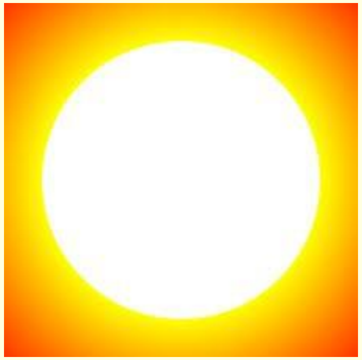
Renewable Energy Resources – an Overview Part II



Y. Baghzouz
Professor of Electrical Engineering

Electricity production from renewables

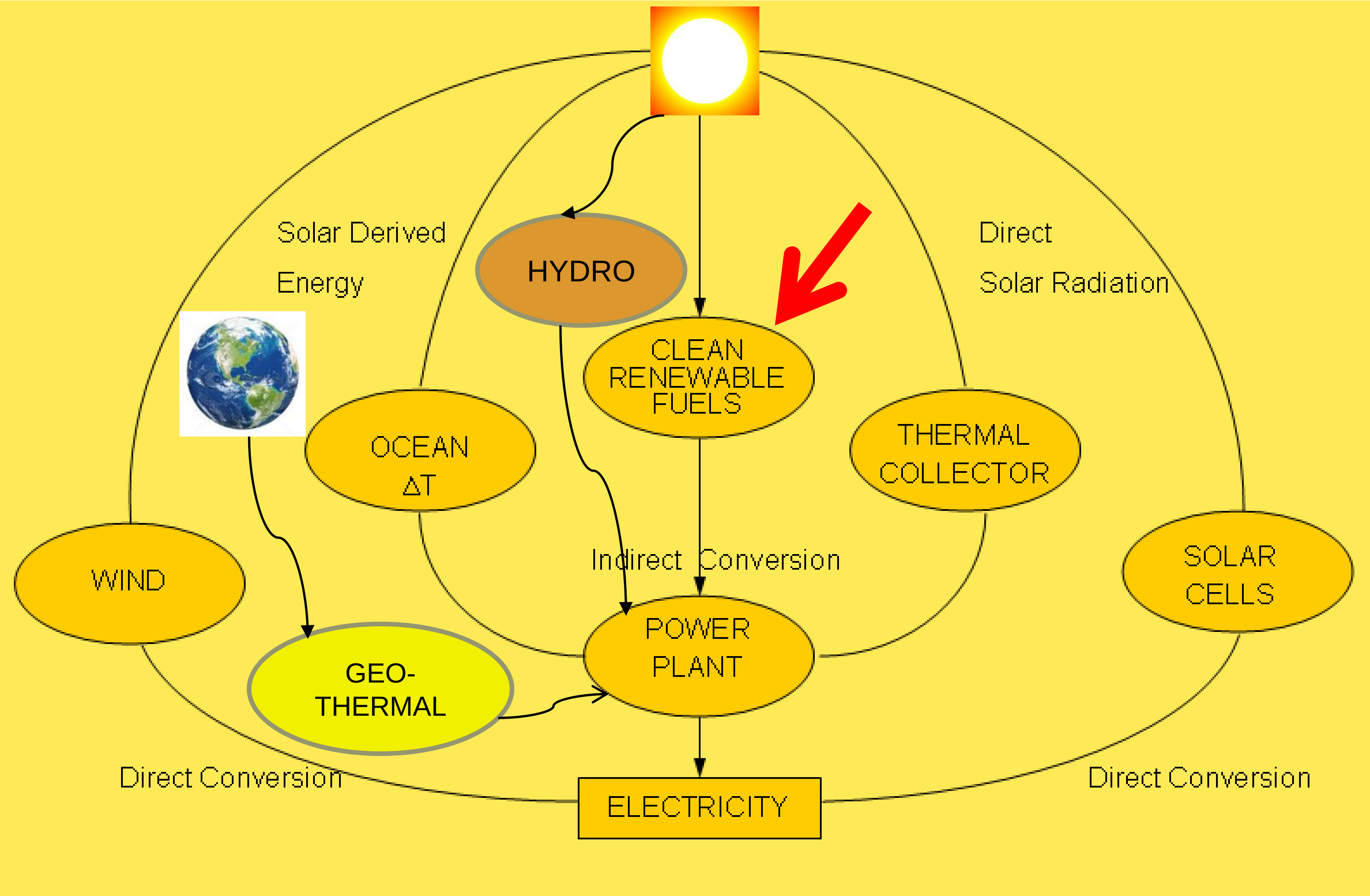
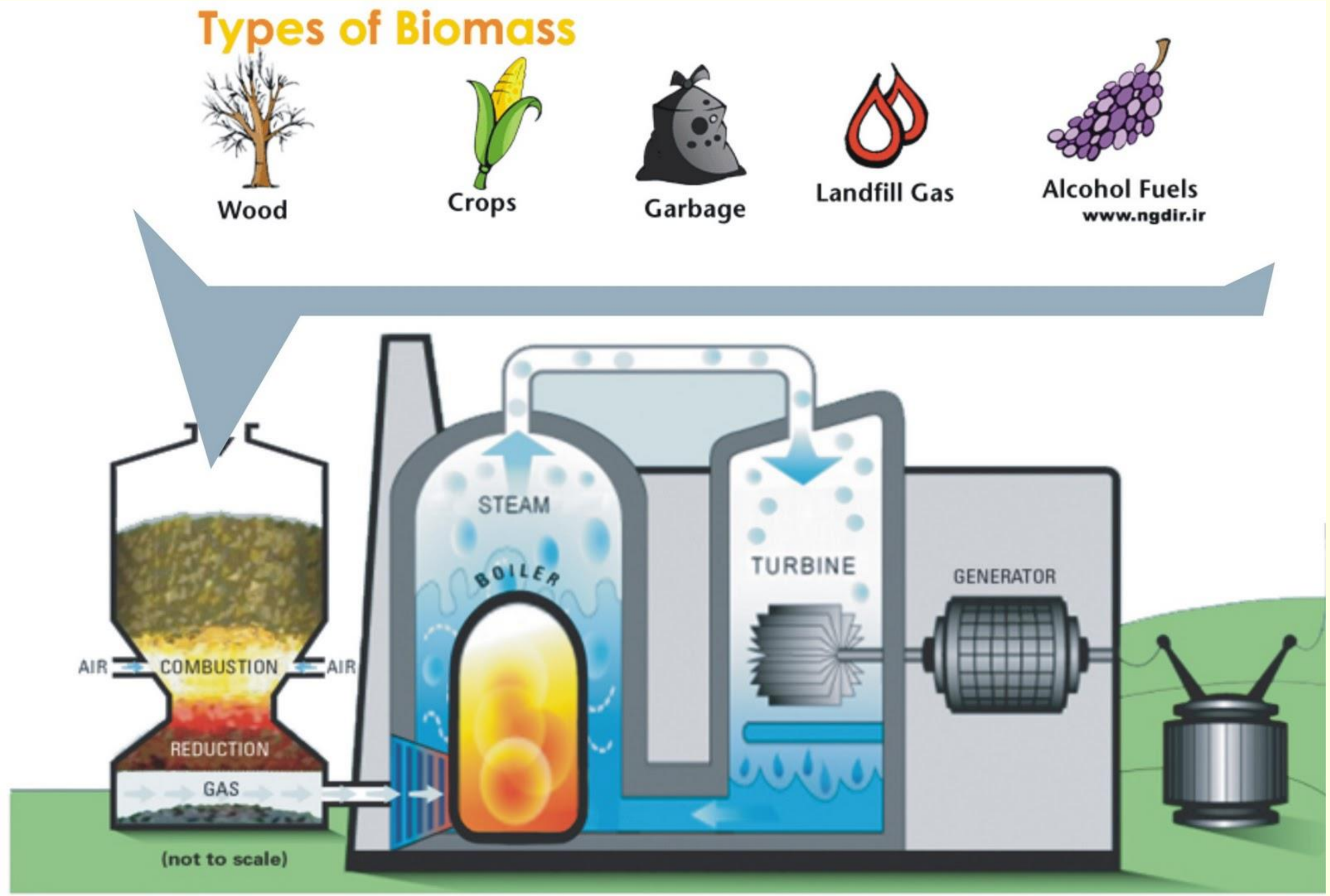
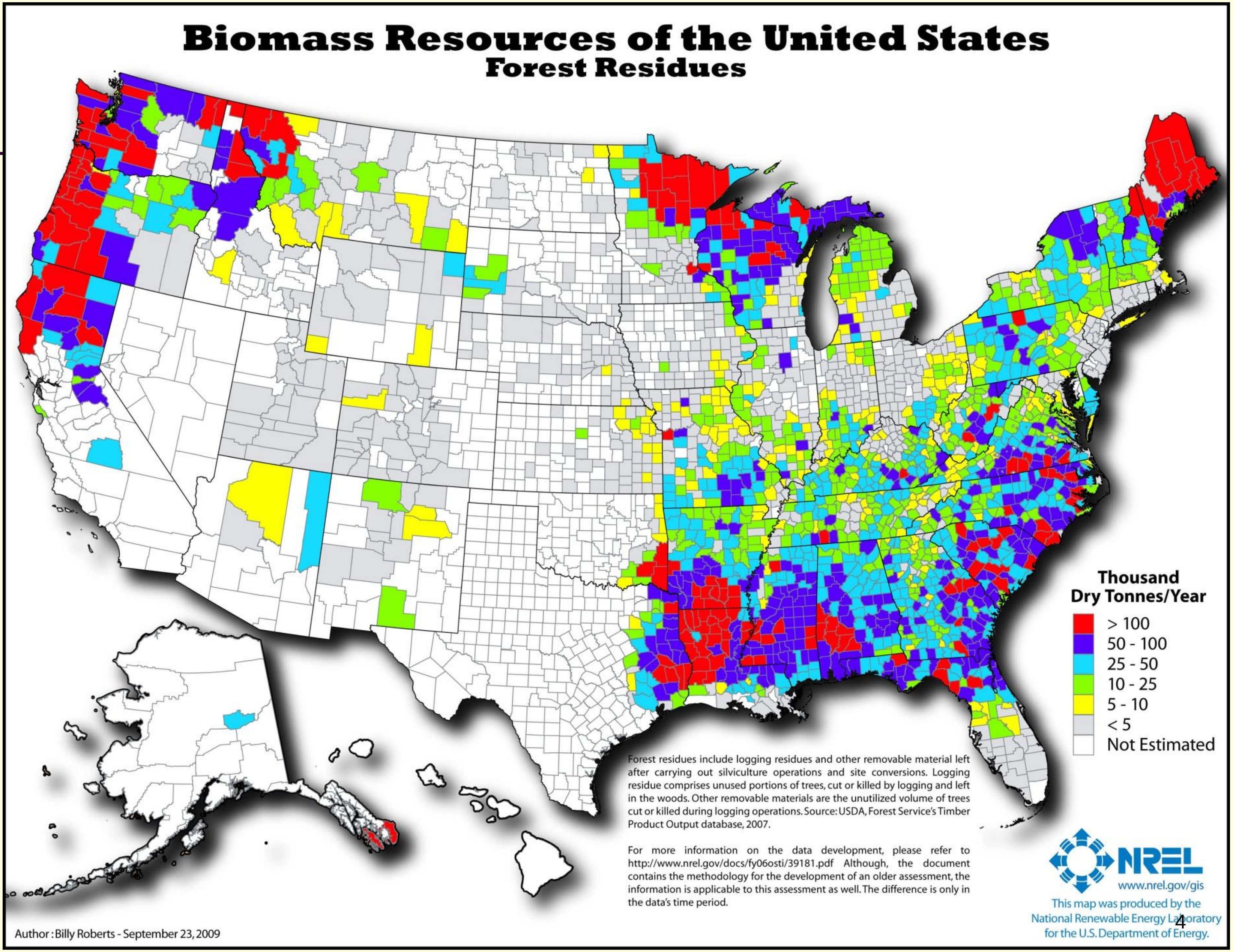


Diagram of a biomass power plant





Biomass Resources of the United States
Forest Residues

Forest residues include logging residues and other removable material left after carrying out silviculture operations and site conversions. Logging residue comprises unused portions of trees, cut or killed by logging and left in the woods. Other removable materials are the unutilized volume of trees cut or killed during logging operations. Source: USDA, Forest Service's Timber Product Output database, 2007.

For more information on the data development, please refer to http://www.nrel.gov/docs/fy06osti/39181.pdf Although, the document contains the methodology for the development of an older assessment, the information is applicable to this assessment as well. The difference is only in the data's time period.

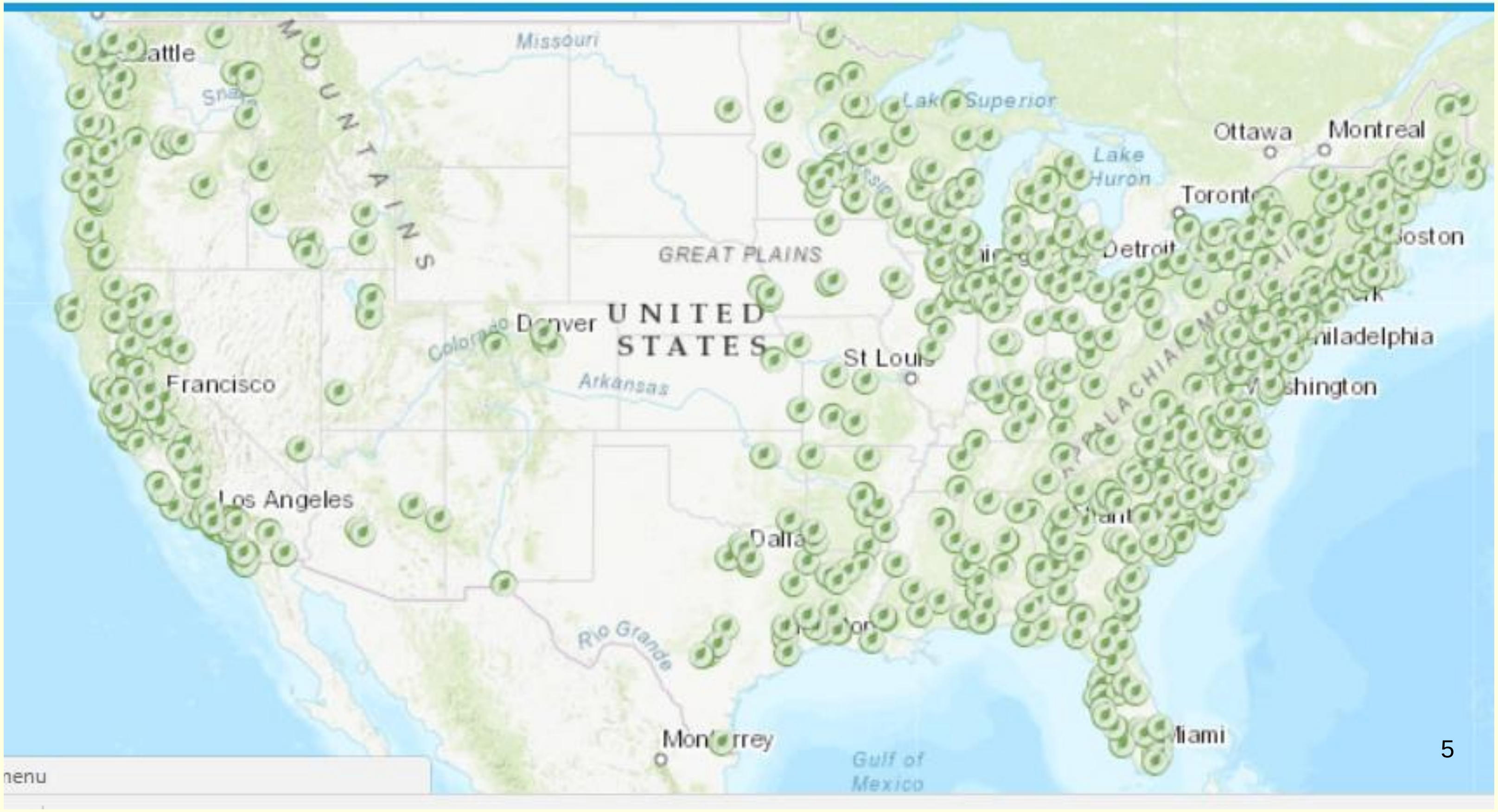
Author : Billy Roberts - September 23, 2009

www.nrel.gov/gis

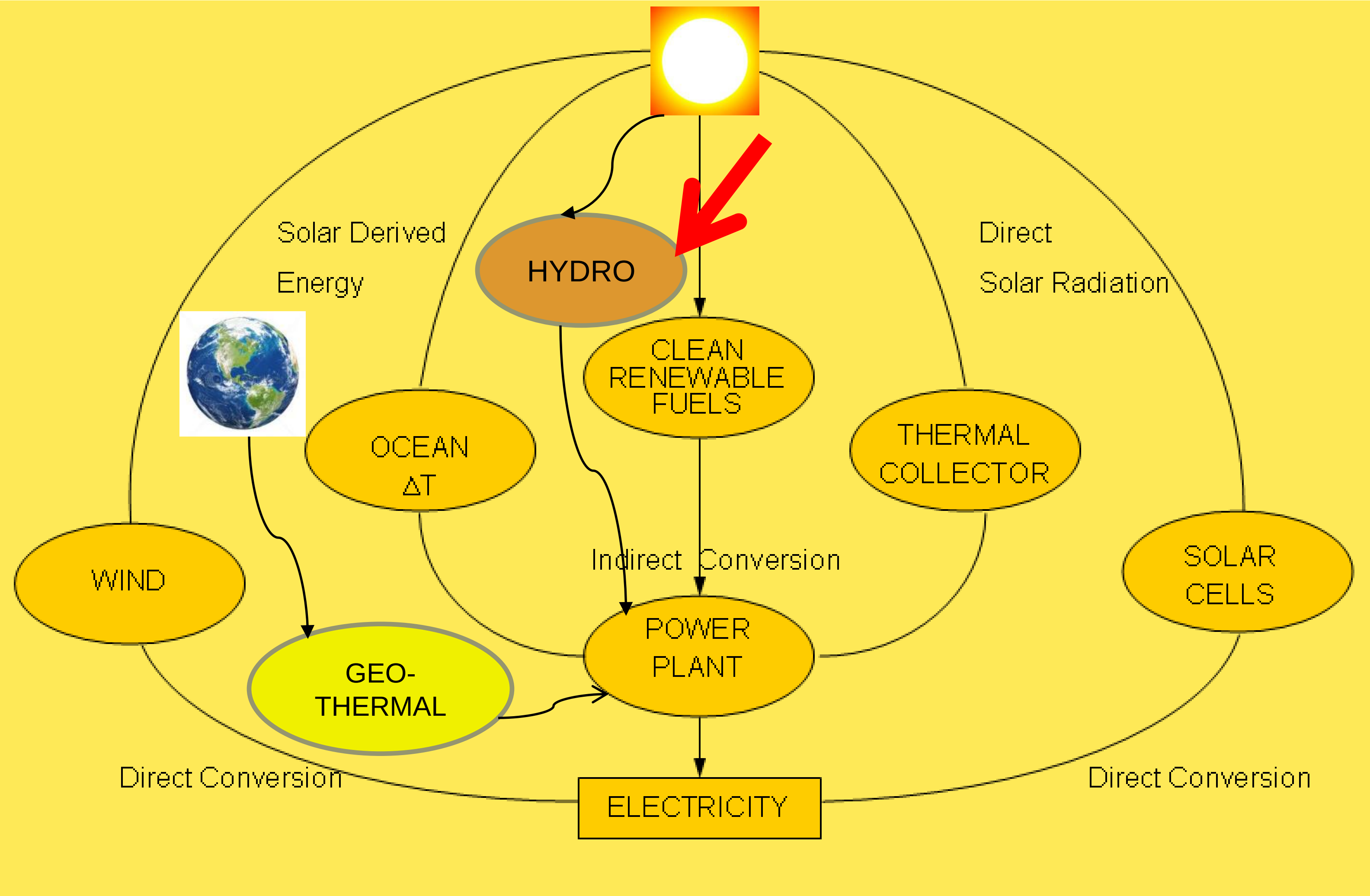
This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

Biomass Plants

- Share of Total Energy Production: 1.5%
- https://www.eia.gov/state/maps.php

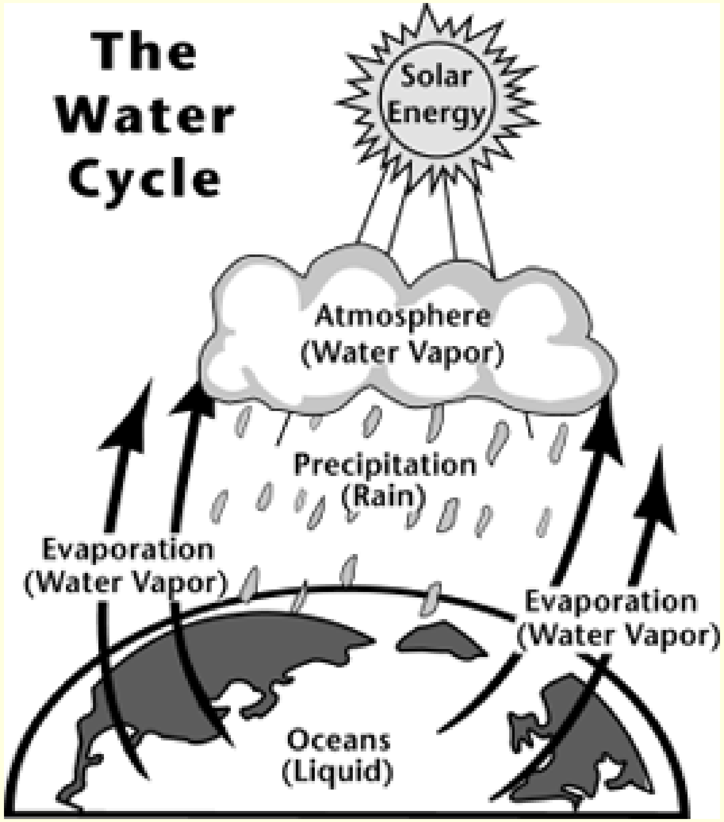


Electricity production from renewables



Hydropower

- Hydropower relies on the water cycle. Herein:
  - Solar energy heats water on the ocean surface, causing it to evaporate.
  - This water vapor condenses into clouds and falls back onto the surface as precipitation (rain, snow, etc.).
  - The water flows through rivers back into the oceans, where it can evaporate and begin the cycle over again



Hydropower 101: See Video Links Below

- http://energy.gov/eere/videos/energy-101-hydroelectric-power

Power of a hydro power generator

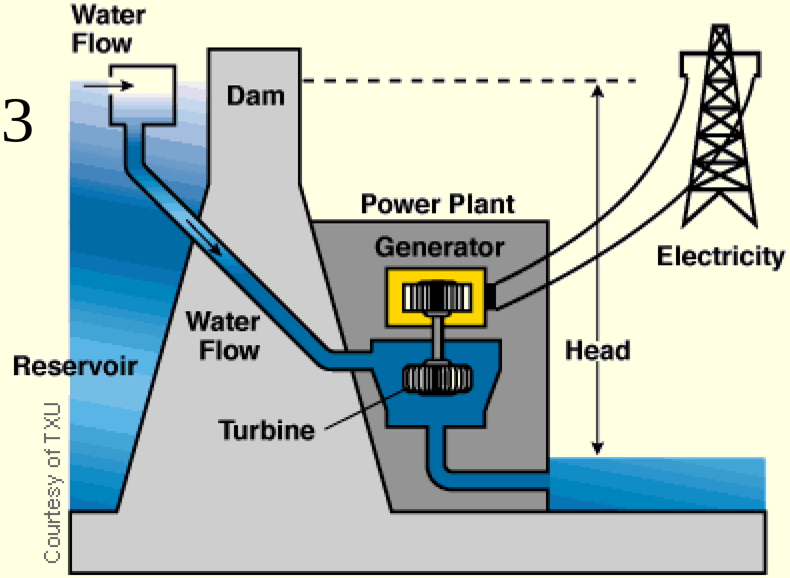
- Ideal case:

$$P = 9.81 Q H_G$$

- When friction losses in the penstock and in the turbine-generator:

$$P = 9.81 \eta Q H_N = \eta Q(gpm) H_N(ft)/5.3$$

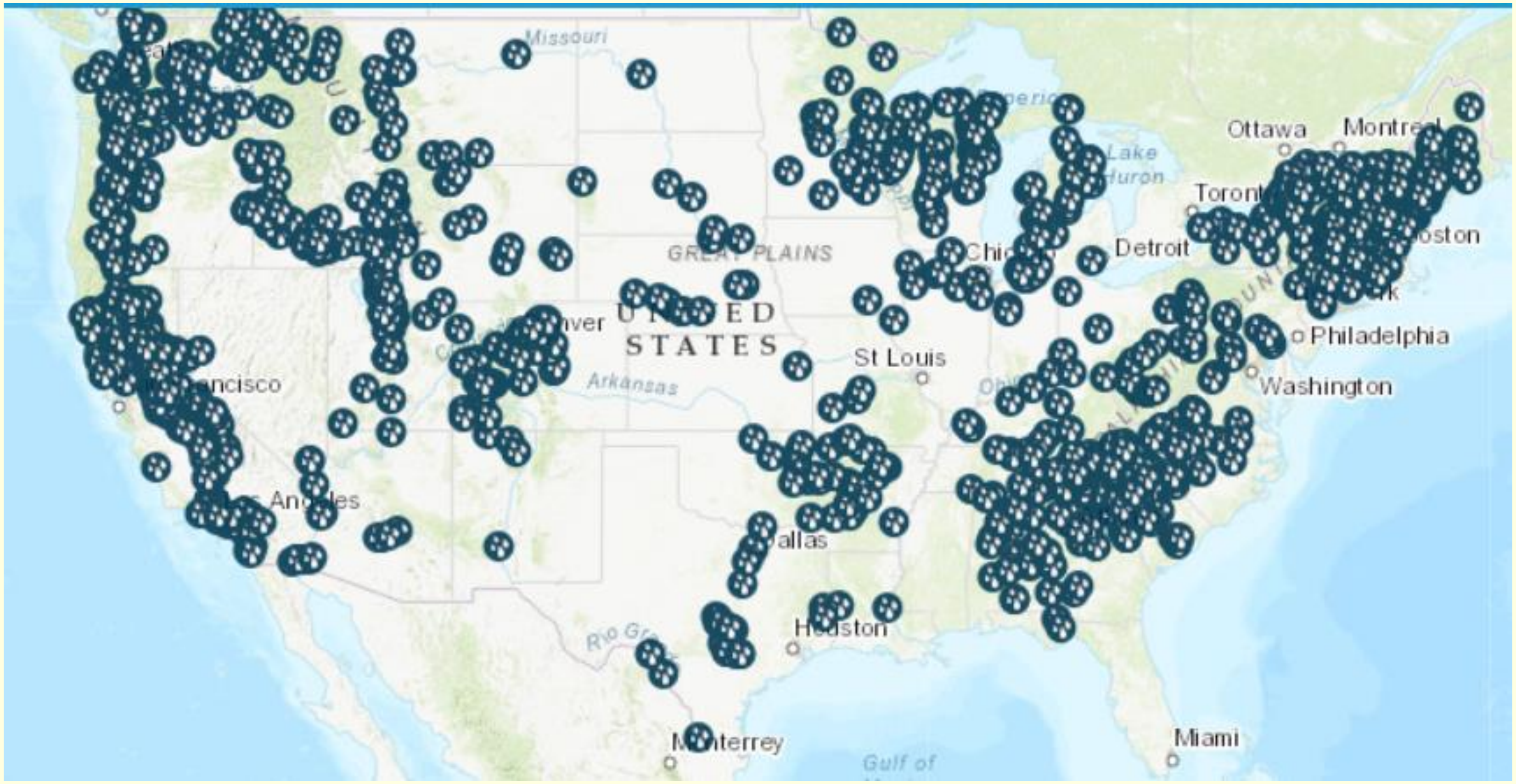
  - P: Power (W)
  - Q: flow rate (m^3/sec)
  - H_G: gross head (m)
  - η: turbine-generator efficiency
  - H_N: net head (m) (= gross head – head loss). Head loss depends on the type of pipe material, diameter, flow rate, and length.



Courtesy of TXU

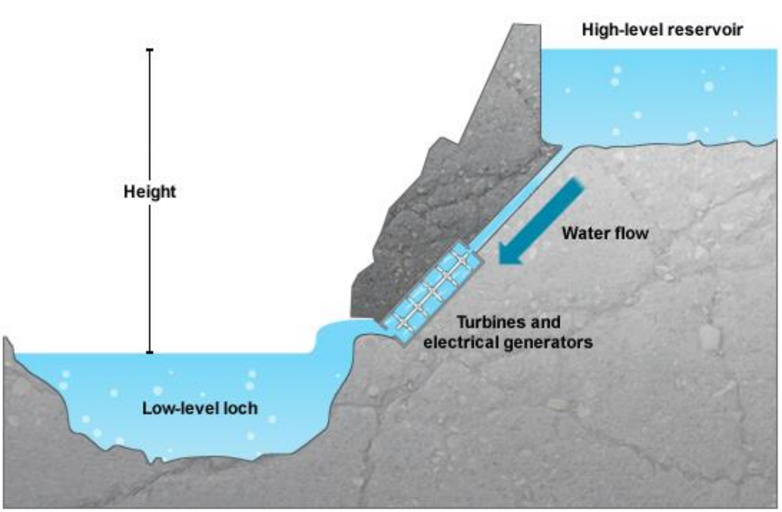
Locate hydro power plants in the US

- https://www.eia.gov/state/maps.php

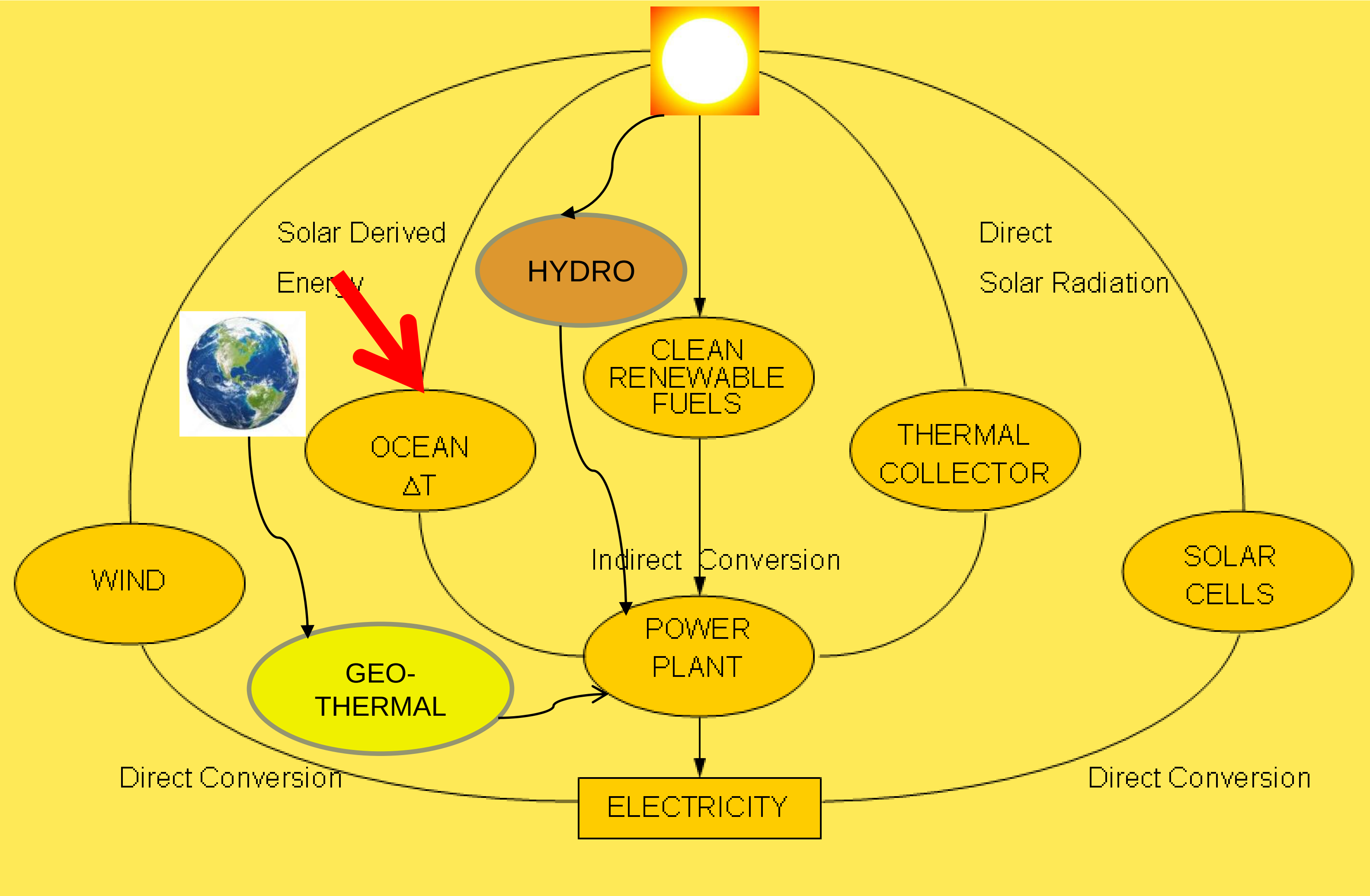


Pumped-Storage Hydro

- Used in bulk power storage applications where water is pumped up at night and released during the day.
- Locate pumped hydro storage systems in the US.
    - https://www.eia.gov/state/maps.php

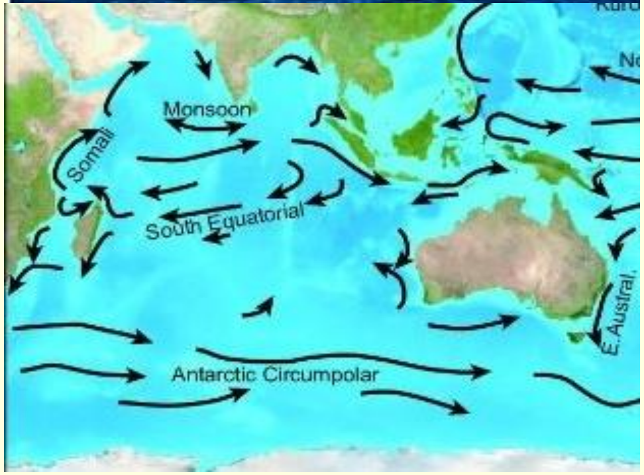


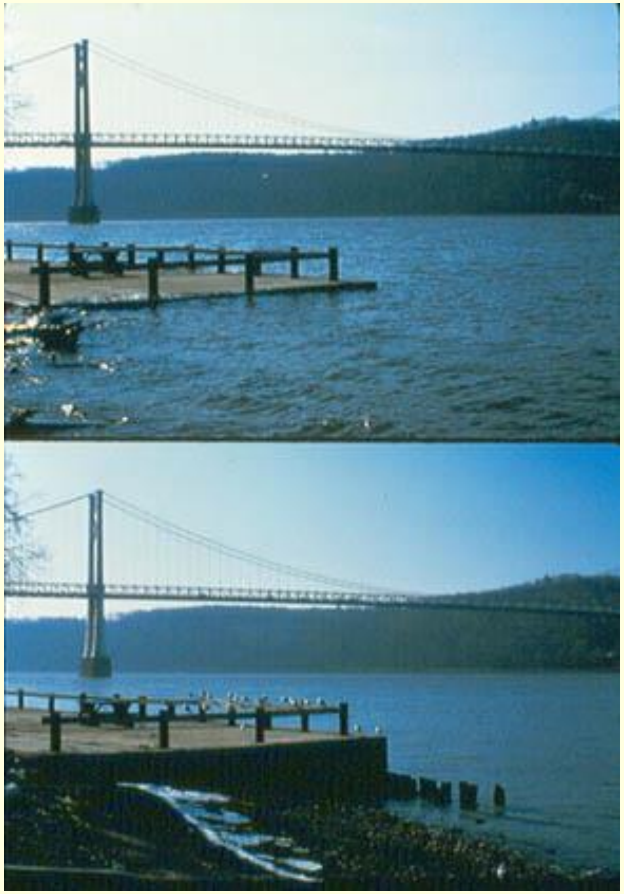
Electricity production from renewables



Ocean Power

- Energy can be extracted from the power of the waves, from the tide, or from ocean currents





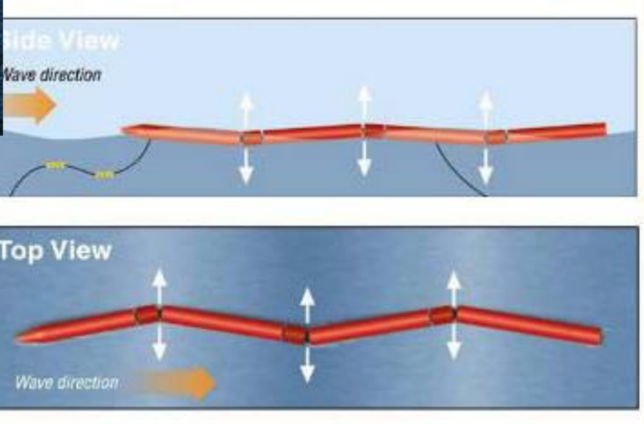
Marine and Hydrokinetic Energy 101: See Video Link Below

- http://energy.gov/eere/videos/energy-101-marine-and-hydrokinetic-energy

4 Ways to Harness Power from Ocean Waves: attenuators, terminators, point absorbers, and overlapping devices

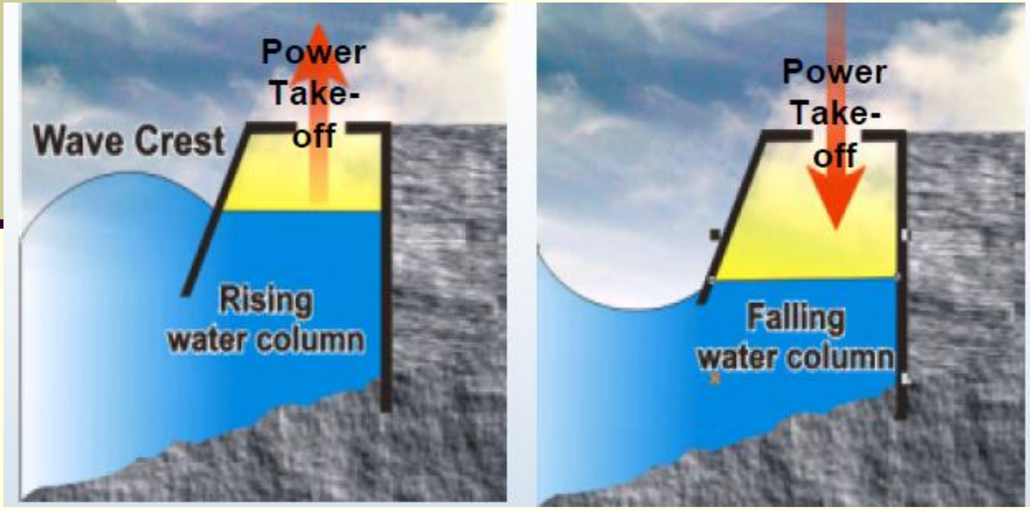
Attenuators: multi-segment floating structures oriented parallel to the direction of the waves. The differing heights of waves along the length of the device causes flexing where the segments connect. This motion is resisted by hydraulic rams which in turn drive electrical generators.

Source: Pelamis Wave Power



Ocean Power - Waves

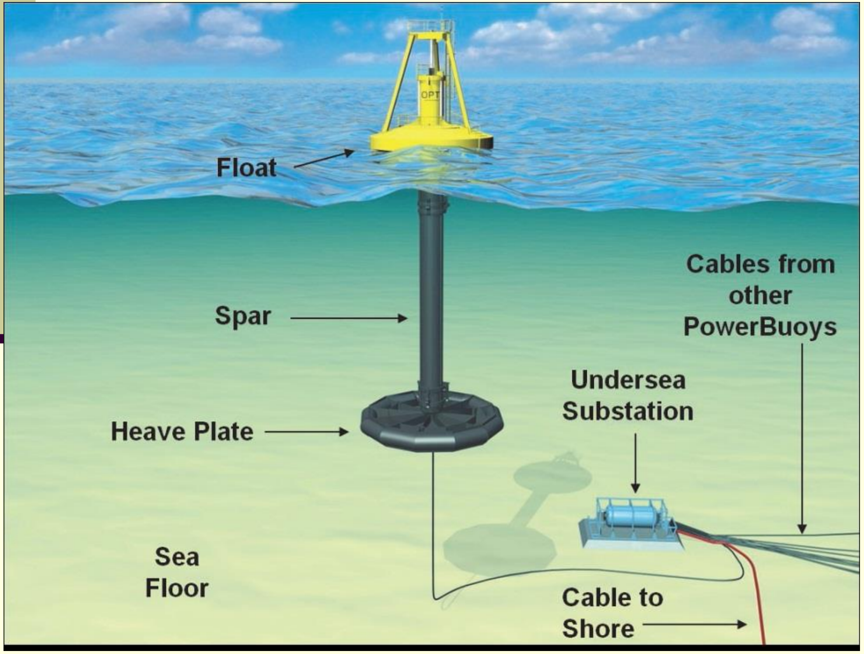
- **Oscillating water column** is a form of terminator in which water enters through a subsurface opening into a chamber with air trapped above it. The wave action causes the captured water column to move up and down like a piston to force the air though an opening connected to a turbine



Source: Oceanlinx, Australia

Ocean Power - Waves

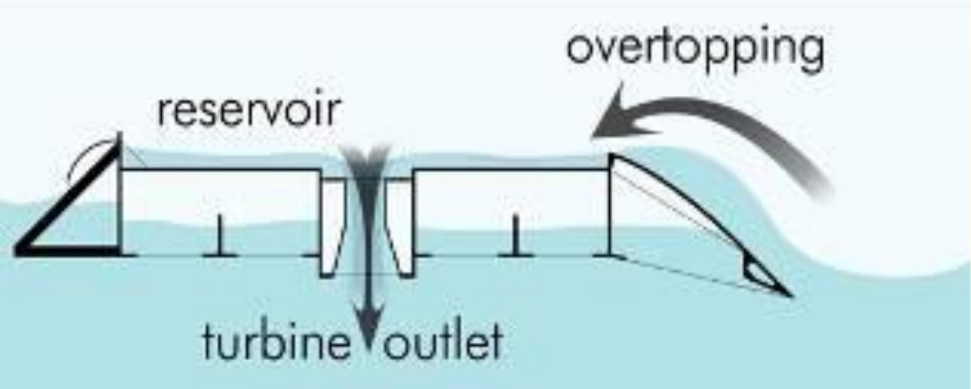
A point absorber is a floating structure with components that move relative to each other due to wave action (e.g., a floating buoy inside a fixed cylinder). The relative motion is used to drive electromechanical or hydraulic energy converters.



Source: Ocean Power Technologies

Ocean Power - Waves

- **An overtopping device** has reservoirs that are filled by incoming waves to levels above the average surrounding ocean. Gravity causes it to fall back toward the ocean surface. The energy of the falling water is used to turn hydro turbines.



Source: Wave Dragon, Danmark

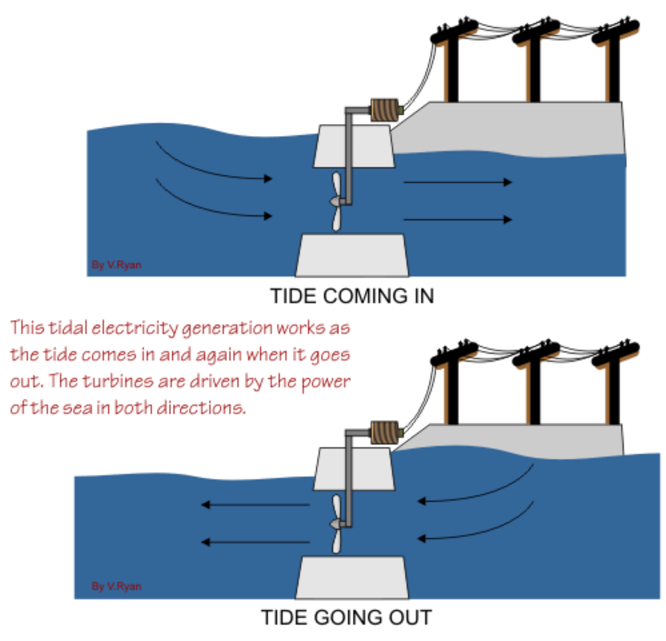
Ocean Cower - Currents

- **Ocean currents** flow in complex patterns affected by the wind, water salinity and temperature, topography of the ocean floor, and gravitational forces exerted by the moon and sun.
- While ocean currents move slowly relative to typical wind speeds, they carry a great deal of energy because of the **density of water** (837 times denser than air). $\mathbf{P = (1/2)\rho A v^3}$
- Many industrialized countries are pursuing ocean current energy. Technical challenges include prevention of marine growth buildup, and corrosion resistance.

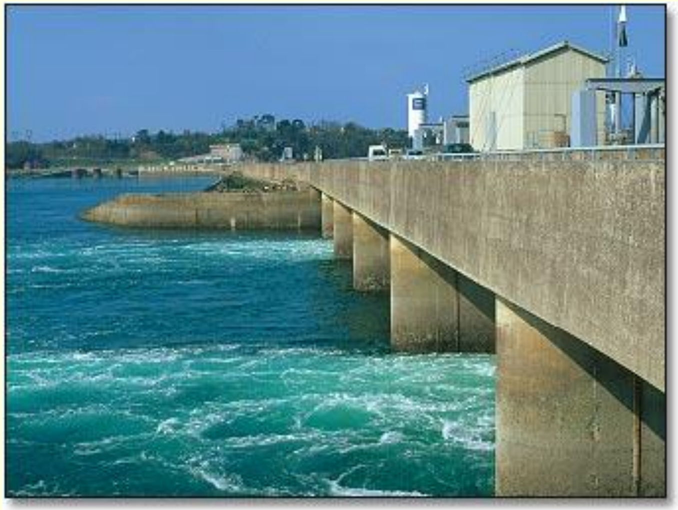
Ocean current power station in Northern Ireland (1.2 MW)

Ocean power - Tide

- The tides are the result of the gravitational attraction between the earth and the moon as well as the earth and sun. The strength of the tide is greatly dependent on the earth-moon system.
- Depending on the location and time of year, one can experience two equal tidal cycles (semidiurnal), on tidal cycle (diurnal) or two unequal tidal cycles (mixed tide).
- Enormous volumes of water rise and fall with the tides each day, and many coastal areas can take advantage of this free energy.

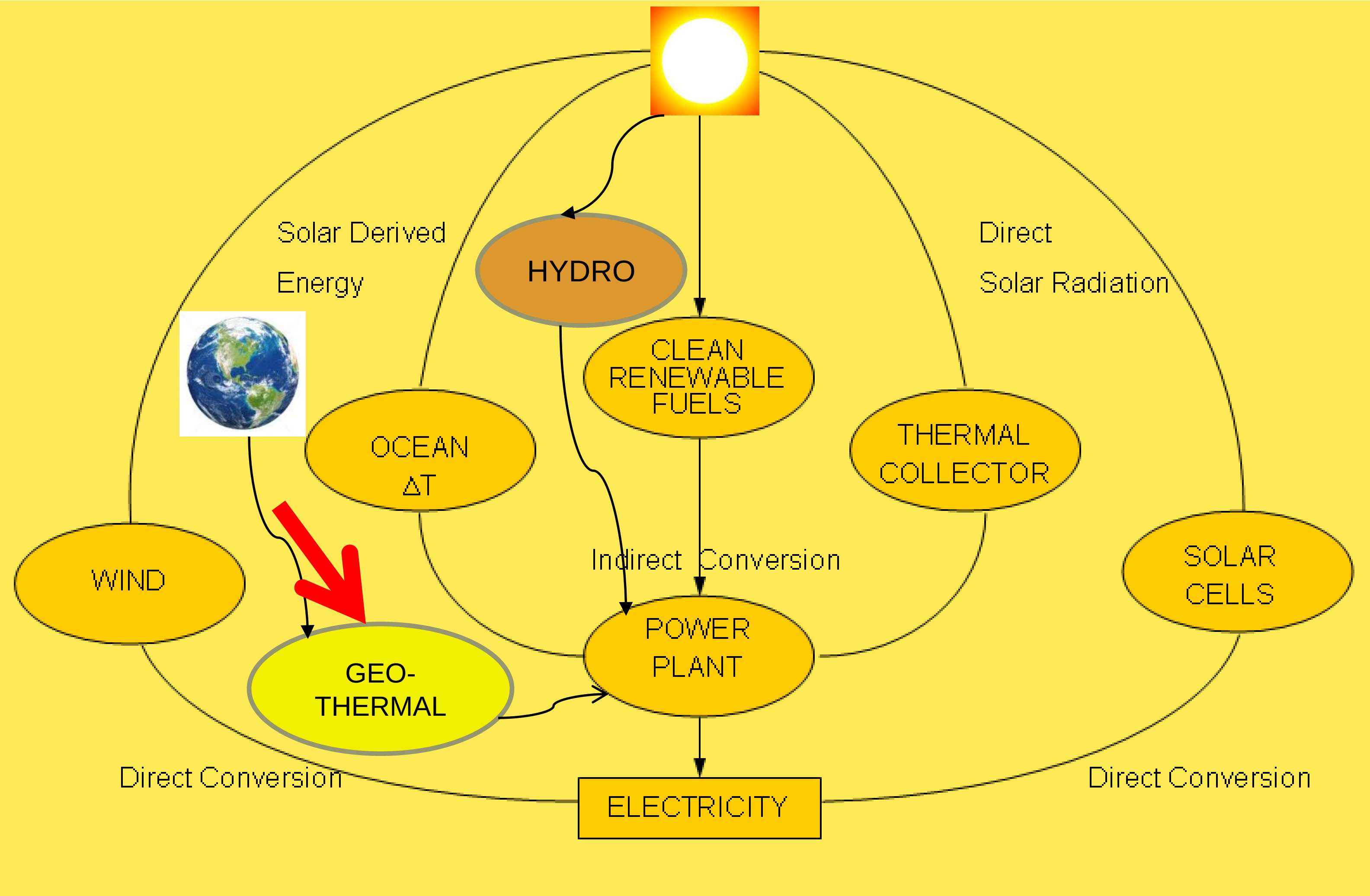


This tidal electricity generation works as the tide comes in and again when it goes out. The turbines are driven by the power of the sea in both directions.



Tidal power plant in Brittany, France (240 MW)

Electricity production from renewables

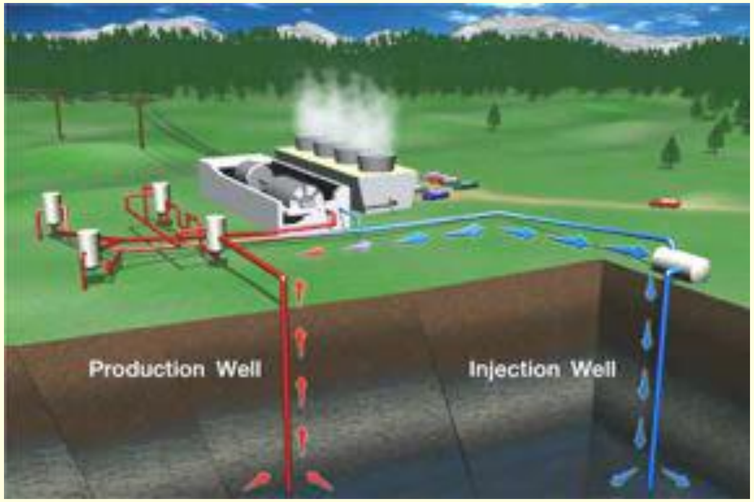


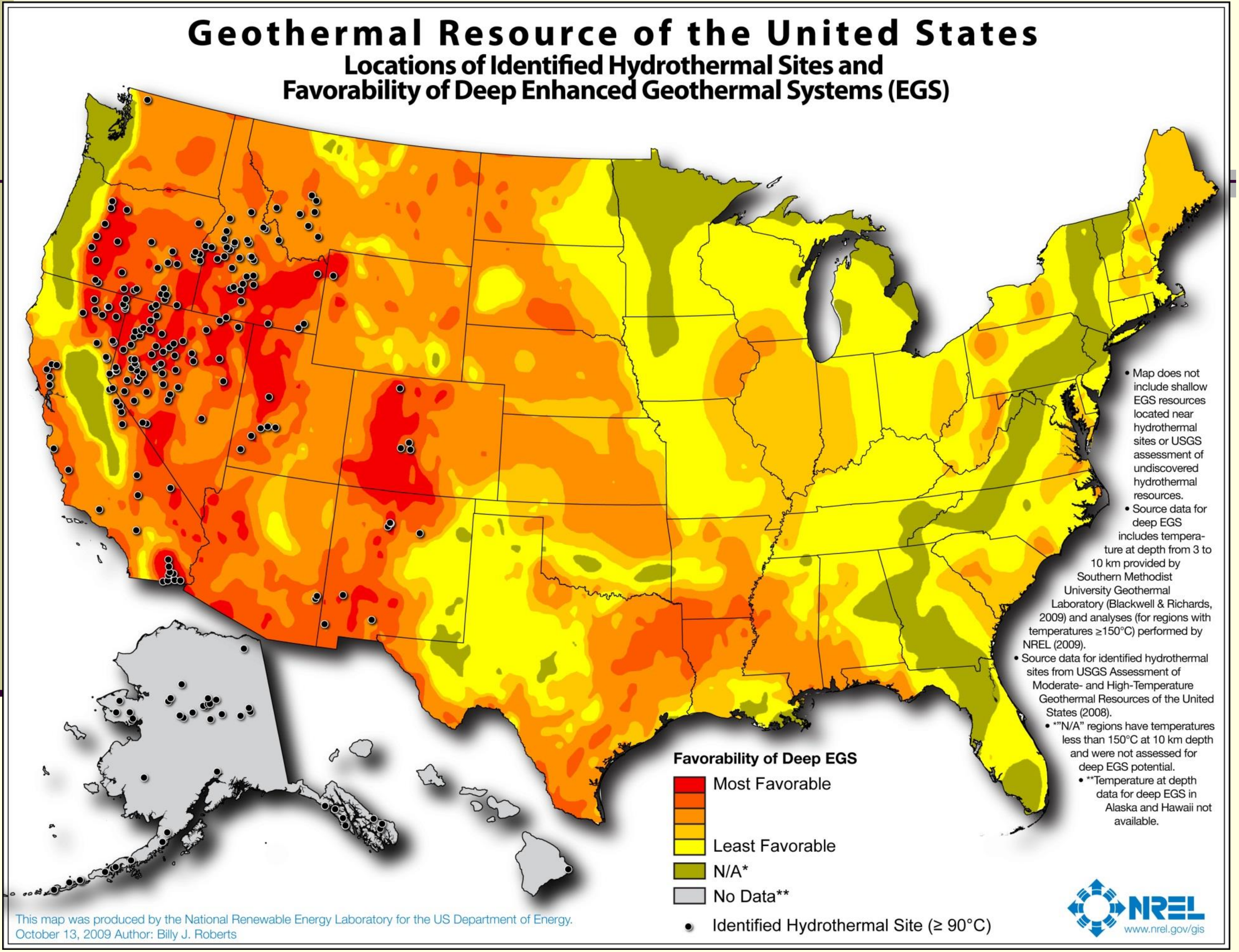
Geothermal Energy 101: See Video Link Blow

- http://energy.gov/eere/videos/energy-101-geothermal-energy

Geothermal

- **Dry steam plants** use steam piped directly from a geothermal reservoir to turn the generator turbines. The first geothermal power plant was built in 1904 in Tuscany, Italy.
- **Flash steam plants** take high-pressure hot water from deep inside the Earth and convert it to steam to drive the generator turbines. When the steam cools, it condenses to water and is injected back into the ground to be used over and over again.





Geothermal Resource of the United States

Locations of Identified Hydrothermal Sites and Favorability of Deep Enhanced Geothermal Systems (EGS)

- Map does not include shallow EGS resources located near hydrothermal sites or USGS assessment of undiscovered hydrothermal resources.
- Source data for deep EGS includes temperature at depth from 3 to 10 km provided by Southern Methodist University Geothermal Laboratory (Blackwell & Richards, 2009) and analyses (for regions with temperatures ≥150°C) performed by NREL (2009).
- Source data for identified hydrothermal sites from USGS Assessment of Moderate- and High-Temperature Geothermal Resources of the United States (2008).
- *"N/A" regions have temperatures less than 150°C at 10 km depth and were not assessed for deep EGS potential.
- **Temperature at depth data for deep EGS in Alaska and Hawaii not available.

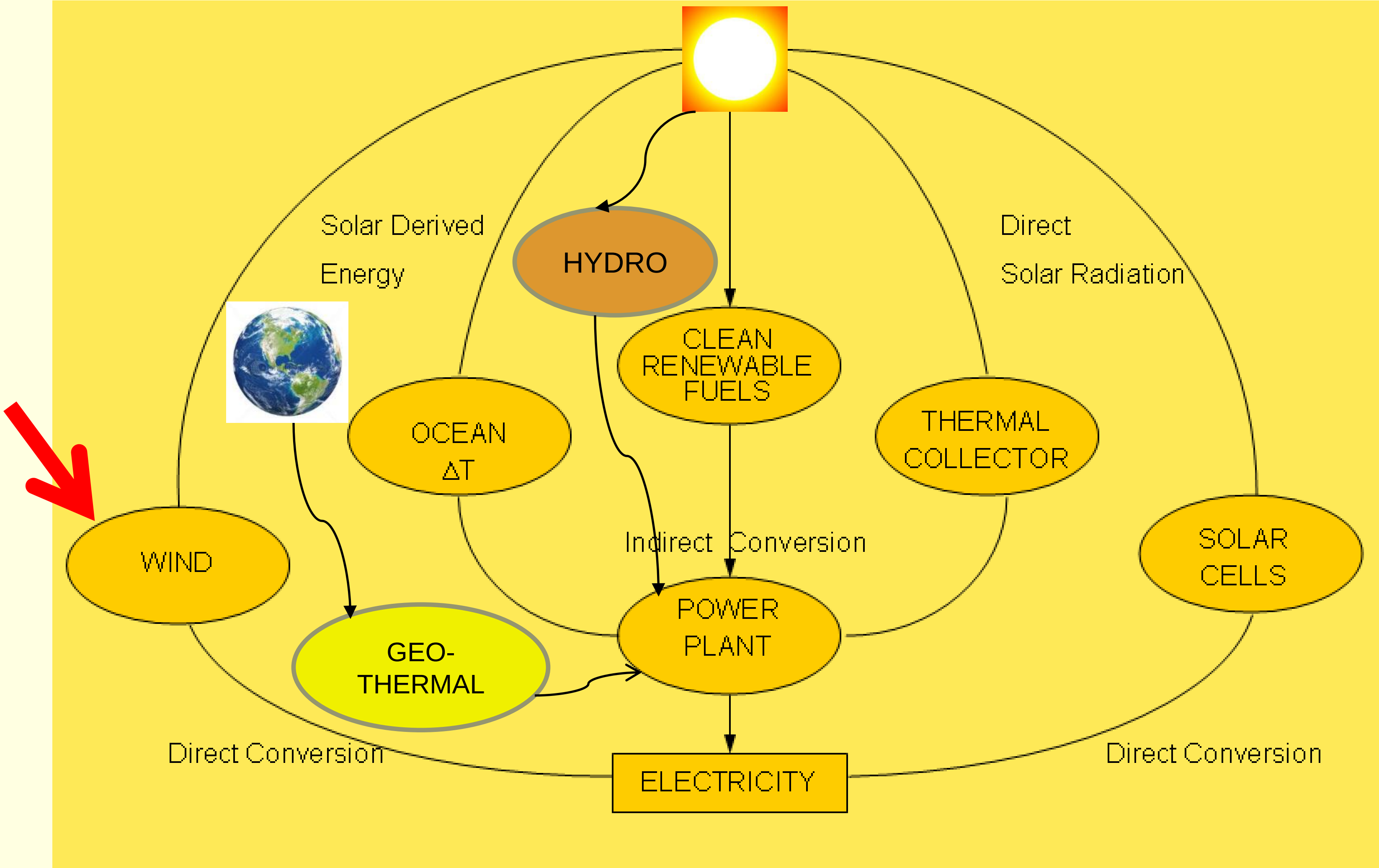
This map was produced by the National Renewable Energy Laboratory for the US Department of Energy.
October 13, 2009 Author: Billy J. Roberts

www.nrel.gov/gis

Locate geothermal power plants in the US

- https://www.eia.gov/state/maps.php

Electricity production from renewables



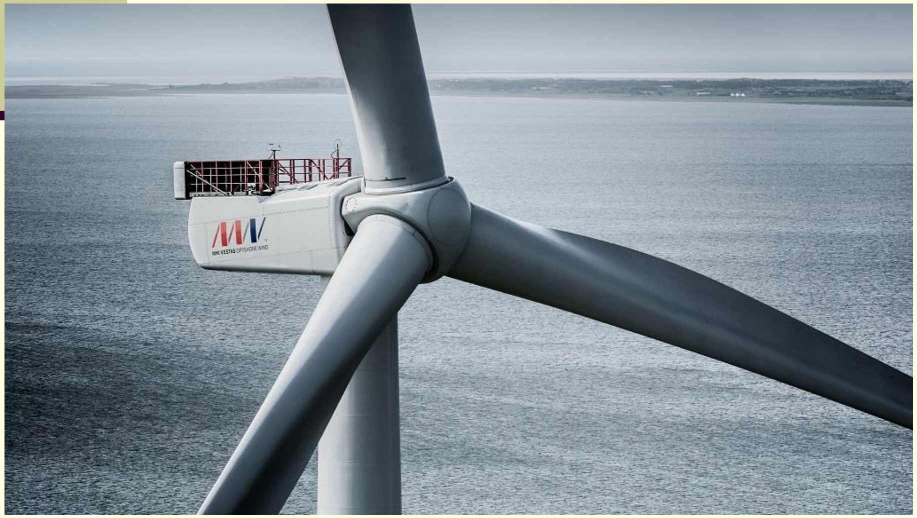
Wind Power … Inland and Offshore

Wind Energy 101: See Video Link Below

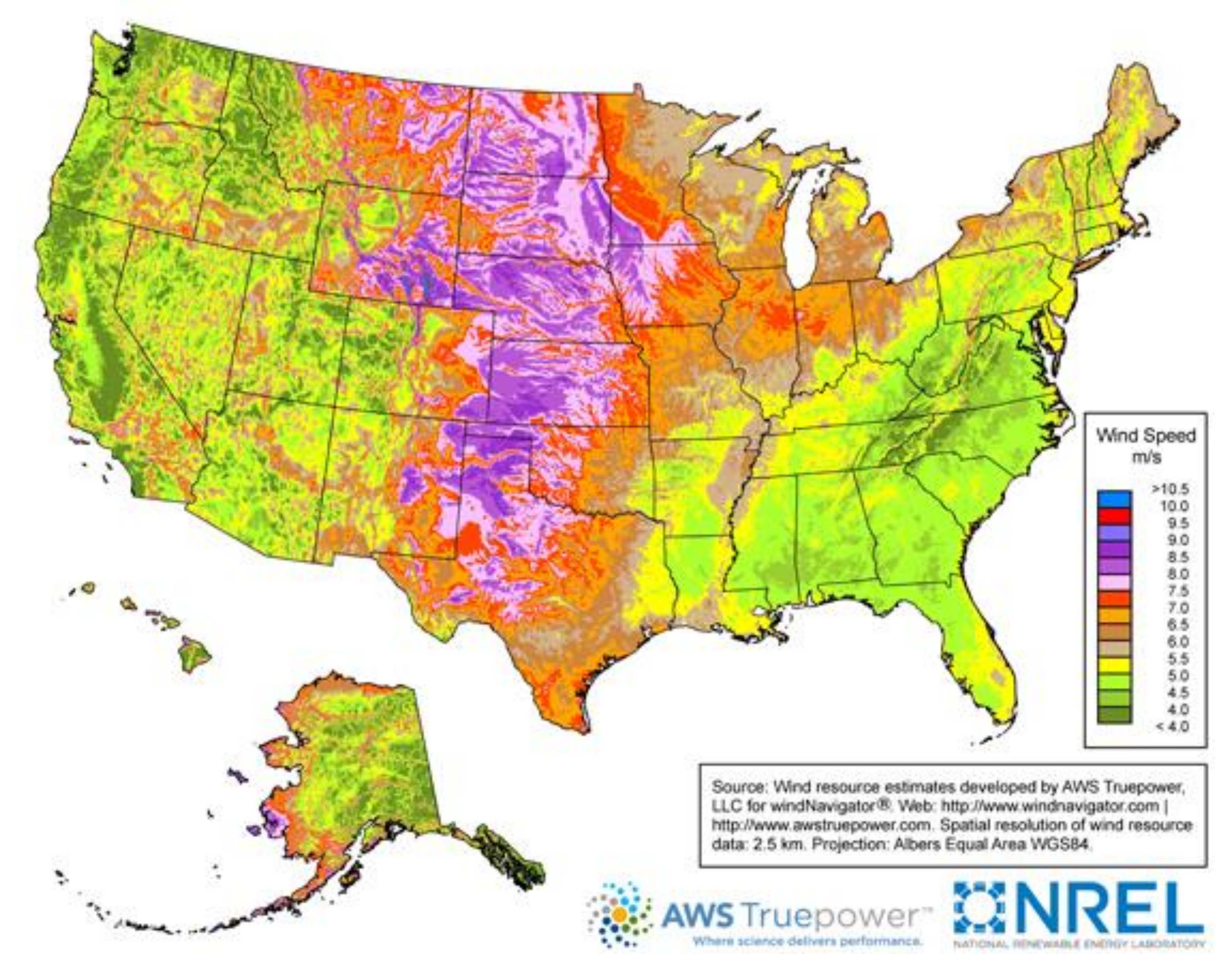
- http://energy.gov/eere/videos/energy-101-wind-turbines-2014-update

Largest wind turbine generator to date:

- Manufacturer: Vestas
- Rated power: 9.5 MW,
- Rotor diameter: 164m.



US Wind Resource Map



Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: Albers Equal Area WGS84.

Locate wind energy plants in the US

https://www.eia.gov/state/maps.php

Wind and Turbine Power

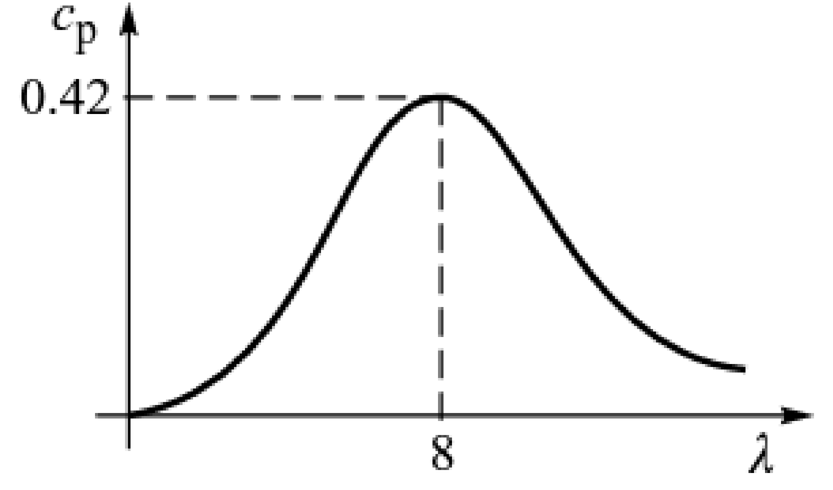
- Power of the wind: $\mathbf{P_w = (1/2)\rho A v_w^3}$
- Where ρ is the air density, A is turbine sweep area, and v_w is the wind speed.
- Power extracted by the turbine: $\mathbf{P_t = c_p P_w}$

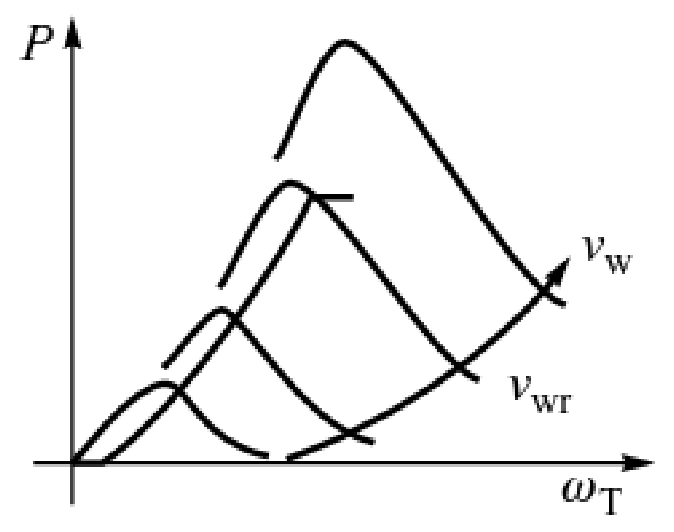
  where c_p is the turbine performance coefficient.
- The theoretical maximum value of c_p (derived from the conservation of mass and energy) is 16/27 ≈ 60%.
- In practice c_p is less than the above value and its varies with the tip speed ratio: $\mathbf{\lambda = \omega r / v_w}$

  where ω is the rotor speed r is the rotor radius and v_w is the wind speed.

Turbine Power

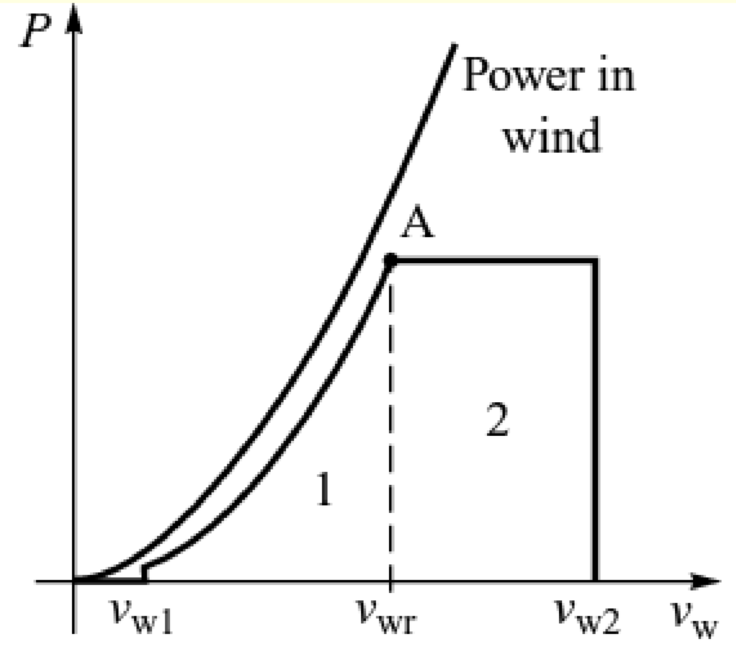
- A typical c_p - λ curve is shown below and is unique to a particular turbine design. Modern wind turbine design can reach 70-80% of the theoretical limit.
- To extract maximum power, the turbine must be operated at the peak of the curve (*peak power tracking*).
- For a given wind speed v_w and the c_p - λ characteristics, the turbine power can be calculated as a function of shaft speed.





Turbine Power

- For a given turbine c_p, the turbine power can be graphed as a function of the wind speed as shown below.
- The figure shows the cut-in speed (around 3-4 m/s), rated speed (around 12.5 m/s), and shut down speed (around 25 m/s).
- Turbines are typically designed to withstand wind speeds of up to 50 m/s (180 km/hr)



Average Power in the Wind

- The average power in the wind is proportional to the average of the cube of the wind velocity, **not** the cube of the average wind speed.

$$P_{avg} = (\frac{1}{2}\rho A v^3)_{avg} = \frac{1}{2}\rho A (v^3)_{avg} \neq \frac{1}{2}\rho A (v_{avg})^3$$

- Example: Calculate the cube of the average value and the average of the cube of the wind velocity if

$$v(t) = V_M \,|\sin t\,|$$

Ans: $(v_{avg})^3 = \frac{8}{\pi^3} V_M^3 \approx 0.26 V_M^3,$ $\qquad (v^3)_{avg} = \frac{4}{3\pi} V_M^3 \approx 0.42 V_M^3$

End of Part II

- Homework Assignment.
  - 8.1 - Note: Entropy change: ΔS(source)=QH/TH, and ΔS(sink)=QC/TC
  - 8.2 – Note: flow rate m= QH/ρcΔT where QH is the thermal input, c is the specific heat, and ρ is density
  - 8.3
  - 8.6
  - 8.7
  - 8.10
  - 8.11 (skips questions e and f)