- Recap: Lecture 8: 22nd January 2013, 0930-1025 hrs.
  - First law for open systems
  - Conservation of mass
  - Flow work and the energy of a flowing fluid
  - Total energy of a flowing fluid
  - Energy analysis of steady flow systems
  - Steady flow energy equation
  - Nozzles/diffusers, compressors/turbines, throttling devices, mixing chambers

- Comparison of steady flow energy equation with Euler and Bernoulli equations

$$\dot{Q}_{in} + \dot{W}_{in} + \sum_{in} \underbrace{\dot{m}\left(h + \frac{V^2}{2} + gz\right)}_{\text{for each inlet}} = \dot{Q}_{out} + \dot{W}_{out} + \sum_{out} \underbrace{\dot{m}\left(h + \frac{V^2}{2} + gz\right)}_{\text{for each exit}}$$

The steady flow equation in differential form

$$\partial Q = dh + \bar{V}d\bar{V} + gdz + \partial W$$

Since $h = u + pv$ and $\partial Q = du + pdv$ (for a quasi - static process involving only pdv work),

$$du + pdv = du + pdv + vdp + \bar{V}d\bar{V} + gdz + \partial W$$

For an inviscid frictionless flow, say, through a pipe

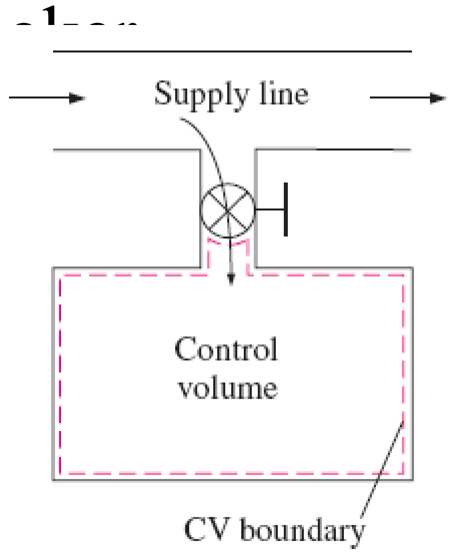
$$vdp + \bar{V}d\bar{V} + gdz = 0$$

This is the Euler equation.

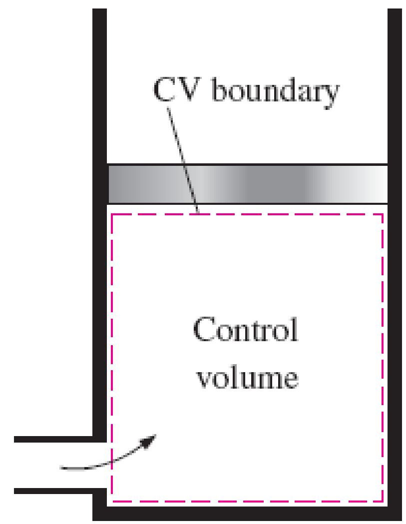
If we integrate between two sections,

$\dfrac{p}{\rho} + \dfrac{\bar{V}^2}{2} + gz = const$. This is the Bernoulli equation.

- **Unsteady flow processes**
  - important to keep track of the mass and energy contents of the control volume as well as the energy interactions across the boundary
  - Charging, discharging of tanks from pipelines, inflating tyres or balloons, cooking in a pressure cooker



Charging if a rigid tank from a supply line is an unsteady process, due to changes within the control volume.



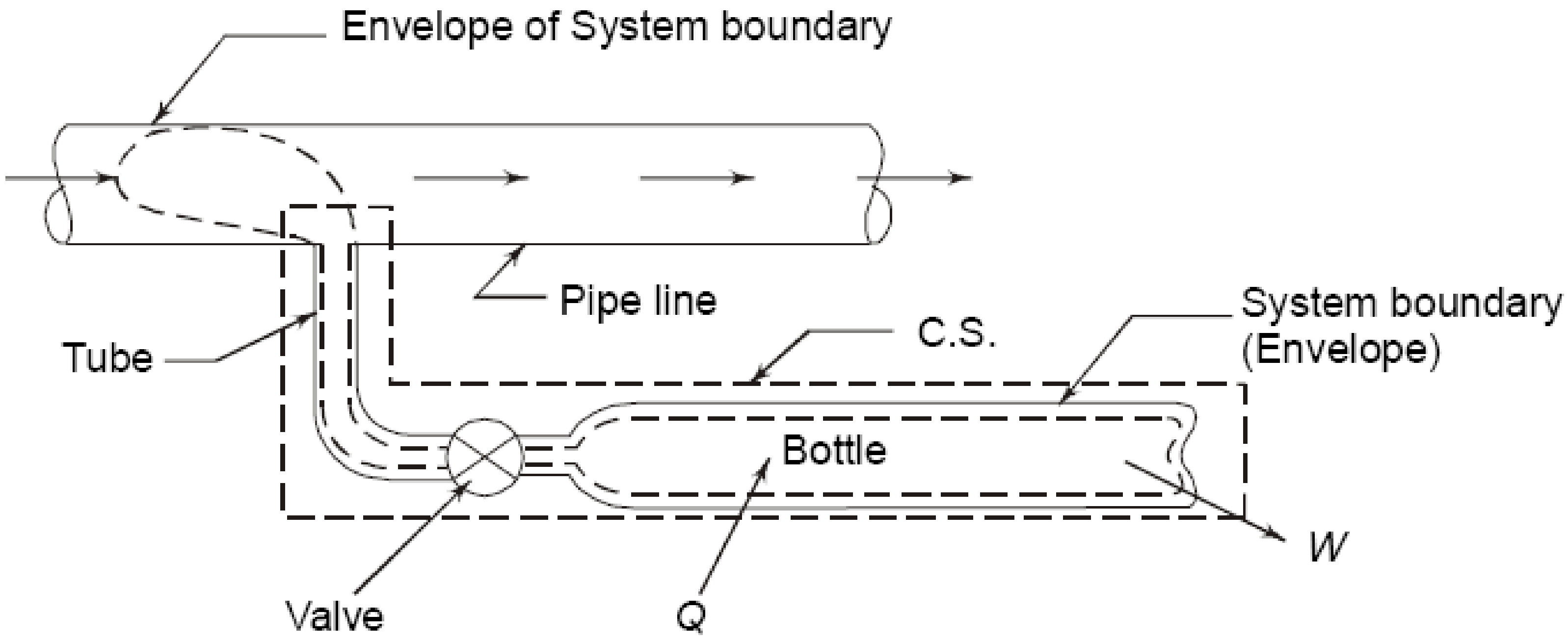
The shape and size of a control volume may change during an unsteady flow process.

The *mass balance* for any system undergoing any process can be expressed as

$$m_{\text{in}} - m_{\text{out}} = \Delta m_{\text{system}} \qquad \text{(kg)}$$

where $\Delta m_{\text{system}} = m_{\text{final}} - m_{\text{initial}}$ is the change in the mass of the system. For control volumes, it can also be expressed more explicitly as

$$m_i - m_e = (m_2 - m_1)_{\text{CV}}$$



- The bottle initially contains a mass m1 at state P1, T1, v1, h1, and u1. As the valve is opened and gas flows into the bottle till mass m2 at state P2, T2, v2, h2, and u2 is attained.
- The state of the gas in the supply pipeline can be assumed to be constant Pp, Tp, vp, hp, up and Vp.

Energy of the gas before filling

$$E_1 = m_1 u_1 + (m_2 - m_1)\left(\frac{V_P^2}{2} + u_P\right)$$

Where, $(m_2 - m_1)$ is the mass of gas in the pipeline and the tube which would enter the bottle.

Energy of the gas after filling, $E_2 = m_2 u_2$

$$\Delta E = E_2 - E_1 = m_2 u_2 - \left[m_1 u_1 + (m_2 - m_1)\left(\frac{V_P^2}{2} + u_P\right)\right]$$

The KE and PE terms have been appropriately neglected.

Work done because of the collapse of the envelope of gas volume, $W = P_P(V_2 - V_1) = P_P\left[0 - (m_2 - m_1)v_P\right]$

$$= -(m_2 - m_1)P_P v_P$$

Using the first for the process, $\mathrm{Q} = \Delta E + W$

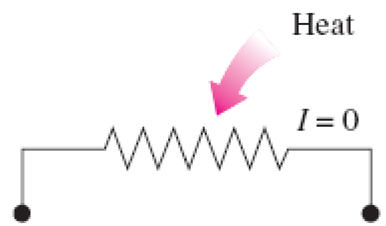
$$Q = m_2 u_2 - m_1 u_1 - (m_2 - m_1)\left(\frac{V_P^2}{2} + u_P\right) - (m_2 - m_1) P_P v_P$$

$$= m_2 u_2 - m_1 u_1 - (m_2 - m_1)\left(\frac{V_P^2}{2} + h_P\right)$$

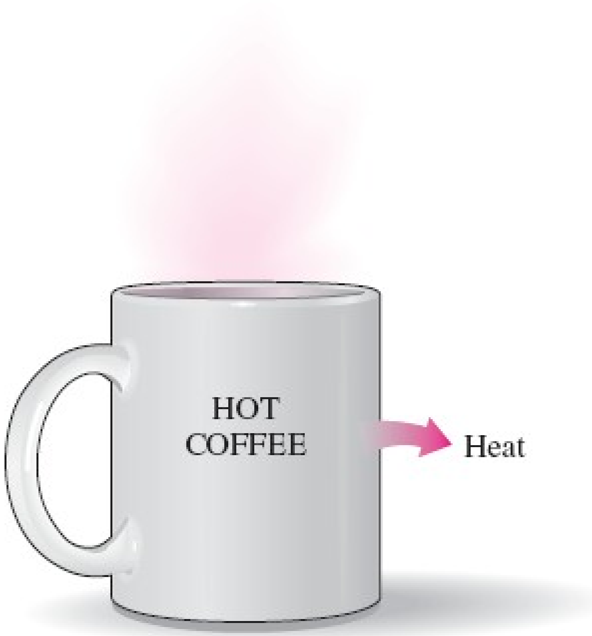
This gives the energy balance for this process. This equation can also be derived using the control volume (Eulerian) approach.

Second law of thermodynamics

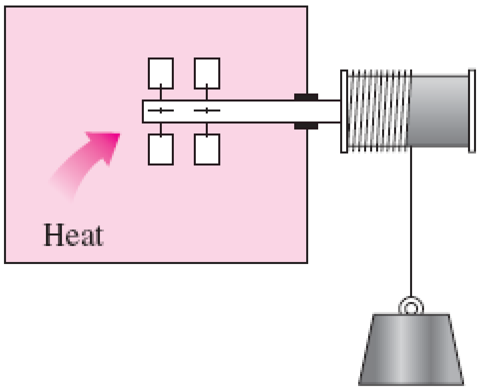
- Need for the second law of thermodynamics
  - Limitations of the first law of thermodynamics
  - Directionality of a process
  - Quality of energy
- Examples
  - A hot object does not get hotter in a cooler room.
  - Transferring heat to a resistor will not generate electricity.



Electricity cannot be generated by transferring heat to a wire



A cup of hot coffee will not get hotter in a cooler room



A paddle wheel cannot be rotated by transferring heat to it.

Second law of thermodynamics

- Processes proceed in a certain direction and not in the reverse direction.
- The first law places no restriction on the direction of a process.
- This inadequacy of the first law to identify whether a process can take place or not is remedied by the second law of thermodynamics.
- A process cannot occur unless it satisfies both the first and the second laws of thermodynamics.

Second law of thermodynamics

- The first law of thermodynamics was concerned only with the quantity of energy and its transformations.
- Second law reveals that energy has quantity as well as quality.
- Second law of thermodynamics determines theoretical limits for feasibility of a process.

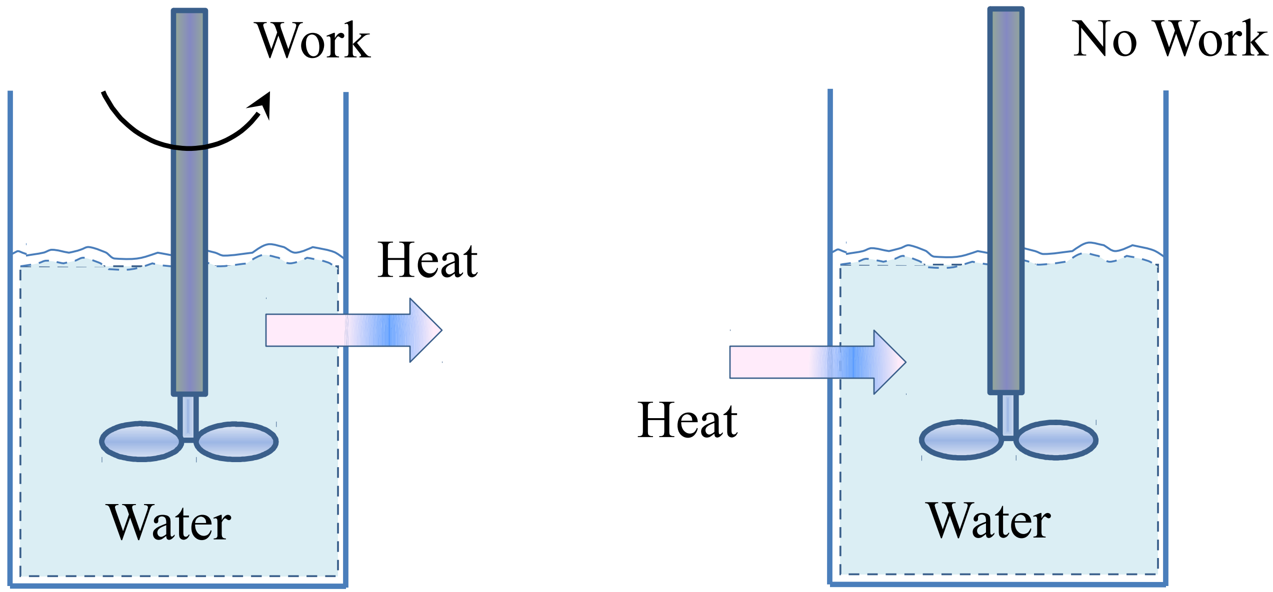
Thermal energy reservoir

- A hypothetical body with a relatively large thermal energy (mass x specific heat).
- Supply or absorb infinite amounts of heat without any change in its temperature
- Eg. Oceans, lakes, atmosphere
- A reservoir that supplies energy in the form of heat: Source
- A reservoir that absorbs energy in the form of heat: Sink

Heat engines

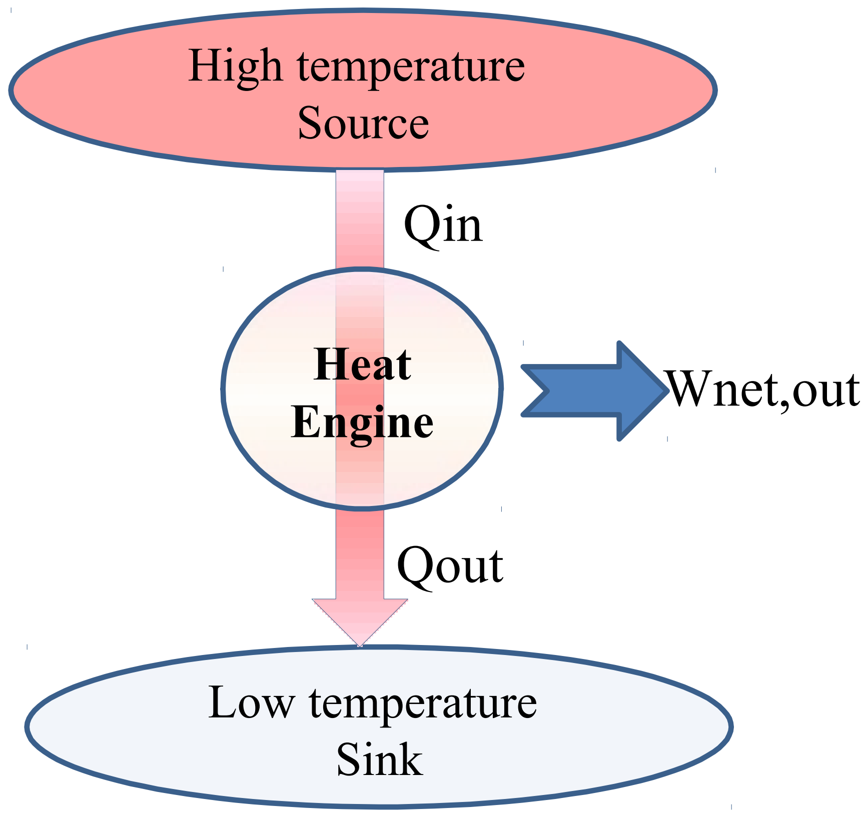
- Work can be rather easily converted to heat.
- The reverse process is not easy and requires special devices: heat engines
- Receive heat from a high-temperature source (solar energy, oil furnace etc.).
- Convert part of this heat to work
- Reject the remaining waste heat to a low-temperature sink
- Operate on a cycle

Heat engines



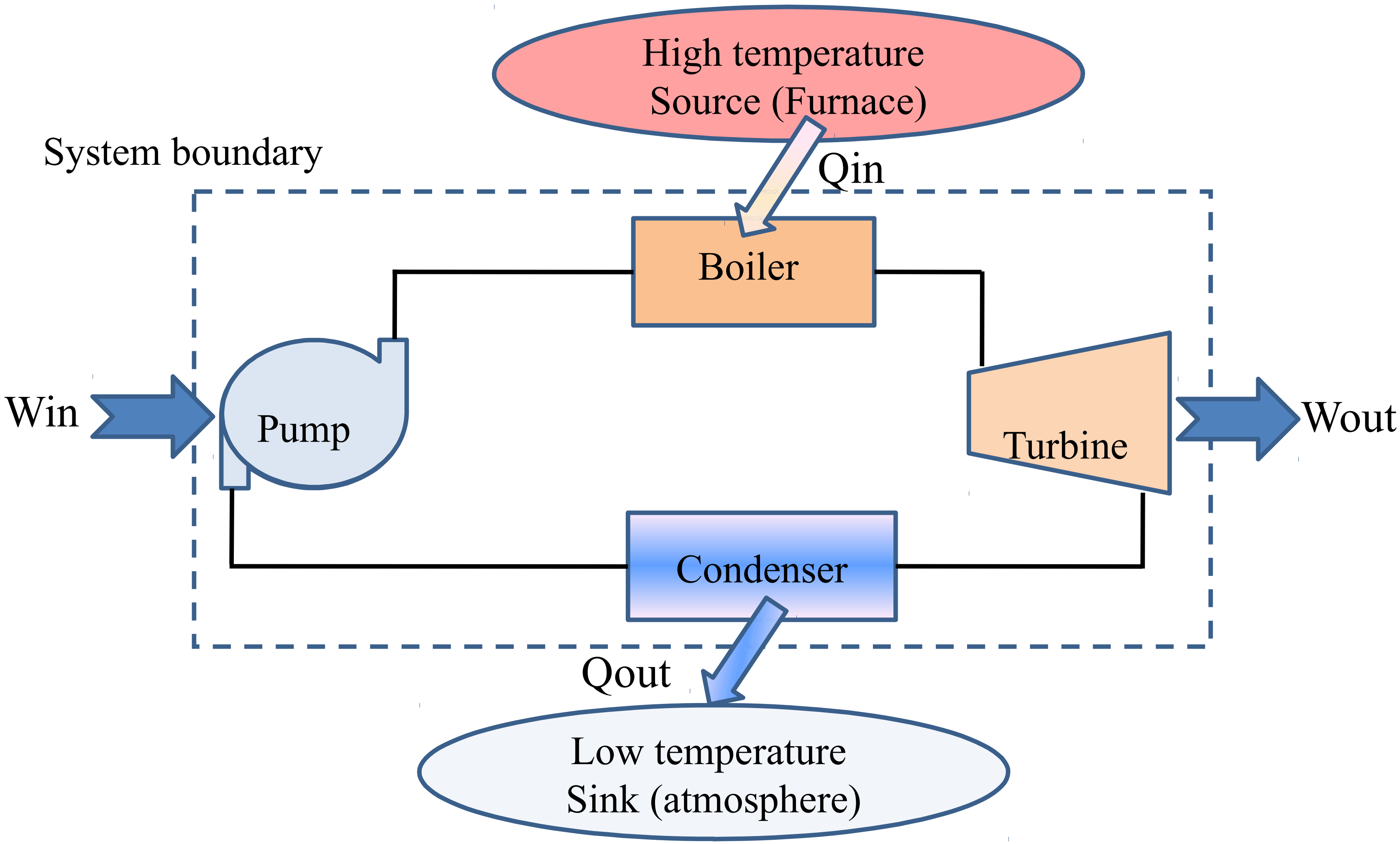
Work can be easily converted to heat, but the reverse does not occur naturally.

Heat engines



Heat engines convert part of Qin to Wnet,out and reject the balance heat to the sink.

Heat engines



Heat engines

- The net work output of the heat engine

$$W_{net,out} = W_{out} - W_{in} \qquad \text{(kJ)}$$

- The heat engine system may be considered as a closed system and hence $\Delta U=0$.

$$W_{net,out} = Q_{in} - Q_{out} \qquad \text{(kJ)}$$

Thermal efficiency

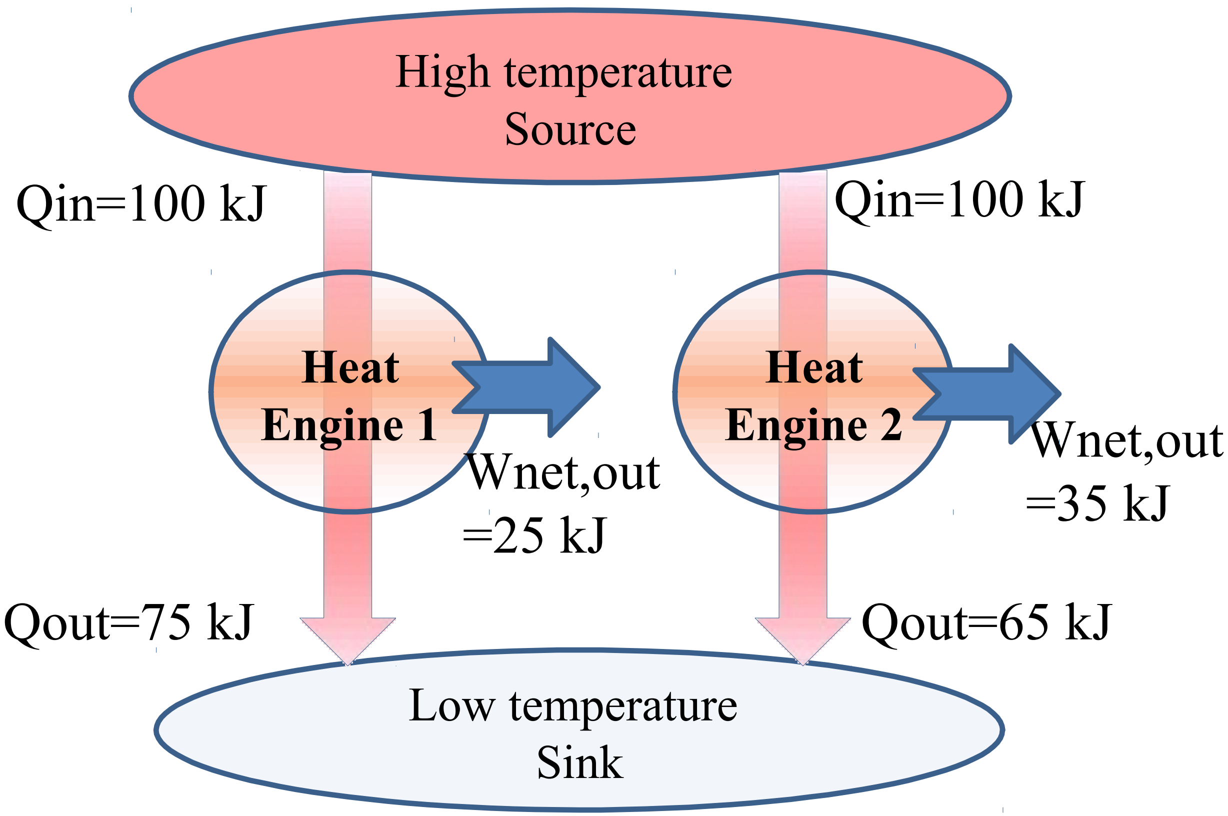
- Qout: energy "wasted" during the process
- Only part of the heat input can be converted to useful work output.
- For heat engines, thermal efficiency is defined as

$$\text{Thermal efficiency} = \frac{\text{Net work output}}{\text{Total heat input}}$$

$$\eta_{th} = \frac{W_{net,out}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$$

$$(\text{since } \mathrm{W}_{\text{net,out}} = Q_{in} - Q_{out})$$

Thermal efficiency



$$\eta_{th1} = \frac{25}{100} = 0.25$$

$$\eta_{th2} = \frac{35}{100} = 0.35$$

All heat engines do not perform the same way.

Thermal efficiency

- Even the most efficient heat engines reject a huge fraction of the input energy.
- Thermal efficiency of common heat engines
  - Automobile engines: 20-25%
  - Aero engines: 25-30%
  - Gas turbine power plants: 40%
  - Combined cycle power plants: 60%