But first, an update on Energy Storage:

**Ultracapacitors** New Technology: ultracapacitors are a new energy storage technology ideally suited for applications needing repeated bursts of power for fractions of a second to several minutes.

ultracapacitors pack up to 100 times the energy of conventional capacitors and deliver ten times the power of ordinary batteries.

An application:

![Energy Storage for Prototype Military Transport Vehicle powered by Hybrid Electric Drive System](image)

**Wind Energy**

Let the wind turn the crank to produce electricity.
Windfarms are now popping up and selling electricity to the grid at around 4 cents per KWH and costs are projected to lower. Modern turbines, such as those pictured below, can achieve efficiencies of up to 40%.

Windfarms containing up to 5,000 individual wind turbines have now been created such as this facility in California (near Stockton).

Of course, the idea of a windmill as a device to turn a wheel has been around for centuries.
which proliferated in Holland (a flat, windy place where Don Quixote hung out).

In the 1920's and 1930's the rotary style windmill, shown belown, became a common mixture on farms in the Midwest as a means of running a water pump

Recently, aviation technology has advanced windmill design quite a bit to produce todays's modern wind turbines:
The concept of the windfarm is now being put into practice:

Main problem with wind is its erratic nature.

Power per square meter goes as (wind velocity)^3 requires good energy storage for later use.

What makes the wind blow?

Wind is the response of the atmosphere to uneven heating conditions. This creates pressure differences in the atmosphere causing the wind to blow from regions of high atmospheric pressure to low atmospheric pressure. The larger the pressure difference the greater the wind velocity.
Air pressure represents the amount of atmosphere that is pressing down on the surface of the earth at some point, as shown here:

Pressure differences yield wind (bulk motion of the air)

Local topography (mountains) can enhance or restrict the natural wind flow downslope winds off of mountain ranges represent ideal locations for wind turbines as do narrow mountain passes and river canyons such as Hood River.

Large scale patterns are thus setup by the interplay of the locations of high and low pressure systems and the topology of the land leading to places in the US which are on average significantly windier than other locations. The overall capacity, in MegaWatts, in the US is large:
A map of the United States showing wind power generation potential. The map uses a color gradient to indicate different wind power classes and speeds.

Power Class (W/m²) and Wind Power Speed (m/s) are as follows:

- Power Class 1: 200 W/m², 5.6 m/s
- Power Class 2: 200-300 W/m², 5.6-6.4 m/s
- Power Class 3: 300-400 W/m², 6.4-7.6 m/s
- Power Class 4: 400-500 W/m², 7.0-7.5 m/s
- Power Class 5: 500-600 W/m², 7.5-8.6 m/s
- Power Class 6: 600-700 W/m², 8.0-8.8 m/s
- Power Class 7: >700, >8.8 m/s

*Equivalent wind speed at sea level for a Rayleigh distribution.*

Source: [http://zebu.uoregon.edu/2001/ph162/111.html](http://zebu.uoregon.edu/2001/ph162/111.html)
While wind is certainly a renewable energy source, it is also an erratic one. Energy storage is probably more critical for wind power than for any other form of alternative energy.

Basics of Wind Energy:

- Kinetic Energy of wind is: $1/2 \times \text{mass} \times \text{velocity}^2$
- amount of air moving past a given point (e.g. the wind turbine) per unit time depends on the velocity.
- Power per unit area = $KE \times \text{velocity} \Rightarrow MV^2 \times V$
- So Power that can be extracted from the wind goes as velocity cubed ($V^3$)
In essence, as shown in the above animation, the power on the windmill is proportional to the kinetic energy transfer per unit time as well as the density of the air (which is represented by the mass of the air above).

- Power going as $v^3$ is a big deal. 27 times more power is in a wind blowing at 60 mph than one blowing at 20 mph.

For average atmospheric conditions of density and moisture content:

$$\text{Power per sq. meter} = 0.0006 \times v^3$$

(Don't memorize $0.0006 \times v^3$; you will never need to know the 0.0006 part!)

- velocity measured in meters per second
- Power then measured in KILOwatts
- 1 meter per second is approximately 2 mph

How much energy is there in a 20 mph wind?

$$20 \text{ mph wind} = 10 \text{ m/s} \times 0.0006 \times 10^3 = 0.006 \times 1000 = 0.6 \text{ KILO watts per square meter}$$
which is 600 watts per square meter
this is identical to average solar power per square meter at
our latitude.

Example Problem:

In your back yard the average wind speed is 10 mph which
yields 100 watts per square meter. If the wind blows 40 mph,
how much power does a wind mill of 2 square meters
generate?

1. \( \frac{40}{10} = 4 \) wind blows 4 times harder
2. \( 4^3 = 64 \) if a 10 mph wind gives you 100 watts per
square meter then a 40 mph wind gives you 64 times
more power per square meter \( 6400 \text{ watts per square meter} \)
3. total power = 6400 watts per square meter * 2 square
meters = 12800 watts = 12.8 Kilowatts this is a lot!

The above calculation is known as a scaling calculation; you
simply need to scale the original conditions to the final
conditions. You only need to know the \( v^3 \) to do this.

Windmill Efficiency

Windmills can not operate at 100% efficiency because the
structure itself impedes the flow of the wind. The structure
also exerts back pressure on the turbine blades as they act
like an air foil (a wing on an airplane).

In most all cases, the efficiency of the wind turbine depends
on the actual wind speed. For the three blade design the
efficiency curve looks like this:
The maximum efficiency of 44% is reached in a 9 m/s wind (18 mph) and falls sharply at higher wind speeds. For a reasonable range of winds, the average efficiency is around 20%.

Because the power goes as $v^3$, there is no real need to optimize design for highest efficiency at highest windspeed because the power capacity in the wind will greatly exceed that which can be obtained by the generator.

- Theoretical maximum efficiency is 59%
- Picaresque Dutch Windmill (4=arms) = 16%
- Rotary, multiblade = 30%
- High speed propeller (vertical) = 42%
- Two blade horizontal = 45%

Rotary type windmills have high torque and are useful for pumping water. High torque means efficient operation at low wind speeds.

High speed propeller types have low torque and are most efficient at high rotational velocities and useful for generation of electricity.

Example calculation:
Windmill efficiency = 42%
average wind speed = 10 m/s (20 mph)
Power = 0.0006 x 0.42 x 1000 = 250 Watts per square meter
Electricity generated is then .25 KWH per sq. meter
If wind blows 24 hours per day then annual electricity generated would be about 2200 KWH per sq. meter

But, on average, the wind velocity is only this high about 10% of the time

typical annual yield is therefore 200-250 KWH per sq. meter

To Generate 10,000 KWH annual then from a 20 mph wind that blows 10% of the time

windmill area = 10,000 KWH/220 KHW per sq. meter = 45 sq meters
This is a circular disk of diameter about 8 meters
This is not completely out of the question for some homes
Even a small windmill (2 meters) can be effective:

- 20 mph 10% of the time 2500 KWH annually
- 40 mph 10% of the time 20000 KWH annually
- 20 mph 50% of the time 12500 KWH annually
- 4 small windmills at 20 mph 10% of the time 10000 KWH annually

Wind Energy can be competitively priced:
Wind turbine technology has steadily improved. Some specs
- Typical capacity for a large single unit is now 250-500 KW. But there are many smaller units in the 10-20 KW range:

- Relatively low capital costs; very low operating costs
- Lots of Wind Projects starting now

Price Comparison from 1998 study Levelized Costs:
(includes start-up costs)
- Wind: 4.3 cents per KWH

http://zebu.uoregon.edu/2001/ph162/111.html
- Coal: 6.2
- Photovoltaics: 16.0
- Advanced Gas Turbine: 4.6

Current Grid Connected Wind Power:

<table>
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<th>Country/region</th>
<th>MW Installed</th>
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<td>50</td>
</tr>
<tr>
<td>China</td>
<td>25</td>
</tr>
</tbody>
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Some aggressive goals for wind power:

- to install 10,000 MW of capacity in the U.S.;
- to build a $4 billion domestic wind industry capable of delivering 3,000 MW annually;
- to create tens of thousands of new, long-term, skilled jobs;
- to achieve levelized costs below four cents per kilowatt-hour;
- to make wind power a major option in achieving the nations global climate change objectives; and
- to make the U.S. wind energy industry the worlds technology leader and lowest cost supplier.

Foote Creek Rim Facility