Resources – Renewables - Hydro

Outline

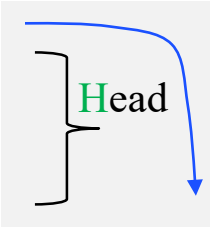
- **Pumped-up Storage**
- **Hydro**
- **Tidal and Wave Power**

Hydro Energy

- Bhakra Dam on Sutlej River, Himachal Pradesh, India.
- About 250 metres high dam opened in 1963.
- "The Bhakra Project is something tremendous, something stupendous, something which shakes you up when you see it. Bhakra, the new temple of resurgent India, is the symbol of India's progress."
  - India's prime minister Jawaharlal Nehru in 1963.

Potential Energy

- Dropping from a high altitude, water loses potential energy - proportional to mass & height
  - If mass in kg, height of drop in meters & gravitational acceleration constant $g = 10\frac{m}{s^2} \approx 9.8\frac{m}{s^2}$, then multiply these to obtain potential energy in Joules.
  - Water gains potential energy when it evaporates with the heat coming from the sun.



- What is the fuel cost at a hydroelectric dam? Zero
- Head is the term in the hydroelectric industry for the height of the drop.

- Potential energy captured by m kgs at h (head) is $m\ g\ h$

  $m = 1000$ kg of water at $h = 100$ meter high has potential energy of 1 million Joules.

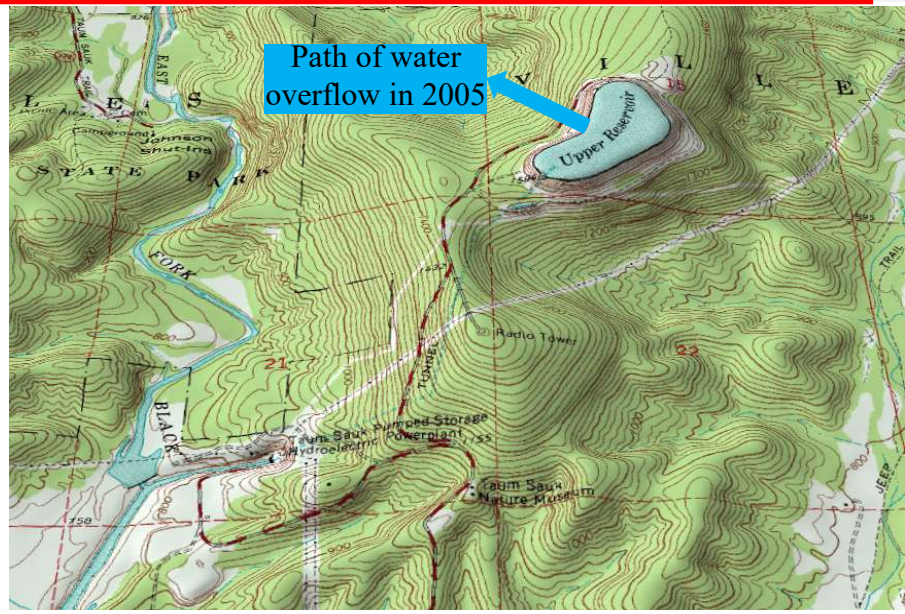
  $$1 \text{ million Joules} = 1{,}000{,}000 \text{ kg}\frac{\text{m}^2}{\text{s}^2} = 1{,}000 \text{ kg} * 10\frac{\text{m}}{\text{s}^2} * 100 \text{ m}$$

- 1 Joule/s = 1 Watt ⇒ 1 million Joules is 1 MWsecond = (1/3600) MWh.
- ⇒ 1 MWh = 3600 MegaJoules
- Example: Hoover Dam generates 2080 MW with 17 turbines and head of about 200 m. How much water should go through a turbine per second to generate 100 MW?

  $100{,}000{,}000 = m * 10 * 200$ so $m = 50{,}000$ kg, a drop of 50 tons of water per second.
- Example: Three Gorges Dam has 24 turbines with 750 MW power and similar head, how much water should pass through each 750 MW turbine?

Taum Sauk Pumped Storage: Heart of Ozarks

- Taum Sauk is a pumped storage reservoir close to Taum Sauk mountain (highest peak in Missouri), a part of Ozark Mountain Range.
- It has two reservoirs:
  - Upper reservoir is on Proffit mountain.
  - Lower reservoir is on the East fork of Black river.
- Upper reservoir has 30 meter walls and holds 5.7 million cubicmeter of water 240 metres above the power turbines.
- Upper reservoir is filled from the lower reservoir during nights through a 2,100 metre tunnel.



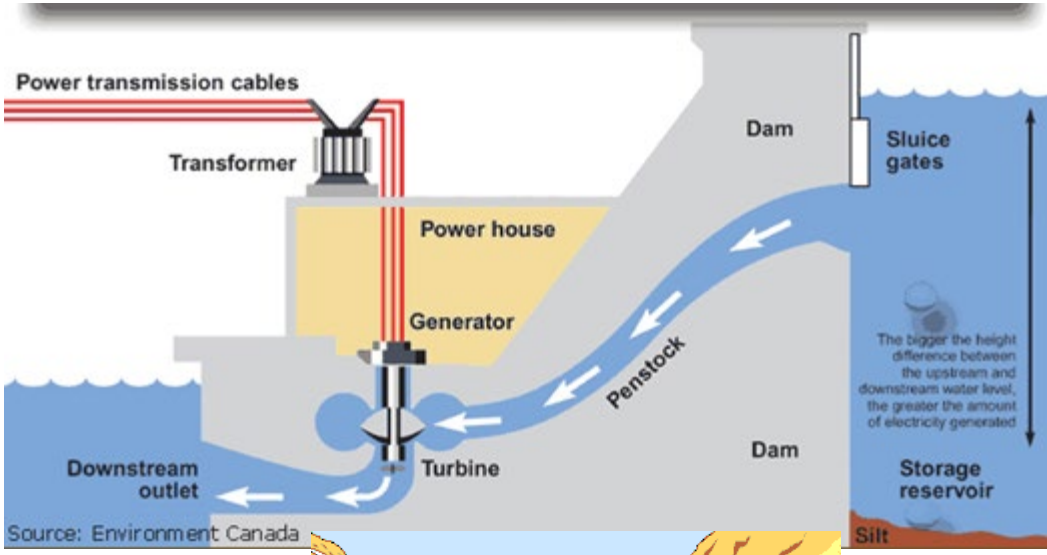

Looking south towards Arkansas Ozarks

- Upper reservoir stores potential energy. How much?
  - m = weight of $5.7 * 10^6$ m^3 = $5.7 * 10^9$ kg
  - h = 240 metres; $g = 10$ m/s^2
  - Potential energy = $1368 * 10^{10}$ Joules = $1368 * 10^4$ MegaJoules = $1368 * 10^4$ MWsecond = $(1368/3600) * 10^4$ MWh = $0.38 * 10^4$ MWh= 3,800 MWh
- Dec 15, 2005, the northwest wall overtopped by water and partially collapsed.
  - Suddenly 6 meter wave of water flowed down the mountain, clearing out the thick forest and a house. Luckily, no fatalities.
  - FERC fined the owner AmerEn for $15 million.
  - Northwest wall was rebuilt and the reservoir is operational since the 2010s.

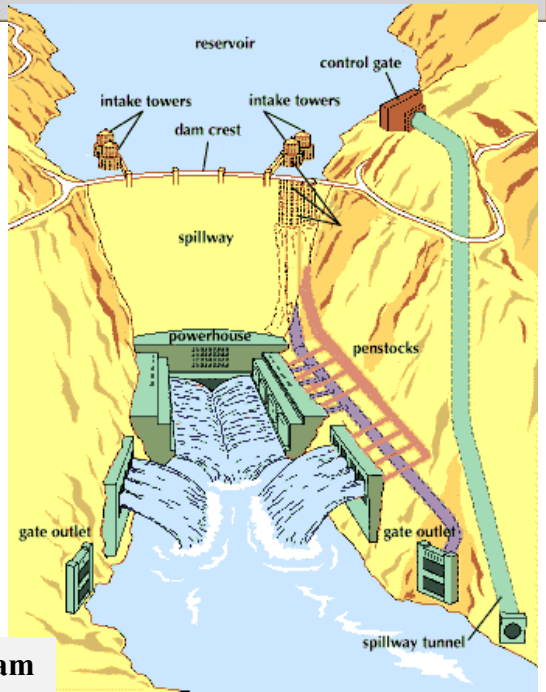
Hydroelectric Dams

A hydroelectric plant includes

- Dam traps the water to build a reservoir.
- Reservoir stores the water at a higher altitude and is connected to the surface of the water behind (downstream) the dam through pipes.
- Pipes (penstock) bring the water down in a controlled fashion to the powerhouse.
- Powerhouse includes the turbines rotated by falling water and electricity generated in the powerhouse is transmitted to the electrical substation.
- Electrical substation increases the voltage for long-distance transmission.

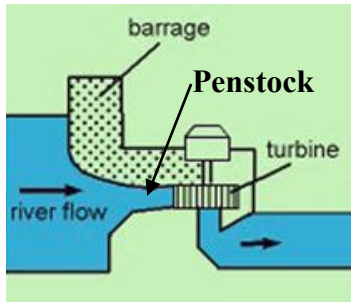


Hoover Dam



Three Types of Hydroelectric Dams

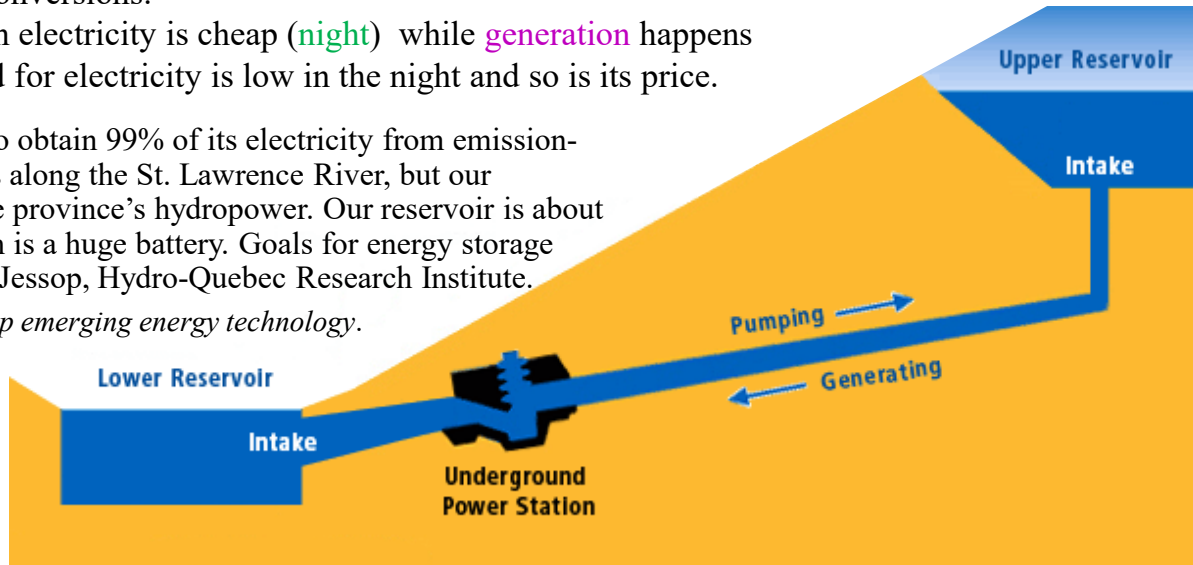
- Impoundment: Reservoir fills naturally with the water flowing from upstream.
  - Advantage: Reduced seasonality of water flow. Flood reduction; agricultural irrigation.
  - Disadvantage: Big footprint. Existing villages and natural life go underwater. Large lakes can change ecology and can create microclimates.
- Diversion: No reservoir. River (a stream thereof) flows through penstock.
  - Advantages: Low cost as no dam is built. It has limited/no footprint.
  - Disadvantage: Exposure to seasonality of water flow.
    - » Seasonality is less in tropical or subtropical climates: Hawaii, Central America or Brazil.
- Pumped storage: Reservoir is filled with recycled water.
  - Water at high elevations can be thought as an energy storage mechanism.
  - Think of a two (artificial) lakes at different altitudes.
  - Water flows from the upper to the lower to generate electricity.
  - Electricity is used to pump water up from the lower to fill the upper.
  - Under ideal conditions, no gain or loss.
  - In reality, friction causes loses during conversions.
  - This is viable as pumping happens when electricity is cheap (night) while generation happens when electricity is expensive (day). Demand for electricity is low in the night and so is its price.



Diversion Dam has a penstock. Figure 4.20 of Narbel et al. (2014)

The naturally pumped storage allows Hydro-Québec to obtain 99% of its electricity from emission-free renewables. "Some 80% of the Quebec demand is along the St. Lawrence River, but our generating capacity is 1,000 or more miles away in the province's hydropower. Our reservoir is about 170 gigawatt-hours (170,000 mWh) of capacity, which is a huge battery. Goals for energy storage include regulating wind and solar …." according to J. Jessop, Hydro-Quebec Research Institute.

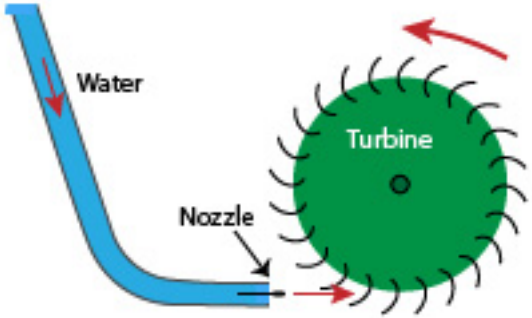
H.K. Trabish. 2015. *Why utility execs say storage is the top emerging energy technology*. Appeared on www.UtilityDive.com on Feb 24.



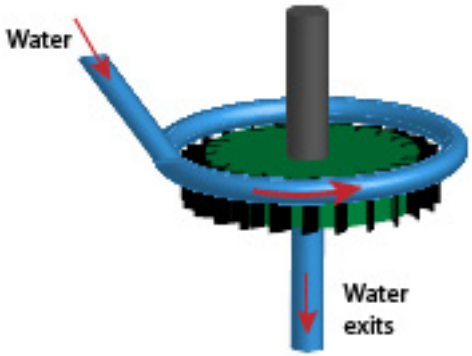
Sizes and Technologies

- Sizes according to Department of Energy
  - Micro: Less than 0.1 MW.
  - Small: Between 0.1 and 30 MW.
  - Large: More than 30 MW.

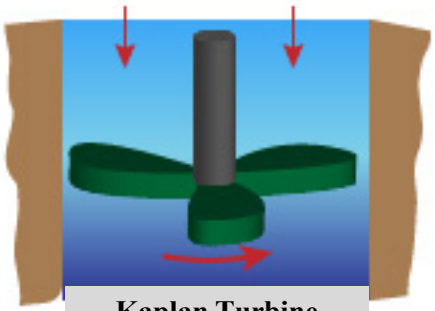
- Types of Turbines



Pelton Turbine:
Radial in and out



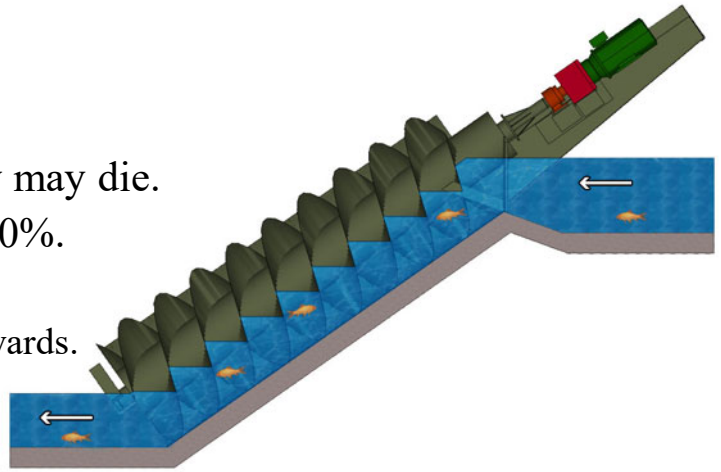
Francis Turbine
Radial in; Axial out



Kaplan Turbine
Immersed into water

Environmental Issues

- Fish mortality
  - When fish enter the penstock and reach the turbines, they may die.
  - Single pass mortality rate in most existing turbines is 5-10%.
  - New turbine designs can reduce it down to 2%.
    - » Screw Turbine. Water rotates the turbine as it flows downwards.



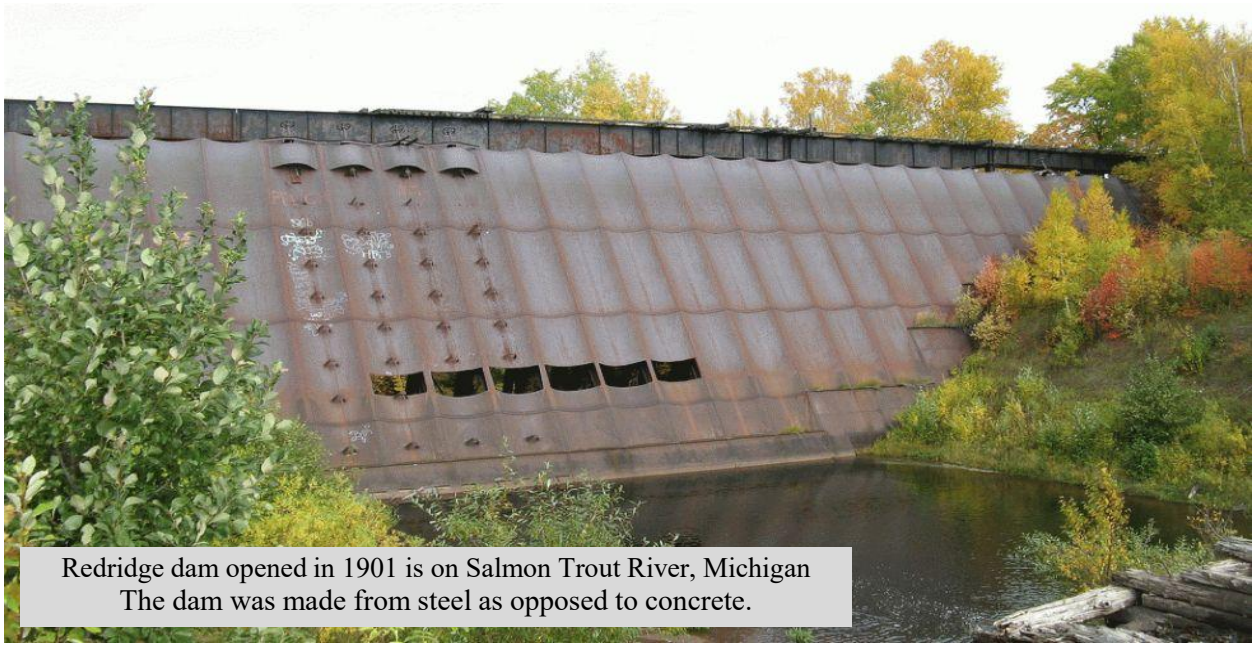
- Water quality standards
  - Dissolved oxygen (DO) in the downstream water can be made more than 6 mg per liter.
  - Dissolved oxygen is more in freshwaters and in Springs.
  - Texas Commission on Environmental Quality
    - » DO mean 6 mg/L is exceptional; 5 is high; 4 is intermediate; 3 is limited; 2 is minimal.
    - » Trinity River Basin Segments
      - Lewisville Lake, Grapevine Lake, White Rock Lake all have 5 mg/L.
    - » San Jacinto River Basin Segments
      - Houston Ship Channel Tidal has 2 mg/L and Buffalo Bayou Tidal has 1 mg/L.

- Carbon dioxide emissions
  - Nothing is burnt – no emissions

Hydropower Capacity and Expansion

- US installed hydropower capacity is 100,000 MW. This is the second after China's 149,000 MW according to an EIA report in 2010.
  - 6.5% of domestic energy generation in US. 16.9% in China. 58.7% in Canada. 98.5% in Norway.
- FERC estimates an additional 73,200 MW capacity by taking only engineering and financial feasibility into account. That is 73,200 MW is the maximum possible capacity.
- DoE refined FERC's 73,200 MW estimate by also considering environmental and legal constraints to arrive at 30,000 MW.
  - 57% of this capacity increase can be from generating electricity at existing dams that do not currently generate.
  - 14% is by increasing the capacity / efficiency / utilization of the existing hydropower plants.
  - 28% by building new dams.
- Why extra capacity not brought into line immediately?
  - Licensing: see the flowchart on www.ferc.gov/industries/hydropower/gen-info/licensing/ilp/flowchart.pdf
    - » National Environmental Policy Act (NEPA) of 1969 and others: Clean Water (CWA), 1977. Fish and Wildlife Coordination (FWCA), 1934. National Historic Preservation (NHPA), 1966. Wild and Scenic Rivers (WSRA), 1968. Endangered Species (ESA), 1973. Coastal Zone Management (CZMA), 1972. Americans with Disabilities (ADA), 1990.
  - Pre-application activity should start 5 years before the expected date of license issuance.
    - 2007-2012 only Texas license: Lake Livingston Hydroelectric Project new license issued to East Texas Electric Cooperative on Aug 26, 2011.
  - Original licenses are issued for 50 years; Re-licences are for 30-40 years. Periods are long enough for the owner to recover financial investment.
  - Owners of capacity in MW: 50% Federal institutions; 24% Private utility; 22% Non-federal public (e.g., municipalities).
  - Owners of dams in numbers: 31% Private utility; 27% Private non-utility (e.g., Hawaiian Commercial and Sugar Company); 24% Non-federal public; 9% Industrial; 7% Federal institutions.
    - » Source: A Study of United States Hydroelectric Plant Ownership. 2006. D.G. Hall and K.S. Reeves.

Hydropower Past & Future: US

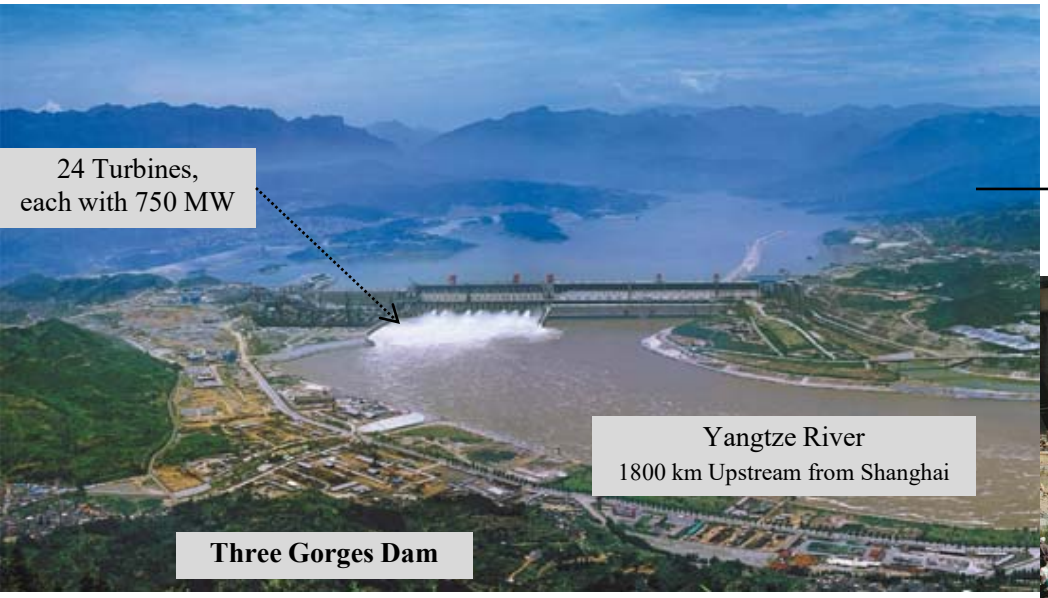


Redridge dam opened in 1901 is on Salmon Trout River, Michigan
The dam was made from steel as opposed to concrete.

- Hydroelectric plants in US,
  - Licensing for smaller plants (<5 MW) is simpler and exemptions are possible.
  - Turbines using naturally dropping water are easier to license.
  - Smart and extensive electricity grids can make small projects viable.
  - A greenhouse gas reduction policy can encourage hydropower plants.
  - Fish-friendly turbines can ease environmental objections.
  - Greater efficiency from advanced turbines.
  - Increased appreciation of stability of hydroelectric power (as opposed to solar /wind power) helps hydro projects.

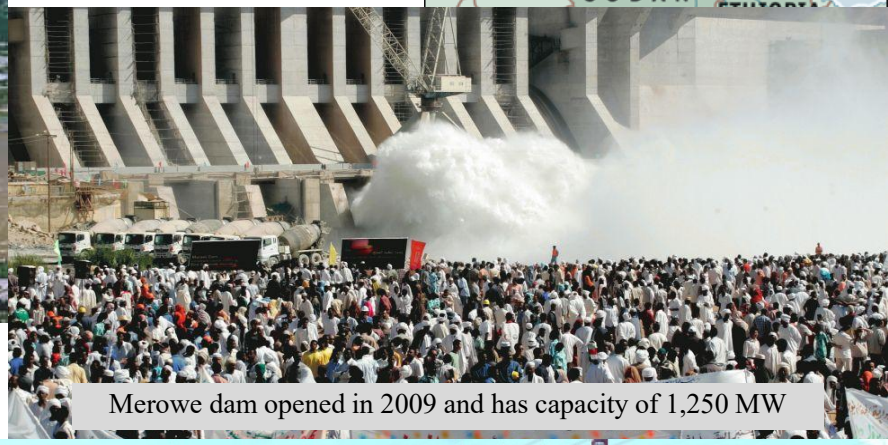
Hydropower Future: International

- Canada, Brazil, China have high hydroelectric power capacity and potential (mountains with rivers).
- China has acquired/developed technology through Three Gorges Dam
  - 22,500 MW capacity with Francis turbines
  - Relocation of towns, Ground slides, Fault line can be triggered by altering water levels in the reservoir.
    Source: China's Three Gorges Dam: An Environmental Catastrophe? M. Hvistendahl, Scientific American, March 25, 2008.



Source: Tap that Water. Economist. May 6, 2010.

Technology Transfer



Merowe dam opened in 2009 and has capacity of 1,250 MW

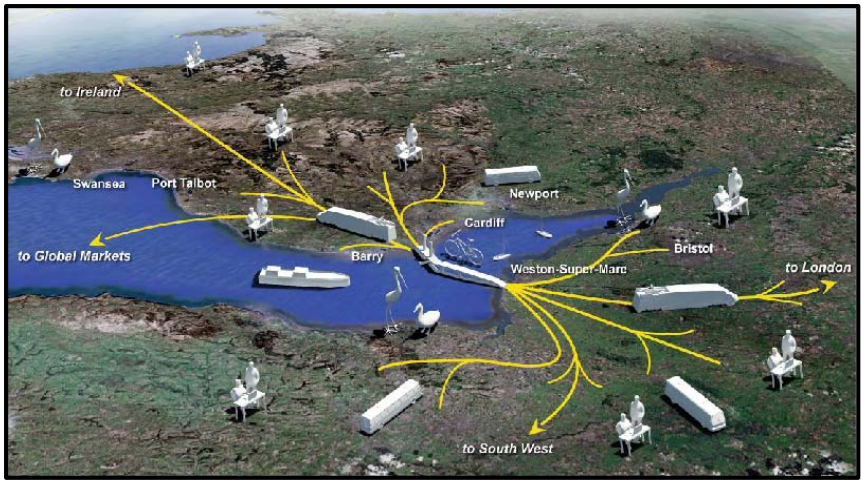
3 significant dams from 3 continents: Asia, Africa, America, clockwise.

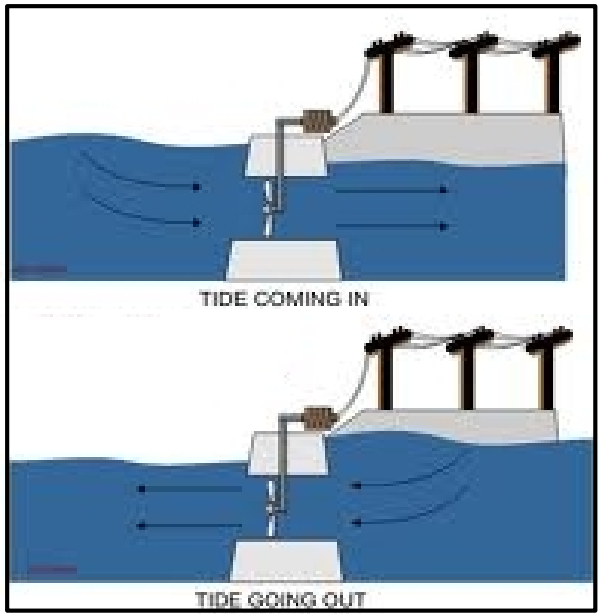
Itaipu dam opened in 1984 and has capacity of 14,000 MW: 20 turbines (visible in the picture) each with 700 MW. On river Parana operated jointly by Brazil and Paraguay.

Hydropower Future: Tidal and Wave Power

Tidal power

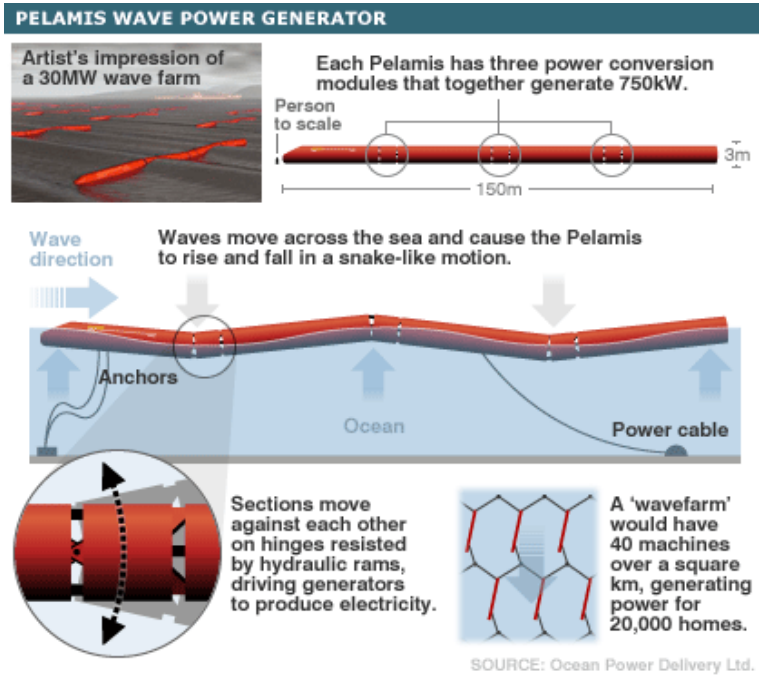
- Tides are created mostly by moon's gravity, and somewhat by rotation of earth and sun's gravity.
- Tides are predictable at each location but differ across locations.
- A tidal dam is efficient ⇐ (high tied−low tide) substantial.
  1) Bay of Fundy, Eastern Canada – Northern Maine, difference > 40 feet.
  2) Cook Inlet in Alaska; 3) Sea of Okhotsk on Eastern Russian Seaboard.
- Examples:
  - Built in 1960, La Rance tidal dam in Northwest France can produce 240 MW with 24 turbines.
  - Roosevelt Island Tidal Energy (RITE) Project license issued on Jan 23, 2012.
  - Severn Estuary Dam between England & Wales; Considered by British government, see www.corlanhafren.co.uk .





Wave Power

- Waves are created by winds, a turbine will not work.
- Instead lay a snake like tube made up of about 5 segments.
- Segments are allowed to rotate with respect to each other at the hinges.
- Rotational energy at hinges captured with pistons.
  - A snake is laid down, west coast of Orkney Island, Scotland in Oct 2010. This is a test by the European Marine Energy Center.



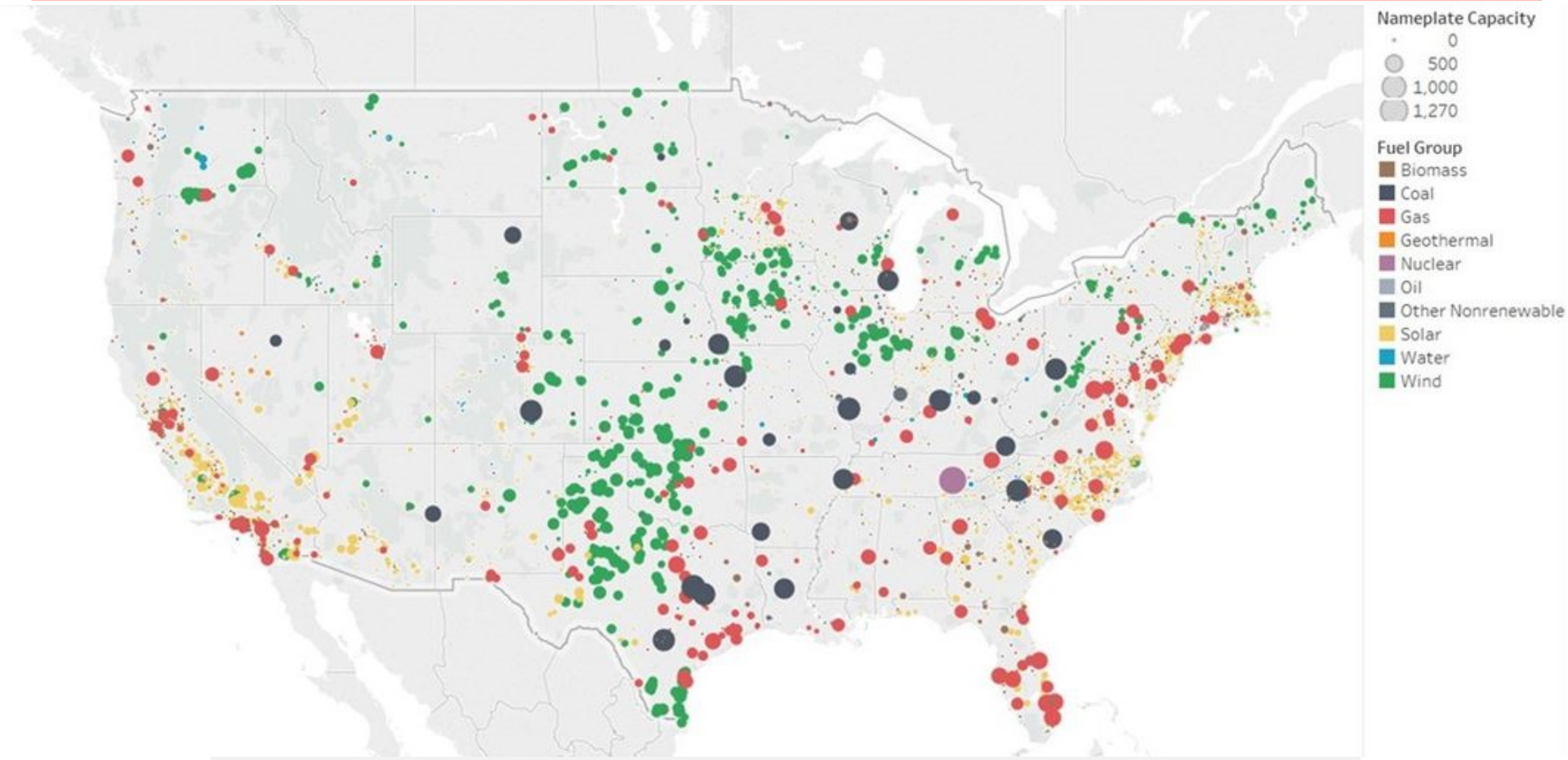
Summary – Renewable - Hydro

- **Hydro**

Based on

- A. Chambers. 2004. **Hydroelectric** Chapter 6 of Renewable Energy in Nontechnical Language.
- R.L. Nersesian. 2007. **Sustainable Energy** Chapter 9 of Energy for the 21st Centrury: A Comprehensive Guide to Conventional and Alternative Resources.

Energy Investments in 2008-2018



- Quite a few mid-size wind farm investments in the middle
- A lot of small-size solar farm investments on the coats
- Several water dams of small-size in the sate of Washington
- More than 10 large-size coal-powered generator investments
- 1 nuclear power plant investment

Source: *How To Build a Better Business Case for Utility Asset Investment Planning*, Zpryme webinar, April 5, 2018.

Some other uses of dams

- Luzzone Dam with reservoir named Lago di Luzzone, Switzerland.
- About 165 metres high dam opened in 1963.
- With its 650 climbing holds, it is used as a climbing wall https://www.youtube.com/watch?v=lARdpsbz8ZQ