Solar Energy IV

Hydroelectricity

and

OTEC

Original slides provided by Dr. Daniel Holland

- Hydro power has a very long history with watermills appearing as early as 100 BC.
- By 1200 it was used to operate hammers in ironworks

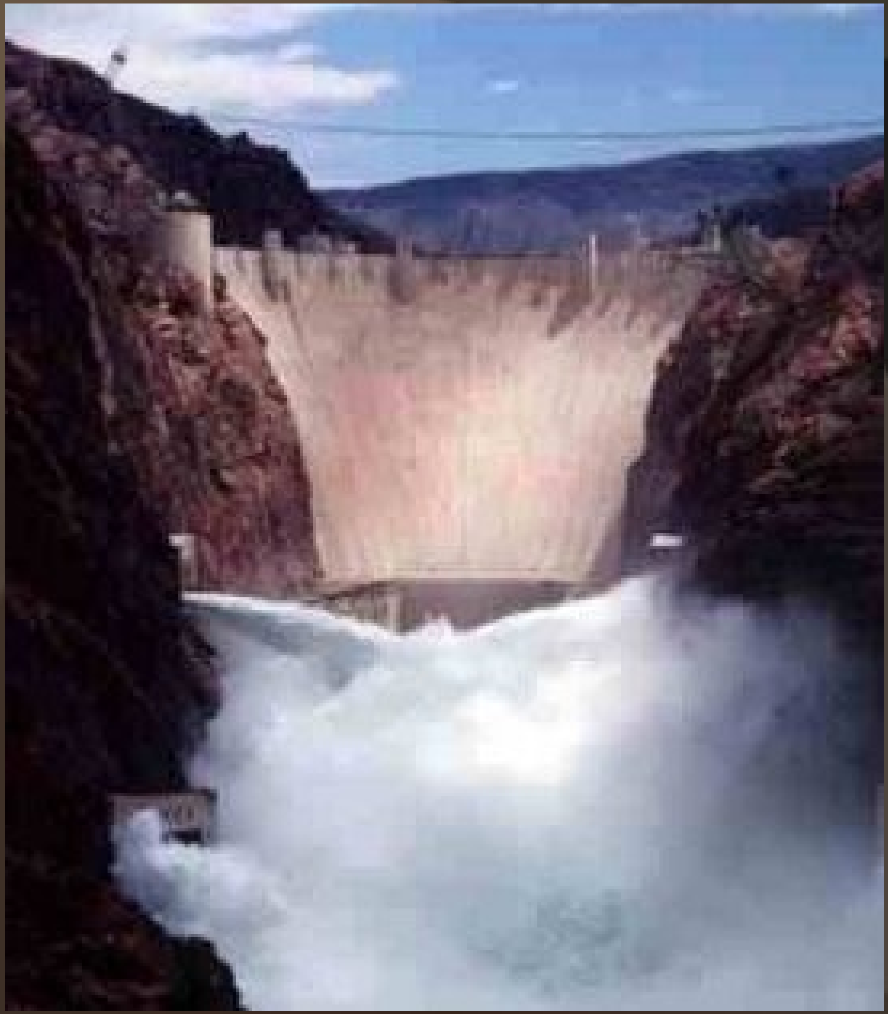
Audio Link

- By 1500 it was the primary source of industrial power.
- Rivers and streams were a critical source of power and transportation in the settling of America.

First Hydroelectric Generator

- Located at Cragside, a country house in Northumberland, England.
- In 1870, water from one of the estate's lakes was used to drive a Siemens dynamo in what was probably the world's first hydroelectric power station.

Today Hydropower is used mainly for generating electricity



Water cycle as a great big heat engine

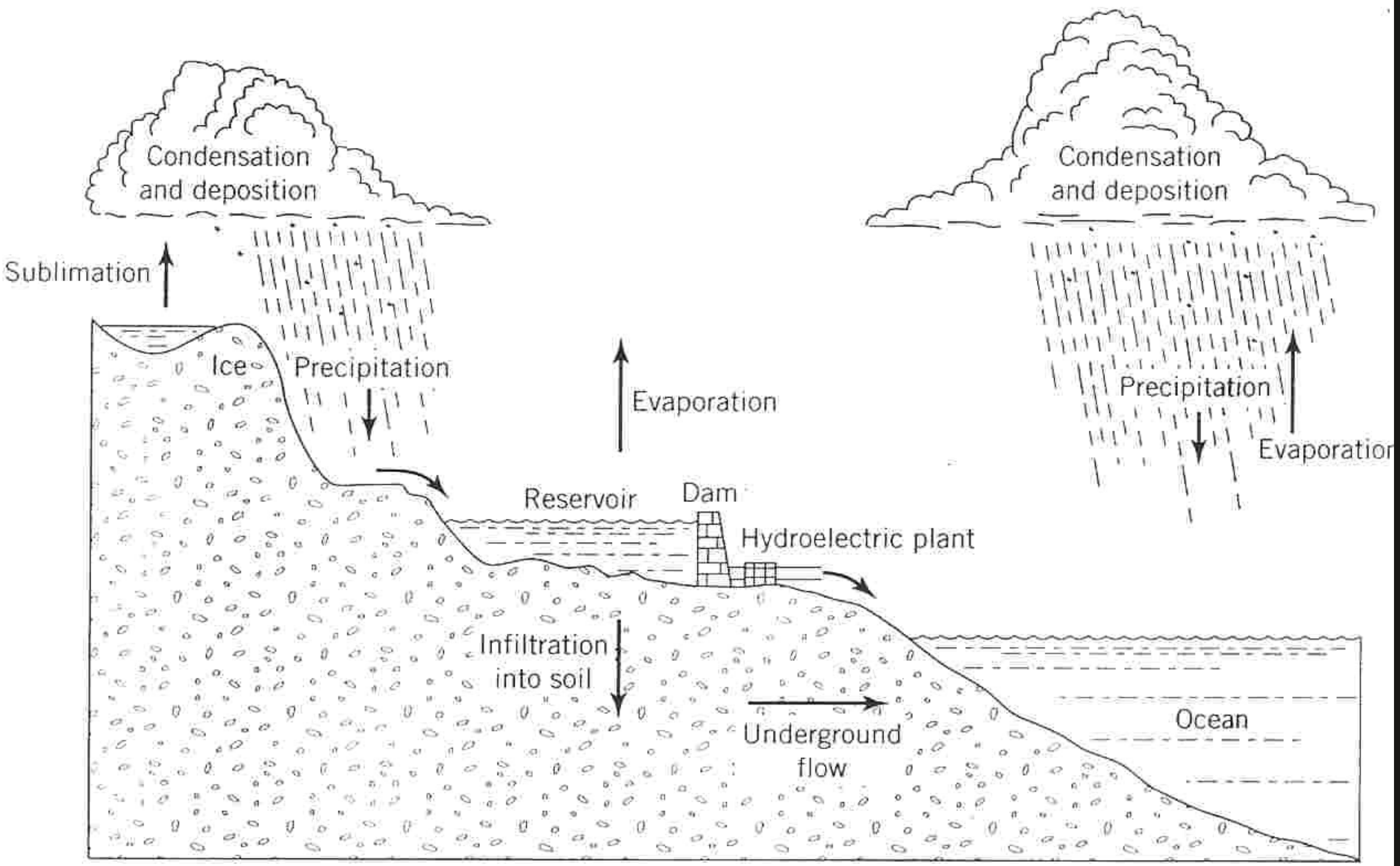
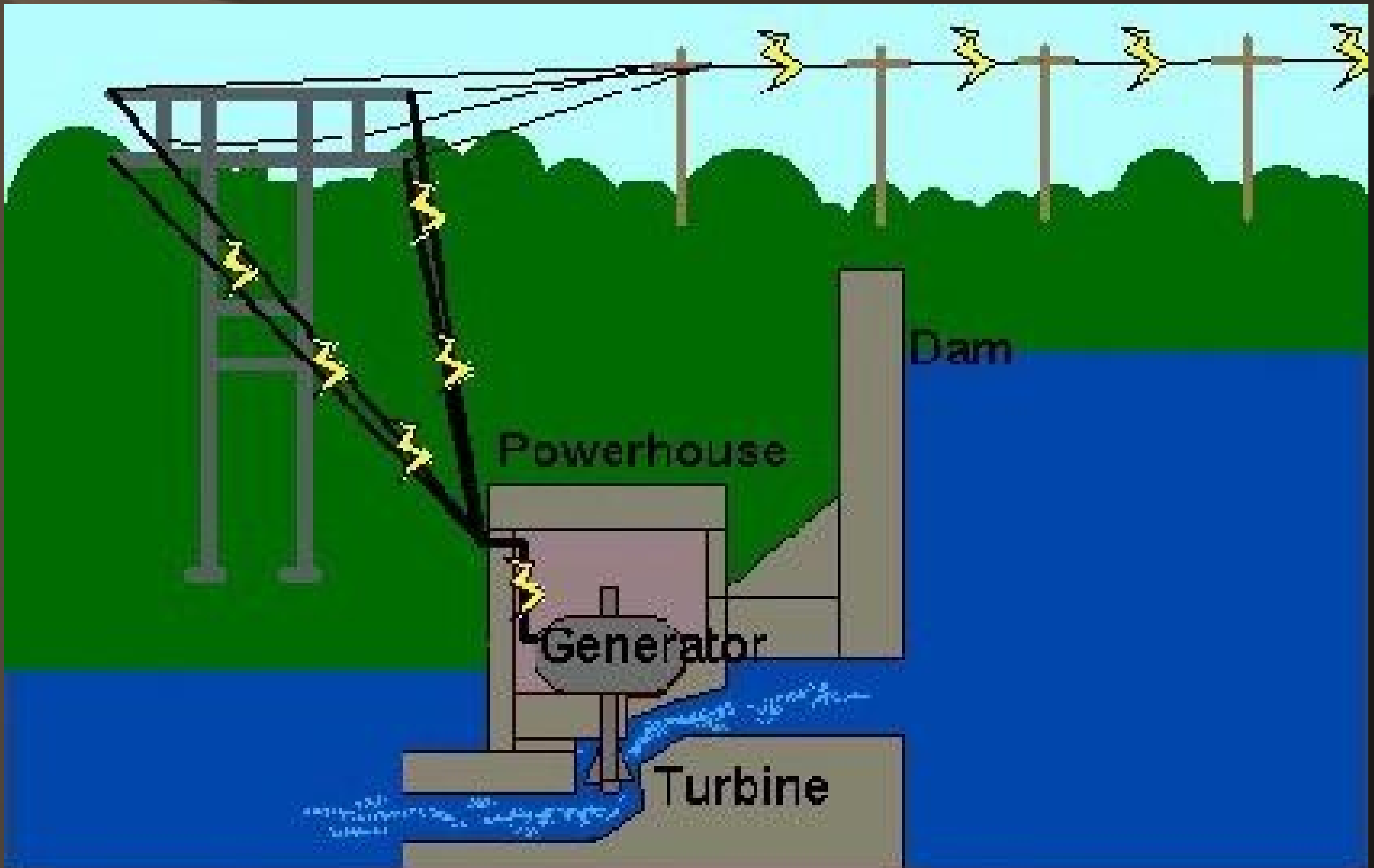


Figure 5.2 The hydrologic cycle. Electricity is produced in the hydroelectric plant by the action of water against a turbine connected to a generator. In this way the stored potential energy of the water in the reservoir becomes electrical energy.



How Dams Produce Electricity

Generators inside Hoover Dam

Convert Potential Energy of Water Into Kinetic Energy to Run a Generator

- $mgh = mv^2/2$
- h is called the "head" of the dam
- Modern hydroelectric plants convert ~90% of PE into electricity

High Head Dams

- h is up to 1000ft.
- A lot of energy per liter of water that flows through.
- Can get by with smaller flows.

Low Head Dams

- As low as 10 ft.
- Not much energy per liter of water.
- Need a higher flow rate to get as much electricity

Sample Calculation

- Useful information: 1 liter of H_2O has a mass of 1kg.
- Height of Hoover Dam = 221 m
- Power rating of Hoover Dam is 2,451 MW.
- Find the amount of water that flows through the dam per second if it is 90% efficient.

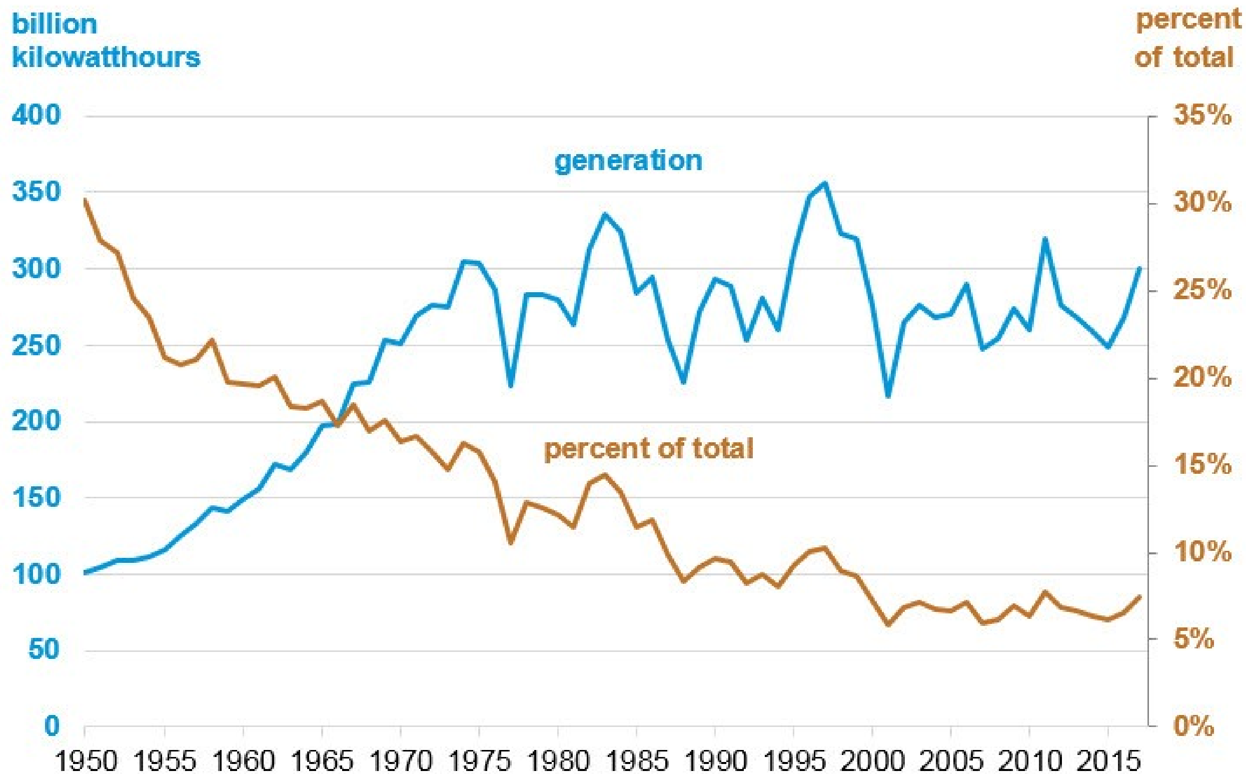
- Electrical power form 1 liter of water per second.
- P=(0.9)(1kg/s)(9.8 m/s^2)(221m)

  =1.949kW

$$\frac{x\,kg/s}{1\,kg/s} = \frac{2451000\,kW}{1.949\,kW}$$

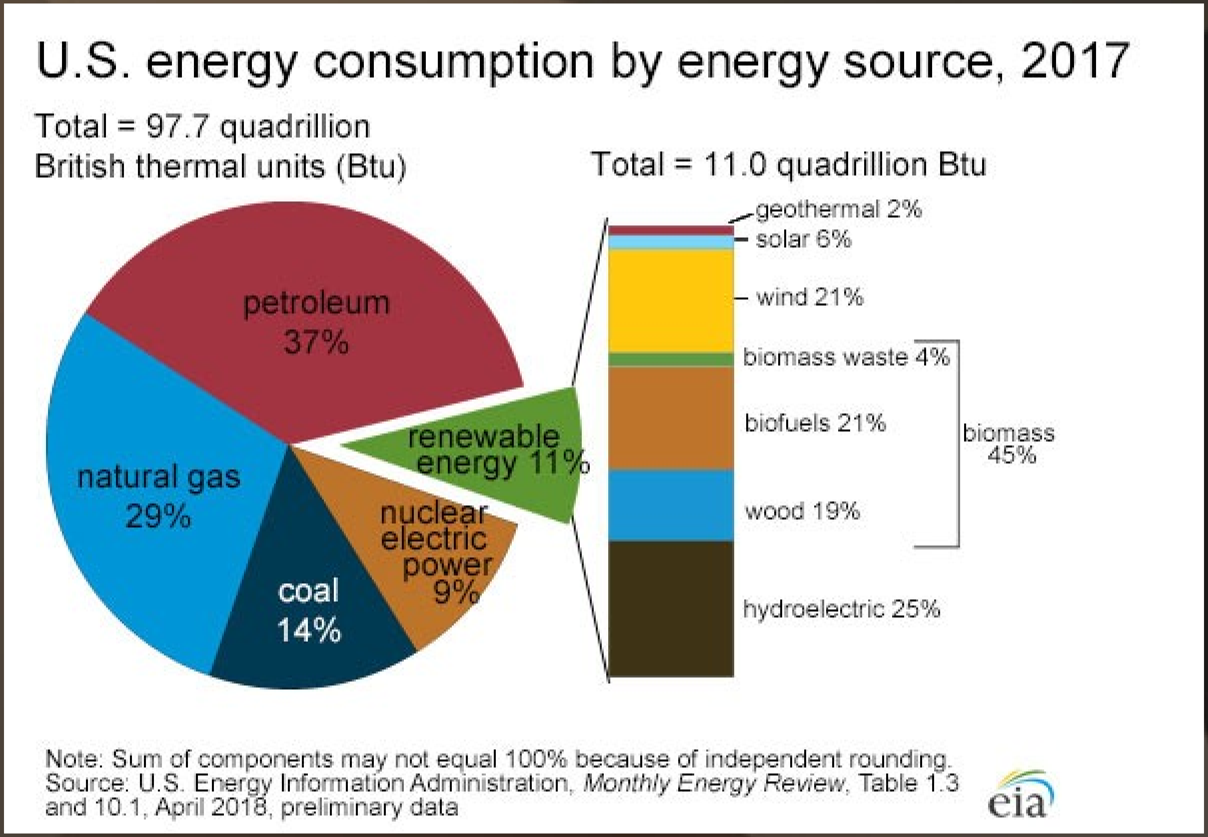
$$x = 1,257,426\,kg/s$$

Hydroelectricity generation and percent share of total U.S. electricity generation, 1950–2017



Note: Utility-scale conventional hydroelectricity.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 7.2.a, March 2018

Just to keep things in perspective...



Principal Dams in the US

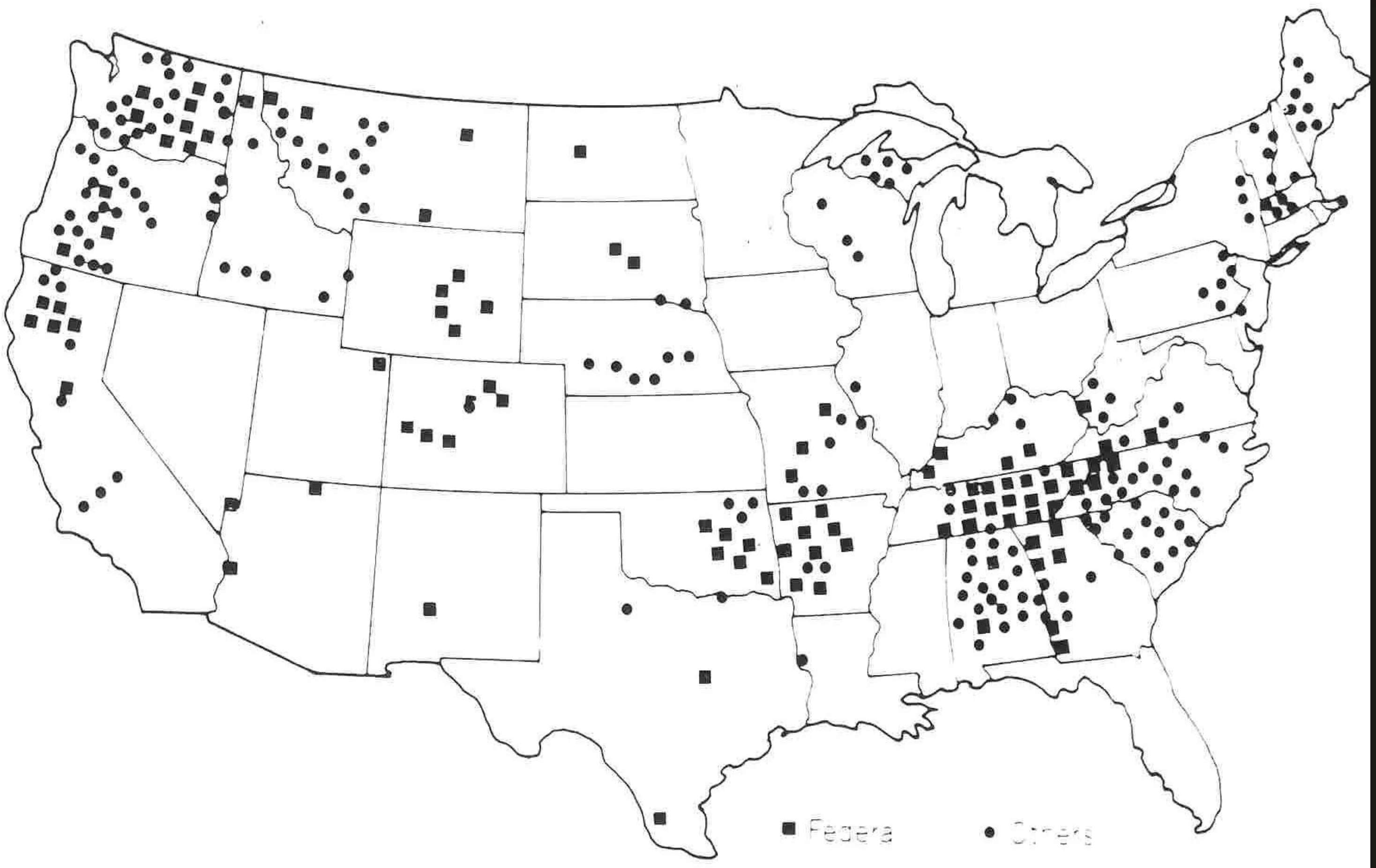
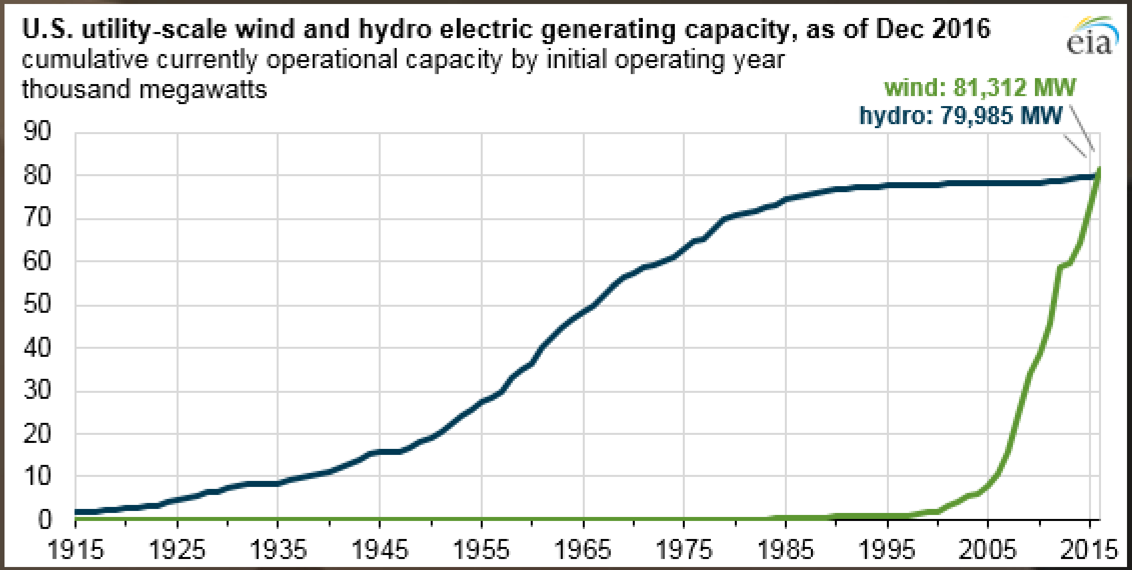


Figure 7–3.
Principal hydroelectric plant locations in the United States. (Adapted from *River* Environmental Report 1970, U.S. Department of the Interior.)

Table 3.2 Hydroelectric Potential in the United States, GW

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

Source: Statistical Abstracts of the United States, 1995.



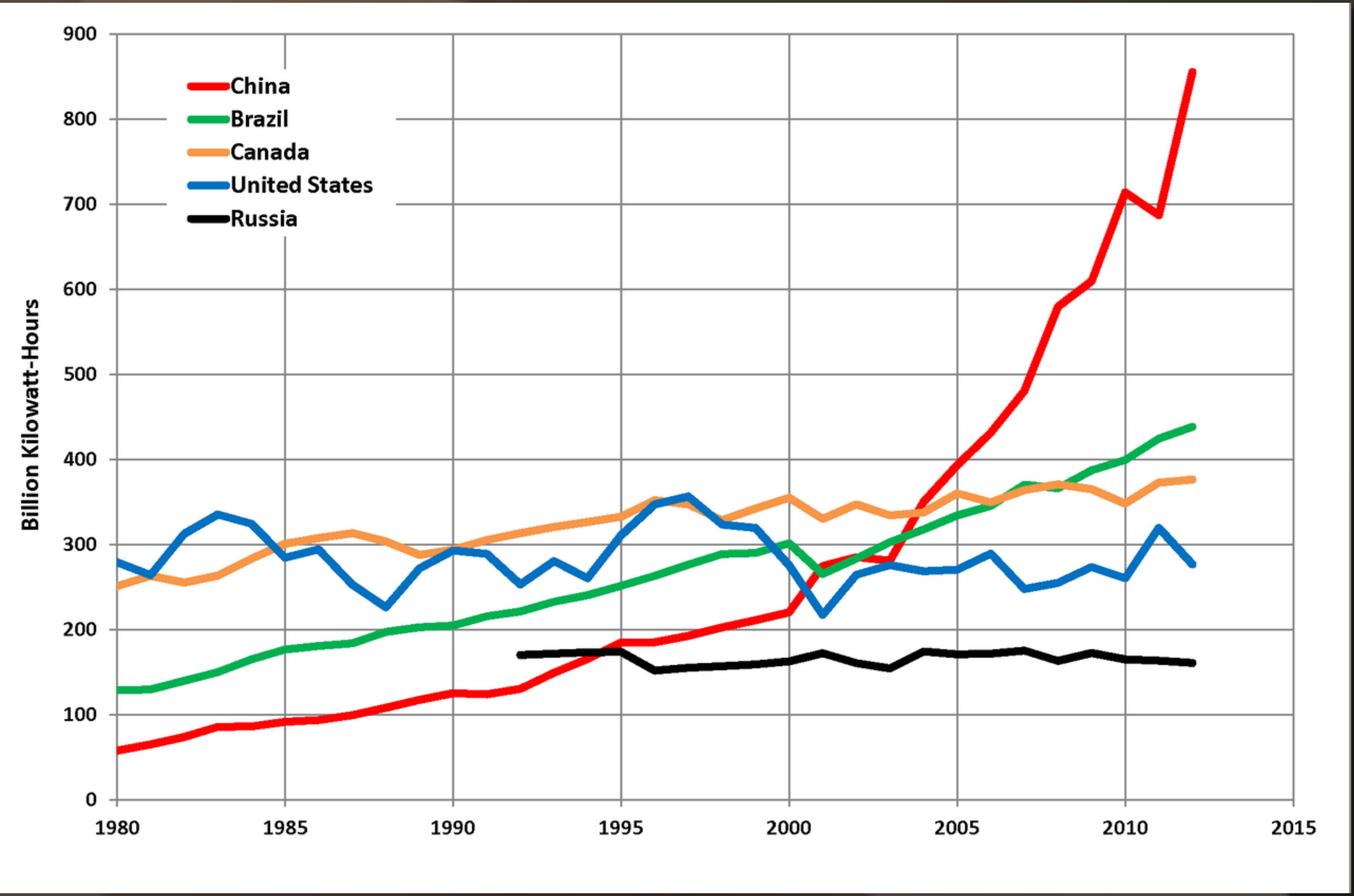
Note that the units here are in Mwatts, not Mwatt-hours. Why is this important? Compare this figure with the slide on hydroelectricity generation and percent share of total U.S. electricity generation, 1950-2017.

https://arstechnica.com/science/2017/03/us-wind-capacity-surpasses-hydro-overall-generation-to-follow/

Countries with the largest hydroelectric potential

Canada	341,312 GWh	(66,954 MW installed)
USA	319,484 GWh	(79,511 MW installed)
Brazil	285,603 GWh	(57,517 MW installed)
China	204,300 GWh	(65,000 MW installed)
Russia	173,500 GWh	(44,700 MW installed)
Norway	121,824 GWh	(27,528 MW installed)
Japan	84,500 GWh	(27,229 MW installed)
India	82,237 GWh	(22,083 MW installed)
France	77,500 GWh	(25,335 MW installed)

Hydroelectric energy produced for various nations.



https://en.wikipedia.org/wiki/Hydroelectricity#/media/File:Top_5_Hydropower-Producing_Countries.png

Ten of the largest hydroelectric producers as at 2014.[50][52][53]

Country	Annual hydroelectric production (TWh)	Installed capacity (GW)	Capacity factor	% of total production
China	1064	311	0.37	18.7%
Canada	383	76	0.59	58.3%
Brazil	373	89	0.56	63.2%
United States	282	102	0.42	6.5%
Russia	177	51	0.42	16.7%
India	132	40	0.43	10.2%
Norway	129	31	0.49	96.0%
Japan	87	50	0.37	8.4%
Venezuela	87	15	0.67	68.3%
France	69	25	0.46	12.2%

https://en.wikipedia.org/wiki/Hydroelectricity

Hydroelectric plants can rarely operate at their maximum capacity. They depend on water levels. Additionally, there are only so many places where dams can be built. We are about half way there in the U.S. This resource has limited growth potential, but is still an important energy source.

Large Hydroelectric Dams

Three Gorges	China	2009	18,200MW
Itaipu	Brazil/Paraguay	1984/91	12,666 MW
Guri	Venezuala	1986	10,200 M
Grand Coulee	United States	1942,80	6,809MW
Sanyno Shushenskaya	Russia	1983	6,400 MW
Robert-Bourassa	Canada	1981	5,616 MW
Churchill Falls	Canada	1971	5,429 MW
Iron Gates	Romania/Serbia	1970	2,280 MW

Advantages

- NO FUEL COSTS.
- Longer lives than fuel-fired plants. (Some plants now in service are 50 to 100 years old.)
- Highly automated so labor cost are low.
- Low maintenance.

- Reservoirs can be used for other purposes such as irrigation, recreation, flood control

Disadvantages

- Lifetime of 50 to 200 years because of silting.
- Large environmental changes downstream.
- Loss of free flowing water.
- Loss of land flooded by reservoir.
- Often upstream from large population centers (Huge catastrophe if dam fails.)

Dam Failures

- From 1918-58 there were 33 dam failures in the US resulting in 1680 deaths.
- Between 1959 and 65 there were 9 large failures worldwide.
- It is unusual, but a significant hazard.
- Terrorists?

Water pouring out of the reservoir of the Teton Dam in Idaho following its catastrophic failure on June 5, 1976.

Ocean Thermo Electric Conversion

- Use temperature difference between the surface and deep water to drive a heat engine.
- Typically very low efficiency, but no cost for fuel.
- Typically $\Delta T \cong 20K$ and $T_h \cong 300K$, thus

$$e_c = \Delta T / T_h \cong 20/300 = 6.7\%$$

Real efficiency more like 2-3%

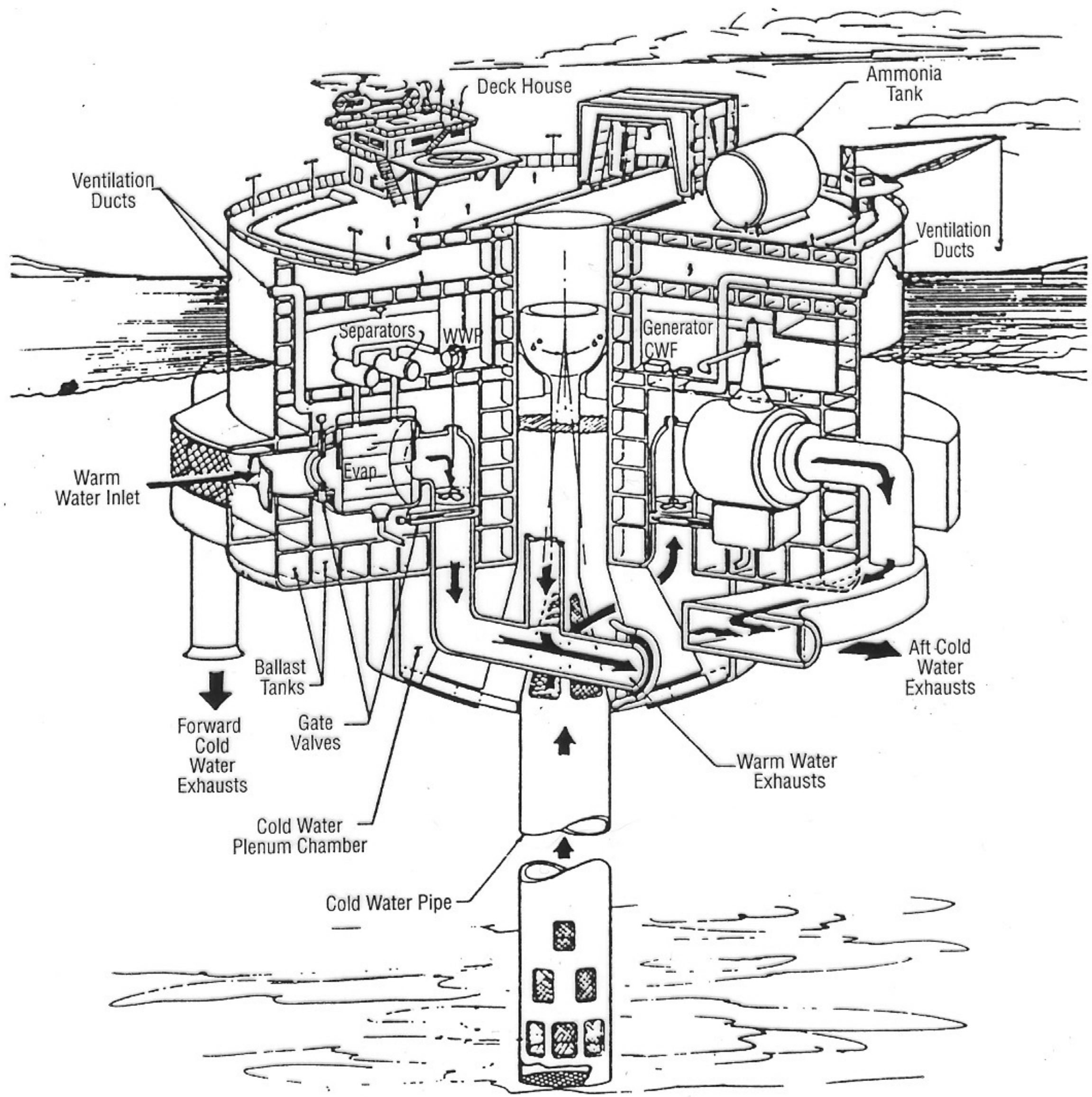
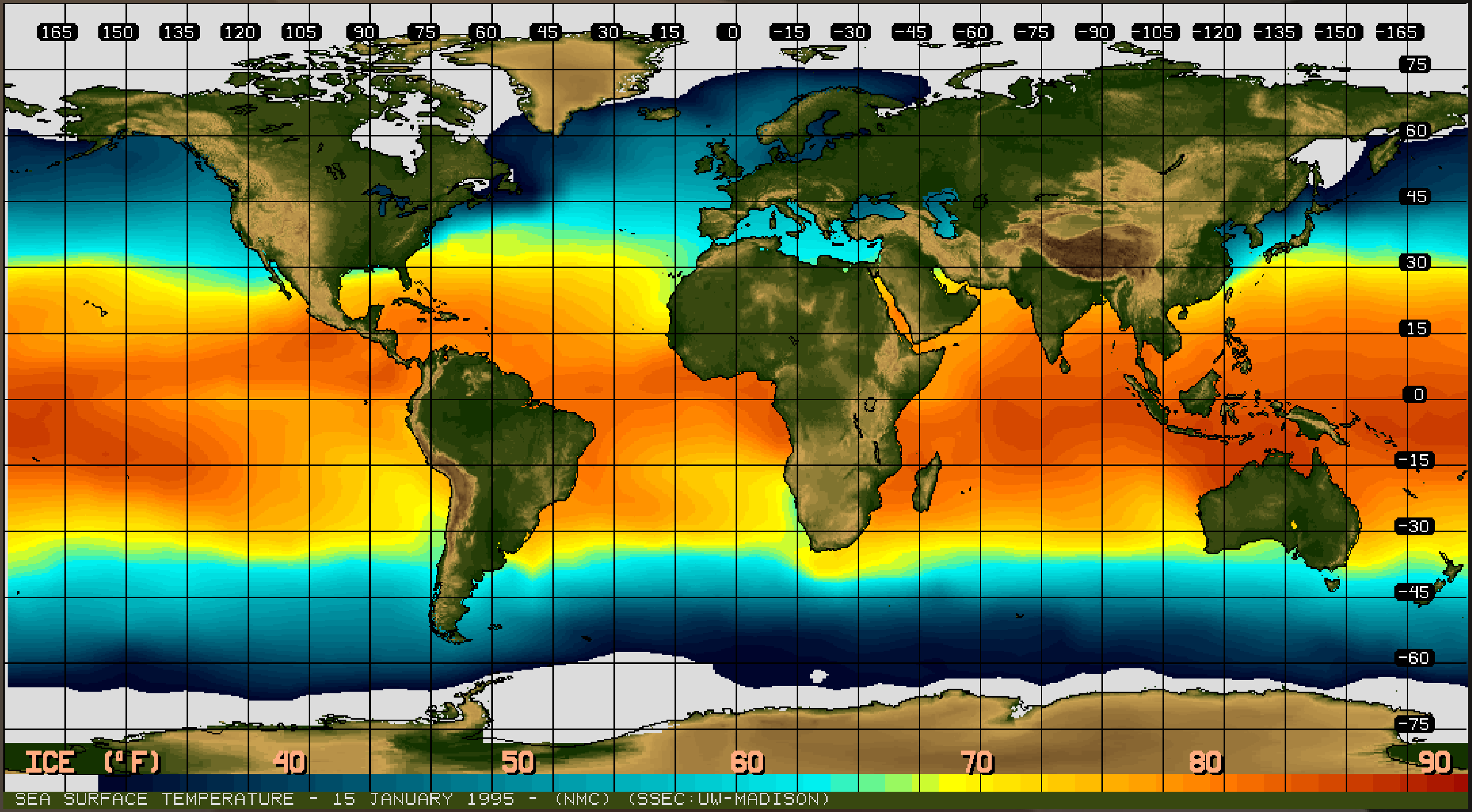


Figure 5.9 A design concept for a 100 MW_e OTEC power plant. One of the 25 MW_e power modules is shown in the cutaway portion. The platform has a diameter of 100 meters. Design by TRW Systems Group, Inc.

- Requires a huge flow of water.
- A 100 MW plant would require approximately 25,000,000 liters per second of both warm and cold water.

- Use in locations with warm surface waters. $\Delta T > 17°C$
- Predictable power output since ΔT is very stable over the course of a day.


165 150 135 120 105 90 75 60 45 30 15 0 -15 -30 -45 -60 -75 -90 -105 -120 -135 -150 -165
75 60 45 30 15 0 -15 -30 -45 -60 -75
ICE (°F) 40 50 60 70 80 90
SEA SURFACE TEMPERATURE - 15 JANUARY 1995 - (NMC) (SSEC:UW-MADISON)

- Not a whole lot currently being developed.
- 1930’s : concept plant built near Cuba generated 22kW of power, but used more than it generated.
- 1970’s : small test plant built in Hawaii.
- No government support since the 1980’s.

Other Ideas

- Large underwater turbines anchored to the sea floor.
- Ex: Gulf stream has a steady flow that is 1000 time larger than the Mississippi River with a maximum velocity of 4mph.