Wind Power

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How electric power is measured

- Electric power is measured in Watt-hours
- A Watt-hour (Wh) is one Watt consumed for one hour. A kiloWatt-hour(kWh) is one thousand watt-hours.

Billing Period: Jul 16, 2008 to Aug 14, 2008

Basic Charges

Customer Number: 0801331247 0002058577 - Standard Residential - ME-RSD

Distribution				Customer Charge	8.11	
	767	KWH	x	0.026167	20.07	
Total Distribution Charges					28.18	**28.18**
Transition	767	KWH	x	0.007760		**5.95**
Generation	767	KWH	x	0.046580		**35.73**
Transmission	767	KWH	x	0.019040		**14.60**
State Tax Surcharge					0.06	
					0.09	
Total State Tax Surcharge Charges					0.15	**0.15**
Total Charges This Billing Period						**84.61**

Wind Resources in the US

- The US consumes 4.18 Trillion kWh of electric power each year (average 477 Billion watts, or 477 Million KW)

- Do we have enough wind?

- C:\WW\Science and Society\2009\us_windmap.

Wind Resources in the US

- Assume that we get 400 W/m^2 in a fair area and 800 W/m^2 in a good area (offshore)
- Assume the windmill has blades 40 m long
- The area swept out by the blades is
  $A = \pi R^2 = 3.14 * (40m)^2 = 5024\ m^2$

$Power_{fair} = 5024 * 400 = 2{,}009{,}600$ watts

$Power_{good} = 5024 * 800 = 4{,}019{,}200$ watts

- 4 MW = 4,000 kW
  4,000 kW * 8760 hrs / year * \$0.04 = \$1.4 M - maint. - debt = ?

Wind Resources in the US

- 4.18 TWh = 477,000 MW * 8760 hours/year
- 477,000 MW / 2 MW = 238,500 wind turbines
- Considering offshore turbines (need fewer) and that a turbine runs only part time (need more), let's say we need 200,000 turbines

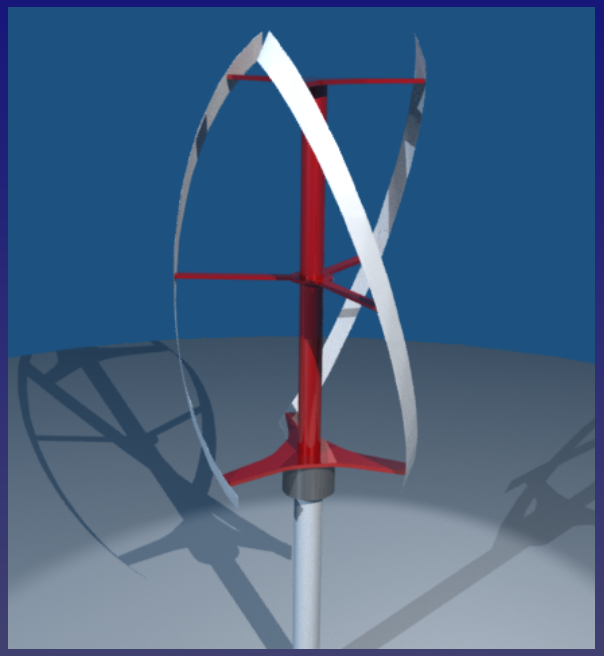
Wind Resources in the US

- 200,000 turbines / 50 states =
  4000 windmills / state
- 200,000 turbines / 3,537,441 square miles
  = 1 windmill / 17.69 mi^2.
- Offshore Eastern US (10 mi * 1000 mi)
  = 10,000 mi^2
- A turbine every ¼ mi. in each direction
  = 160,000 turbines

How does a windmill work?

How does a windmill work?
Types

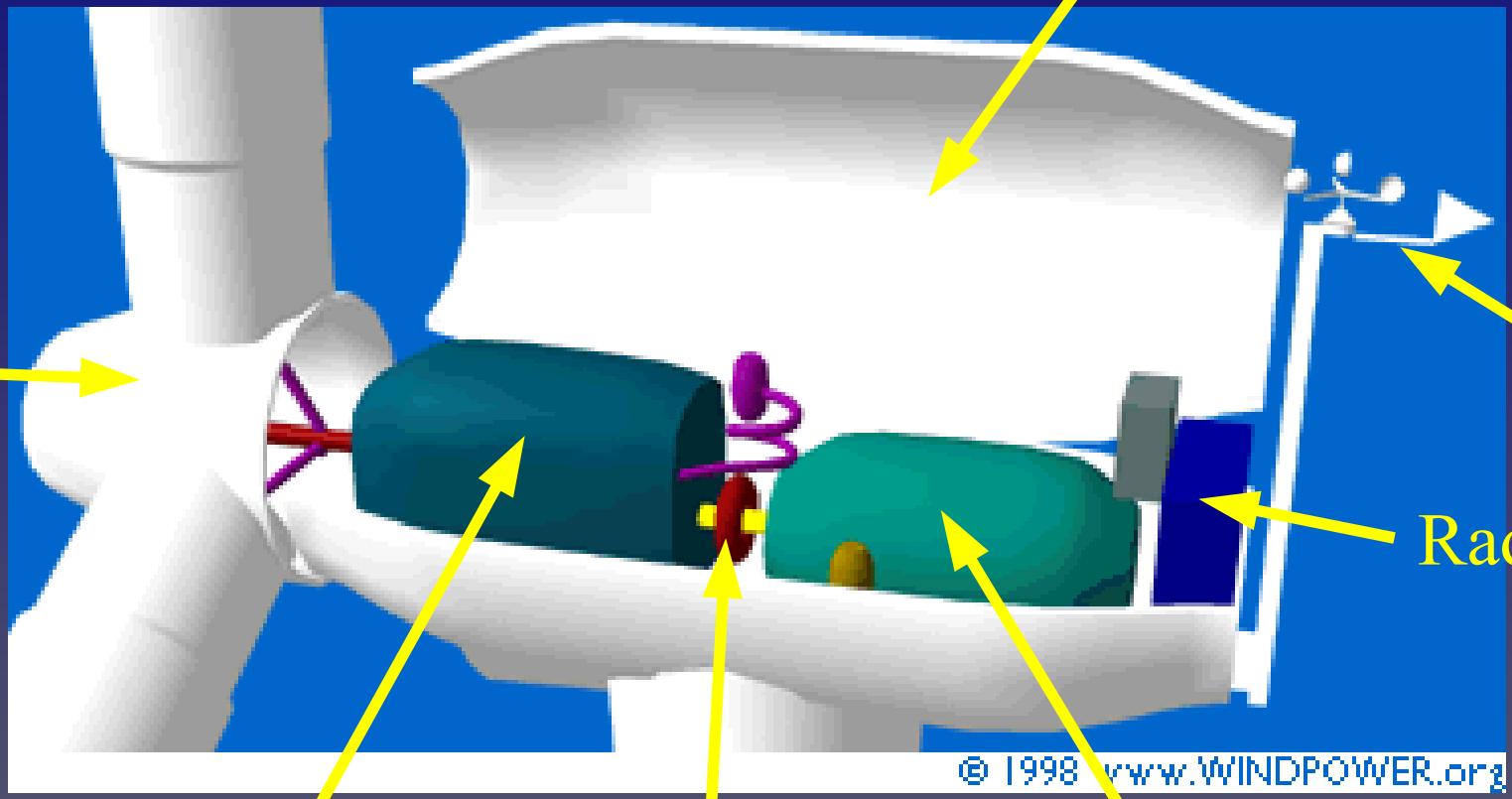
Horizontal axis
wind turbine (HAWT)



Vertical axis
wind turbine (VAWT)
Darrieus, eggbeater

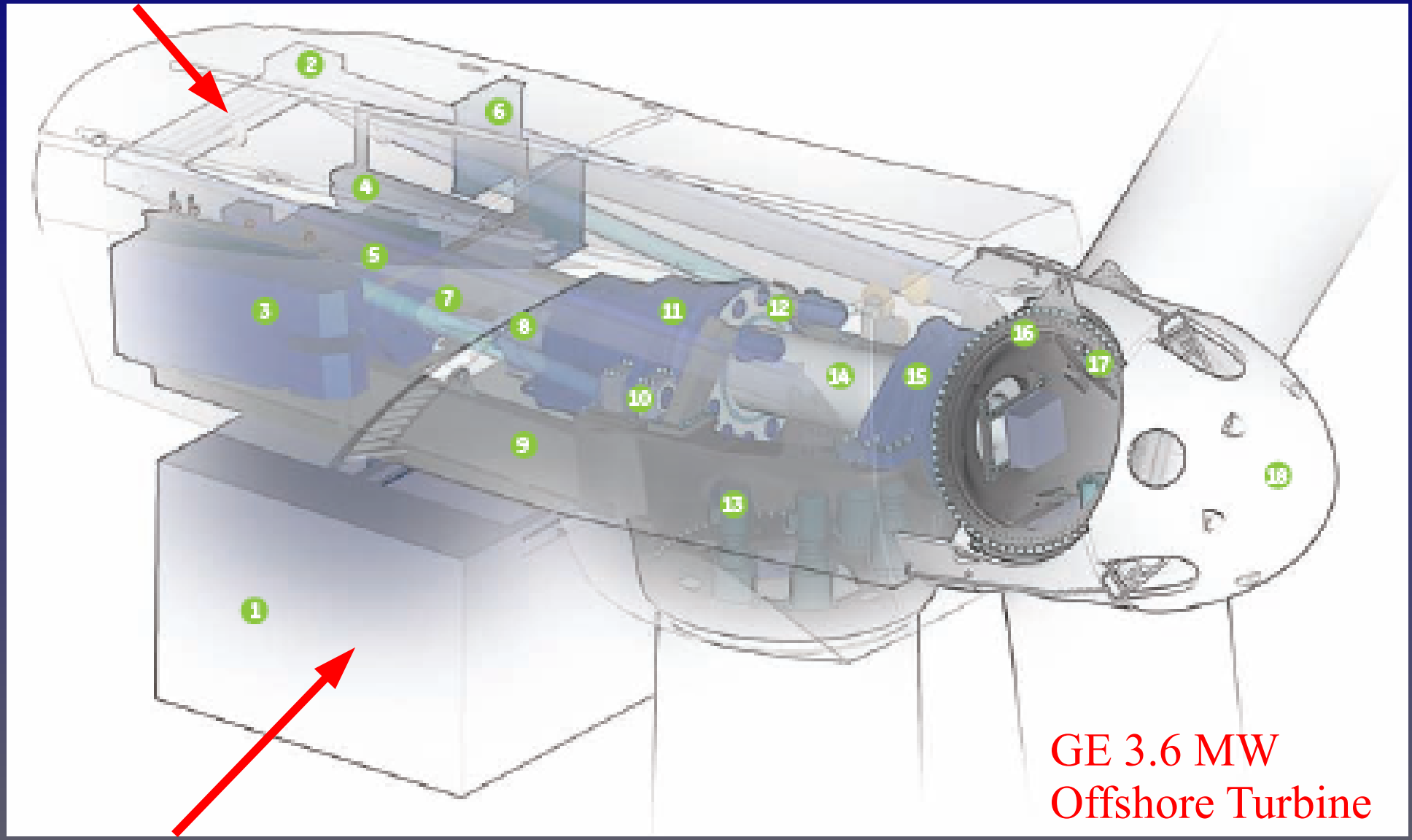
How does a windmill work?

HAWT



How does a windmill work?

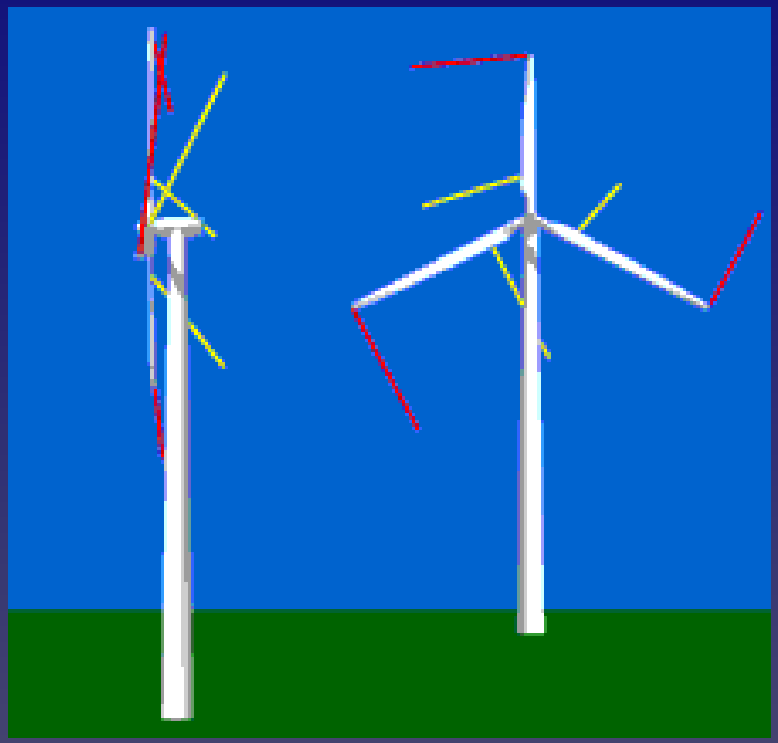
Gantry crane

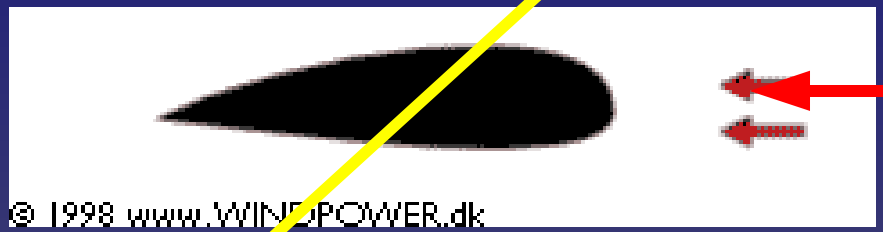


Storage and control room

How does a windmill work?

Aerodynamics



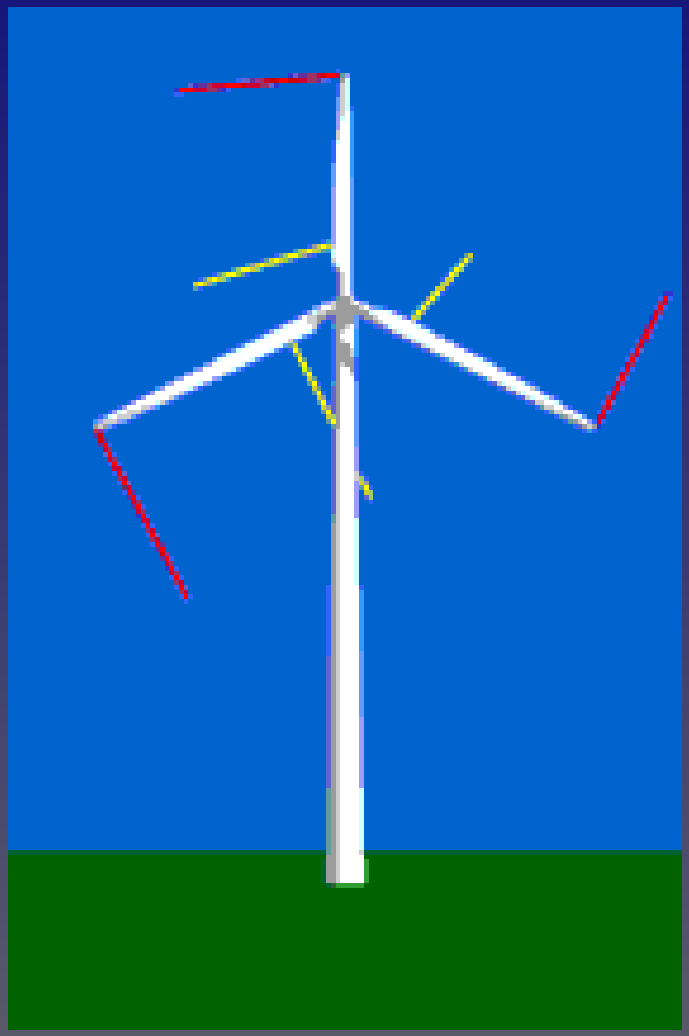


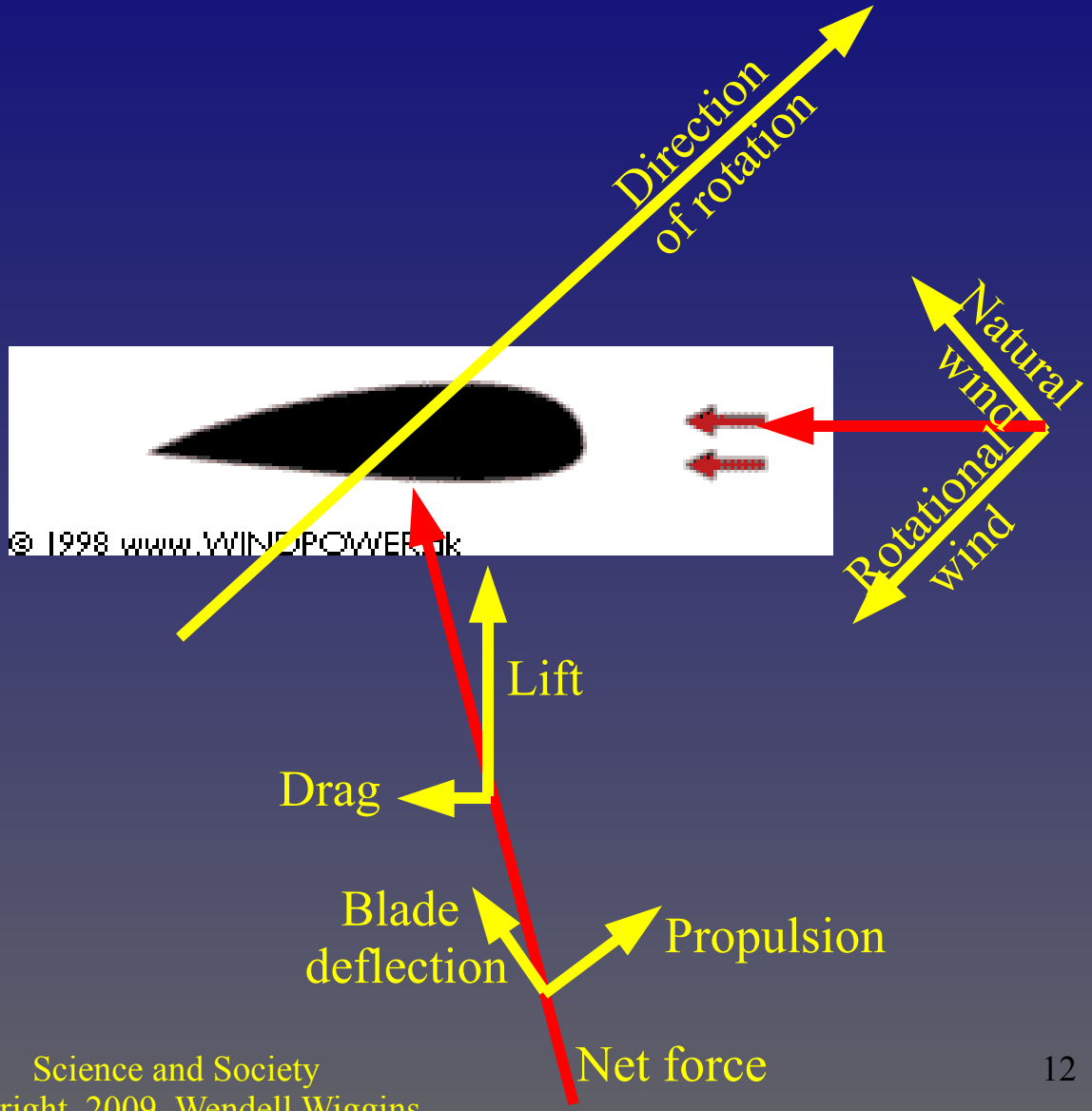
Direction of rotation

Natural wind

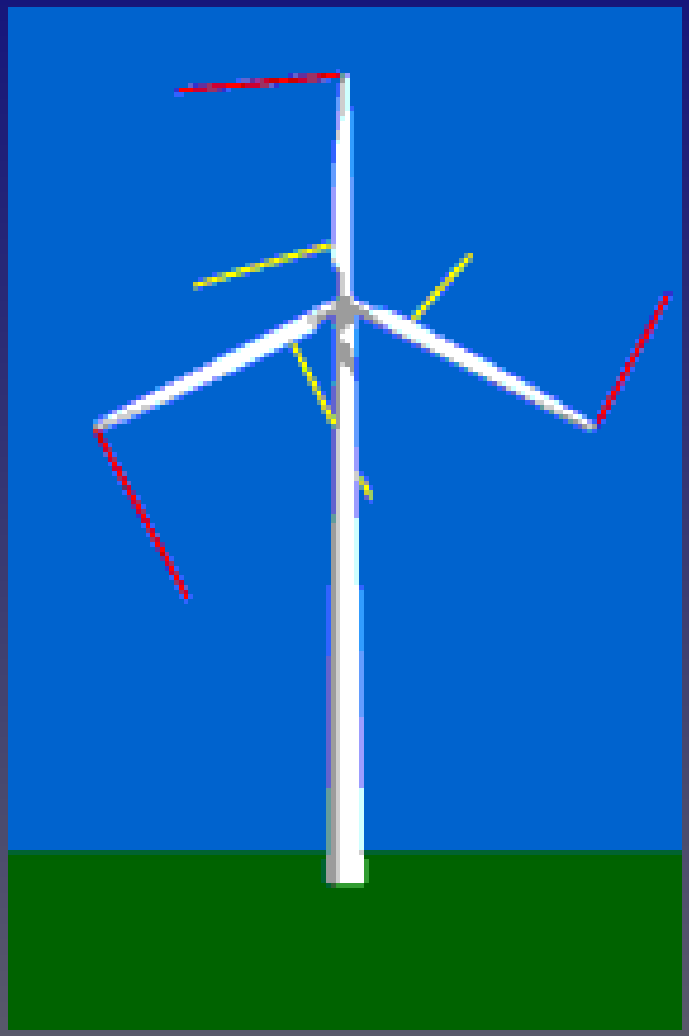
Rotational wind

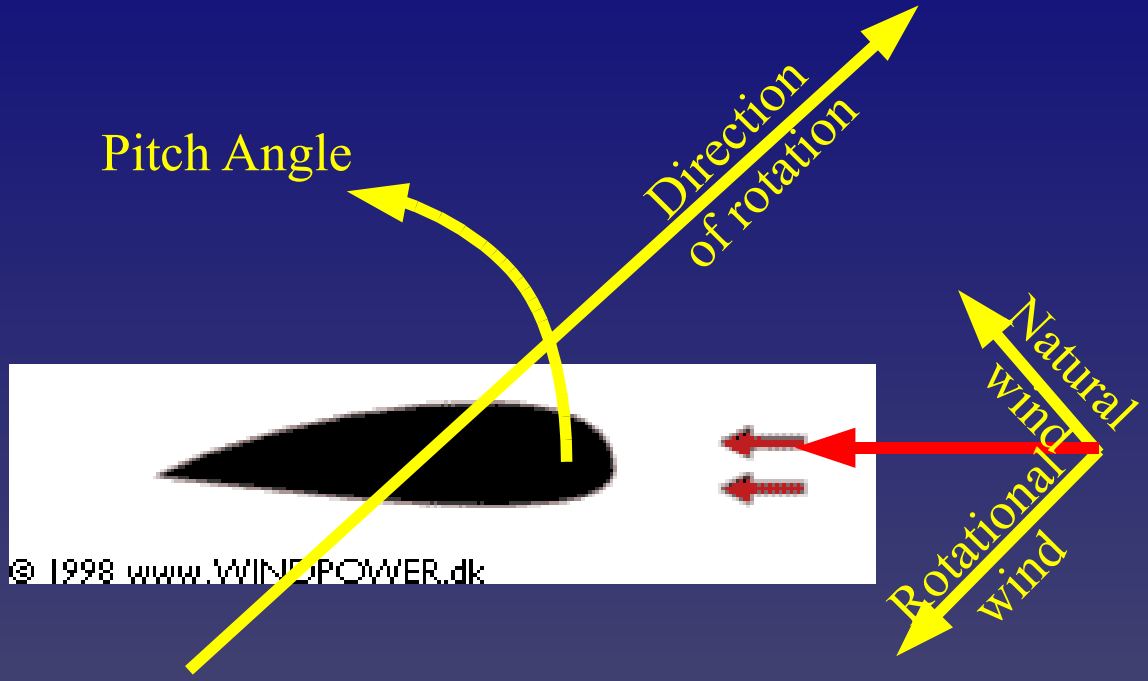
How does a windmill work?
Aerodynamics



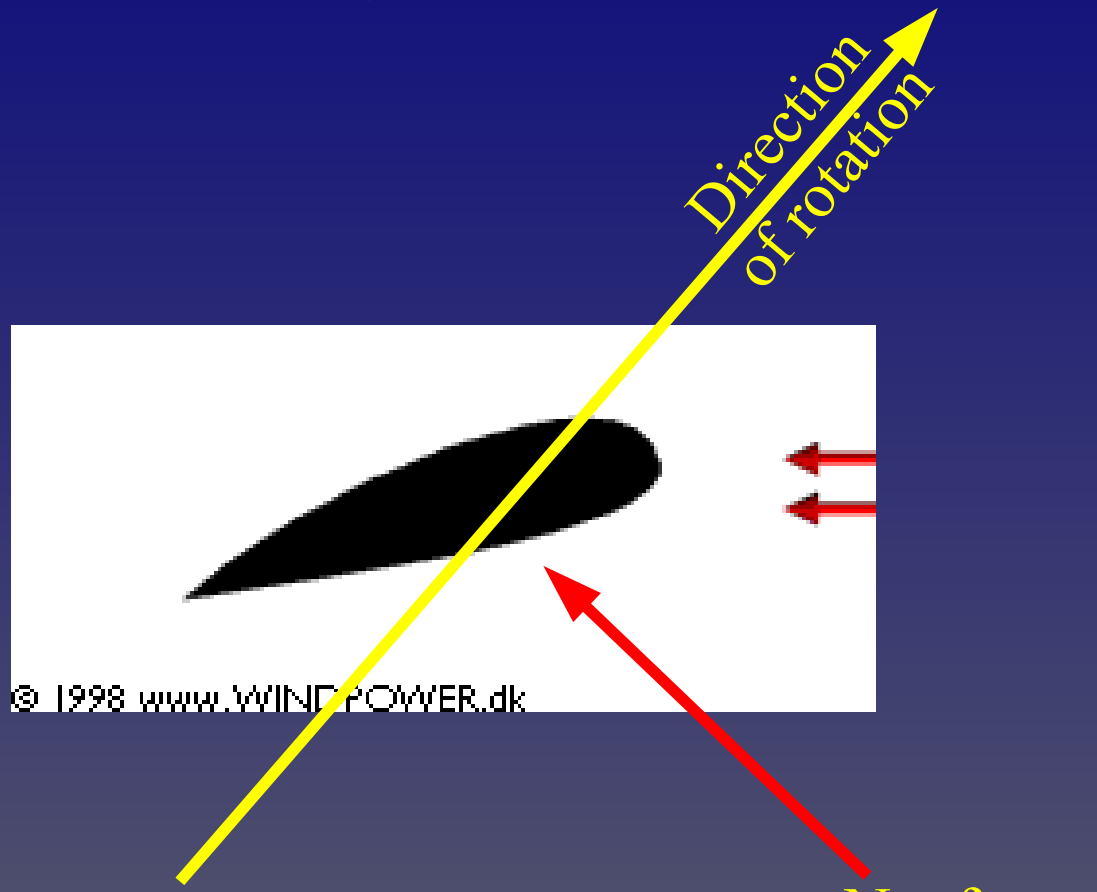


How does a windmill work?
Aerodynamics



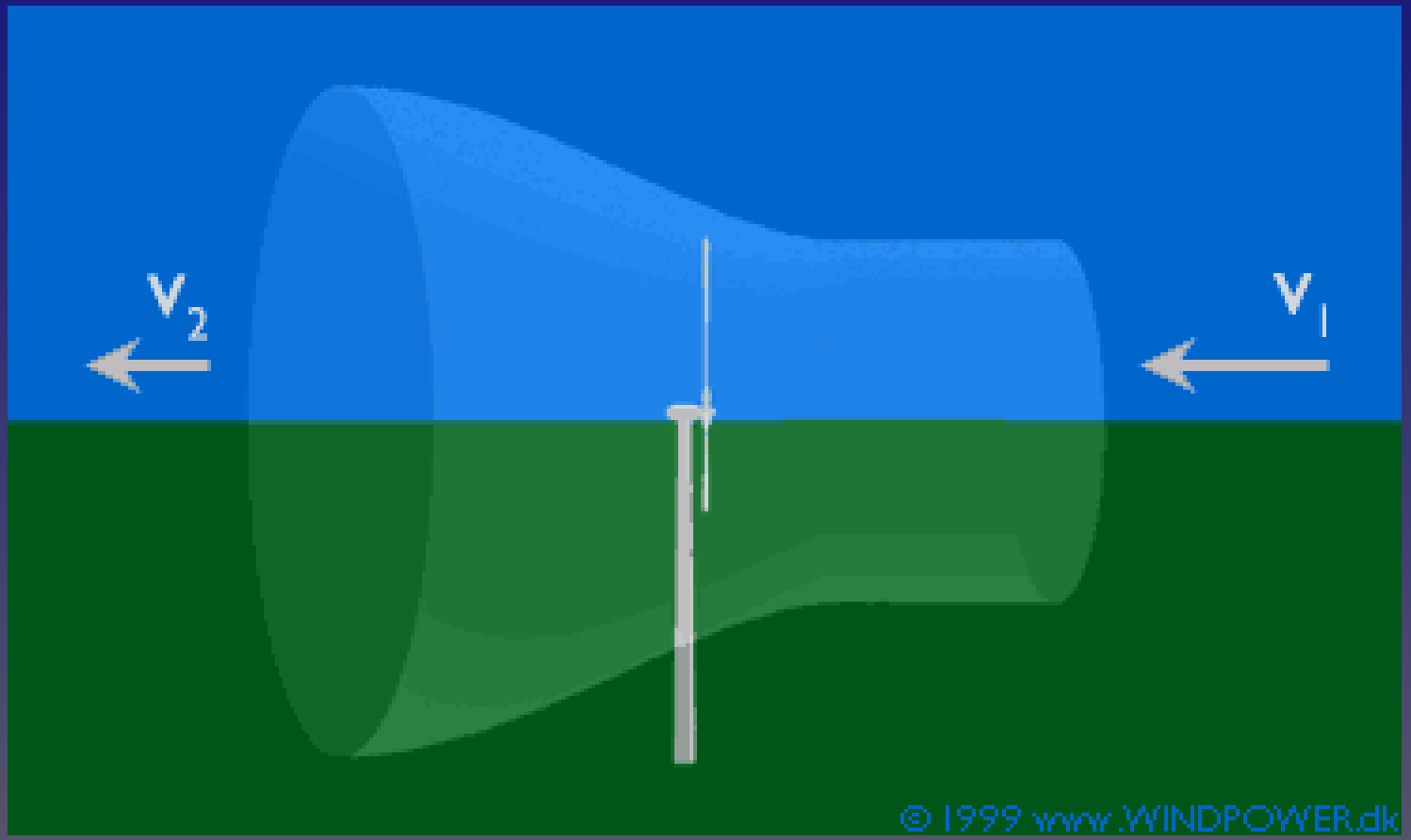


How does a windmill work?
Lift, Drag, and Stall



Simulation

How does a windmill work?
Air flow

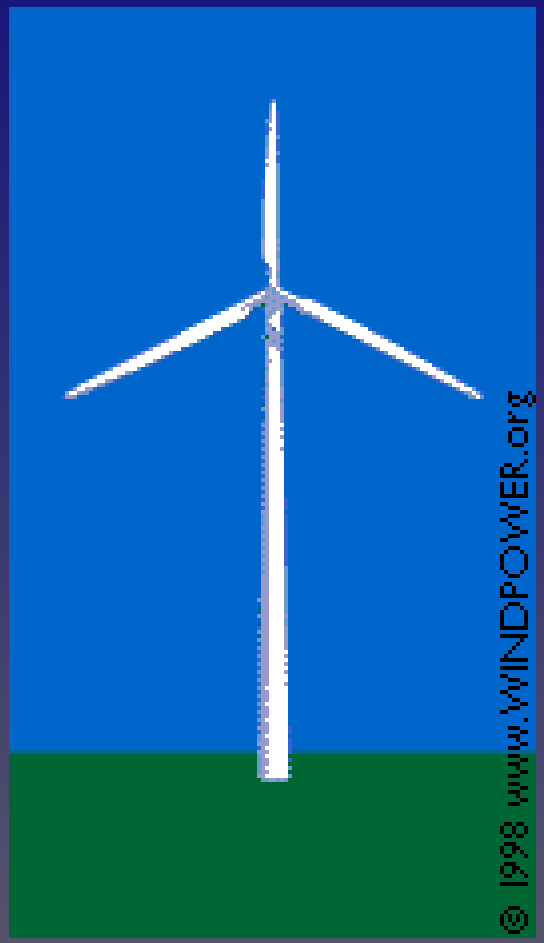


How does a windmill work?
Power Control

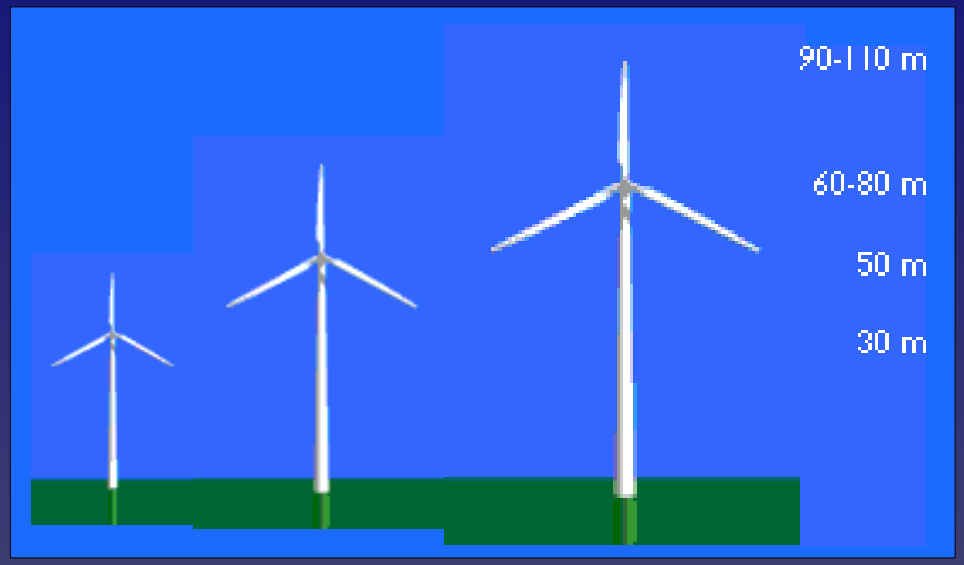
- Low wind speed → Need to optimize for highest output
- High wind speed → Need to avoid transmission and generator overload and structural damage

  - Method 1: Design the blades to stall at high wind speeds (simple in practice, but requires complex blade design)
  - Method 2: Provide a control system to vary the pitch of the blades (works best, but requires complex transmission)

How does a windmill work?
Yaw Control

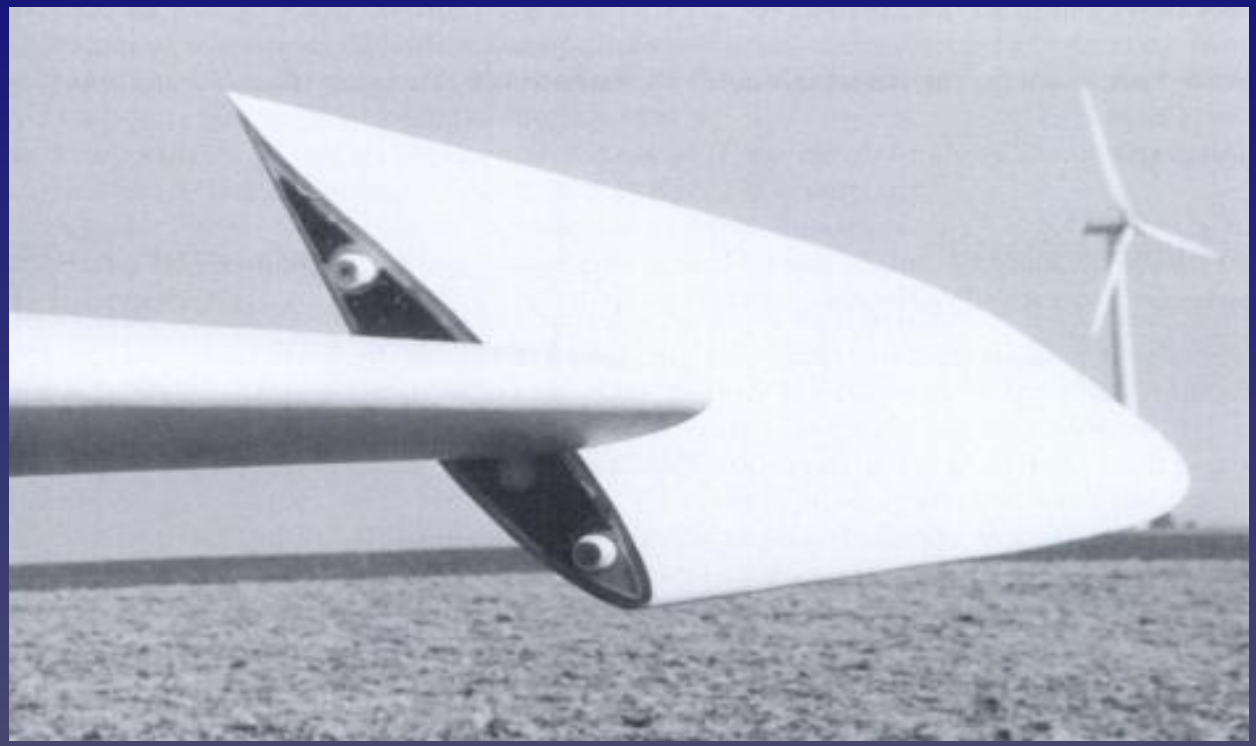


How does a windmill work?
Tower Height



- Blade length
- Wind speed
- Tower cost (including foundation)
- Other site conditions

How does a windmill work?
Brakes



Blade tip brake

Mechanical Brake

What happens when the wind stops blowing?

- Several renewable energy sources--wind, solar, tidal--require storage facilities
- The storage should be efficient
- It should be large enough to carry the load through the worst-case outage
- It must be quickly reversible

What happens when the wind stops blowing?

Excess capacity

- Assume that some renewable energy generator runs from 6am to 6pm
- Assume we need 2000 kW during the day and 1000 kW at night
- Assume that the storage has 50% efficiency
- Generating capacity will have to be 2000 kW for daytime usage +
- 2000 kW x 50% effic. = 1000 kW for nighttime
- Total capacity = 4000 kW, twice the actual daytime use

What happens when the wind stops blowing?

- Batteries (instantly available but small)
- Flywheels (instantly available but small)
- Compressed air (maybe stored in abandoned salt mines)
- Reversible hydroelectric dams
- Hydrogen generation
  - Fuel cells
  - Good ol' burning
- Other short-term generation

What happens when the wind stops blowing?

- Reversible hydroelectric dams can be 70% to 85% efficient
- Water is consumed by evaporation
- The US currently has about 2.5% of generating capacity in hydroelectric storage
- A lake about 1 sq. mi. elevated 300 ft and 100 ft deep could store 24 Million kWh of energy, about 1/500th of our daily use

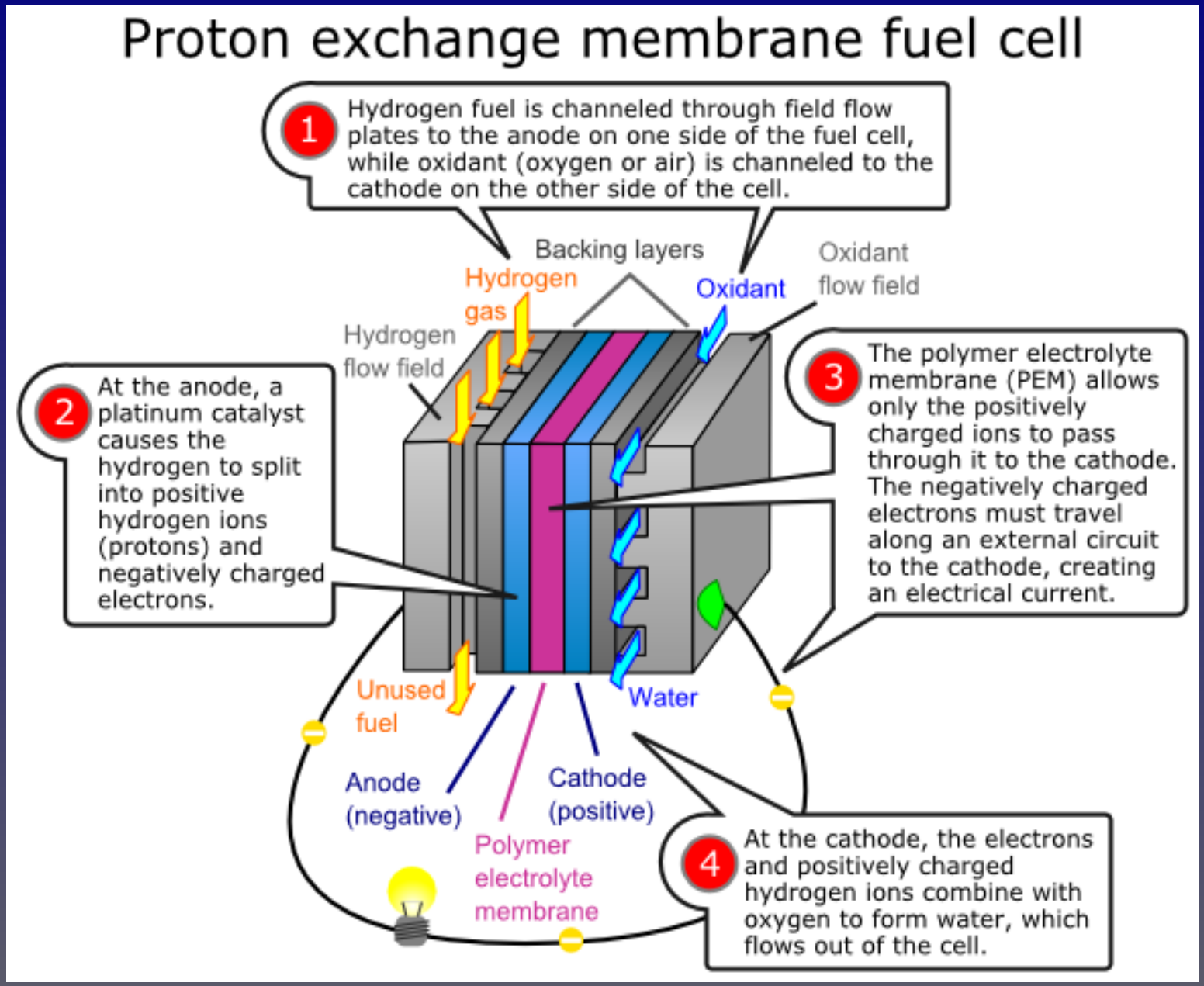
What happens when the wind stops blowing?

Electrolysis of water

- $2H_20 + 1.229$ volts $\longrightarrow$ $2H_2 + O_2$
- In practice, it requires more than 1.229 volts to split the water molecule
- Some reports cite 75% efficiency
-
- Hydrogen is stored and transported like natural gas (has 1/3rd the energy density)

What happens when the wind stops blowing?

Hydrogen fuel cell



Efficiency is about 50%

Bad, huh?

What happens when the wind stops blowing?

Compressed air storage

- Use electricity to compress air when the generators are running; use the air to drive a turbine when you need it
- Store the air underground
- Efficiency requires that the air be very efficiently cooled as it is compressed
- At present, less than 50% efficiency; likely much improved with development
- Might be about same energy density as batteries

Wind Power
Environmental Issues

Photo from a GE Brochure on their 3.6 MW turbine.
A 25.2 MW installation in Ireland

How does a windmill work?
Environmental Issues

- The blades kill birds
- The blades kill bats
- Some people think they are ugly, or they dislike the low-pitched sound
- Improper installation has produced soil erosion

How does a windmill work?
Mechanical Stress and Fatigue

Crash!

Bang!

How does a windmill work?
Safety

Ladder inside a wind turbine tower

Wind turbine erection

Infomercial

Inside