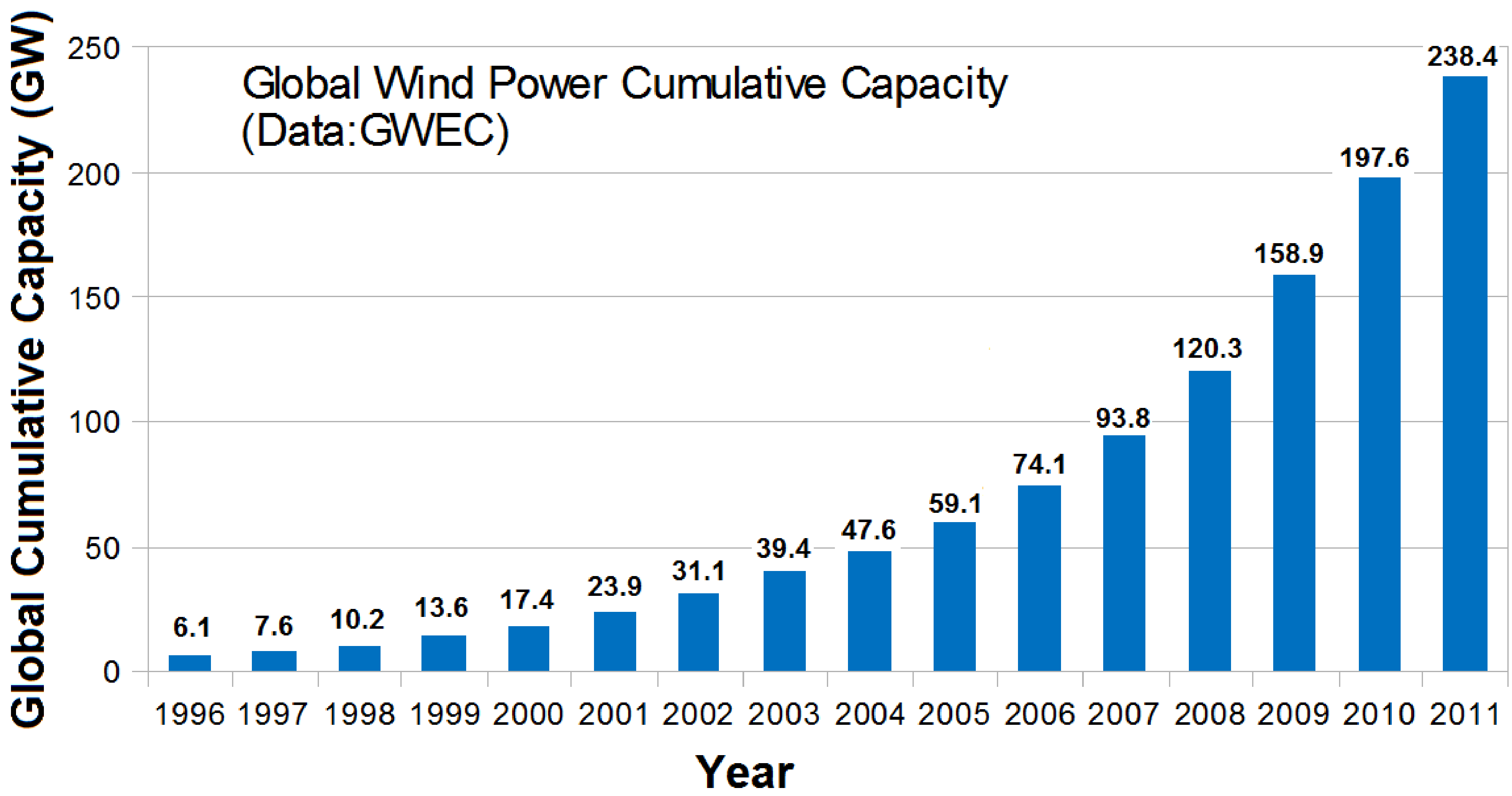
$$P_{\rightarrow rotor}/P_{initial} = (1/2)(1+v_2/v_1)(1-(v_2/v_1)^2)$$

Study the graph below! What does it tell us about how much the wind should slow passing through the rotor? I.e., for an incoming wind velocity of 10 m/s, what is the outgoing wind velocity for optimal efficiency?



# Wind power growth




282.5 GW in 2012