Power Plants, Turbines I
GEOS 24705/ ENST 24705

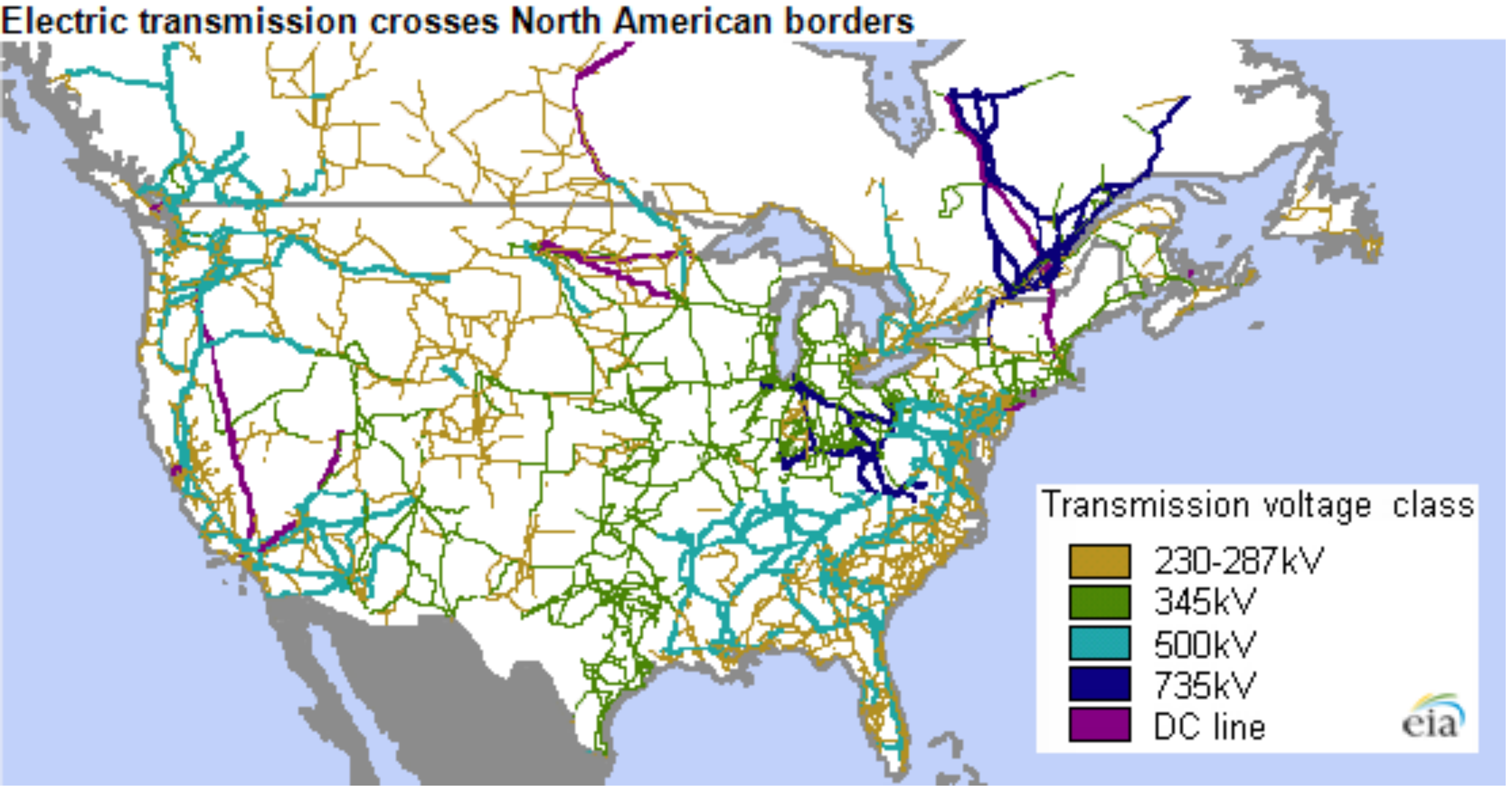
High-voltage DC (HVDC) has lower losses than AC transmission

Transformation from DC → AC is possible but expensive

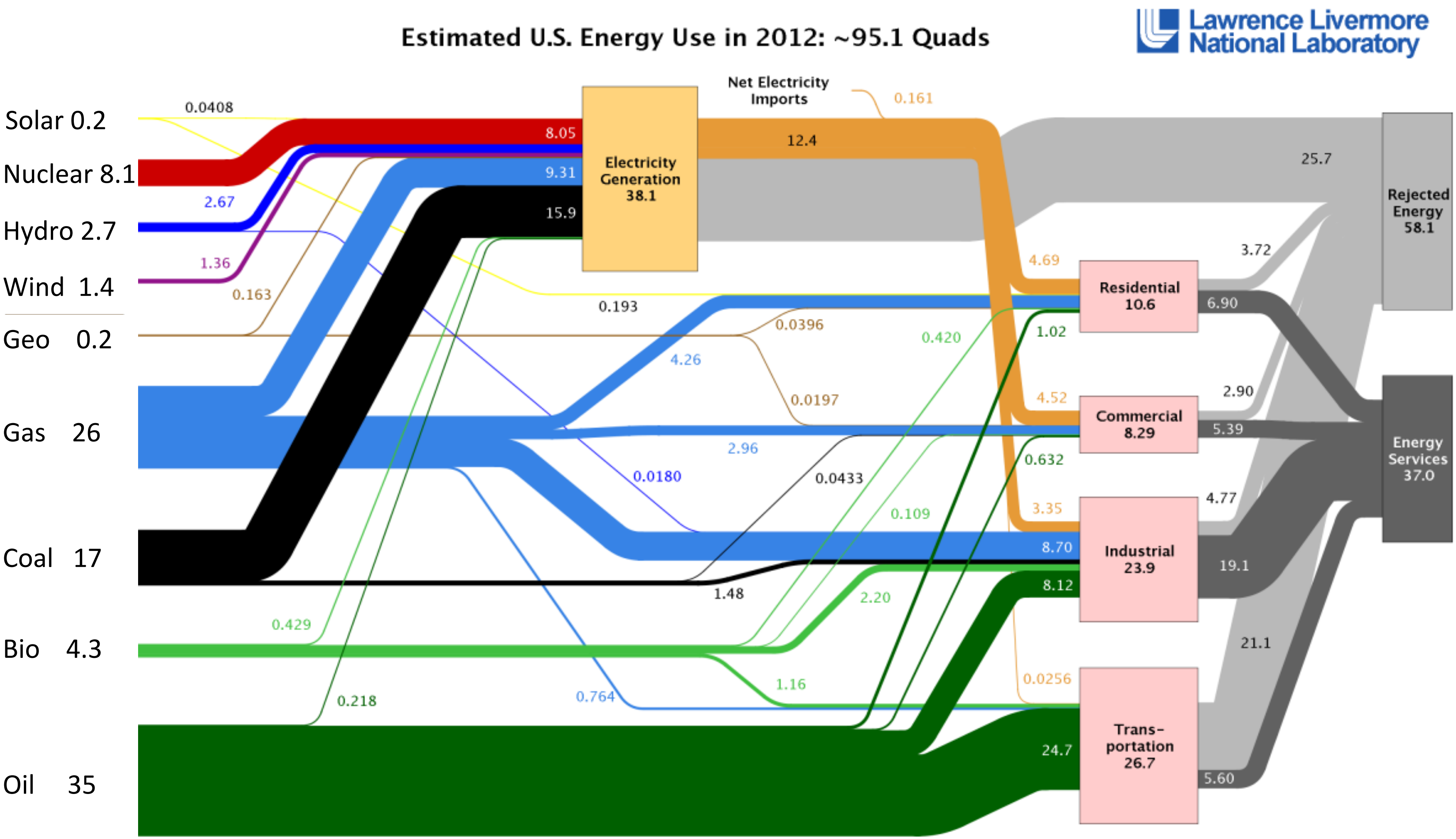
HVDC is worthwhile for long lines from single generator to major source

Pacific DC intertie

DC lines carry 4% of U.S. electricity

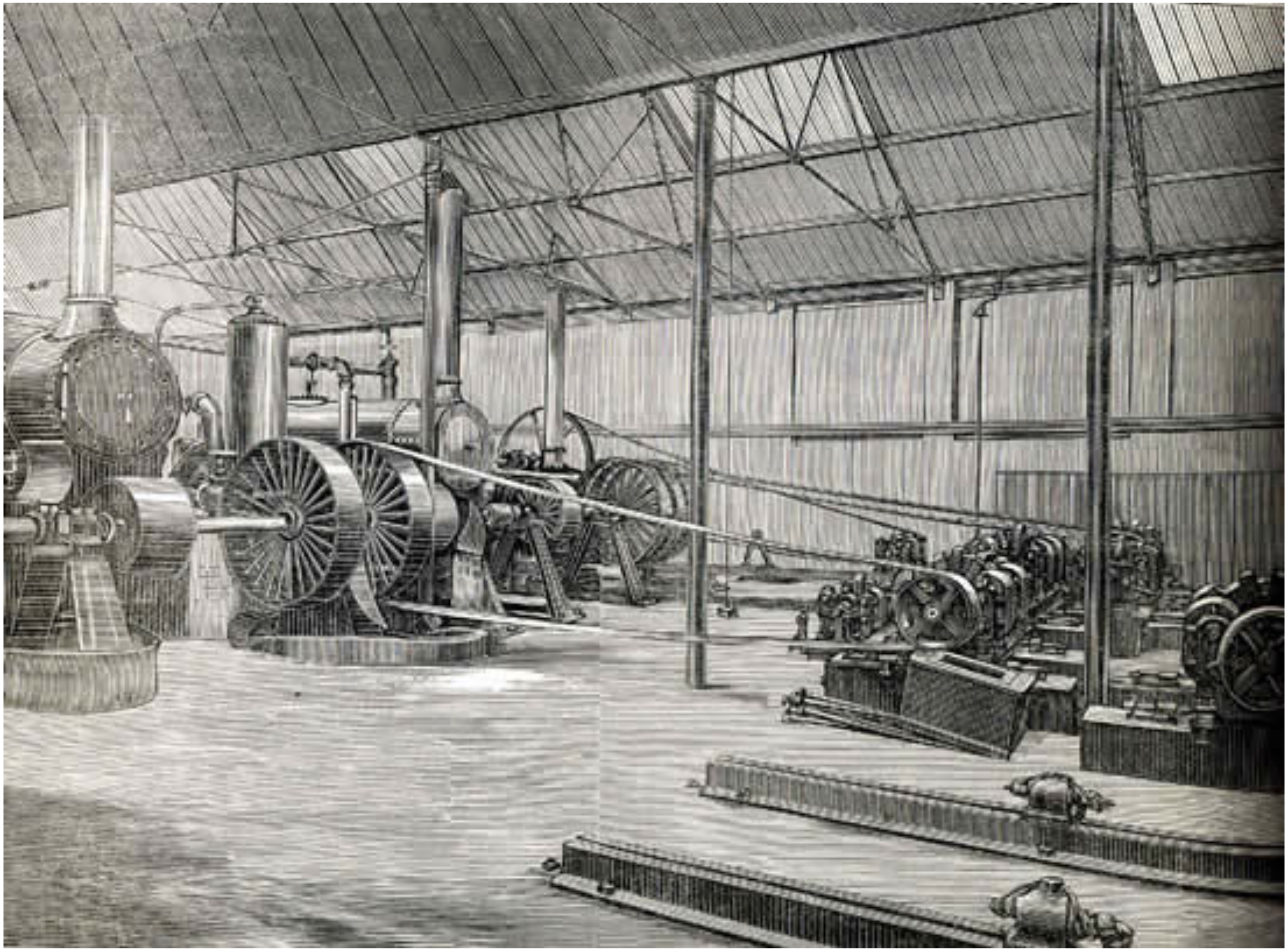


1/3 of U.S. energy use goes through electricity



Source: LLNL 2013. Data is based on DOE/EIA-0035(2013-05), May, 2013. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

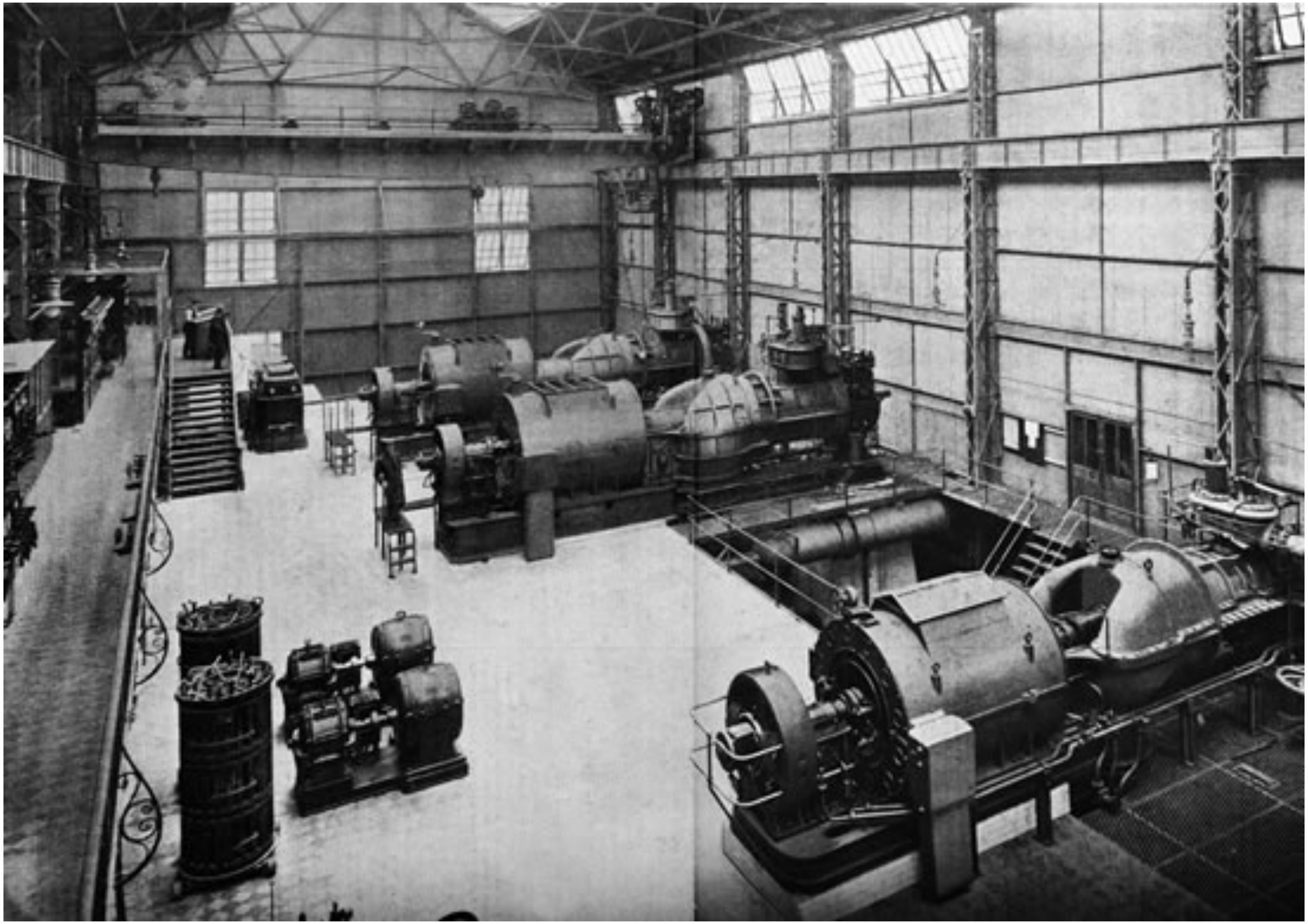
The technology for heat → motion that was described in class is gone



Generating station, with reciprocating engines, DC generators, 1887

Brighton, U.K.

The technology for heat ➔ motion that was described in class is gone



Generating station with steam turbines, AC generation, 1904

Tyneside, U.K.

Turbo-generators are virtually unchanged in 100 yrs

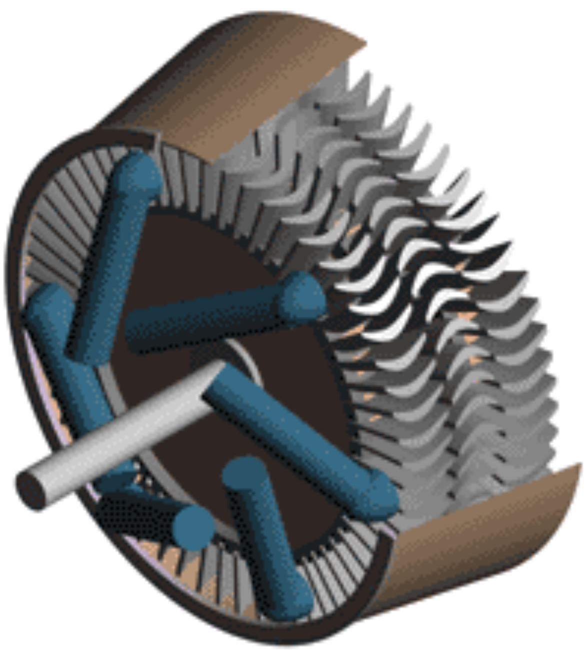
The turbine hall of Bruce Power's Bruce A nuclear power plant in Ontario, Canada.

Photo: Bruce Powell

Turbines: use flowing fluid to rotate something

Can extract energy from fluid in two ways

- Expanding gas and letting it drop in pressure
- Bumping into blades and transferring kinetic energy

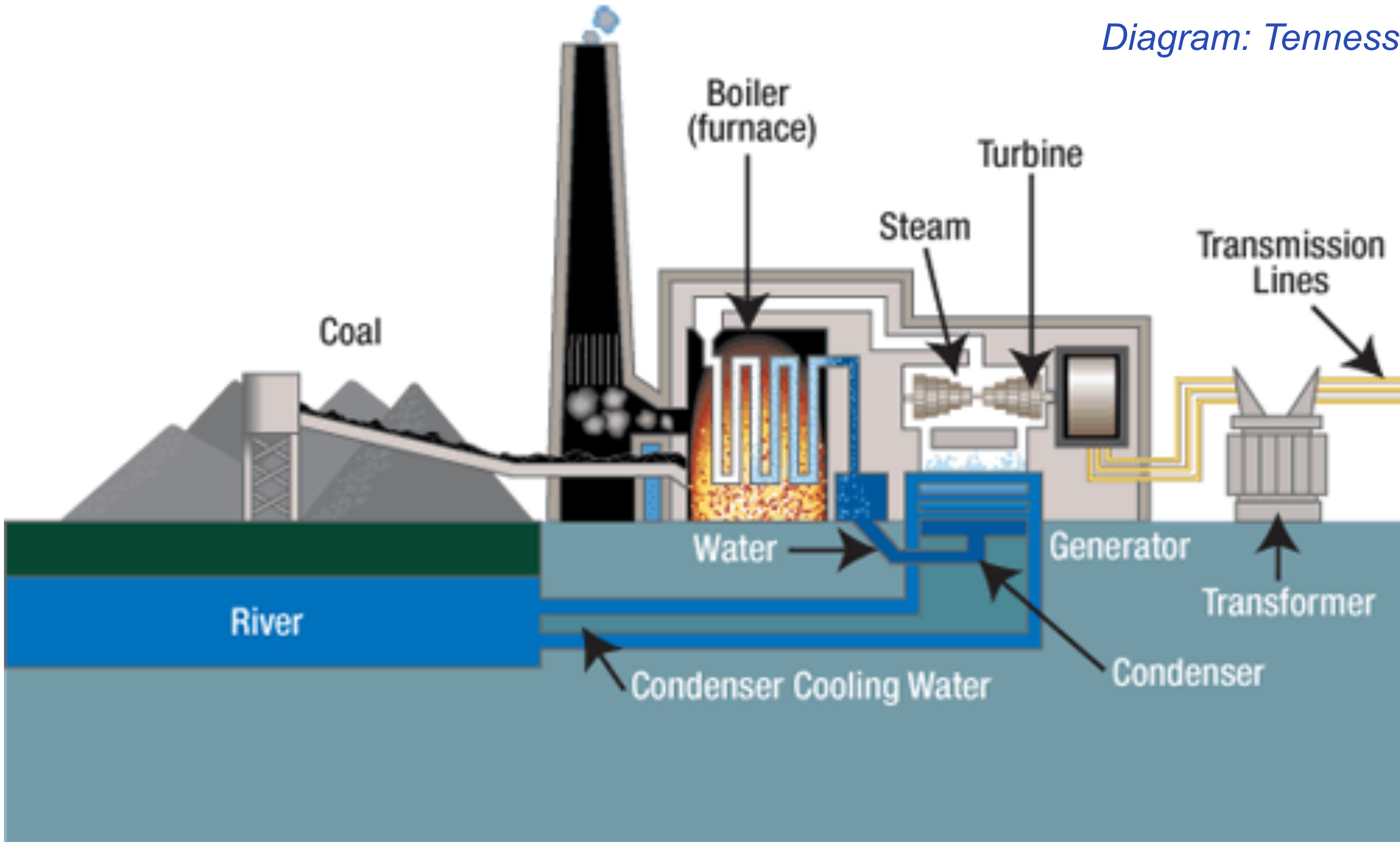


"reaction":
pressure change drives motion

"impulse" :
kinetic energy of gas striking blades

Coal-fired or nuclear power always involve steam

Diagram: Tennessee Valley Authority

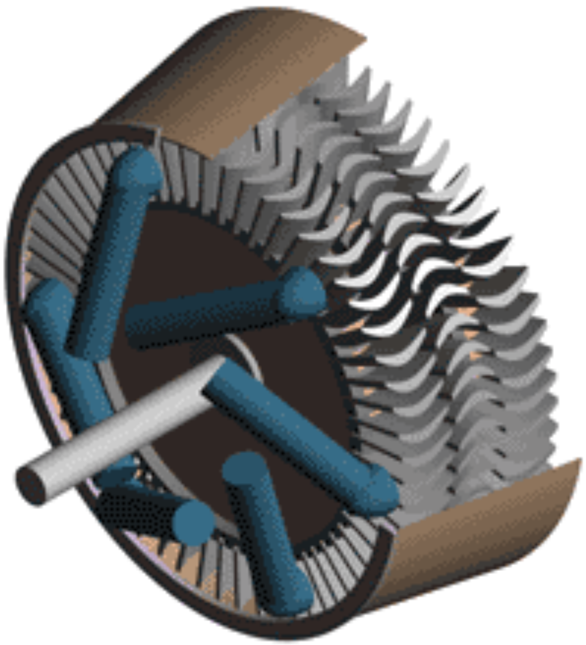


see animation

Items to note: 1) Compressor (not labeled here) compresses liquid water to high pressure. 2) Steam is recirculated, to permit use of purified water and final P drop below atmospheric, as in Newcomen engine.

Steam T ~ 550 C, P up to 200 atmospheres.

1. STEAM TURBINE



Invented in 1884 (Parsons)

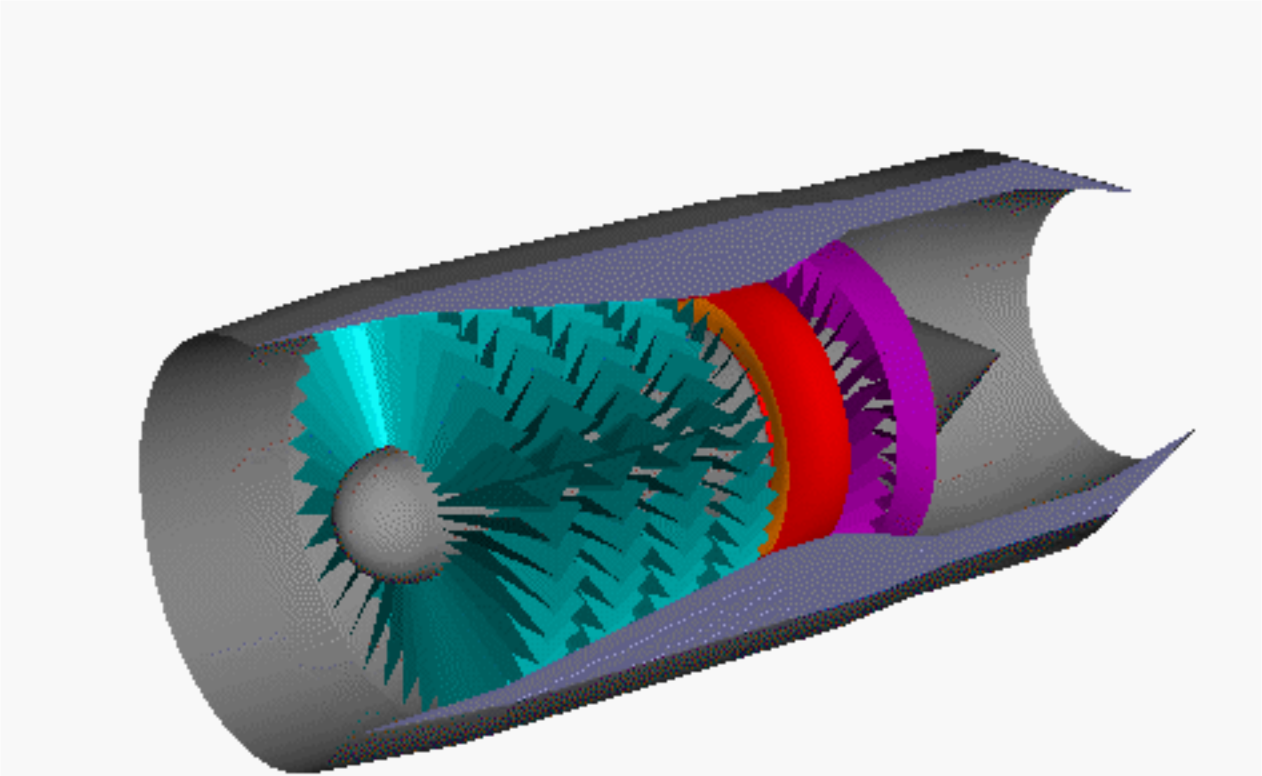
80% of world's electricity today
(all external combustion)

Power growth rapid: first turbine 75 kW (1890), by 1912 Chicago (Fisk!) was 25 MW, > 50 MW in Parson's lifetime, > 1 GW now

2. GAS TURBINE

First built in 1903 (Elling).
(Conceived of in 1791, but was not buildable)

Adoption slow: no commercialization til 1918, no routine use til 1930s.

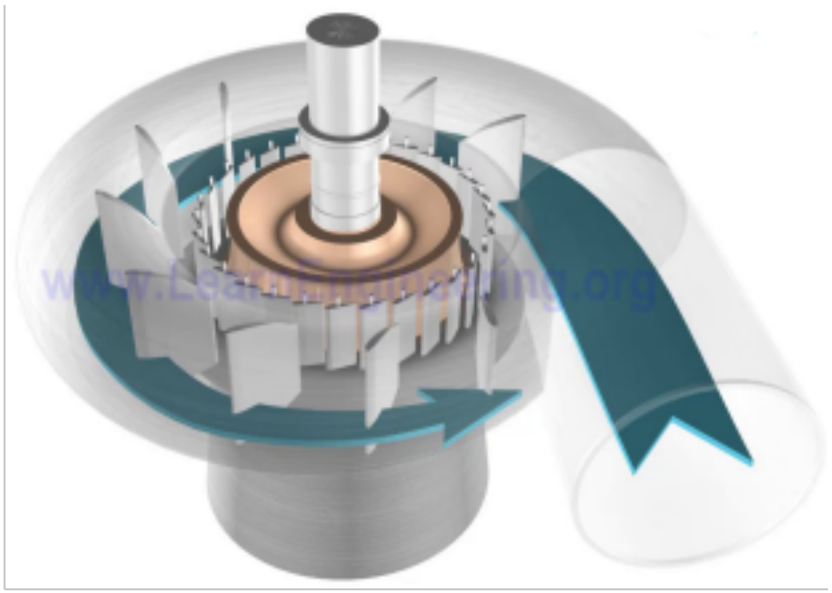


3. HYDRO TURBINE
(Francis)

Invented in 1848 (James Francis).

For the textile mills at Lowell, MA – improved efficiency over traditional water wheel design

Most common hydro turbine in use today

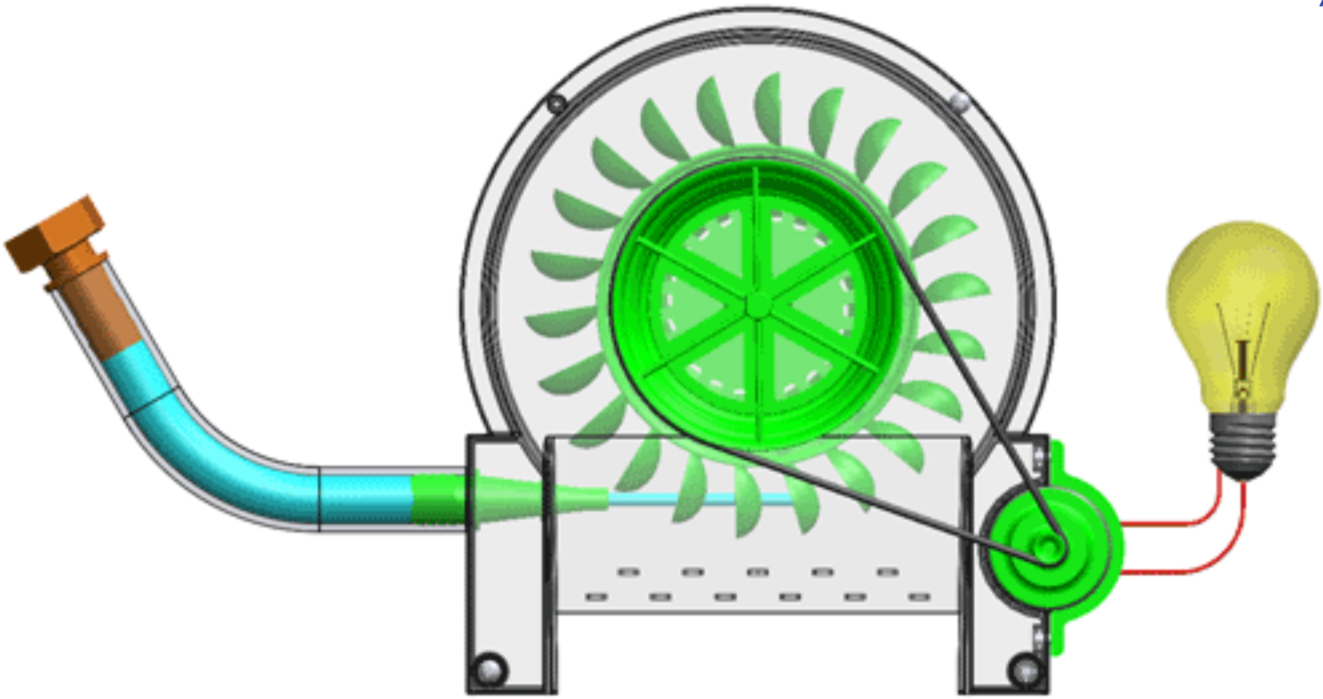


4. HYDRO TURBINE
(Pelton wheel)

Invented in 1870s (Lester Pelton).

Improvement on traditional water wheel used in CA gold mining in small streams

Preferred hydro turbine in certain conditions:
small flow, large drop



Turbines are diverse in design

even though all designed to use flowing fluid to rotate something

Features that may matter to turbine design

- **Fluid velocity**
- **Fluid density**
- **Pressure drops**

  ...whether turbine works by changing fluid pressure ("reaction turbine") or just allowing molecules to push on blades ("impulse turbine"), or something in between ("impulse-reaction")

Features that may matter to turbine design

Wind:

low velocity, low density, no pressure drop

Water wheel or run-of-river hydro:

low velocity, high density, no pressure drop

Dam hydro:

low velocity, high density, large pressure drop

Gas or steam turbine:

high velocity, low density, large pressure drop

Steam and gas turbine similarities

Both

- Are heat engines
- Start with hot, high-pressure gas
- Let that gas expand and cool
- Extract energy partially from pressure change ...
- ... and also turn turbine by the “wind” of expanding gas

→ *Combination impulse-reaction turbines*

Steam turbine – external combustion

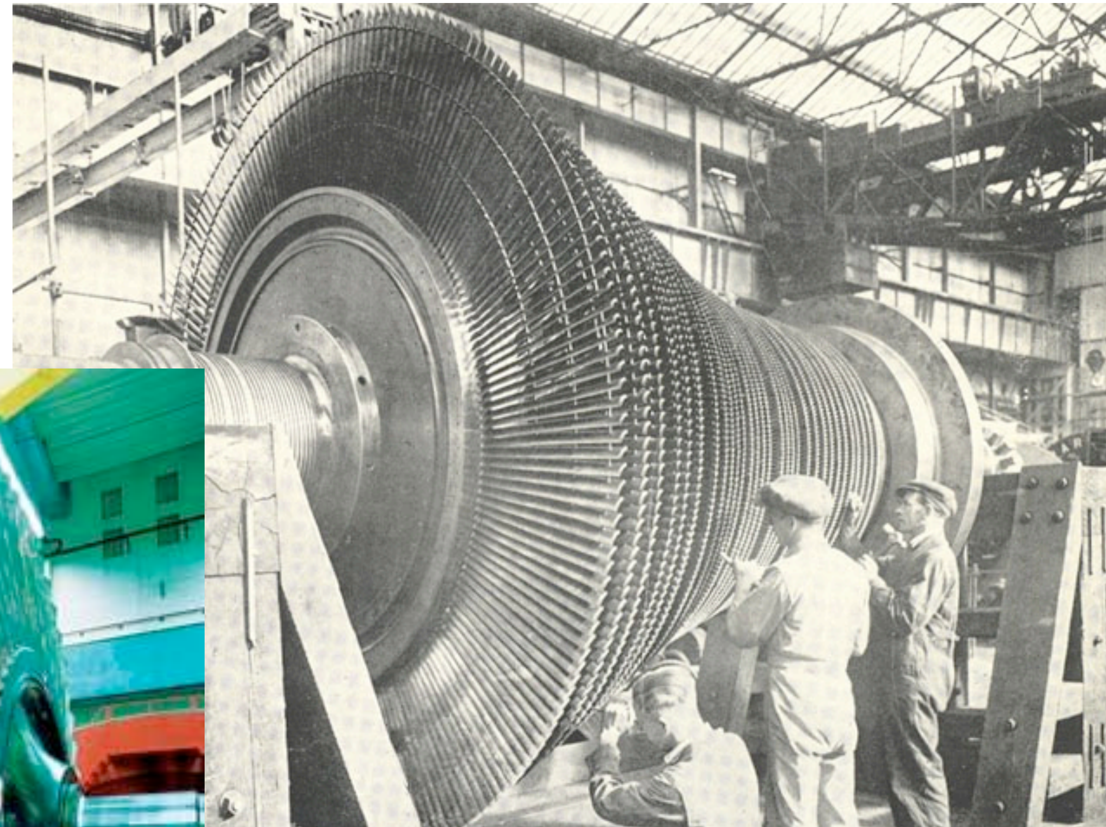
Alstom steam turbines, Ulchin Nuclear Power Plant, S. Korea *(copyright unknown)*

Steam turbine – external combustion

Image: from LidyaSavitri.wordpress.com; Copyright unknown.

Steam turbines are virtually unchanged in 100 yrs

Low-pressure turbine rotor, for installation in a nuclear power plant (Siemens SST5 9000)
Photo: Siemens Power Generation



Low-pressure turbine rotor, 50 MW turbine, ca. 1929

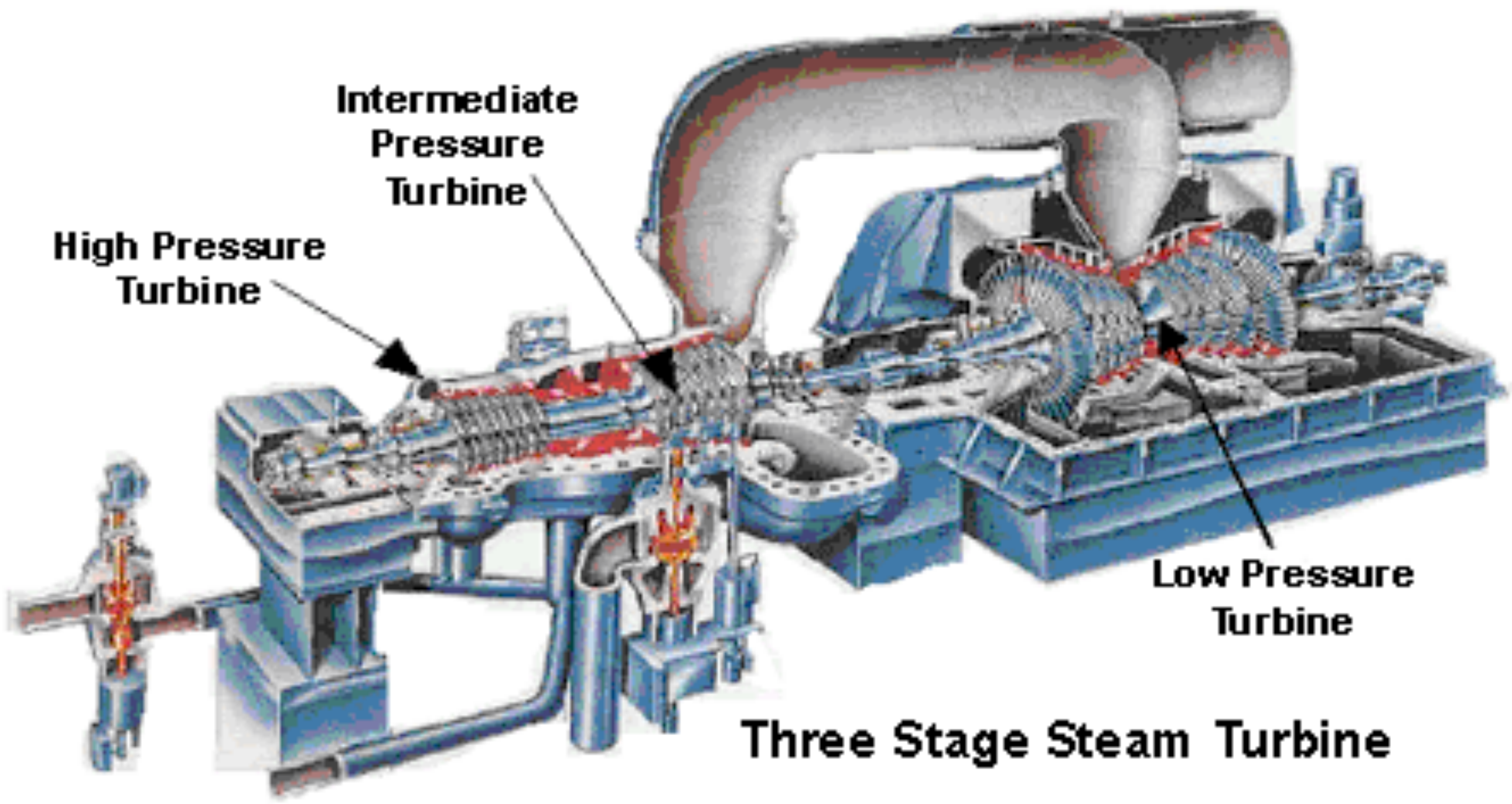
Photo: "The Steam Turbine and Other Inventions of Sir Charles Parsons, O.M." R.H. Parsons, 1942. Copyright, The British Council

Where is steam injected? How do you know?

Steam turbine efficiency achieved with multiple stages

Original idea: Parsons, 1910s

Diagram: Govt. of Australia



Steam enters at L. Blades increase in size as P drops. Steam is removed and reheated (superheated), then reintroduced at the low-pressure stage.

Gas turbine – internal combustion

Why are blades so different on the sides of the turbine?

Image: from LidyaSavitri.wordpress.com; Copyright unknown.

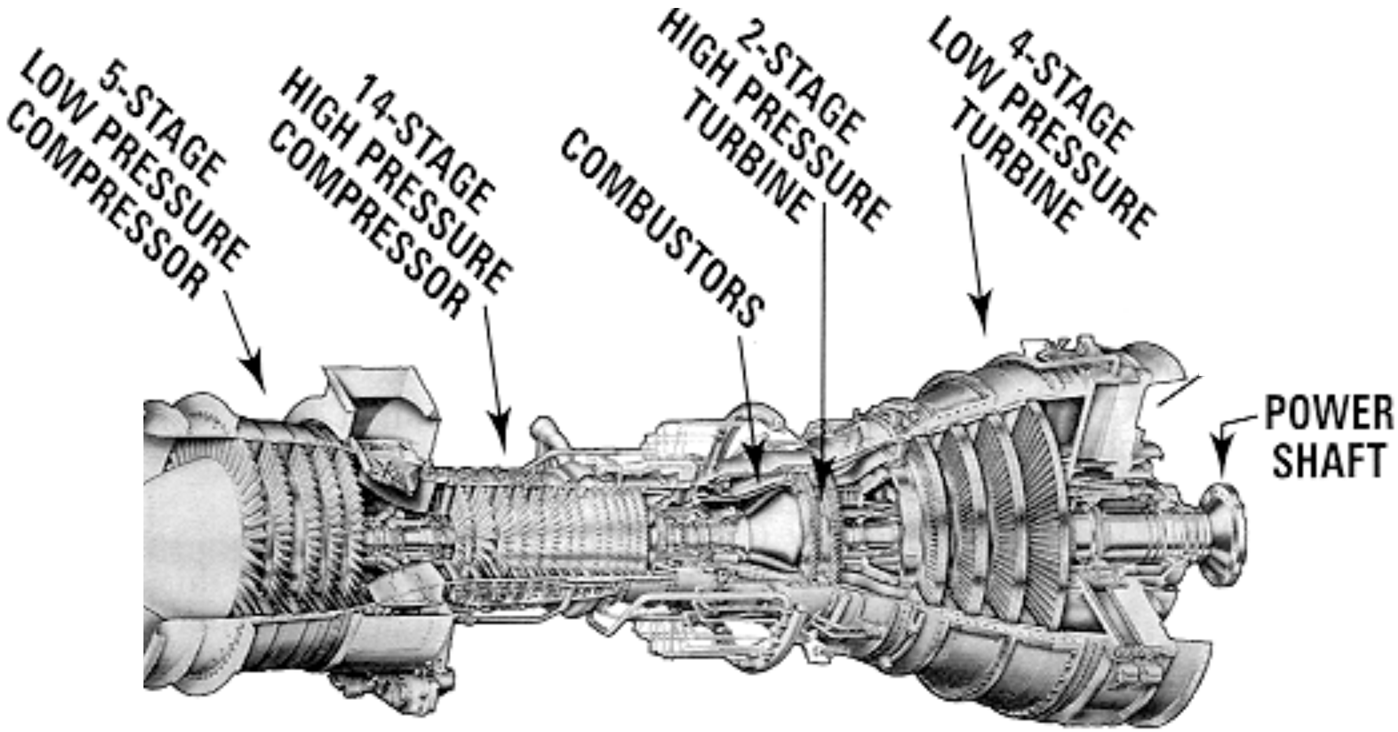
Brayton cycle patented 1791 (John Barber), first use in piston engine 1872 (George Brayton)

First successful turbine build: 1903 (Aegidius Elling)

… by 1918 General Electric has a gas turbine division.

Now generator of choice for fast installation.

Gas turbine – internal combustion



Where does air/gas enter?

What is compression ratio?

Gas turbine thermodynamic cycle: Brayton cycle

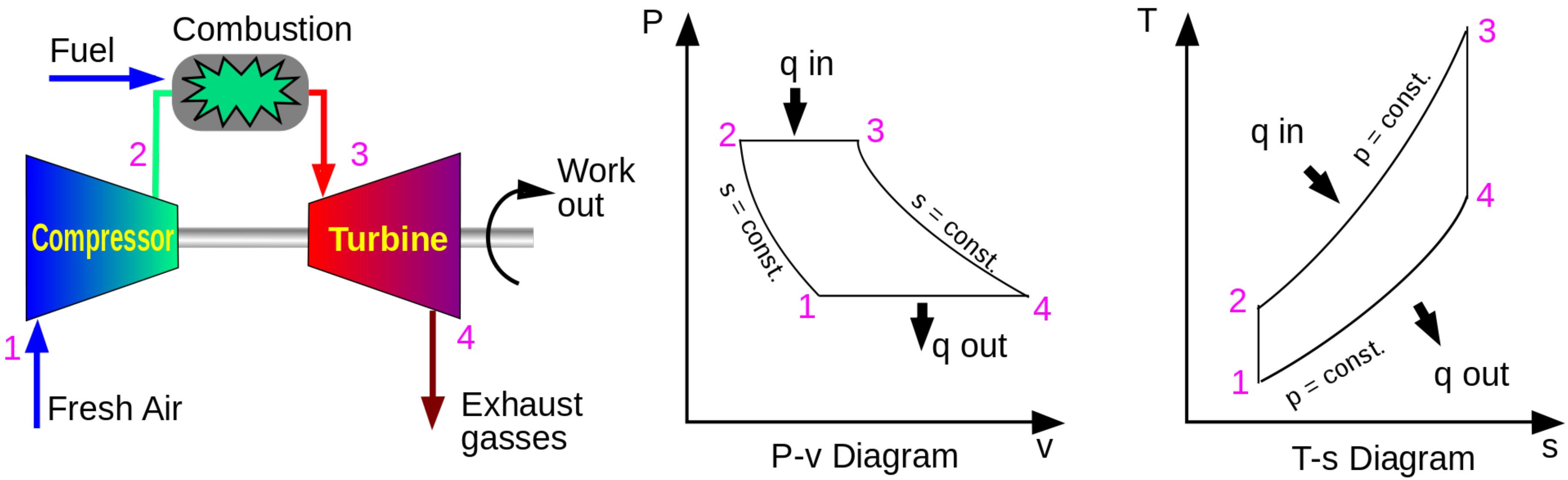


Diagram: Wikimedia Commons

Two adiabats and two isobars. Intrinsically less efficient than the Carnot cycle

But temperatures are hot! (~1200 C). (Efficiency depends on P, T)

Carnot efficiency ~75%. Ideal Brayton cycle ~ 60%. Commercial units ~ 40-50%.

Steam and gas turbine differences

Steam – Rankine cycle

- external combustion
- condensible species *(must add energy as latent heat)*
- T_{max} ~ 550 C
- ε ~ 30-35%
- slow to dispatch *(hours - must heat water to make steam)*
- expensive to build & install *(needs firebox, boiler)*

Gas – Brayton cycle

- internal combustion
- non-condensible species
- T_{max} ~ 1200 C
- ε ~ 40-50%
- fast to dispatch *(ca. 10 minutes)*
- cheap to build & install *(compact, single unit)*

What's not to like about gas?
…only that coal is cheaper!

Gas turbines are hotter than steam

Steam

Steam T ~ 550 C
P up to 200 atmospheres.

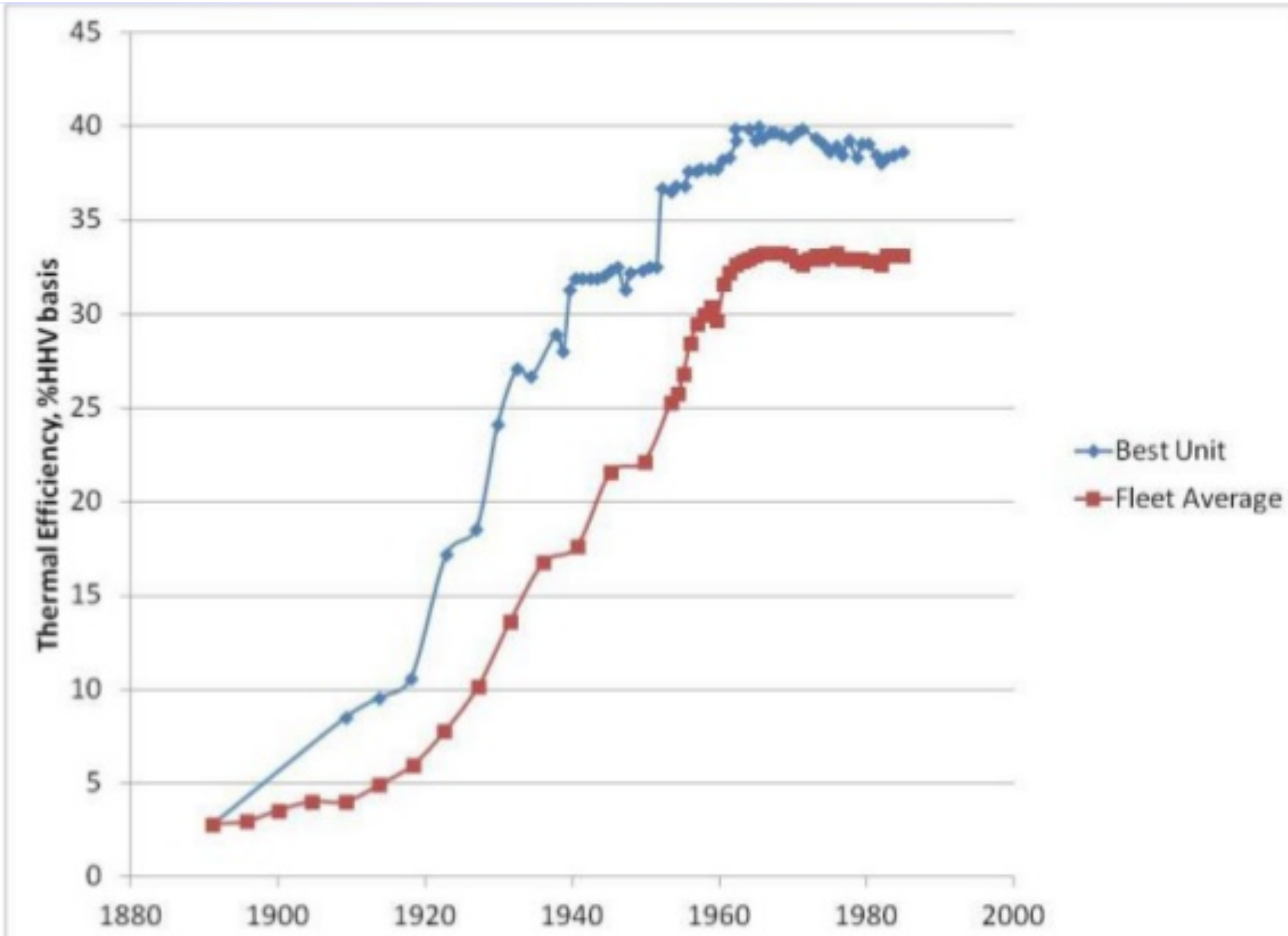
why is steam temperature not higher?

Gas

Gas combustion T ~ 1200 C, exhaust ~ 550 C
P ~ 15 atmospheres.

why is gas pressure not higher?

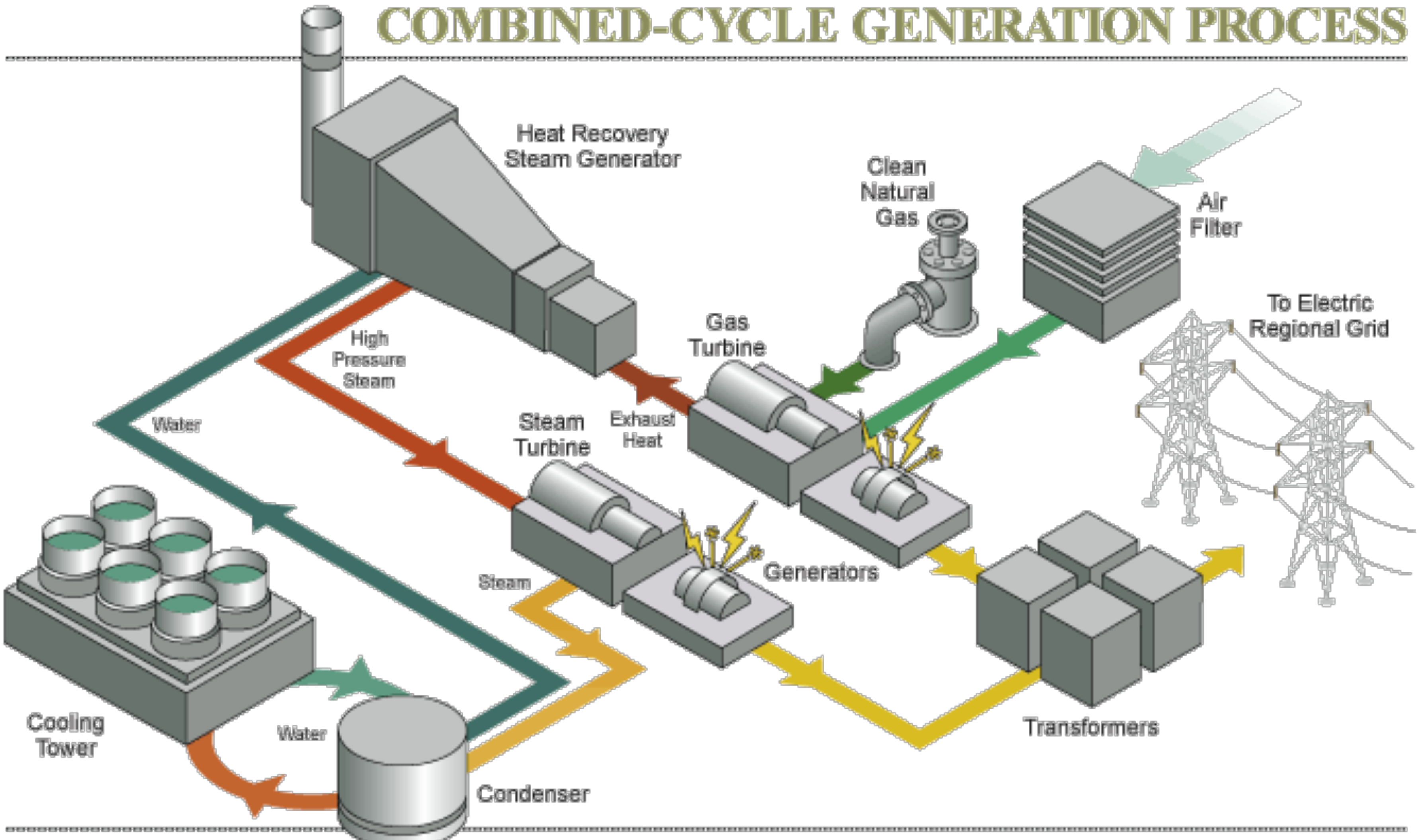
Materials limitations mean steam turbine temperature and efficiency are topped out



EPRI ELECTRIC POWER RESEARCH INSTITUTE

Combined cycle = combining gas and steam

Exhaust from gas turbine still hot enough to be hot side of steam turbine



Get ~ 40% from gas turbine, 60% waste. But then get 30% of that waste back.
0.3*0.6 ~ 0.2. Total efficiency rises to 60%!