Electricity Generation II
GEOS 24705/ ENST 24705
First commercial generating stations

1) Used reciprocating engines rotating at around 2000 rpm (33 Hz)

2) Turn generators via belt drives

3) AC frequency didn’t matter much – each grid was separate, and electricity was used mostly for lighting anyways (where frequency doesn’t matter)

Westinghouse commercial AC generating station, 1888
Edison vs. Tesla: war of the currents

**DC**

**Edison’s company:** General Electric, founded 1890, now ranked (Forbes, 2009) the largest company in the world. Precursor: Edison Illuminating Co., 1880

**Technical achievement:** First steam-powered electricity & electric utility, 1882, first U.S. transmission standard, multiple power plants (1.5 mi. transmission)

**PR stunt:** invented (AC) electric chair, attempted execution, 1890

**AC**

**Tesla’s company:** Westinghouse Electric Company, founded 1886, now (after purchase of CBS) knows as CBS Corp. (sold power generation to Siemens, itself provider of first electric street lighting in 1881). Hired first woman electrical engineer in 1890s.

**Technical achievement:** long-distance transmission of hydropower at Niagara Falls to factories in Buffalo New York, 1895 (25Hz)

**PR stunt:** lit Chicago World’s Fair, 1893
Edison vs. Tesla at 1893 Chicago World’s Fair

Tesla’s system already had most characteristics of the modern electricity system in 1893. But choice was not yet clear.

Comparatively little evolution after choice was made.
Electric lighting common only a decade after invention

Individual private grid systems operation on their own standards, AC from 25-133 Hz or DC

W.L. Sontag, 1895, *The Bowery at Night*
The engine that drives the world’s electricity supply

*Parson’s steam turbine*, 1884: manufactures 80% of world’s electricity today (all external combustion).

**Power growth rapid**: first turbine 75 kW (1890), by 1912 turbo-generator system installed in Chicago was 25 MW, -> 50 MW in Parson’s lifetime

**Efficiency gain rapid**: e ~ 37% by 1916, with regenerative heating of feed water. More efficient than reciprocating engines, also simpler – fewer moving parts.

**Maritime use**: demonstration of turbine-propelled ship, the *Turbinia*, 1897

**Chief drawback**: high rotation rates
Generators are virtually unchanged in 100 yrs

Stator, 3-phase generator, Wellduck Co., China, 12.5 MW, 2010

Stator, 3-phase generator, Brakpan, South Africa, 1897. *Photo: Siemens*
First major hydropower station, Niagara Falls, 1895

Adams power station, 10 5MW AC generators. Photo: Tesla Society
Hoover Dam hydropower station, upgraded 1961

17 generators, average 120 MW. *Photo: source 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

Turbo-generators are virtually unchanged in 100 yrs

Turbine hall with steam turbine & generators, ca 20 MW each, 1929

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
Modern electricity production:  
**Coal-fired power plant**

Fuel burns to make heat; heat boils water to make steam; steam drives steam turbine; turbine spins generator; generator make electricity.

Items to note: 1) Compressor (not labeled here). Liquid water is compressed to high pressure, and steam from the boiler is drawn off at constant pressure. 2) Condenser. Water is reused, both to use purified water and to permit a final drop in P below atmospheric, as in the Newcomen engine. 2) Tube boiler for better heat transfer. 

Operating conditions: Firebox T ~ 2200 C, Steam T ~ 550 C, P up to 200 atmospheres. (Steam is somewhat superheated so can bypass the Clausius-Clapeyron relationship).
Steam turbine efficiency is achieved with multiple stages

*Original idea: Parsons, 1910s*

Steam turbines typically have multiple stages on the same shaft: high, intermediate, and low-pressure, with blades increasing in size as P drops. Steam is removed and reheated (and superheated) before being reintroduced at the low-pressure stage.

*Diagram: Govt. of Australia*
Steam turbine efficiency is achieved with multiple stages

*Original idea: Parsons, 1910s*

*Image: from LidyaSavitri.wordpress.com; Copyright unknown.*
Modern electricity production:  
**Steam turbine thermodynamic cycle (Rankine cycle)**

The Clausius-Clapeyron relationship of liquid and vapor prevents raising T at constant entropy, so cannot make the same rectangular T-S diagram as the Carnot cycle. 1-2 is compression of liquid, followed by heating and evaporation of liquid. In many systems, steam is superheated (3'-4' instead of 3-4). The superheat and reheat cycles are designed to make the cycle more Carnot-like and yield higher efficiency: think of making the cycle on a T-S plot more rectangular.
Gas turbine

*No reheat, but see blades change from high-P to low-P end of turbine*

Temperatures typically higher than in steam turbines: > 1000 °C (1300 K) as opposed to ~600 °C (900K) for steam. Note that the walls of the turbines must be kept cooler than the gases inside else their metal would degrade, and even so, special steel is required to withstand such high Ts.
Modern electricity production:
Gas turbine thermodynamic cycle (Brayton cycle)

Air and natural gas first compressed, then combusted, and then hot pressurized gases are expanded through turbine blades. The rotor turns both a generator and drives the compressor itself (which can take up ½ the power output of the turbine).

All gas turbines run on the Brayton cycle, which consists of adiabatic legs but then isobars (constant pressure) instead of isotherms as in the Carnot cycle. It is intrinsically less efficient than the Carnot cycle, but approximately the same as Rankine with reheat.
Combining gas and steam

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

Note: combined cycle is not the same as cogeneration (also called “combined heat and power” or CHP). In cogen, waste heat is simply used to heat a building. You can however make a plant is both combined cycle AND cogen, using waste heat from the steam turbine for building heating.

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