Ninevah University
College of Electronics Engineering
Systems & Control Engineering

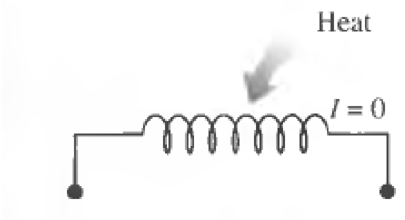
Second Law of Thermodynamics

The first law of thermodynamics states that energy is a conserved property and thus it cannot be created or destroyed but it can be converted from one form to another (heat, work, etc.). That is:

$$\Delta U = Q - W$$

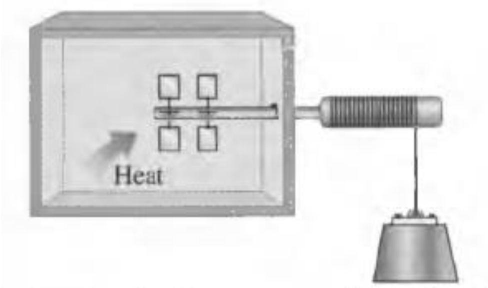
I: The Second Law of Thermodynamics states that a process can occur in a ***certain direction*** and not in the ***reverse direction***. For example:

1. consider the heating of a room by passing electric current through a resistor. the first law states that the amount of electric energy supplied to the wires is equal to the amount of energy transferred to the room air as heat. To reverse this process. It is obvious that transferring some heat to the wires does not cause an equivalent amount of electric energy to be generated in the wires.



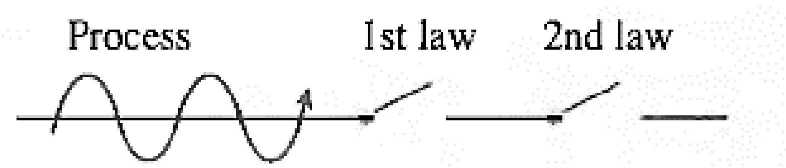
Transferring heat to a wire will not generate electricity.

2. consider a paddle-wheel mechanism that is operated by the fall of a mass. As the mass drops, the potential energy of the mass decreases and the internal energy of the fluid increases according to the conservation of energy principle. However, the reverse process of raising the mass by transferring heat from the fluid to the paddle wheel does not occur in nature.



Transferring heat to a paddle wheel will not cause it to rotate.

Therefore, the first law places no restriction on the direction of a process, but satisfying the first law does not ensure that the process can actually occur. A process can only occur if it satisfies both the first and the second laws of thermodynamics.



II: The Second Law of Thermodynamics also states that energy has ***quality*** as well as **quantity**. This can be easily detected with the help of a property called ***entropy.***

Entropy: A measure of the amount of energy unavailable to do work.

III: The Second Law of Thermodynamics is also used in determining the ***efficiency*** of commonly used engineering devices such as heat engines and refrigerators.

Thermal Energy Reservoirs

a body with a relatively large ***thermal energy capacity*** (mass X specific heat) that can supply or absorb finite amounts of heat without undergoing any significant change in temperature.

Ex: Atmosphere, oceans and rivers

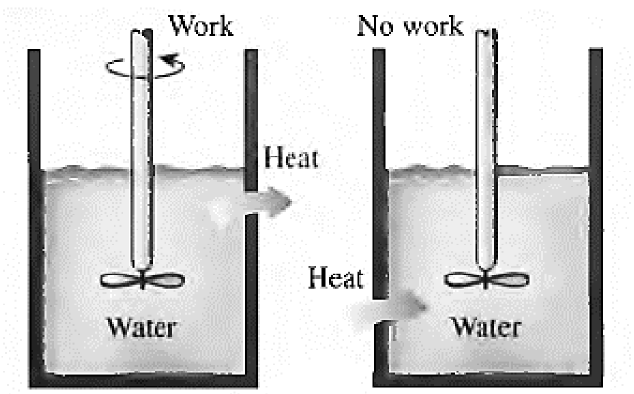
Reservoirs

Source: A reservoir that supplies energy in the form of heat Q_{in} (Furnaces). It is also known as the high temperature T_H reservoir.

Sink: A reservoir that absorbs energy in the form of heat Q_{out} (Atmosphere). It is also known as the Low temperature T_L reservoir.

Heat Engines

Work can always be converted to heat directly and completely, but the reverse is not true. Converting heat to work requires the use of some special devices. These devices are called **heat engines**.



In general, the working principle of heat engines is as follow:

1. They receive heat from a high-temperature source

   (solar energy, oil furnace, nuclear reactor, etc.).

2. They convert part of this heat to work

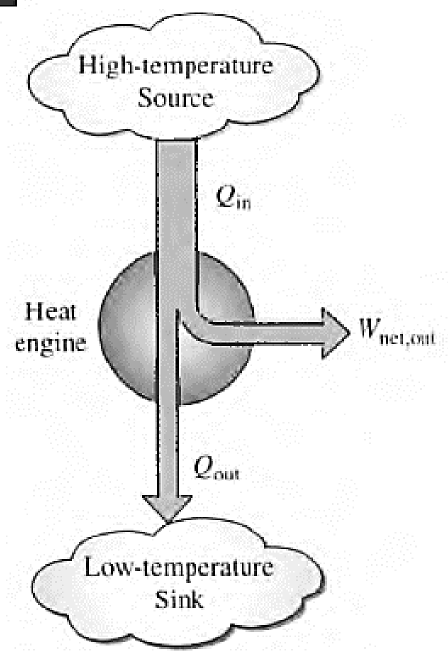
   (usually in the form of a rotating shaft).

3. They reject the remaining heat to a low-temperature sink

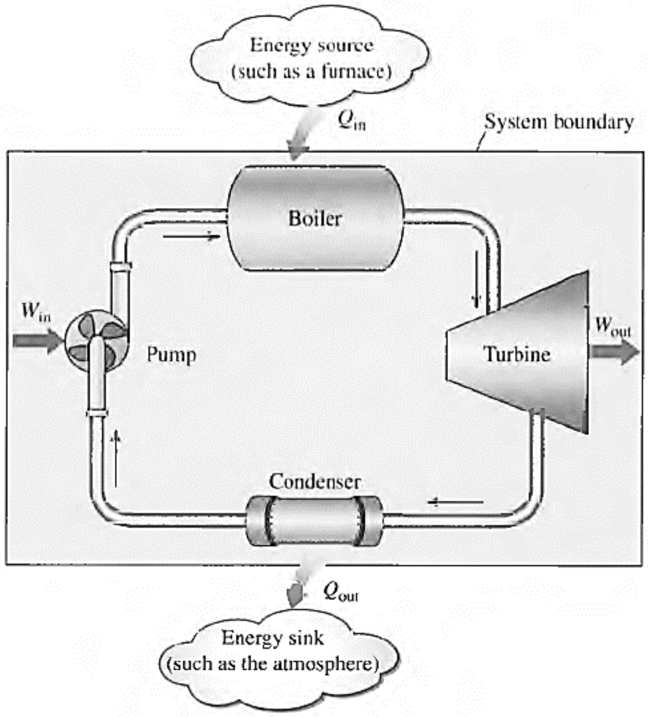
   (the atmosphere, rivers, etc.).

4. They operate on a cycle.

$$\boxed{W_{out} = Q_{in} - Q_{out}}$$



An example of a heat engine is the ***steam power plant,*** which is an external-combustion engine in which the combustion takes place outside the engine.



Q_{in}: amount of heat supplied to steam in boiler from a high-temperature source (furnace)

Q_{out}: amount of heat rejected from steam in condenser to a low temperature sink (the atmosphere, a river, etc.)

W_{out} = amount of work delivered by steam as it expands in turbine

W_{in} = amount of work required to compress water to boiler pressure

$$W_{out} = Q_{in} - Q_{out}$$

$$W_{net} = W_{out} - W_{in}$$

Thermal Efficiency

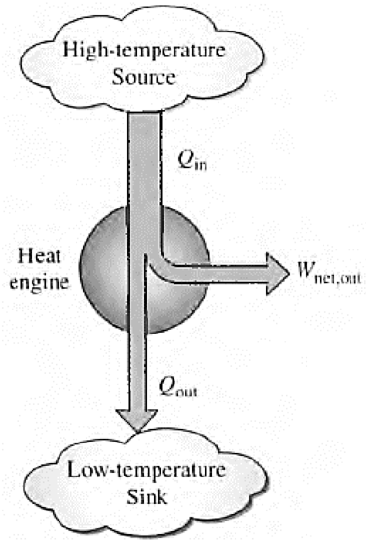
Only part of the heat transferred to the heat engine (Q_{in}) is converted into a work (W_{out}). Therefore, thermal efficiency is a measure of how efficiently a heat engine converts the heat that it receives to work. The thermal efficiency of a heat engine can be expressed as the ratio of the output work to the supplied input heat.

$$\eta = \frac{W_{out}}{Q_{in}}$$

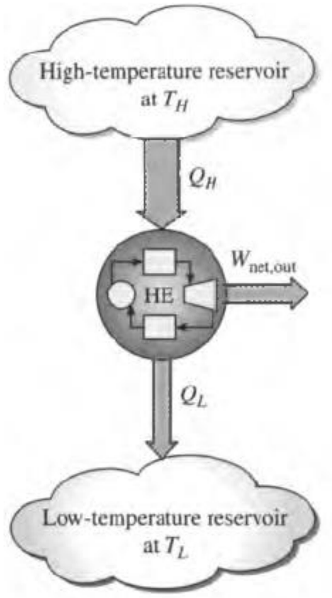
$$W_{out} = Q_{in} - Q_{out}$$

$$\eta = \frac{Q_{in} - Q_{out}}{Q_{in}}$$

$$\eta = 1 - \frac{Q_{out}}{Q_{in}}$$



Cyclic devices such as heat engines and refrigerators operate between a high-temperature reservoir at temperature T_H and a low-temperature reservoir at temperature T_L. *Thus*



$$\eta = \frac{W_{out}}{Q_H}$$

$$\eta = 1 - \frac{Q_L}{Q_H}$$

The thermal efficiencies of **work-producing devices** are relatively **LOW**. The table below shows thermal efficiency of several devices

Device	Efficiency
Ordinary spark-ignition automobile engines	About 25 %
Diesel engines	As high as 40 %
Single cycle gas turbine	Typical 30 %
Combined cycle gas turbine	As high as 60 %

That is, an automobile engine converts about 25 percent of the chemical energy of the gasoline to mechanical work.

Ex) Heat is transferred to a heat engine from a furnace at a rate of 80 MW. If the rate of waste heat rejection to a nearby river is 50 MW, determine the net power output and the thermal efficiency for this heat engine.