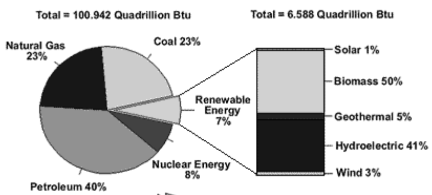
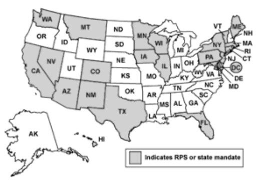
Introduction to Renewables





What Are We Looking For?

- Current Problems We Need To Address
  - exponential growth in demand
  - limited supplies
  - pollution
  - climate change
- How Does Nature Provide Energy?
  - *mechanical kinetic energy*
  - *mechanical potential energy*
  - *thermal energy (microscopic ke)*
  - *chemical and nuclear bonds (microscopic pe)*
  - *radiant energy*
- We've Only Just Begun To Tap The Potentital!

Estimating Available Energy

- Total Energy Available is relatively easy to estimate
  - most of the main renewables have a total energy available equal to or greatly in excess of our energy requirements!
- Technical Potential is always much less
  - usually comparable to or less than our total energy requirements
  - e.g. temperature or velocity *difference* required
  - only land area suitable
  - some of the energy must be saved for other things (e.g. food production; atmospheric sinks; etc.)
- Practical/Economic Potential is generally much less
  - current ideas for extracting energy are maybe not optimal
  - investment required can never be justified
  - other unacceptable impacts

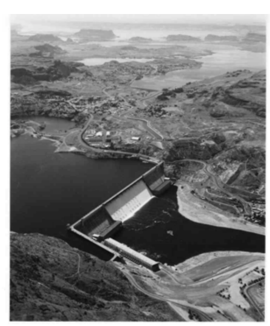
Power v. Energy

- Total Energy Content is not necessarily the critical parameter
  - unless we can "save" energy through fuels, reservoirs, etc
  - energy is typically distributed in low density over large area
- Power = Energy / time; Energy = Power integrated over time
  - Electricity, Engines, etc. require power (energy now!)
  - Peak Power Capacity v. Average Power Production
  - MW_{peak} v. $MW_{thermal}$ v. $MW_{electric}$
  - Efficiency and Down Time and Duty Cycle
  - a 1 GW_e plant doesn't produce 24x7x365 GWh per year!
  - and it may take 3 GW_t to produce it's peak output
- Power not always available when it is needed
  - no sunlight during the night
  - wind doesn't always blow
  - tides follow their own cycle

Paradigm Shift

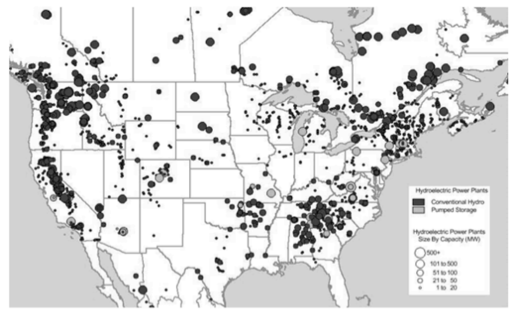
- Before Fossil Fuels and the Grid
  - energy production was colocated with energy use
  - renewables were used wherever possible and practical
  - industry was centralized where power was available
  - efficiency was very important (but the machines were typically very low efficiency compared to today's)
- Fossil Fuels and the Grid have led to
  - a distributed population and industry
  - high capital cost, large-scale, fairly efficient power plants
  - energy production is out of sight and out of mind
- New Paradigm? Back to the Future?
  - Renewables and Efficiency cannot replace our current infrustructure
  - Most are not very good at meeting the "base load"; This will require a mixture of sources
  - But they can meet growth and gradually diminish our need for fossil fuels

Part 1: HydroElectricity

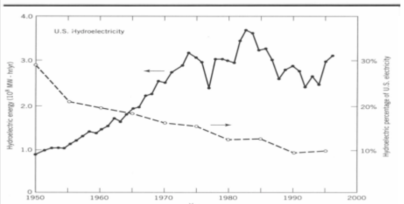


Hydo-Electricity

- Tap into natural mechanical energy
  - water flowing downhill
  - waves
  - tides
  - wind
  - others?
- Cyclic, renewable, non-polluting
- Very Old, established technology (mills)
- Energy content = weight of water x height = mgh = volume of water x density of water (1 g/cc) x height
- Power available = flow rate x mgh
- We can improve upon nature by increasing h (“head”); we can’t do much about increasing flow rate, but we can control it somewhat with dams and reservoirs



Region	Potential	Developed	Undeveloped	% Developed
New England	6.3	1.9	4.4	30.1
Middle Atlantic	9.8	4.9	4.9	50.0
East North Central	2.9	1.2	1.7	41.3
West North Central	6.2	3.1	3.1	50.0
South Atlantic	13.9	6.7	7.2	48.2
East South Central	8.3	5.9	2.4	71.1
West South Central	7.3	2.7	4.6	36.9
Mountain	28.6	9.5	19.1	33.2
Pacific	64.4	38.2	26.2	59.3
Total	147.7	74.1	73.6	50.2

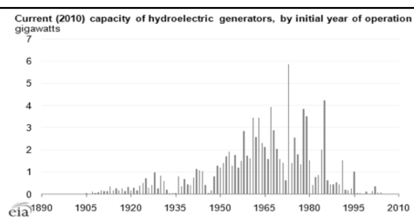


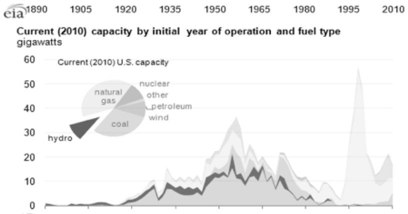
Hydropower Generating Capacity in Top 10 U.S. States, 2005

Washington	21,010 MW
California	13,475 MW
Oregon	8,261 MW
New York	5,659 MW
Tennessee	3,950 MW
South Carolina	3,455 MW
Georgia	3,313 MW
Virginia	3,091 MW
Alabama	2,961 MW
Arizona	2,890 MW

Table 12.5 HYDROPOWER OUTPUT (2008)

	Electricity Generated (Billion kWh)	Installed Capacity (Thousand MW)
China	538	171
United States	272	78
Brazil	380	77
Canada	380	73
Russia	163	46
India	131	35
Norway	139	27
Japan	94	22
Sweden	80	17





Hydo-Electricity (cont.)

- Can use “run of the stream” with water wheels
- To get more from nature
  - natural dams
  - artificial dams
  - water falls
  - better wheels; turbines
- 114 large dams produce 40% of total; 113 over 150m
- Itaipu Falls (10.5 GW); Grand Coulee (9.8 GW;168m)
- Total available 6-10 million GW! (but...)
- Big ideas: Dead Sea 400m lower than Mediterranean; can produce 1600 GW by slowly draining the Med

Hydo-Electricity (cont.)

- Small Ideas:
  - > 750 HE plants abandoned since 1940
  - > 2800 small dams in New England
  - ~250 now produce electricity, thanks to PURPA
  - could add 7% to New England's capacity
  - Michigan currently gets 2.7% from minihydro
  - 90,000 small dams in China
- We can regulate output
  - control flow rate with floodgates
  - pump water back during times of low demand (~2% of US)
  - largest pump from Lake Michigan can produce 2 GW (85m)
  - Kinuza Dam in PA w/ h=220m pumps for $0.02/kwh and sells to Cleveland for $0.05/kwh

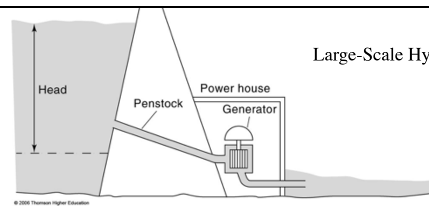
What's The Downside?

- Reservoirs "drown" some of the most productive land
- Stagnant water increases insects and disease
- Change in groundwater level can ruin farmland by creating marshes or bringing salt to surface
- Decomposition of vegetation -> acidic lakes. Corosive and harmful to life.
- Stagnant water can encourage growth of plants that clog reservoir and or water intakes.
- Cost of relocating displaced people
- Deep water -> stratification of temperature and de-oxygenation. Lake can be warmer than river.

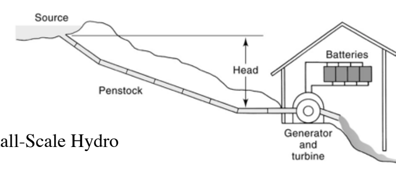
What's The Downside? (cont.)

- Large reservoirs increase evaporation loss. Alters climate downwind and downstream. Extreme case (Colorado River) flow directed 100% into atmosphere.
- Changes in speciation. Loss of species. Interference with aquatic migration.
- Siltation of reservoir! Loss of siltation downstream.
- Catastrophic failure of dam!

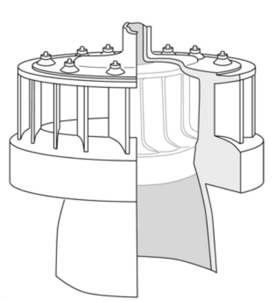
Some of these problems can be mitigated.
Some are less serious for low-head hydro.
It's not nice to fool Mother Nature.



Large-Scale Hydro



Small-Scale Hydro



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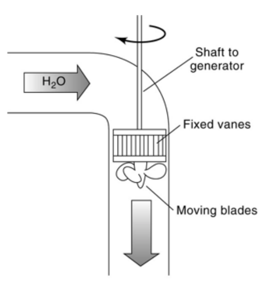

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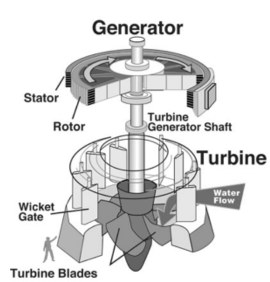
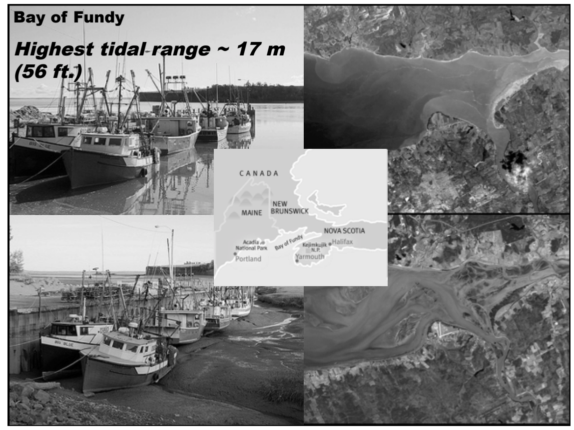


Part 2: Tidal Energy



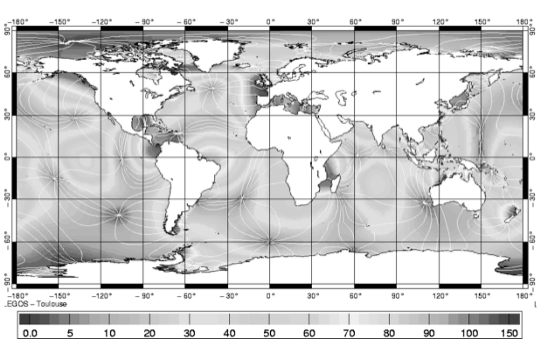
Tidal Energy

- Tidal mills have been in use for a long time
- Use “stream flow” of changing tides
- Can boost with dams and natural basins
- Largest plant at La Rance, France (240 MW)
- Largest tide range at Bay of Fundy (15m)
- What causes tides? How do we predict times of high and low tides? What are spring and neap tides?

Tidal Energy

- Potential yield:
  - tidal friction ~ 4000 GW (~1 millionth of the solar constant)
  - primarily slows Earth’s rotation; also grinds rock into sand, etc.
  - varies with sea level
  - capturing 1/3 of flow in every basin we could get 50 to 100 GW
  - therefore it’s not the ultimate resource

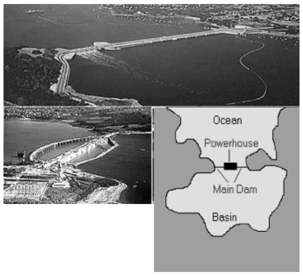
Potential Tidal Power Generation Sites



Tidal Energy

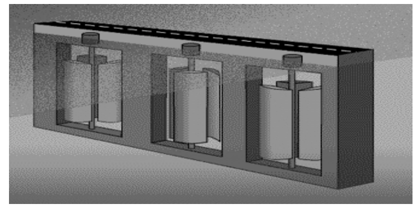
- Possible Problems:
  - all the problems of dams
  - introducing resonances that could alter tidal range elsewhere or alter ocean currents
  - e.g. damming Bay of Fundy could swamp Boston
- Examples of Tidal Mills and Barriers...

Barrier + Basin; Ebb and Flow



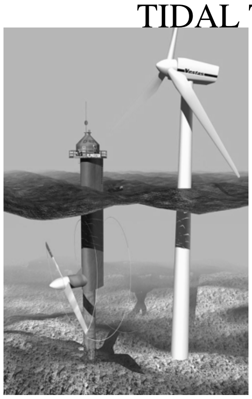
- Most Basic Generating System for Tidal Plants.
- Characterized by a barrage, or dam, that is constructed across an estuary.
- Can combine run of the tide with traditional methods (i.e. release at low tide)

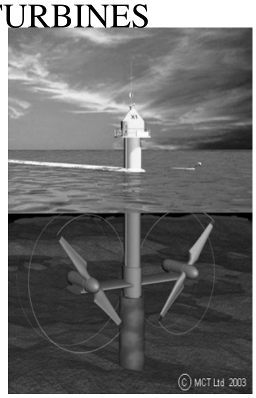
Tidal Fences



- Tidal Fences function similar to giant turn styles. They completely block a channel, forcing all of the water through them.
- Tidal fences, unlike barrage tidal plants, can be used in unconfined basins, such as in the channel between the mainland and a nearby off shore island, or between two islands.
- A 22MW tidal fence using a Davis turbine is being planned for the San Bernadino Strait.

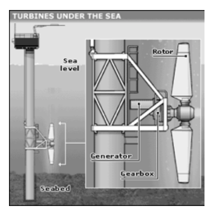
TIDAL TURBINES

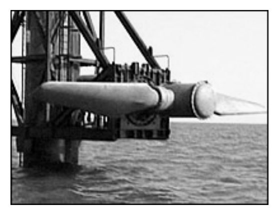




TIDAL TURBINES

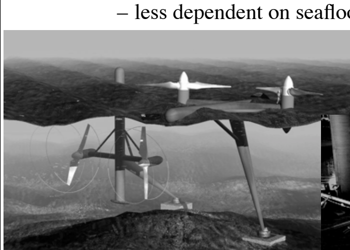
- prototype off Devon Coast in England
- 11 metre-long rotor blade
- capable of producing 300 kW
- only operate with the tide in one direction





TIDAL TURBINES

- Semi-submersible bouyant
  - easier to construct, easier to maintain
  - less dependent on seafloor conditions

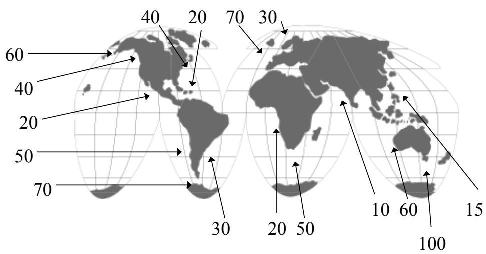


Part 3: Wave Energy

Wave Power

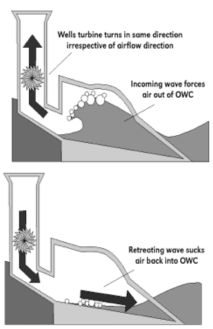
The rate at which energy is propagated per unit length of a wave crest.

For the world, in kW/m of wave crest length:



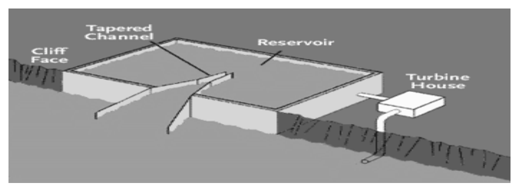
Wave Power Generators

Oscillating Water Column



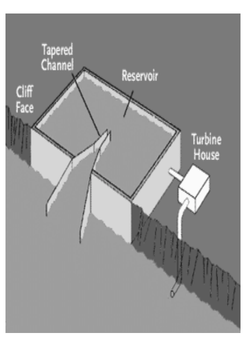
- Wave enters column, forcing trapped air up the closed column and past a turbine, and increases the pressure within the column
- Wave retreats, air is drawn back past the turbine due to reduced air pressure on the ocean side of turbine

Tapered Channel System



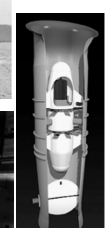
- A tapered channel is built upon a cliff face and feeds into a reservoir constructed within the cliff.
- The narrowing of the channel causes the waves to increase their amplitude (height), forcing the waves to spill over the walls of the channel and into the reservoir.

- Kinetic energy of moving wave is converted to potential energy and stored within the reservoir
- The collected water is then run past a turbine on its way back out to sea (similar to a hydroelectric plant).



The Limpet

- Designed by Wavegen
- 0.5 MW generator
- Can be incorporated into new or existing breakwater devices

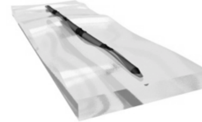


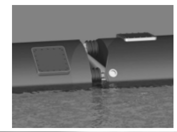
Offshore Devices

Osprey

- Similar in design to the Limpet, based on OWC
- Anchored in 15m of water, approximately 1 km from the shore
- Can also be used to protect shorelines from waves

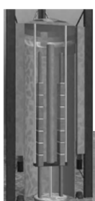
Pelamis

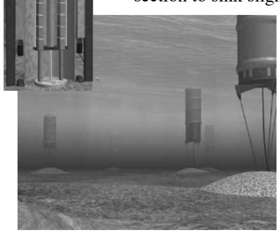




- Consists of a series of hollow cylinders, oriented lengthwise into the waves
- Each joint has hydraulic pumps, and as the cylinders move, the pumps run a generator
- Multiple units (approx. 130m long) can be set up in “farms”
- A 1 km^2 farm could provide 30 MW

Archimedes Wave Swing

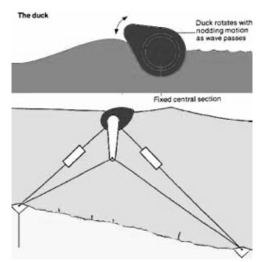




- Top section contains air, floats above bottom
- As waves pass overhead, pressure causes top section to sink slightly
- Differential movement of the two sections drives a linear electric generator
- Uses permanent magnets

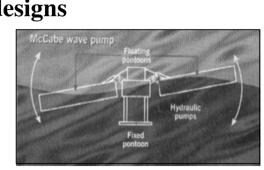
Salter’s duck

- Series of duck-shaped floats
- Nodding motion of floats drives generator
- Can capture approximately 65% of the wave’s energy



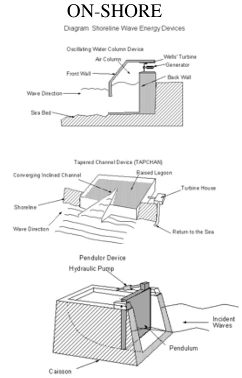
Other designs

- McCabe wave pump
  - Similar to Pelamis, but uses 3 rafts instead of cylinders
  - 40 m long prototype installed off the coast of Ireland

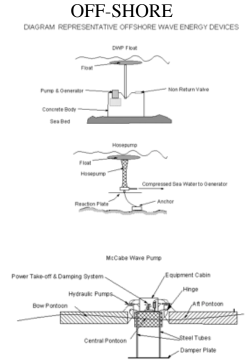


- Energetech Wave Power System
  - Onshore system
  - Uses parabolic device to focus the power of the waves
  - Only at model status currently
- Combination wind and wave power generator

ON-SHORE



OFF-SHORE

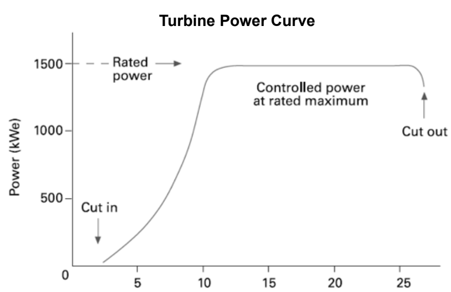


Part 4: Wind Power

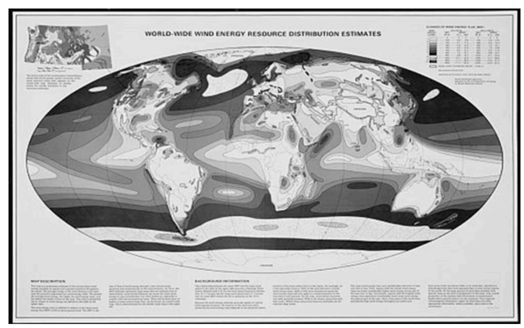
National Wind Technology Center, near Boulder, CO

Wind Power

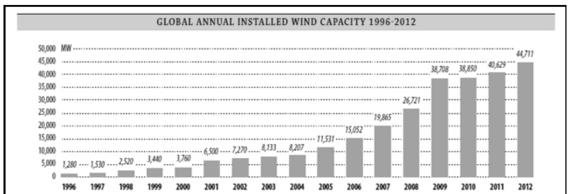
- On the verge of being economically favorable to coal (~5 cents/kwh) even without subsidy in US
- Proven economically feasible in Europe
- Costs keep coming down
- Resistance is diminishing
- Texas is the biggest producer now (was CA)
- Upper midwest/great plains has greatest capacity
  - and it fits in well with land-use
  - but consumers are far away
- Not just any wind will do!
  - not too fast; not too slow
  - not too gusty

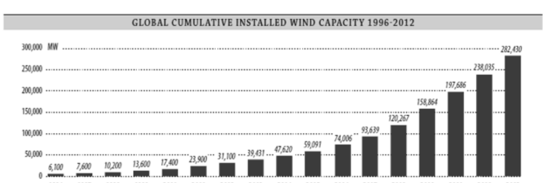


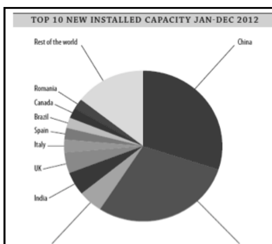
- Rated Power : Maximum power generator can produce.
- Capacity factor: Actual energy ÷ maximum energy
- Cut-in wind speed: Speed at which energy production begins
- Cut-out wind speed: Speed at which energy production ends.

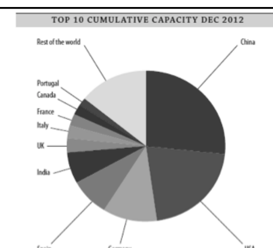


- 2.5% of world energy supplied by Wind
- 199,064 turbines were in use at end of 2011. China has 45,894

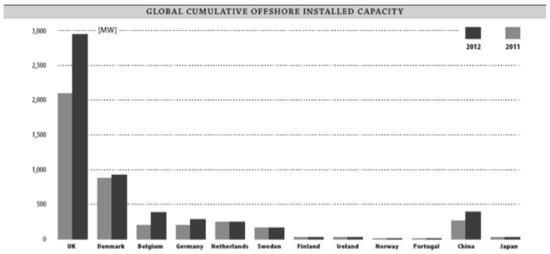


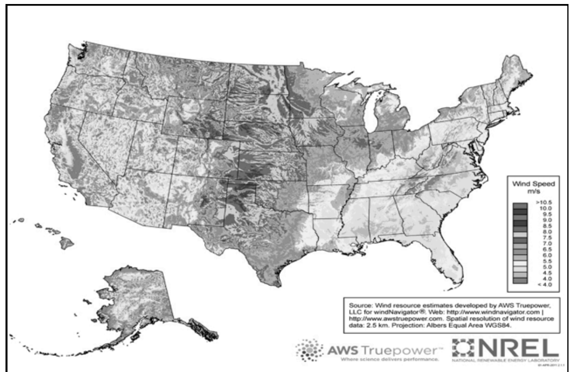


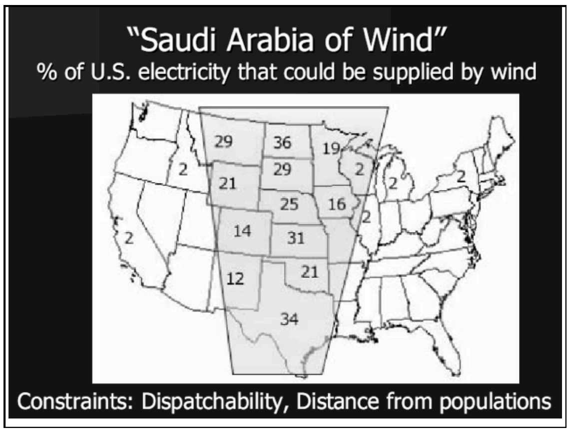


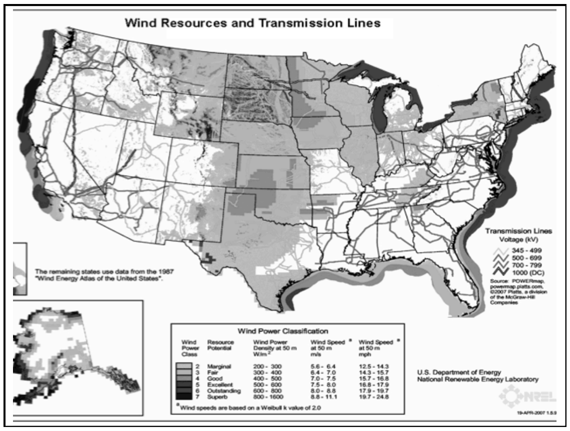


- In the first 6 months 2012 China added 5.4 GW of Wind Energy to its supply (down from 8 GW 2011).
- China's annual growth in the wind market 39.4%.

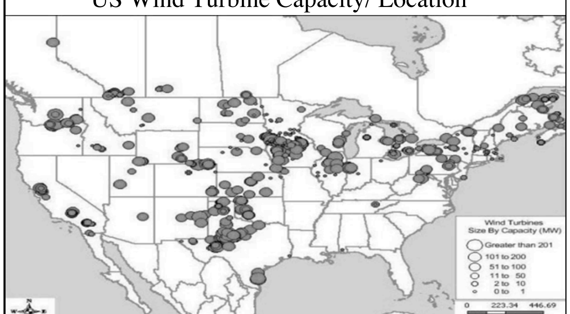






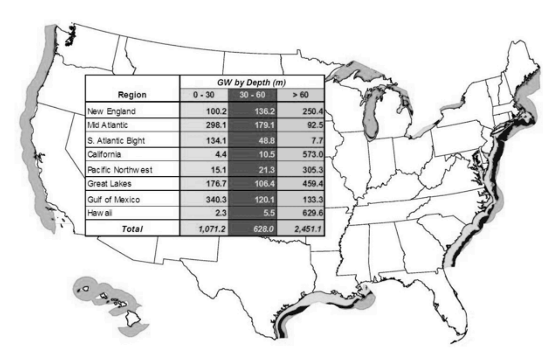


US Wind Turbine Capacity/ Location



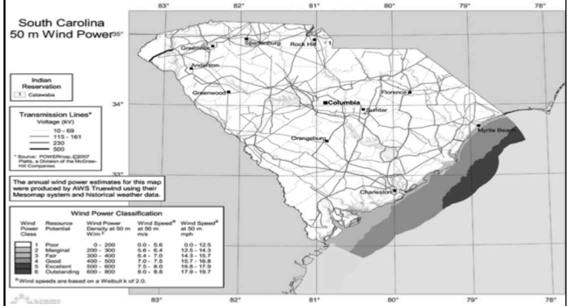
- US Capacity = 60 GW
- Approximately 45,000 turbines at beginning of 2012

US Offshore Distribution



Region	GW by Depth (m) 0 - 30	30 - 60	> 60
New England	100.2	136.2	250.4
Mid Atlantic	298.1	179.1	92.5
S. Atlantic Bight	134.1	48.8	7.7
California	4.4	10.5	573.0
Pacific Northwest	15.1	21.3	305.3
Great Lakes	176.7	106.4	459.4
Gulf of Mexico	340.3	120.1	133.3
Hawaii	2.3	5.5	629.6
Total	*1,071.2*	*628.0*	*2,451.1*

South Carolina



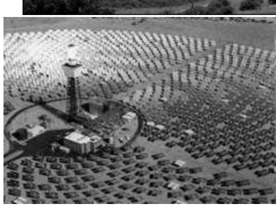
Part 5: Solar Energy

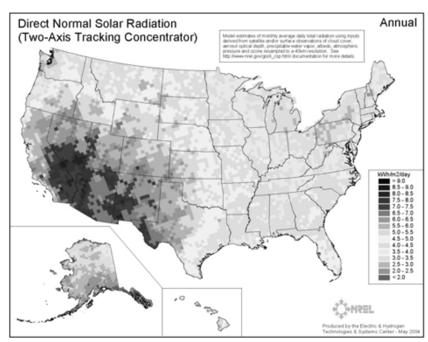
PhotoVoltaics

- Make use of photoelectric effect and “doped” silicon semiconductor technology
- Energy of photon -> KE of weakly-bound electrons, which frees them.
- PN junction establishes potential difference. Sunlight drives “current”.
- Only blue light is energetic enough; most of solar spectrum does not produce photoelectric effect, so efficiency is limited (20 to 30%).

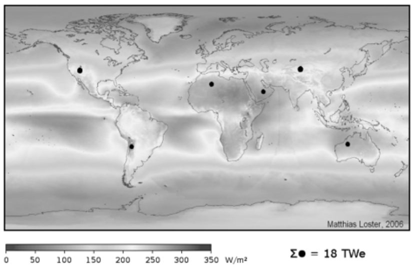
Solar Thermal

- Collect and concentrate sunlight with mirrors
- Heat water (or other working fluid) at focus
- Steam -> conventional turbines
- Largest power plants 10 to 20 MW
- Must track mirrors to follow the Sun
- Also: “trough” collectors or parabolic dishes
  - some examples...

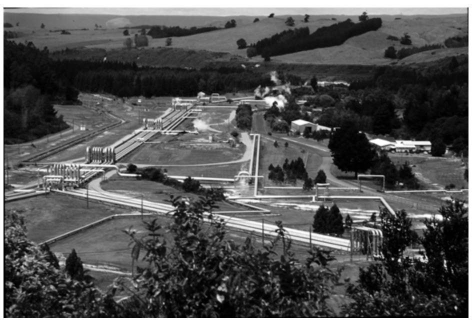
Global Solar Irradiance Averaged Over 3 Years



Passive Solar

- text

Part 6: Geothermal

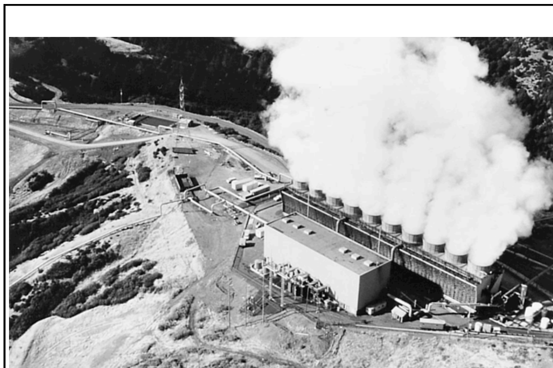


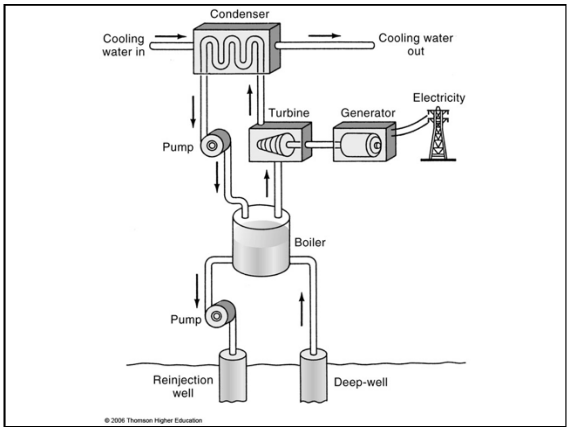
Ohaaki Geothermal Power Station, New Zealand

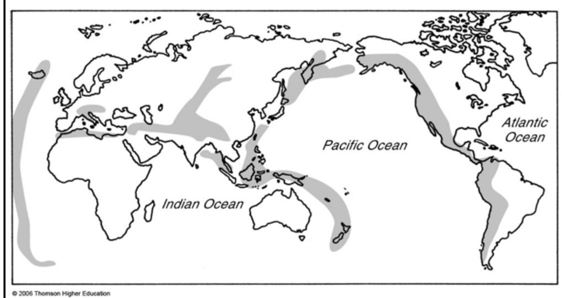
Table 18.1 GEOTHERMAL POWER PLANTS

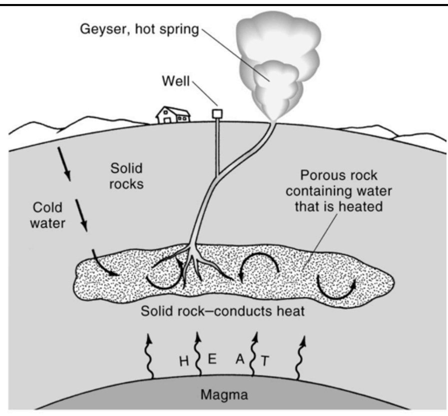
Site	Installed Capacity (MWe) 1990	2003
United States	2775	2200
Philippines	890	1931
Mexico	700	953
Italy	545	790
Indonesia	145	807
Japan	215	561
New Zealand	283	421
Iceland	45	200
El Salvador	95	162
Costa Rica	0	161
Kenya	45	127

Source: International Geothermal Association.









Part 7: Electric and Fuel Cell Cars

Large Base Load w/o Fossil Fuels

- Hydroelectric
  - run of stream gets energy out, but to get large amounts of power, we need to increase "head"
  - dams and all the problems associated with them
  - but if there's a dam, it makes no sense to not have an electric generator
- Nuclear Fission
  - proven technology; proven safety record
  - can be improved with new technology & mass production
  - with breeding and reprocessing, will last a long time
  - waste disposal and proliferation are huge concerns
- Nuclear Fusion
  - still a thing of the future

Other "Renewables"

- Tides
  - proven technology, but not in widespread use
  - works best when estuaries are dammed
- Waves
  - lots of little ideas; very few developed
  - power localized to coastlines
- Wind
  - widespread, though not all areas are equal
  - wind is intermittent and uncontrollable
  - better energy storage, a more efficient grid, and mass production would further enable wind power
  - cost is coming way down, and wind turbines are sprouting all over the place; economically competitive now

- Passive Solar
  - Sun is perfectly capable of heating and lighting
  - building design should work with environmental factors to minimize the amount of extra energy needed
  - solar water (pre)heating could be done everywhere
  - there's a lot more that can be done
- Solar Thermal
  - solar-thermal turbines demonstrated, but not popular
  - can be more efficient than PV arrays, though
- Solar Photovoltaic
  - most widespread energy source, but power is spread over large area
  - solar cells still expensive and inefficient
  - already economically competitive off-grid
  - solar roofing materials could lead to paradigm shift

- Geothermal
  - geographically isolated activity near surface
  - not without environmental impacts, but so long as water is returned to ground, it can be "renewable"
  - hot rocks everywhere, but low power volume
- Ocean Thermal
- Fuel Cells
  - developed technology, but need cleaner fuel source
- People and Animal Power
- Natural electricity (e.g. lightning)

Transportation and Fuels

- Not generally an energy "source", b/c it takes energy to make them.
  - They just allow us to "move stuff around" without being attached to a fixed infrastructure.
  - But the infrastructure CAN be energized
- Batteries/electric motors work well, but we need a quantum leap in power/weight and energy storage capacity. Money can't buy a quantum leap, but lack of investment can guarantee there won't be one.
  - But electricity must be generated somewhere else.
- Everything can be "hybridized" to get more mpg.
- Biofuels can help meet growing demand, or they can help deal with decreasing supply, but they can never substitute directly for gasoline and diesel fuel.