Pembangkit Tenaga Listrik

Pertemuan 5:
Thermodynamic Power Cycles

Dosen Pengampu:
Frida Hasana, S.Pd. M.Eng.

Power Producing Engine Cycles

1. Carnot Cycle

2. Rankine Cycle

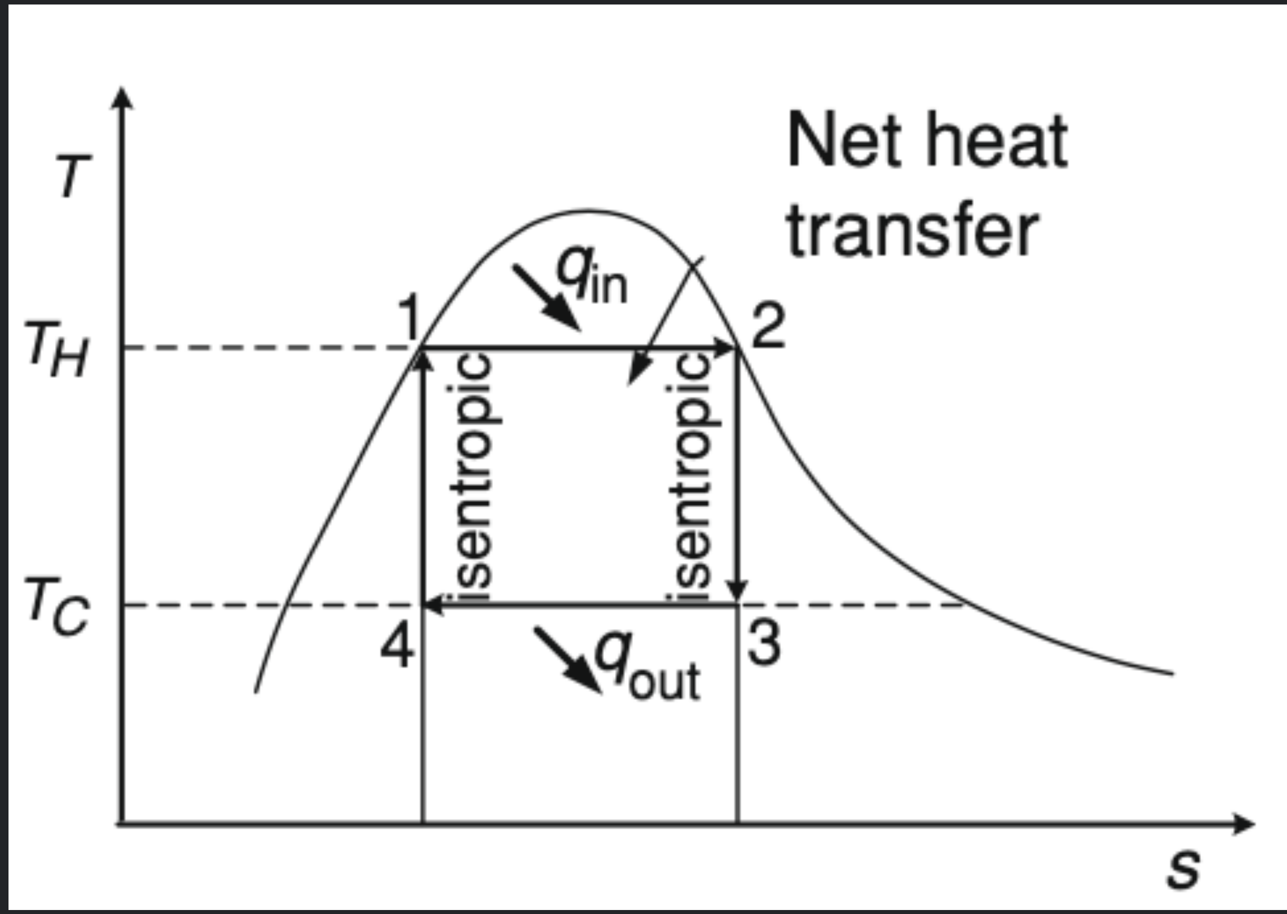
3. Brayton Cycle

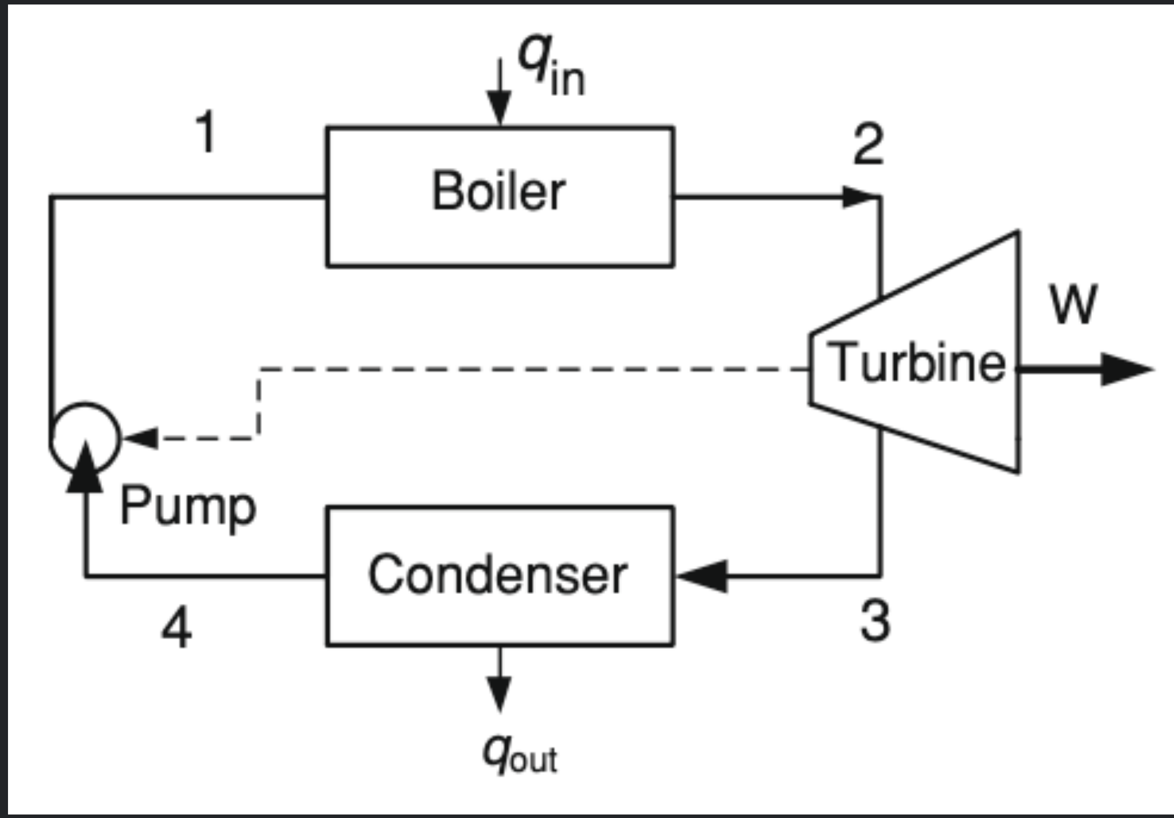
4. Combined Cycle

1. Carnot Cycle #1

- Sebuah mesin kalor **Carnot** melakukan konversi panas menjadi energi mekanik dengan membawa fluida kerja dari kondisi suhu tinggi T_H ke kondisi suhu yang lebih rendah T_C.
- Siklus Carnot merupakan siklus termodinamika ideal yang digunakan sebagai acuan atau batas maksimum efisiensi suatu mesin kalor.
- Secara teoritis, efisiensi siklus Carnot hanya bergantung pada temperatur sumber panas dan temperatur lingkungan, sehingga menghasilkan efisiensi tertinggi dibandingkan siklus lainnya. Namun, karena seluruh prosesnya harus berlangsung secara sempurna dan reversibel, siklus ini tidak dapat diterapkan secara nyata di dunia industri. Oleh karena itu, Carnot lebih berfungsi sebagai standar pembanding bagi siklus-siklus praktis.

1. Carnot Cycle #2





Process 1–2: Isothermal heat addition at constant temperature T_H

Process 2–3: Isentropic expansion at constant entropy $S_2 = S_3$

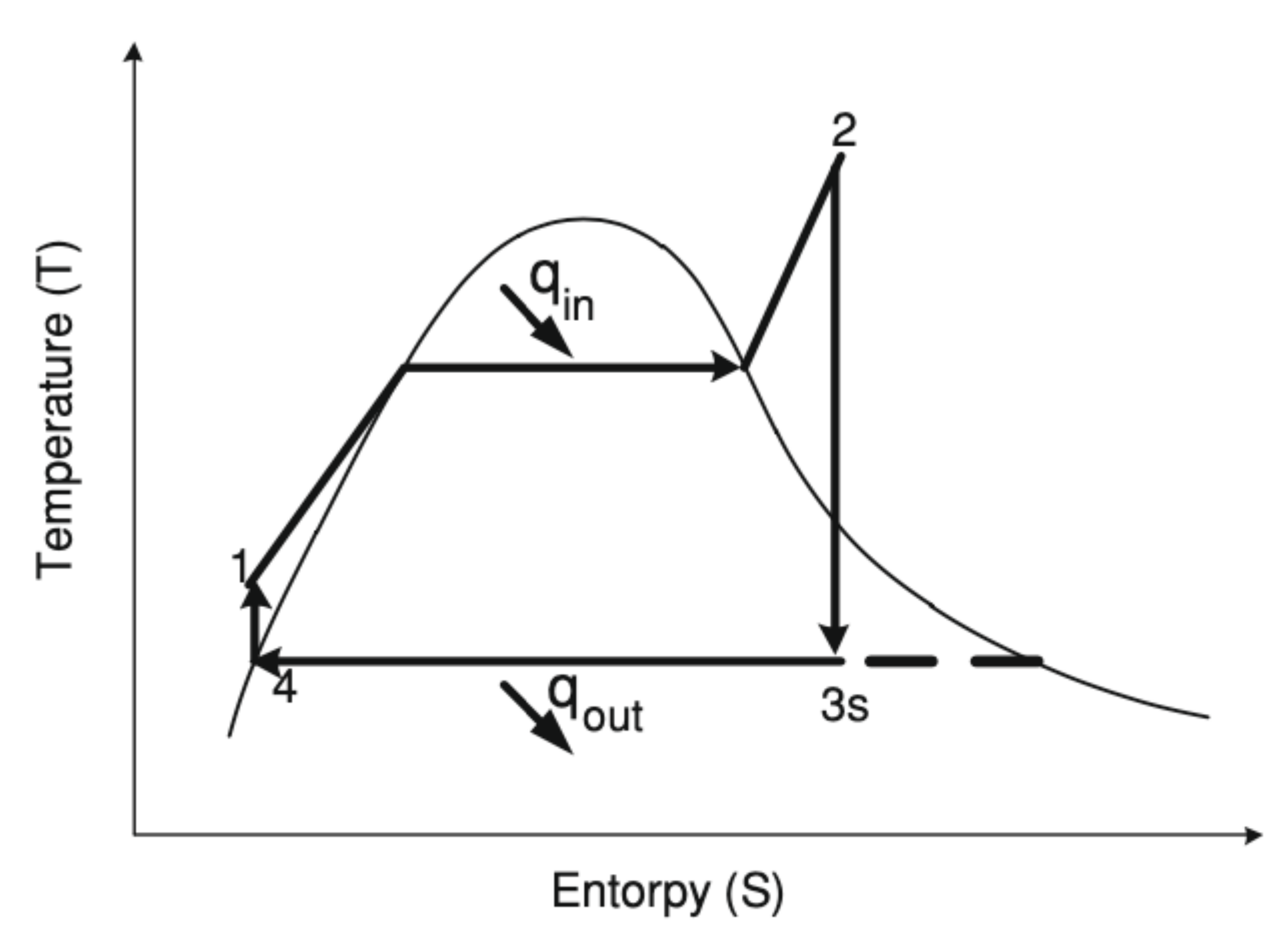
Process 3–4: isothermal heat rejection at constant temperature T_C

Process 4–1: isentropic compression at constant entropy $S_4 = S_1$

2. Rankine Cycle #1

- **Siklus Rankine** mengubah panas menjadi kerja dan menghasilkan sekitar 80% dari seluruh tenaga listrik yang digunakan di seluruh dunia. Sumber panas yang umum digunakan adalah pembakaran menggunakan batu bara, gas alam, minyak, dan fisi material nuklir.
- Siklus ini berbasis uap air, sehingga perlu dilengkapi sistem pendingin (condenser)
- Siklus jenis ini biasanya digunakan di PLTU, PLTN, geothermal karena bersifat **stabil untuk skala besar**

2. Rankine Cycle #2



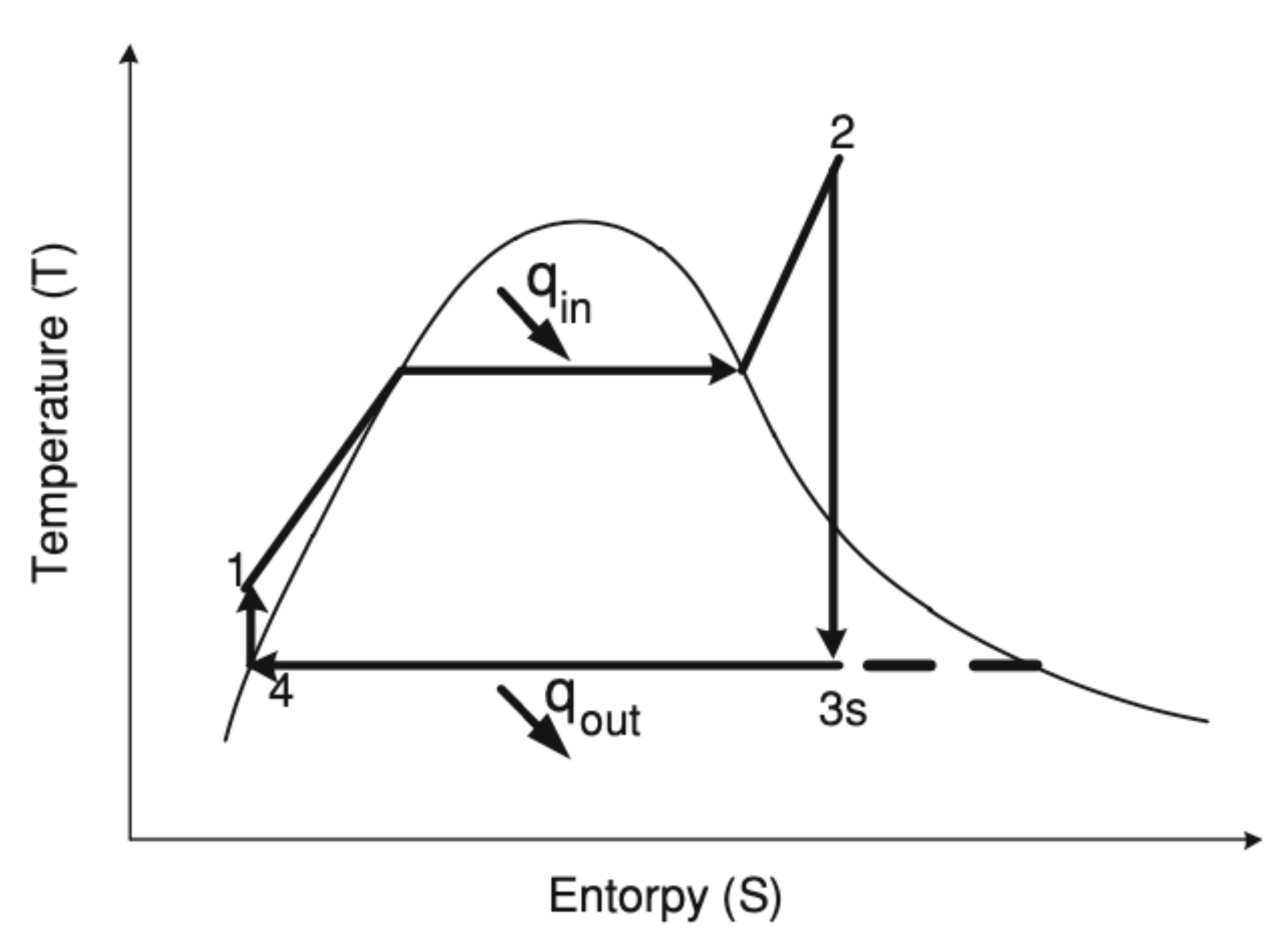
Process 1–2: The high pressure liquid enters a boiler where it is heated at constant pressure by an external heat source to become a dry saturated vapor.

Process 2–3: The dry saturated vapor expands through a turbine, generating power. This decreases the temperature and pressure of the vapor, and some condensation may occur.

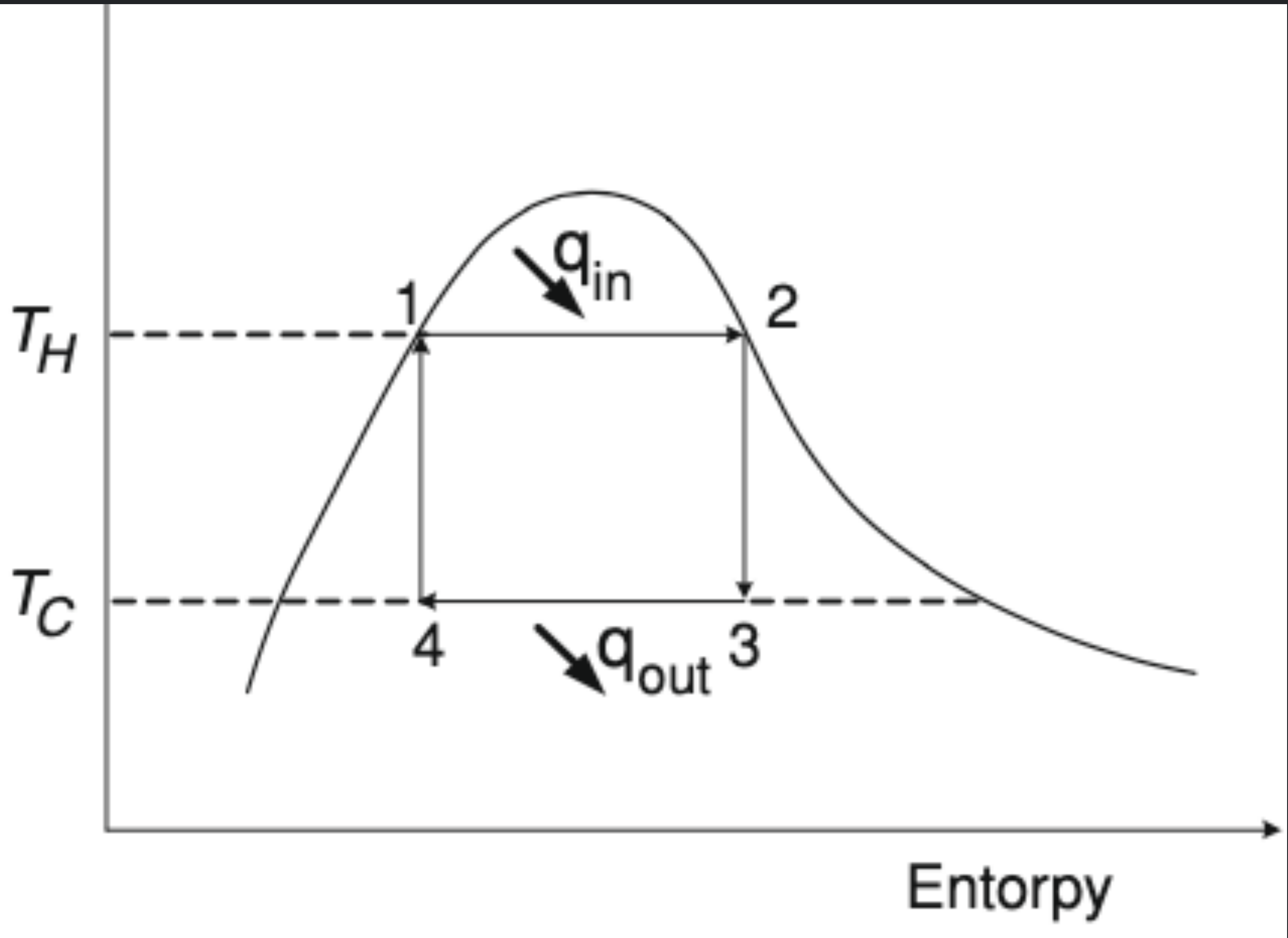
Process 3–4: The wet vapor discharged from the turbine enters a condenser where it is condensed at a constant pressure to become a saturated liquid.

Process 4–1: The water is pumped from low to high pressure to start a new cycle.

2. Rankine Cycle #3



Rankine Cycle



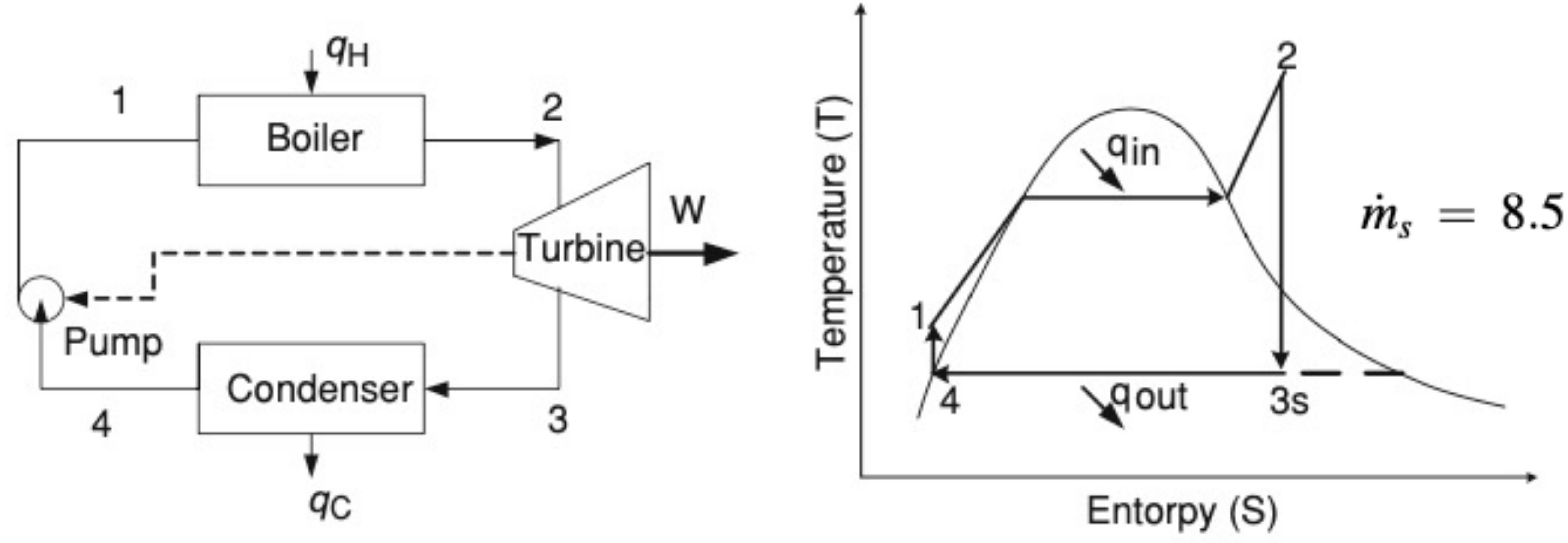
Carnot Cycle

- Menunjukkan siklus yang lebih realistis.
- Garis dari 4 ke 1, itu adalah proses pemompaan air cair
- Garis melandai dari 1 ke garis uap menunjukkan air yang perlahan dipanaskan sebelum akhirnya mendidih

2. Rankine Cycle #e.g.

Contoh:

A steam power plant operates on a simple ideal Rankine cycle shown below. The turbine receives steam at 698.15 K and 4100 kPa, while the discharged steam is at 40 kPa. The mass flow rate of steam is 8.5 kg/s. Determine the net work output.



$$\dot{m}_s = 8.5 \text{ kg/s}$$

2. Rankine Cycle #e.g.

Solution (refers to equation 6.5 – 6.11):

Assume that the kinetic and potential energy changes are negligible.

$\dot{m}_s = 8.5\ \text{kg/s}$

$P_2 = P_1 = 4100$ kPa; $H_2 = 3272.3$ kJ/kg: $S_2 = 6.8450$ kJ/kg (Table F4)

Saturated steam properties at $P_3 = P_4 = 40$ kPa, $V_4 = 0.001022\ \text{m}^3/\text{kg}$ (Table F3)

$H_{3\text{sat vap}} = 2636.9$ kJ/kg; $H_4 = H_{3\text{sat liq}} = 317.65$ kJ/kg;

$S_{3\text{sat vap}} = 7.6709$ kJ/kg K; $S_{3\text{sat liq}} = 1.0261$ kJ/kg K

Basis: mass flow rate of 1 kg/s:

2. Rankine Cycle #e.g.

Solution (refers to equation 6.5 – 6.11):

1

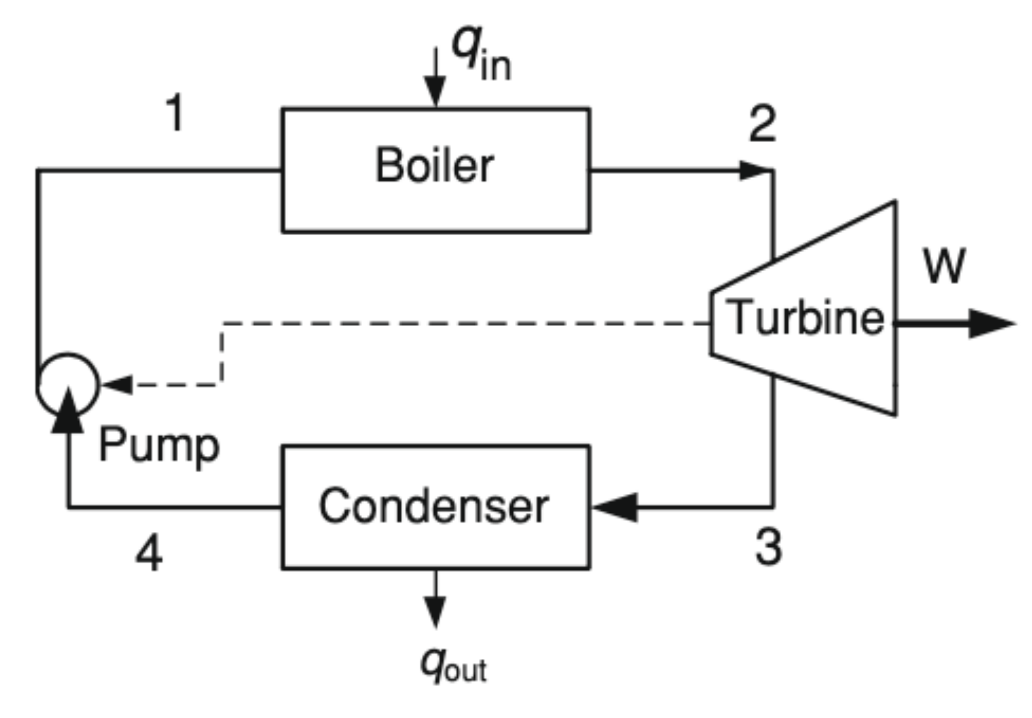
$$\dot{W}_{p,\text{in}} = \dot{m}V_4(P_1 - P_4) \qquad (6.5)$$

$$W_{p,\text{in}} = V_1(P_1 - P_4) = (0.001022)(4100 - 40)\left(\frac{1\text{kJ}}{1\ \text{kPa m}^3}\right) = 4.14\,\text{kJ/kg}$$

2

$$\dot{m}H_1 = \dot{m}H_4 + \dot{W}_{p,\text{in}} \qquad (6.6)$$

$$H_1 = H_4 + W_{p,\text{in}} = 321.79\ \text{kJ/kg}$$



2. Rankine Cycle #e.g.

Solution (refers to equation 6.5 – 6.11):

3

$$x_{3s} = \frac{(S_3 - S_{3\text{sat liq}})}{(S_{3\text{sat vap}} - S_{3\text{sat liq}})} \quad (6.7)$$

Isentropic process $S_1 = S_4$ and $S_3 = S_2$. The quality of the discharged wet steam ($S_3 < S_{3\text{sat vap}}$):

$x_{3s} = (6.845 - 1.0262)/(7.6709 - 1.0261) = 0.875$

4

$$\dot{m}H_3 = \dot{m}[(1 - x_{3s})H_{3\text{sat liq}} + x_{3s}H_{3\text{sat vap}}] \quad (6.8)$$

$$H_3 = 317.65(1 - 0.875) + 2636.9 \times 0.875 = 2356.6 \text{ kJ/kg}$$

2. Rankine Cycle #e.g.

Solution (refers to equation 6.5 – 6.11):

5

$$\dot{q}_{in} = \dot{m}(H_2 - H_1) \quad (6.9)$$

$$q_{in} = H_2 - H_1 = 2950.5 \text{ kJ/kg}$$

6

$$\dot{q}_{out} = \dot{m}(H_4 - H_3) \quad (6.10)$$

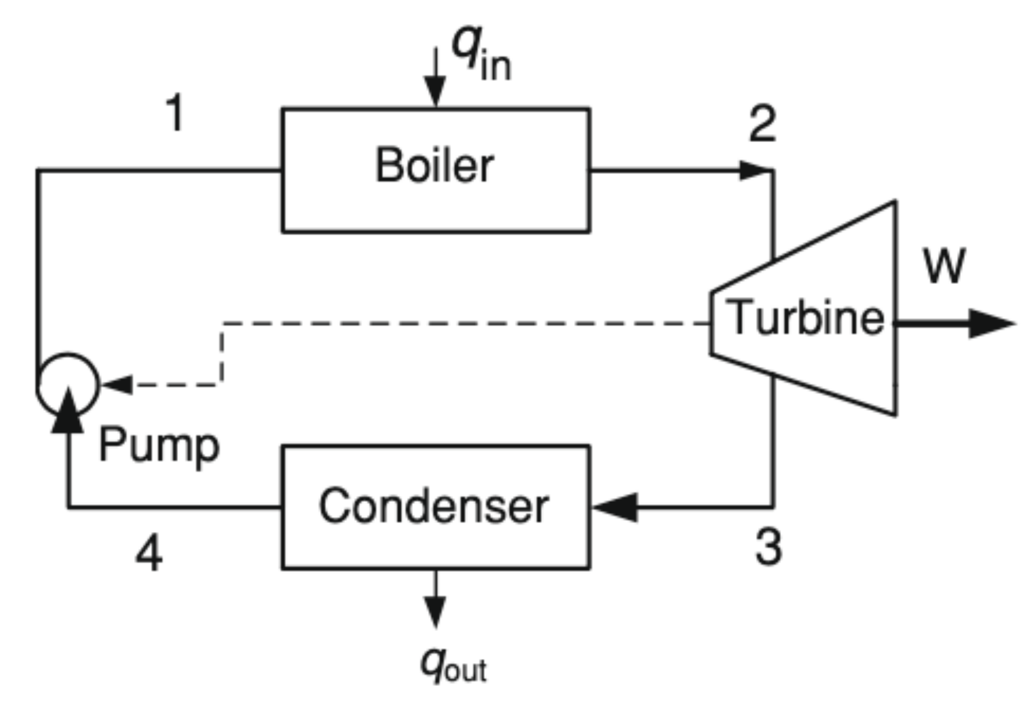
$$q_{out} = H_3 - H_4 = 2038.9 \text{ kJ/kg}$$

7

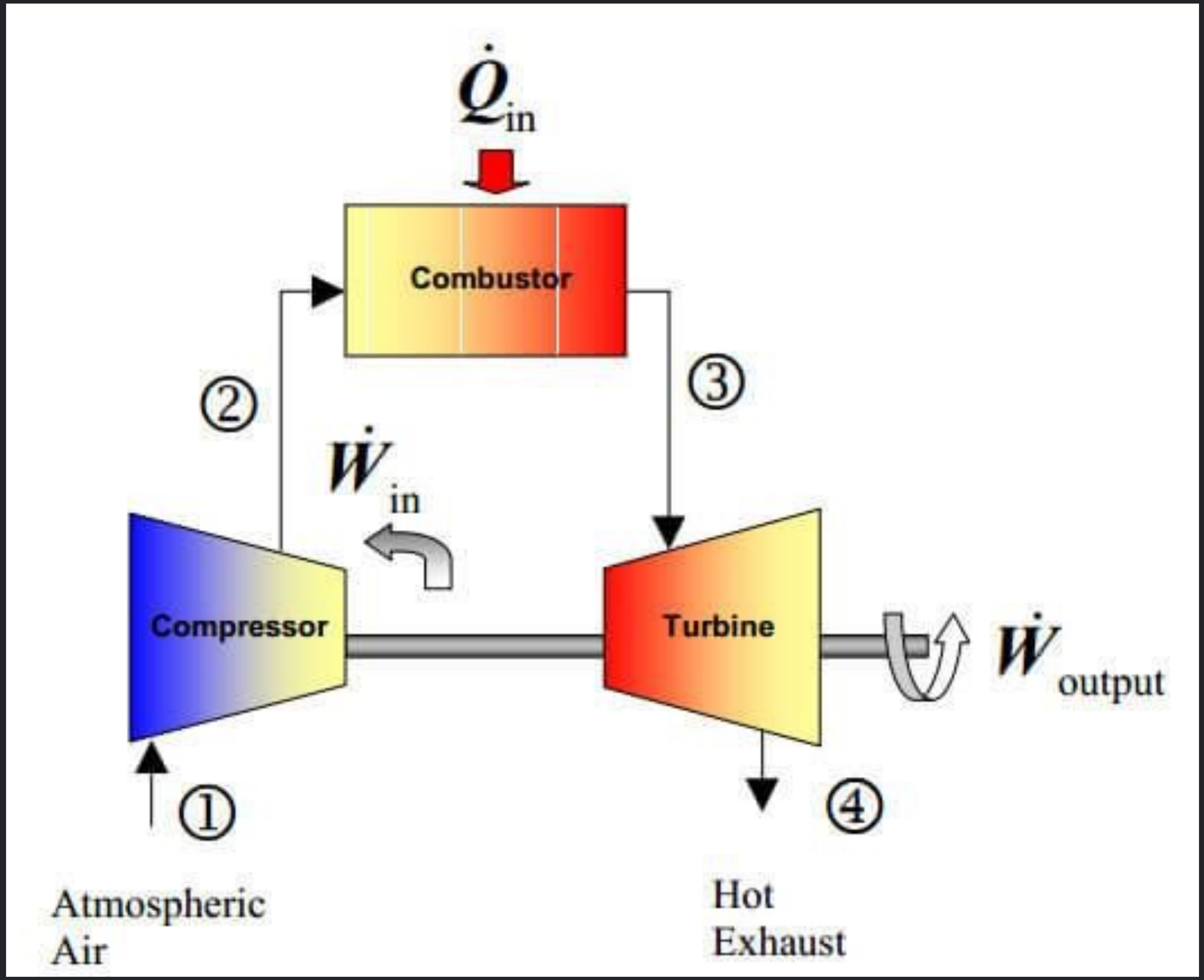
$$\dot{W}_{net} = (\dot{q}_{in} - \dot{q}_{out}) \quad (6.11)$$

With a steam flow rate of 8.5 kg/s, we have

$$\dot{W}_{net} = \dot{m}(q_{in} - q_{out}) = 7748.6 \text{ kW} = \mathbf{7.75\,MW}$$



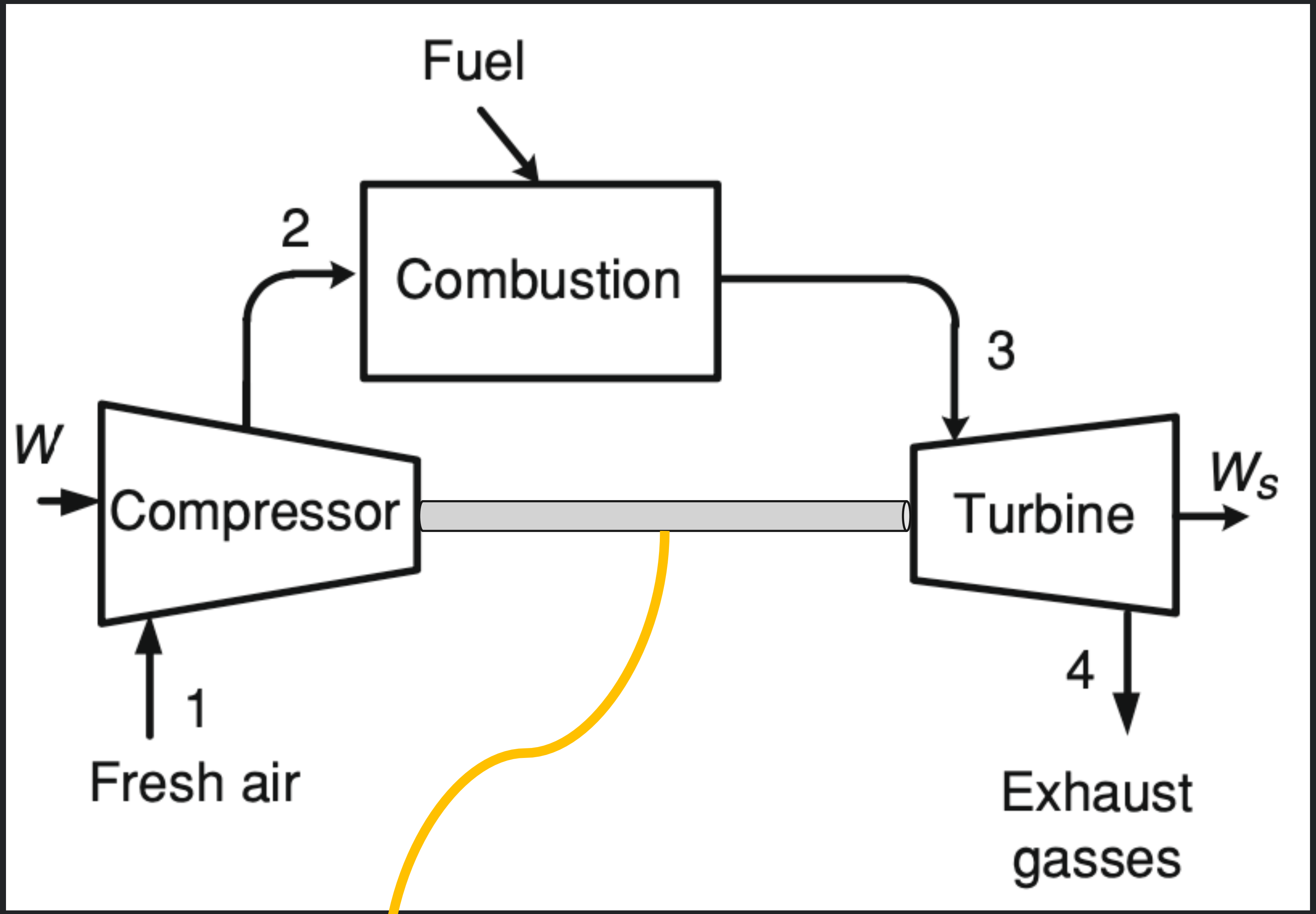
3. Brayton Cycle #1



- Siklus Brayton merupakan dasar kerja turbin gas dan banyak digunakan pada Pembangkit Listrik Tenaga Gas (PLTG)
- Siklus ini menggunakan fluida kerja berupa gas yang kemudian diberi tekanan tinggi (compressed air) untuk kemudian diarahkan ke combustor
- Keuntungan: starting point yang cepat, cocok untuk peak load
- Kekurangan: efisiensi rendah (harus dikombinasi)

3. Brayton Cycle #2

Process 2: isobaric
The compressed air then runs through a combustion chamber where fuel is burned, heating the air at a constant-pressure process.



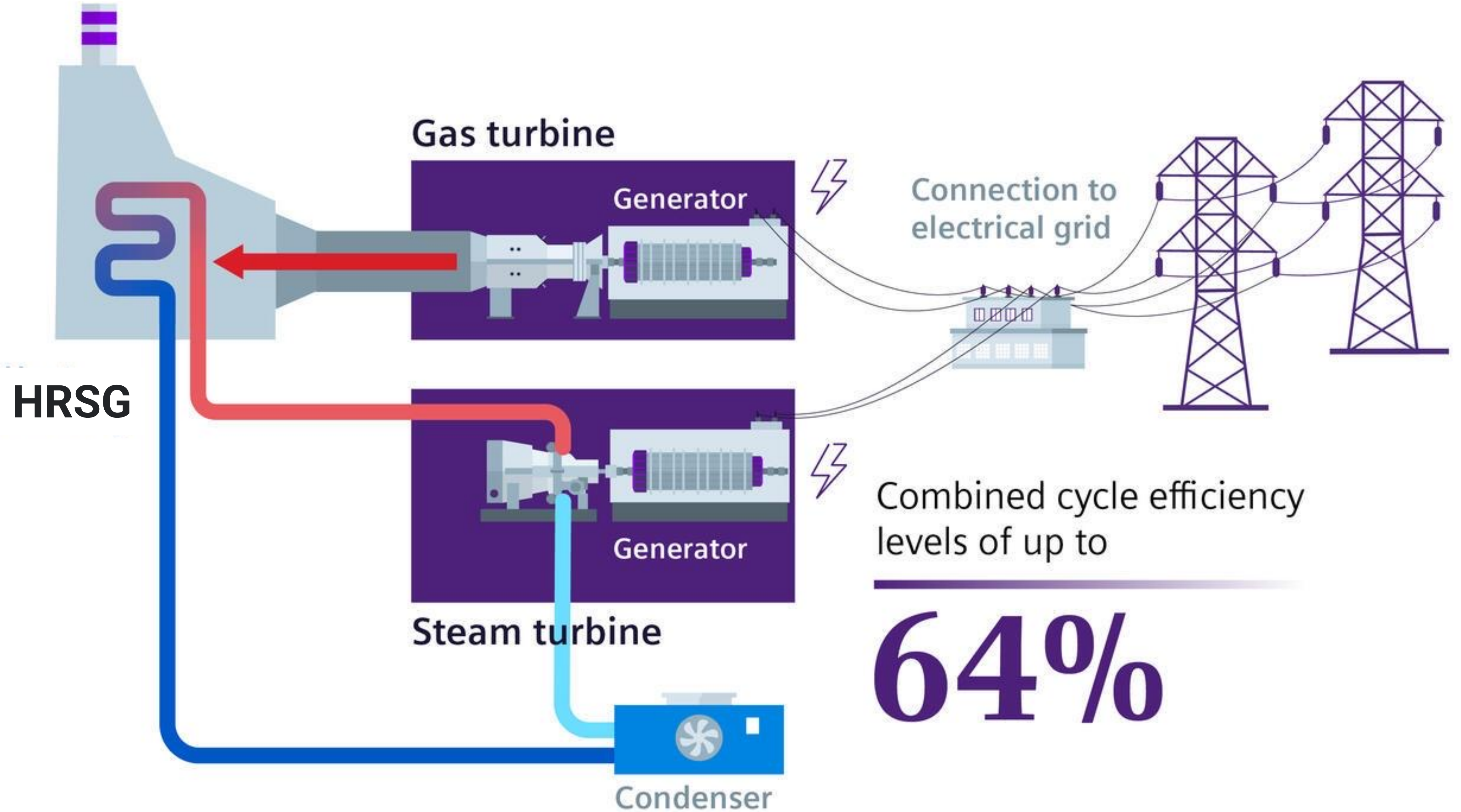
Process 3: Isentropic
The heated, pressurized air then gives up its energy by expanding through a turbine (or series of turbines)

Process 4: Isentropic
Heat rejection to the surroundings.

Process 1: Isentropic
Ambient air is drawn into the compressor

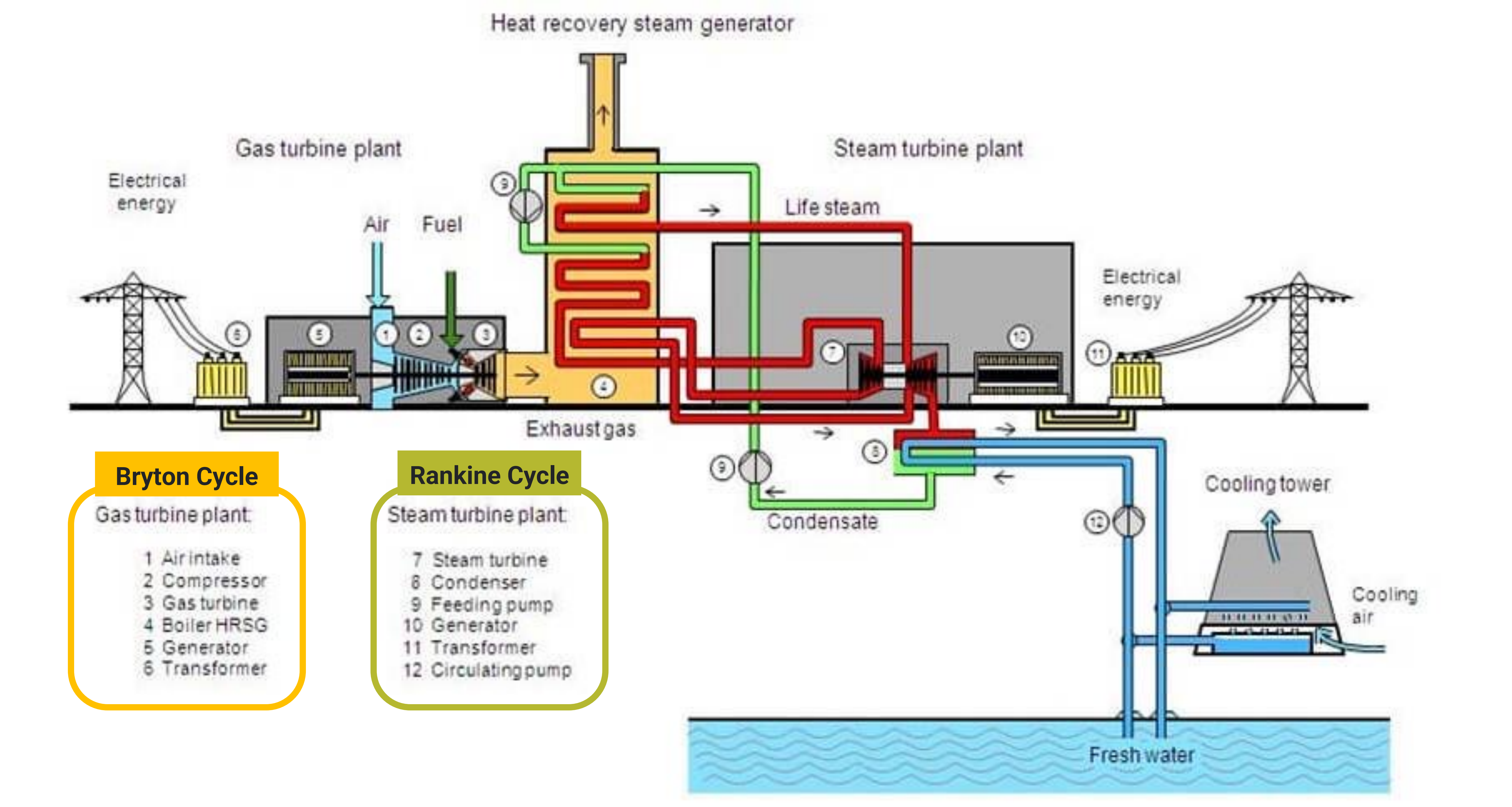
Shaft (poros mekanis)
The rotational power generated by the turbine can be directly used to rotate the compressor.

4. Combined Cycle #1



- Combined Cycle menggabungkan dua siklus utama, yaitu **Brayton Cycle (turbin gas)** dan **Rankine Cycle (turbin uap)**
- Bertujuan untuk meningkatkan efisiensi
- **Heat Recovery Steam Generator (HRSG)**, yaitu alat penukar panas yang berfungsi untuk menghasilkan uap dari air tanpa perlu pembakaran tambahan yang signifikan.

4. Combined Cycle #2



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