EEE 102 Basic Electrical Engineering

Lecture 2: Generation I

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Generation: Classification of Sources

- By Origin
  - **Renewable:** Naturally replenished energy sources
  - **Non-Renewable** Finite sources depleted faster than replenishment
- By Climate Impact
  - **Clean Energy:** Minimal environmental impact
  - **Dirty Energy:** High environmental impact:

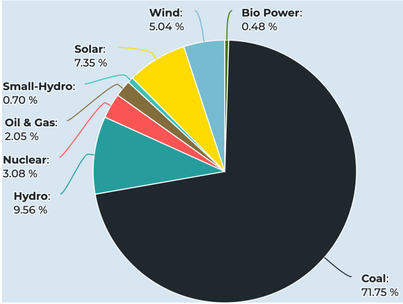


Figure: India's Generation Mix

Electricity Generation ≈ Boiling Water

Thanks to Gemini for generating these clip-arts

Thermal Power Plant- A Heat Engine

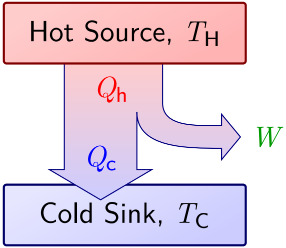


Figure: Conceptualization of Heat Engine

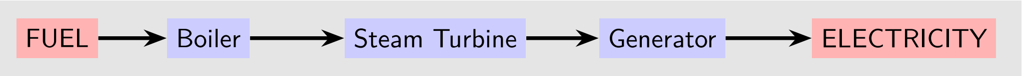
- Heat will flow from hot to cold naturally
- Losses are inherent in Q_c
- Water is used as **Conducting Fluid**
- Heat Engine(closed system) – Carnot Efficiency

$$1 - \frac{T_C}{T_H} \quad \texttt{Carnot Efficiency}$$

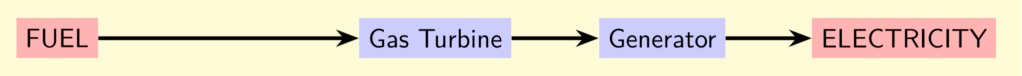
Temperatures must be in K.

Thermal Power Plant: Types

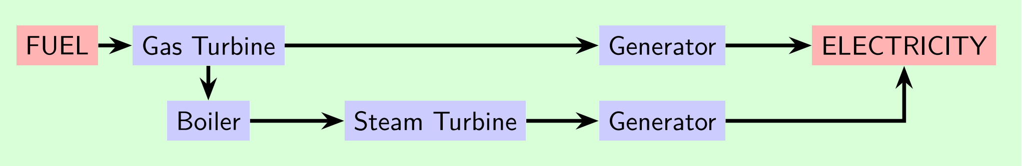
1. **Rankine "Steam" Cycle:** Boil water using any fuel



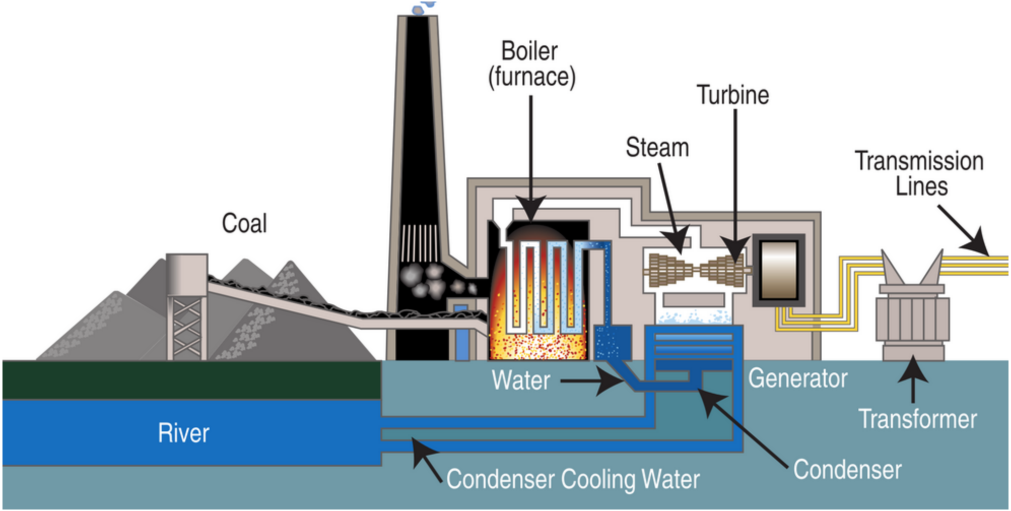
2. **Brayton "Simple" Cycle:** Gas or Vaporized Liquid fuel only



3. **Combined Cycle:** Gas Turbine + Steam



Coal Fired Thermal Power Plant



Source: By Tennessee Valley Authority - tva.com, Commons Archive, Public Domain, https://commons.wikimedia.org/w/index.php?curid=24393916

Boiler

- Boiler heats water (combustion, nuclear) to make steam
- Increased temperature means higher plant efficiency (remember Carnot!)
- Types of Boilers: Subcritical, Supercritical, and Ultra Supercritical
  - **Subcritical:** Up to $\mathbf{374}\,^{\circ}\mathrm{C}$ and **3,208 psi** (the critical point of water).
  - **Supercritical:** Up to **538–566** $^{\circ}\mathrm{C}$; requires advanced materials.
  - **Ultra-supercritical:** Up to $\mathbf{760}\,^{\circ}\mathrm{C}$) and pressure levels of **5,000 psi**; additional innovations (not specified) would allow even more efficiency.

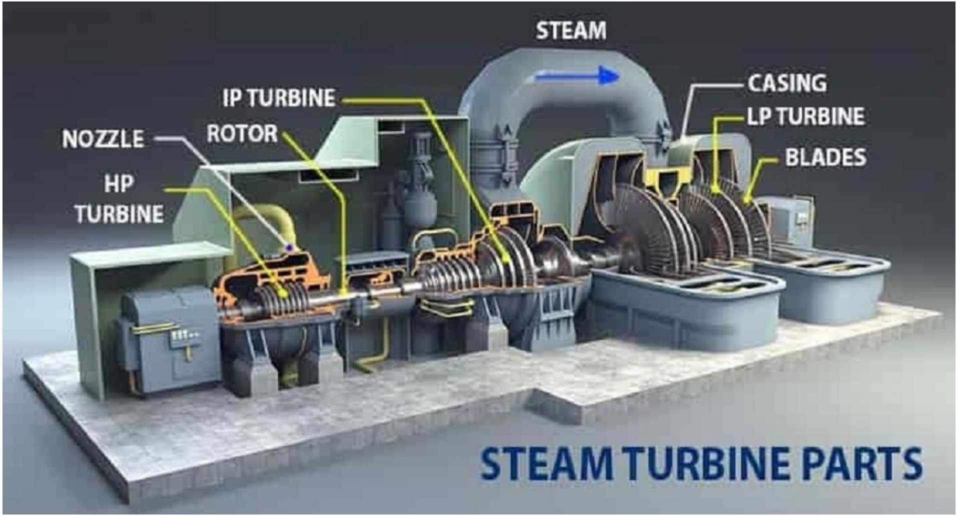
Steam Turbine: Overview and Operation

- Steam turbine converts thermal energy from pressurized steam into mechanical work – `Heat Engine`
- Moving blades capture steam's kinetic energy; nozzles accelerate steam and create pressure drops.
- Multiple stages enable gradual steam expansion, improving thermodynamic efficiency.

Operation:

- High-pressure steam is produced in a boiler – $> 350^{\circ}\mathrm{C}$ & $> 3000\mathrm{psi}$
- Steam enters through nozzles at $> 1500\,\mathrm{kmph}$, converting pressure to kinetic energy.
- Steam passes through blades, spinning the shaft.
- Steam exits at lower temperature and pressure – $65 - 100^{\circ}\mathrm{C}$ & $\ 20\mathrm{psi}$

Steam Turbine: What it looks like?



Source: Google Search

Steam Turbine: What it looks like?

Efficiencies of Generation

Conversion Technology	Type	Efficiency Limit (ideal world)	Today's Actual Efficiencies (real world)
Steam-Cycle Power Plant (Heat Engine)	Carnot Efficiency	∼60%	30-40%
Hydroelectric Turbine	-	∼100%	Up to 95%
	Multi-Junction Limit	86.6%	(47.6% record)
Internal Combustion Engine (Gasoline)	Otto Cycle	∼50%	∼20%

Source: NREL Solar PV Efficency EPRI Journal. Coal at the Crossroads. (Summer 2005); Green Car Reports. Toyota Gasoline Engine Achieves Thermal Efficiency of 38 Percent. (April 2014)

Catch-22 of Efficiency in Thermal Power Plants

Efficiency v/s Auxiliary Power Consumption

- Increasing η_{Carnot} can be achieved by lowering cold reservoir temperature T_C.
- Higher η_{Carnot} means more useful power output P_{out} for the same primary input.
- However, reducing T_C excessively requires additional cooling (e.g., condensers).
- Cooling systems consume energy, increasing the cooling power demand P_{cool}
- The net power output is reduced

✈ Efficiency improvements have diminishing returns due to the energy cost of cooling at very low T_C.

✈ This consumption falls under the **Auxiliary Power Consumption** which is $\sim 8\%$ for Thermal Power Plants in India[1]

[1] Source: Review of Performance of Thermal Power Stations-2018