SOUTH VALLEY UNIVERSITY
FACULTY OF ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING

Applied Thermodynamics MPEG223

UNDERGRADUATE COURSES

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Gas Turbines

The objective of the present lecture is to study power systems utilizing working fluids that are always a gas. Included in this group are;

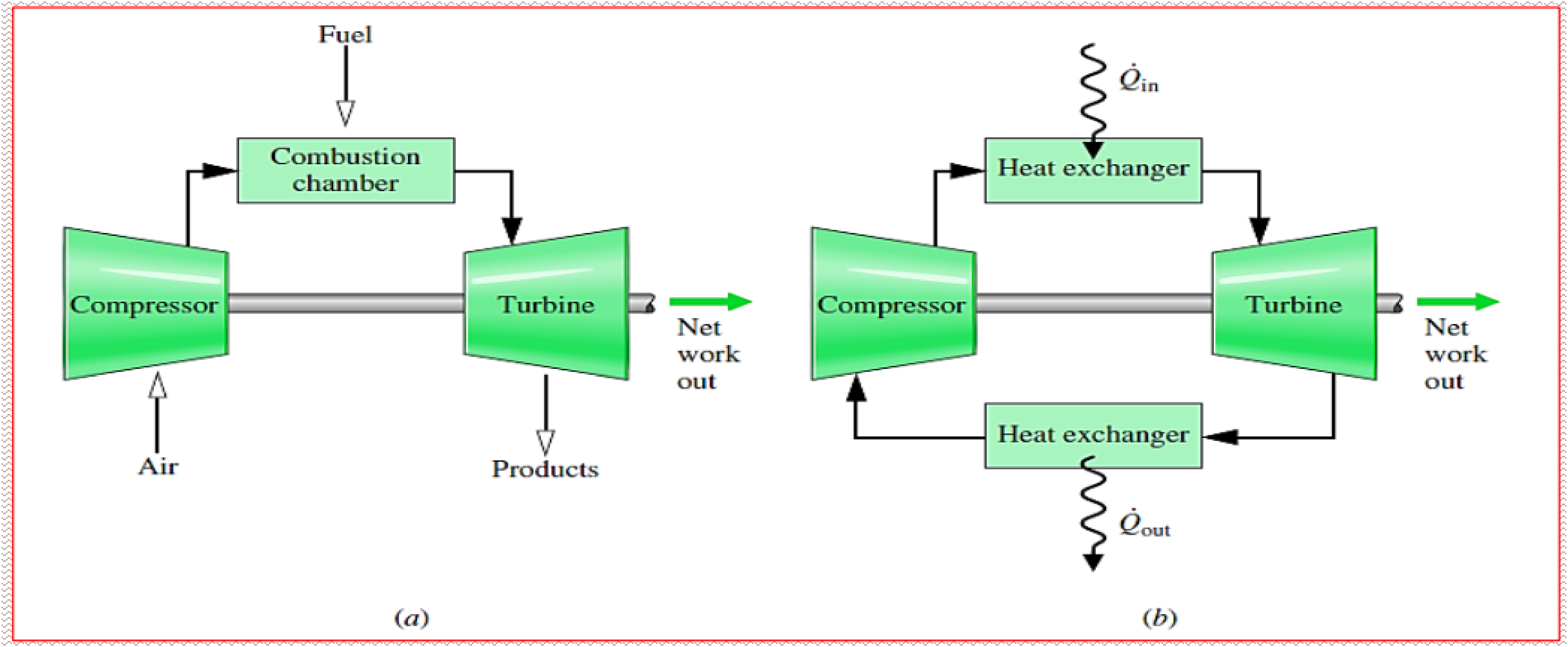
- ❑ Gas Turbine Power Plants
    - ➢ Air-Standard Brayton Cycle.
    - ➢ Regenerative Gas Turbines.
    - ➢ Regenerative Gas Turbines with Reheat and Intercooling.
    - ➢ Gas Turbine–Based Combined Cycles.
    - ➢ Combined-Cycle Power Plants.
    - ➢ Gas Turbines for Aircraft Propulsion.

ADVANTAGES OF GAS TURBINE OVER STEAM TURBINE

- The Gas Turbine Plant is simple in design and construction and is lighter in weight.
- In Steam Turbine Plant, water is used for cooling purpose, hence there are chances of freezing in winter nights.
- The Gas Turbine is quite useful in the regions where due to scarcity it is not possible to supply water.
- The Gas Turbine has been built to operate at the inlet temperature of 800°C and even more, while the steam turbine and boiler have been built for temperatures up to about 580°C.
- The efficiency of Gas Turbine is much higher than that of steam turbine due to high inlet temperature, when other parameters being equal in both turbines.

- The gas turbine does not require any boiler as like in steam turbine, hence the weight and space of Gas Turbine are less than those of steam turbine.
- For the same output, the gas turbine is more compact than a Steam Turbine.
- The capital cost of gas turbine is much lower than steam turbine.
- Shorter starting-time than fossil fired steam plants.
- Gas turbine offer the advantage of a high quality heat stream that can be used in steam production, drying and other applications.
- Gas turbines have the lowest emissions of any combustion power plant. Compared to the typical coal boiler, gas combined-cycle has:
  - More than 2 times lower CO_2 emissions;
  - Over 12 times lower NO_x emissions; and
  - Over 3000 times lower SO_x emissions

MODELING GAS TURBINE POWER PLANTS

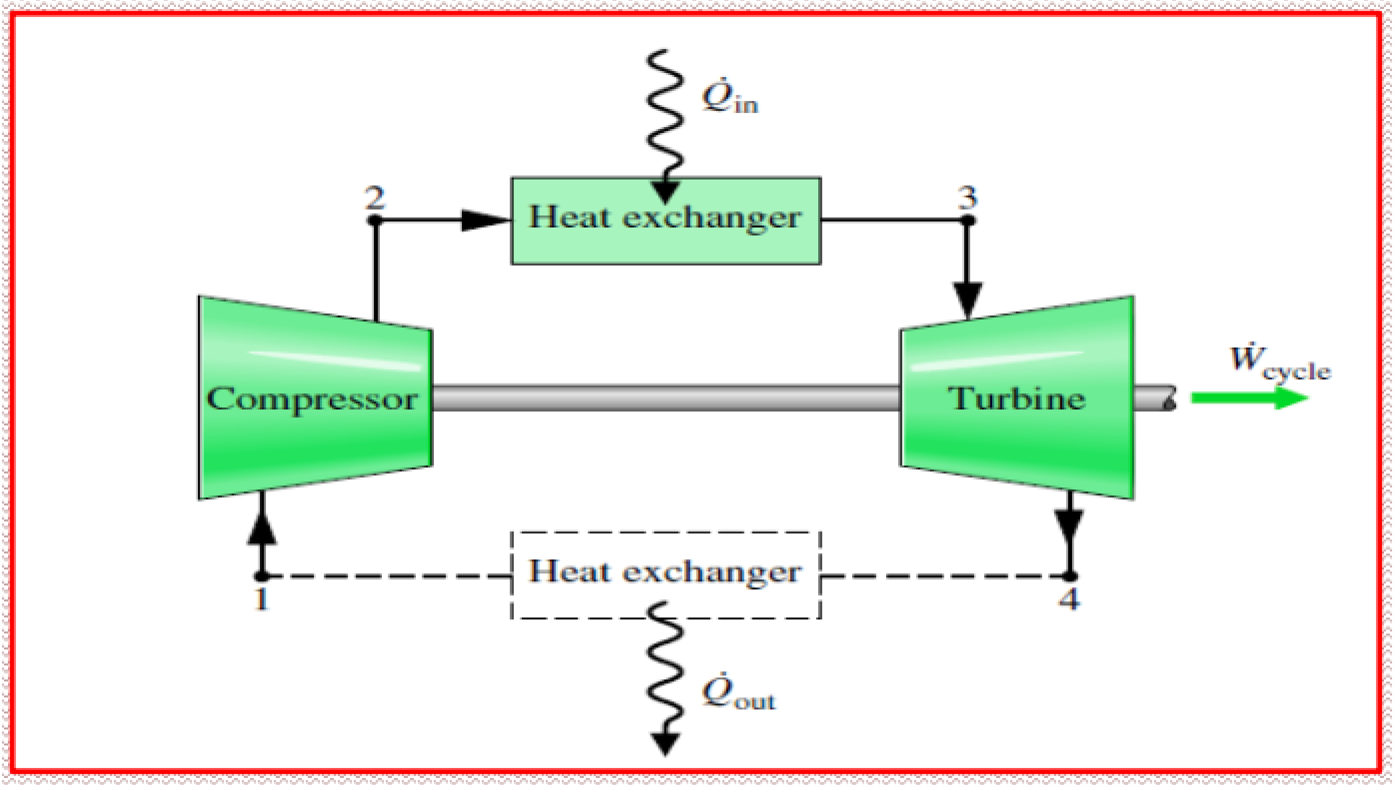


Simple gas turbine. (a) Open to the atmosphere. (b) Closed.

THERMODYNAMICS CONSIDERATIONS OF GAS TURBINE

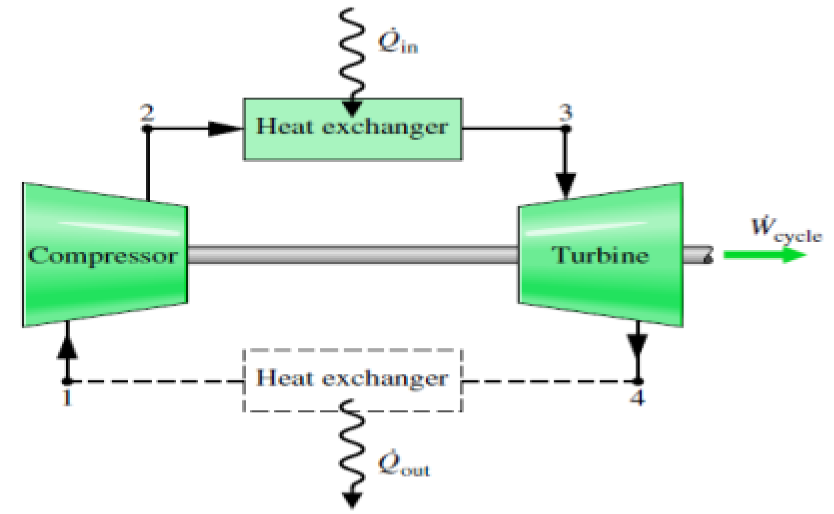
- ❑ An idealization often used in the study of open gas turbine power plants is that of an air-standard analysis.
- ❑ In an air-standard analysis two assumptions are always made:
  - The working fluid is air, which behaves as an ideal gas.
  - The temperature rise that would be brought about by combustion is accomplished by a heat transfer from an external source.
- ❑ It is avoid dealing with the complexities of the combustion process and the change of composition during combustion.

AIR-STANDARD BRAYTON CYCLE

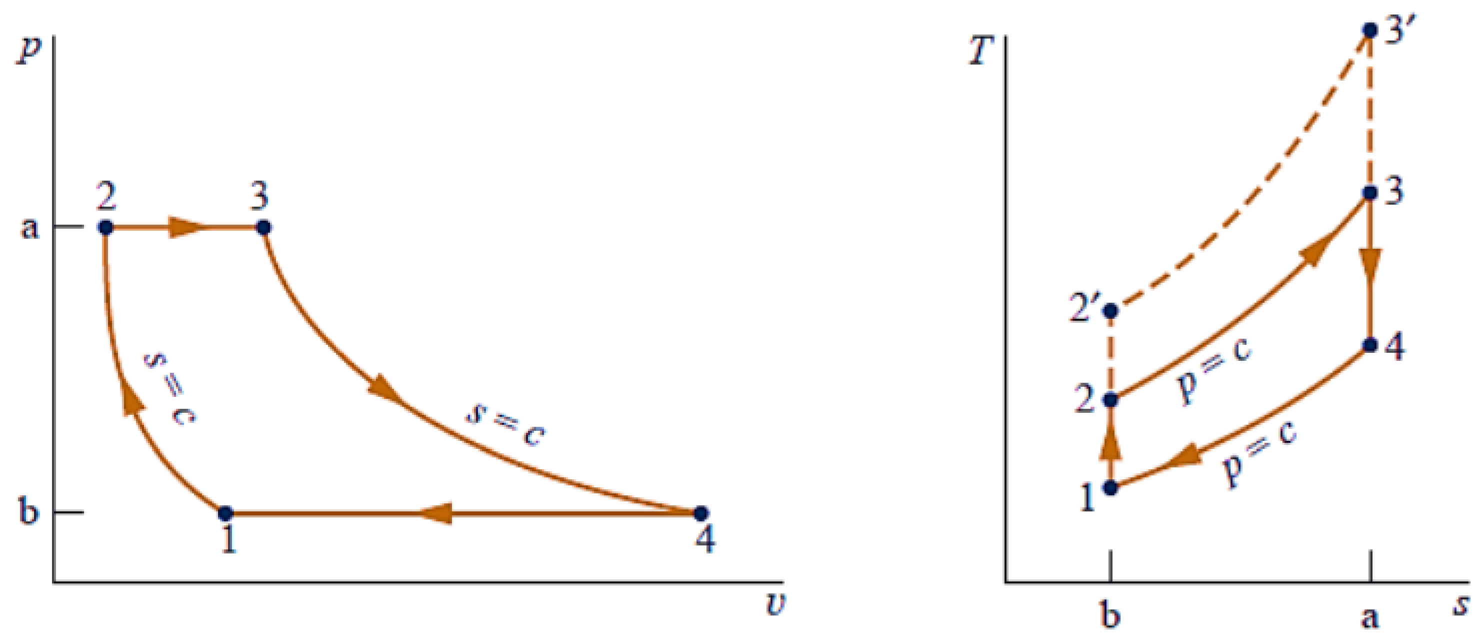


A schematic diagram of an air-standard gas turbine

ANALYSIS OF BRAYTON CYCLE



- The air-standard Brayton cycle consists of:
  - 1-2 Compression process (s=c).
  - 2-3 Heat addition process (p=c).
  - 3-4 Expansion process(s=c).
  - 4-1 Heat rejection process(p=c).
- Expressions for these energy transfers are obtained by energy balance assuming that changes in kinetic and potential energy can be ignored.
- Note that when analyzing air standard cycles, it is frequently convenient to regard all work and heat transfers as positive quantity and write the energy balance accordingly.



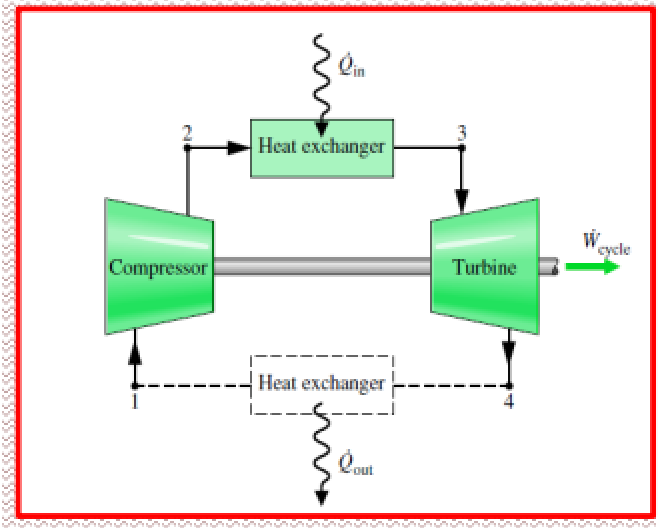
P-v and T-s diagrams of Air-standard ideal Brayton cycle.

EVALUATING PRINCIPAL WORK AND HEAT TRANSFERS

❑ Note that when analyzing air standard cycles, it is frequently convenient to regard all work and heat transfers as positive quantity and write the energy balance accordingly.

1–2 ____Isentropic compression (s=c)

$$\boxed{\frac{\dot{W}_c}{\dot{m}} = h_2 - h_1}$$



where $\dot{m}$ denotes the mass flow rate. With the same assumptions,

2–3 ____heat addition (p=c)

The heat added to the cycle per unit of mass is;

$$\boxed{\frac{\dot{Q}_{in}}{\dot{m}} = h_3 - h_2}$$

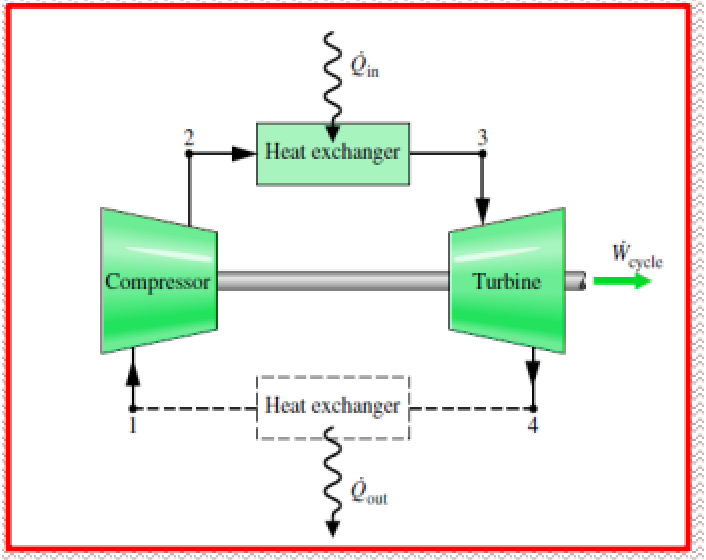
3-4 Isentropic expansion (s=c)

the turbine work per unit of mass is

$$\frac{\dot{W}_t}{\dot{m}} = h_3 - h_4$$

4-1 heat rejection (p=c)

$$\frac{\dot{Q}_{out}}{\dot{m}} = h_4 - h_1$$



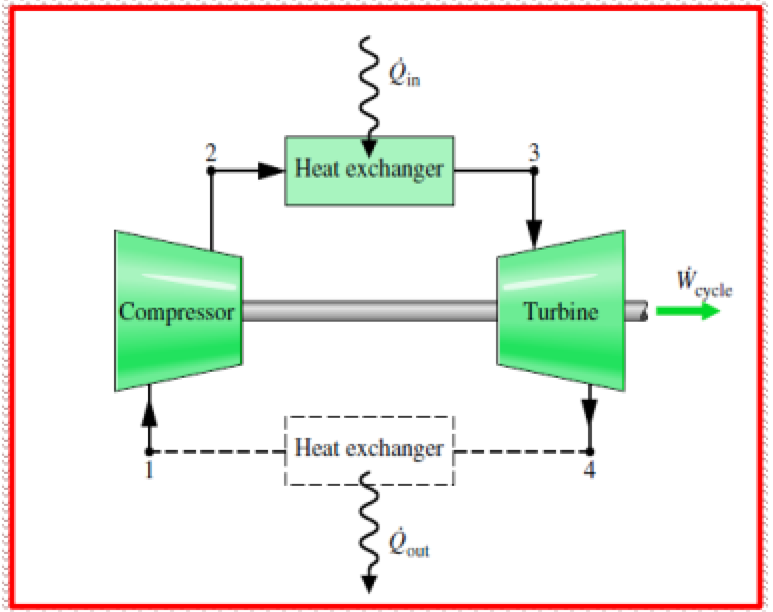
The net work of the cycle is expressed as:

$$\dot{W}_t/\dot{m} - \dot{W}_c/\dot{m}$$

The thermal efficiency of Air-standard ideal Brayton cycle:

The thermal efficiency is the ratio of the net work of the cycle to the heat added;

$$\eta = \frac{\dot{W}_t/\dot{m} - \dot{W}_c/\dot{m}}{\dot{Q}_{in}/\dot{m}} = \frac{(h_3 - h_4) - (h_2 - h_1)}{h_3 - h_2}$$



The back work ratio for the cycle is;

$$\text{bwr} = \frac{\dot{W}_c/\dot{m}}{\dot{W}_t/\dot{m}} = \frac{h_2 - h_1}{h_3 - h_4}$$

For the isentropic processes 1–2 and 3–4

$$p_{r2} = p_{r1}\frac{p_2}{p_1}$$

$$p_{r4} = p_{r3}\frac{p_4}{p_3} = p_{r3}\frac{p_1}{p_2}$$

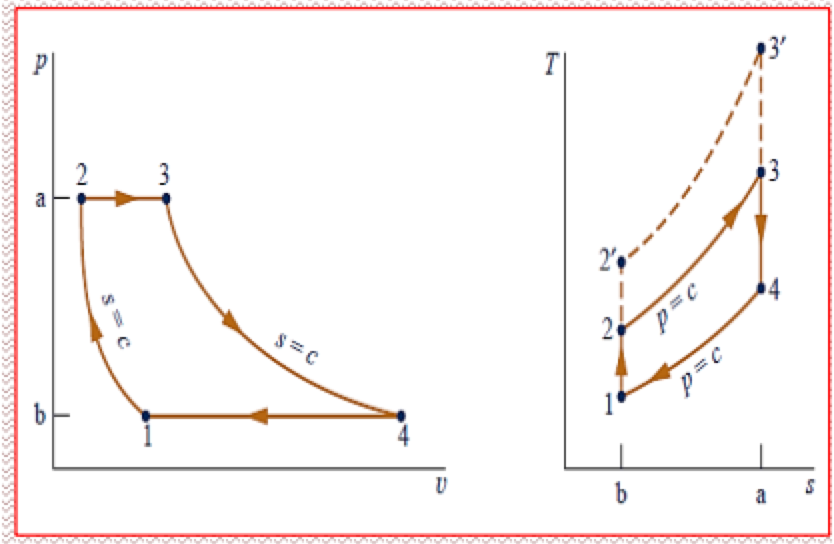
- When an Ideal Brayton cycle is analyzed on a cold air-standard basis, the specific heats are taken as constant. The previous relations are replaced, respectively, by the following expressions;

$$T_4 = T_3\left(\frac{p_4}{p_3}\right)^{(k-1)/k} = T_3\left(\frac{p_1}{p_2}\right)^{(k-1)/k}$$

Where

$$p_4/p_3 = p_1/p_2.$$

$$T_2 = T_1\left(\frac{p_2}{p_1}\right)^{(k-1)/k}$$



Where $\frac{p_2}{p_1}$ is the compressor pressure ratio;

EFFECT OF PRESSURE RATIO ON PERFORMANCE

An increase in the pressure ratio changes the cycle from 1–2–3–4–1 to 1–2"–3"–4–1. Since the average temperature of heat addition is greater in the latter cycle and both cycles have the same heat rejection process, cycle 1–2–3–4–1 would have the greater thermal efficiency

$$\eta = \frac{\dot{W}_t/\dot{m} - \dot{W}_c/\dot{m}}{\dot{Q}_{in}/\dot{m}} = \frac{(h_3 - h_4) - (h_2 - h_1)}{h_3 - h_2}$$

$$\eta = \frac{c_p(T_3 - T_4) - c_p(T_2 - T_1)}{c_p(T_3 - T_2)} = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)}$$

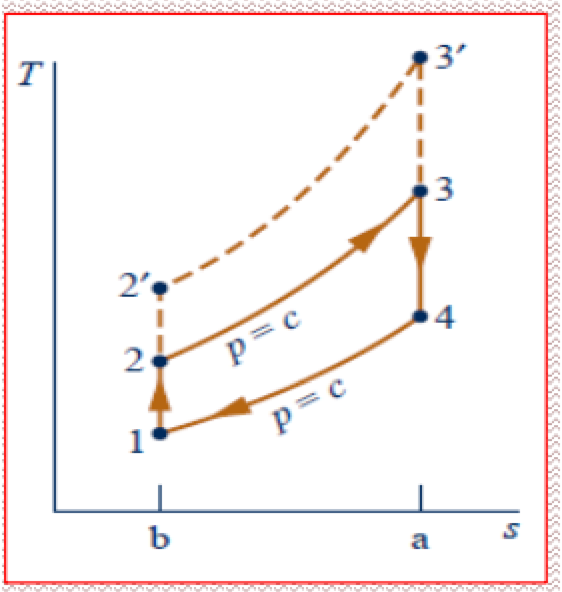
$$\eta = 1 - \frac{T_1}{T_2}\left(\frac{T_4/T_1 - 1}{T_3/T_2 - 1}\right)$$

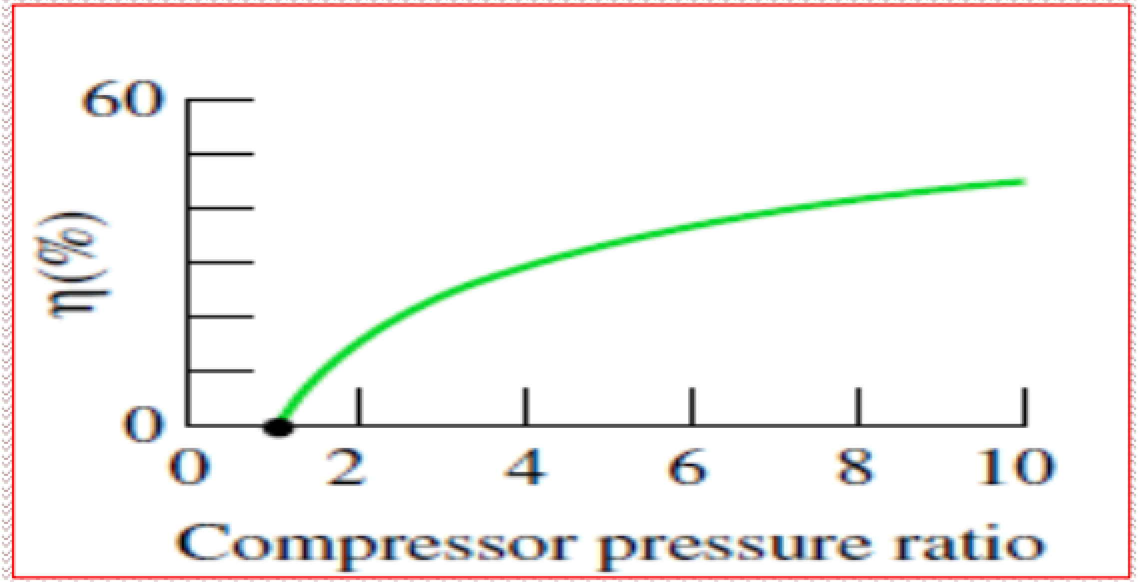
where

$$T_4/T_1 = T_3/T_2$$

$$\eta = 1 - \frac{T_1}{T_2}$$

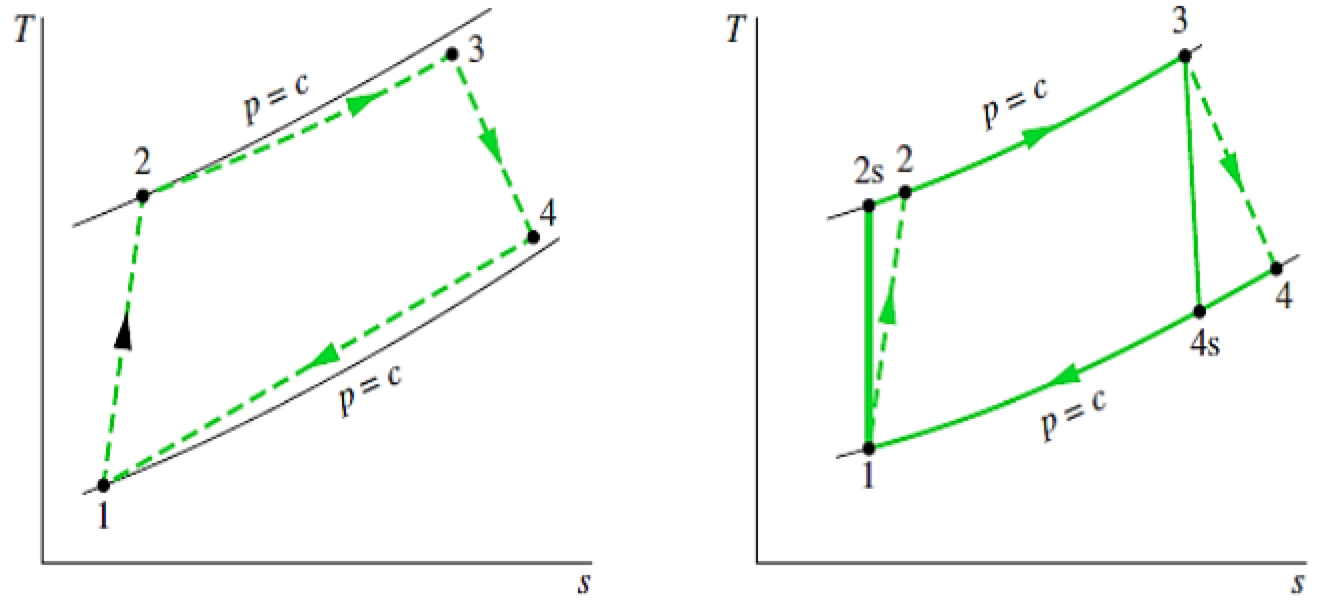
$$\eta = 1 - \frac{1}{(p_2/p_1)^{(k-1)/k}}$$





Brayton cycle thermal efficiency versus compressor pressure ratio

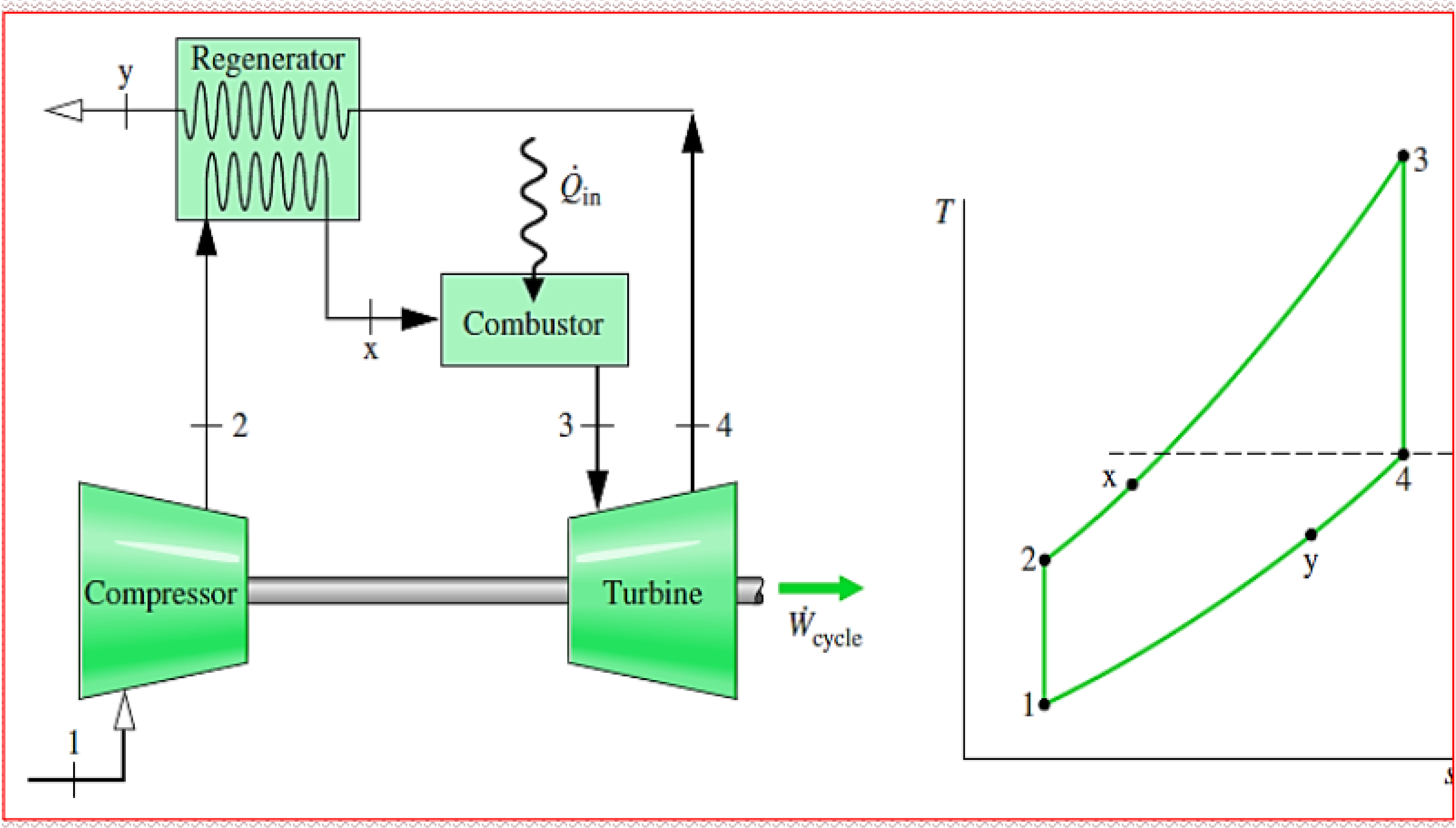
Gas Turbine Irreversibilities and Losses



$$\eta_t = \frac{(\dot{W}_t/\dot{m})}{(\dot{W}_t/\dot{m})_s} = \frac{h_3 - h_4}{h_3 - h_{4s}}$$

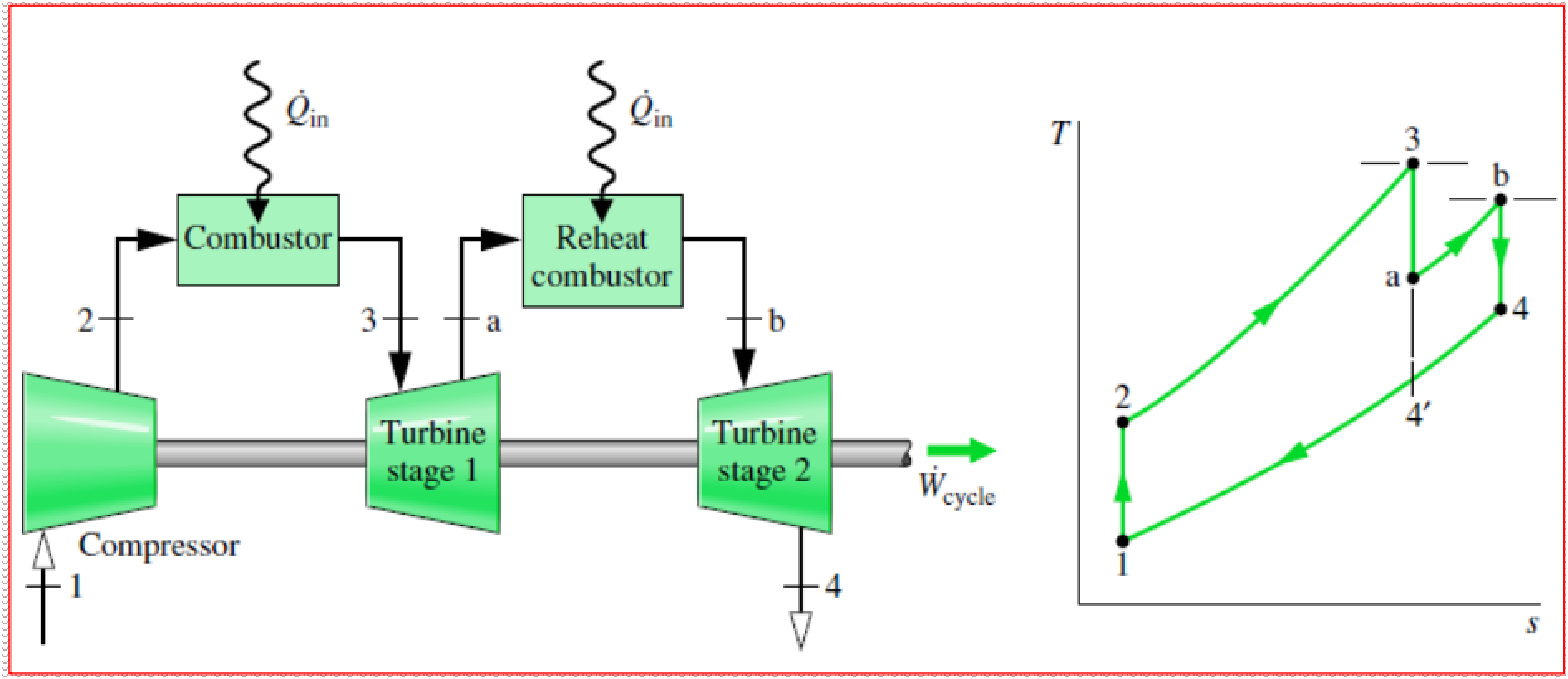
$$\eta_c = \frac{(\dot{W}_c/\dot{m})_s}{(\dot{W}_c/\dot{m})} = \frac{h_{2s} - h_1}{h_2 - h_1}$$

REGENERATIVE GAS TURBINES



$$\frac{\dot{Q}_{in}}{\dot{m}} = h_3 - h_x$$

GAS TURBINES WITH REHEAT

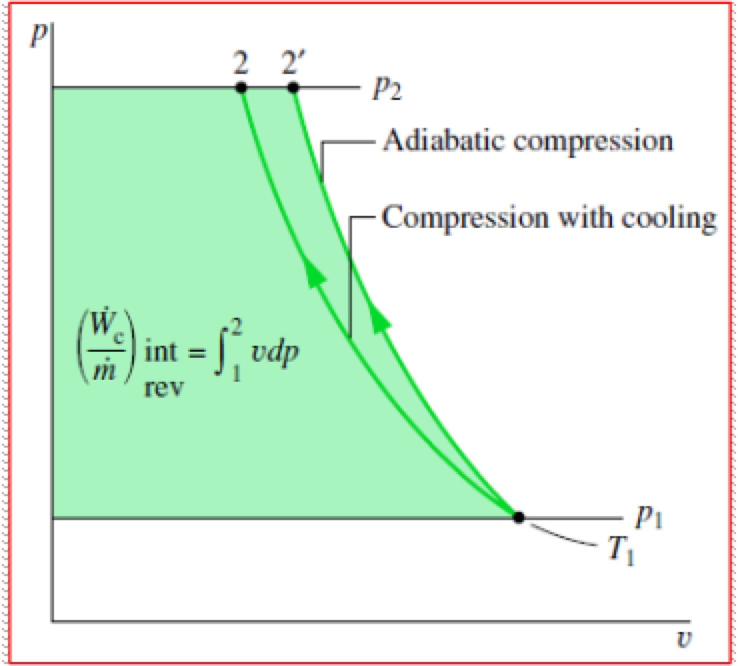


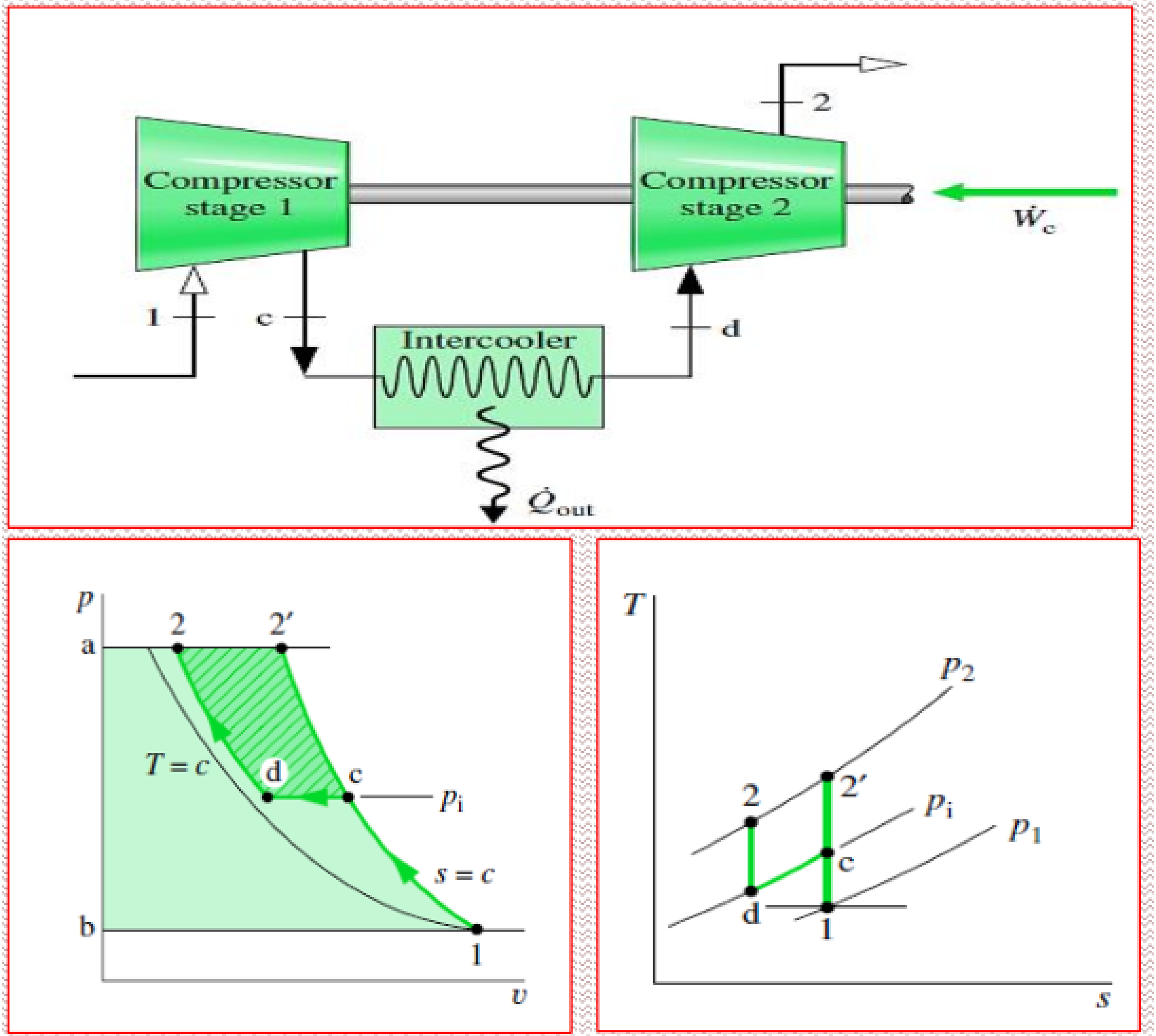
Brayton cycle with reheat

GAS TURBINES WITH INTERCOOLING

- The net work output of a gas turbine also can be increased by reducing the compressor work input. This can be accomplished by means of multistage compression with intercooling.

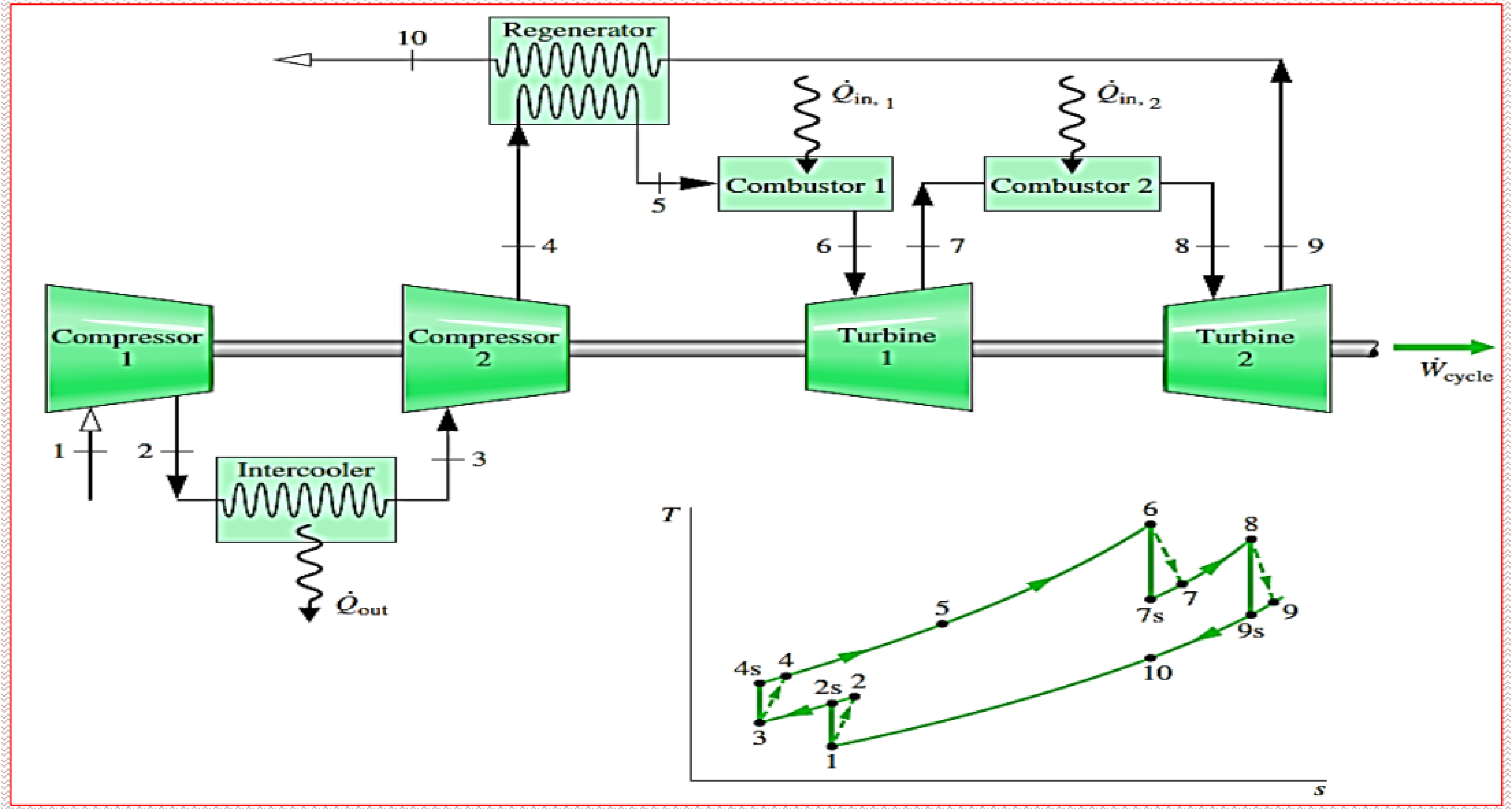
- Path 1–2’ is for an adiabatic compression.
- Path 1–2 corresponds to a compression with heat transfer from the working fluid to the surroundings.
- The area to the left of each curve equals the magnitude of the work per unit mass of the respective process.





Two-stage compressor with an intercooler

GAS TURBINES WITH REHEAT AND INTERCOOLING



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