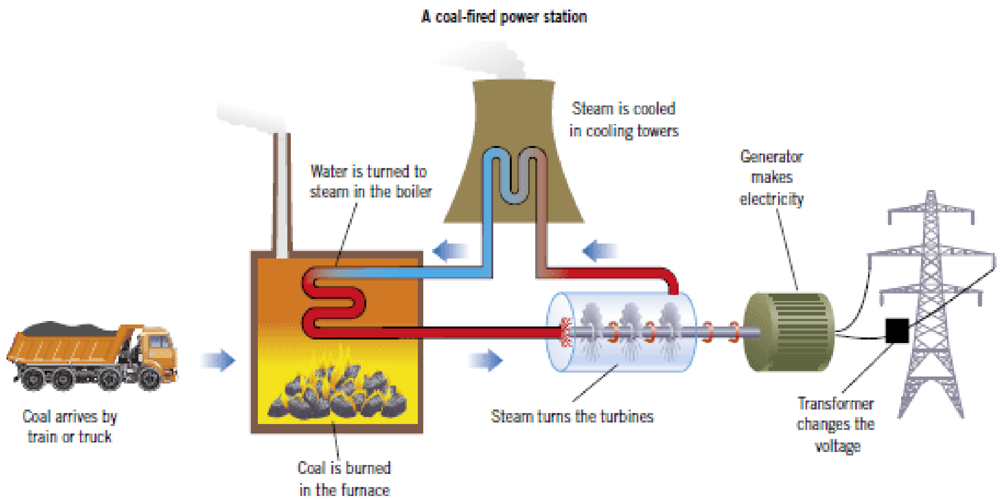
2^{nd} Law of Thermodynamics

Most of our energy resources come from the burning of fossil fuels (coal, oil, and gas) and from nuclear reactions. These resources supply energy that is transferred as heat.



Thus, it is very important for us to know how to take heat from a source and convert it as much as possible (highest efficiency) into mechanical work.

Heat Engines

A. Heat Engine - A device that transforms heat into work or mechanical energy.
B. A heat engine carries a working substance through a cyclic process:

1. Working substance absorbs energy from a high T reservoir.
2. Work is done by the engine.
3. Energy is expelled by engine to a lower T reservoir.

Ex. Working Substances

1. Air & fuel – internal combustion engine
2. Water – steam engine

The working substance usually absorb and expel heat, expand/compress, and sometimes experience phase changes.

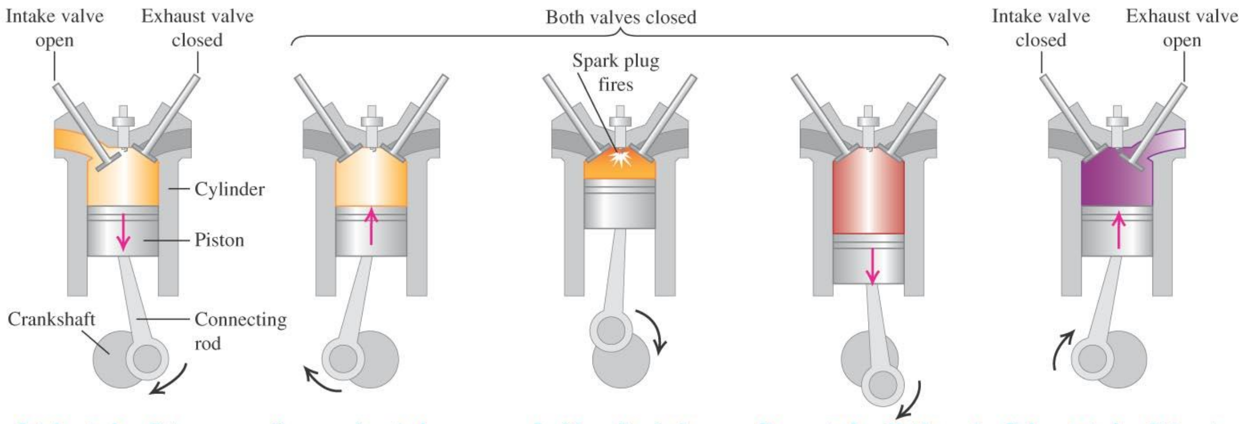
ALL heat engines absorb heat from a source at a relative high T, perform mechanical work, and discard some heat at a lower T.

Cyclic Process:

$$\Delta U = 0 = Q - W$$
$$Q = W$$

The net heat flowing into an engine in a cyclic process equals the net work done by the engine.

Ex. Four-Stroke cycle of a conventional gas engine.



Intake stroke: Piston moves down, causing a partial vacuum in cylinder; gasoline–air mixture enters through intake valve.

Compression stroke: Intake valve closes; mixture is compressed as piston moves up.

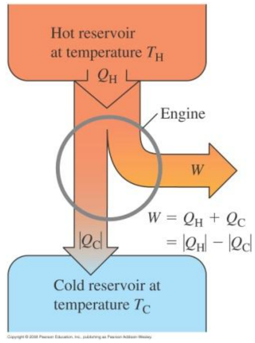
Ignition: Spark plug ignites mixture.

Power stroke: Hot burned mixture expands, pushing piston down.

Exhaust stroke: Exhaust valve opens; piston moves up, expelling exhaust and leaving cylinder ready for next intake stroke.

Energy-Flow Diagrams and Efficiency

We can represent energy transformations in a heat engine by an energy-flow diagram.



For a given energy cycle Q_H and Q_C represent the quantities of heat absorbed and rejected. The net heat Q absorbed during one cycle is:

$$Q = Q_H + Q_C = |Q_H| - |Q_C|$$

The useful output of the engine is the net work done by the working substance. From the 1st Law:

$$W = Q = Q_H + Q_C = |Q_H| - |Q_C|$$

Ideally we would like to convert ALL the heat Q_H into work and thus:

$$\boxed{\begin{array}{l} W = Q_H \\ Q_C = 0 \end{array}}$$ Impossible!!

Experimentally we find that this is impossible and $Q_C \neq 0$!

We define the efficiency 'e' of an engine as:

$$\boxed{e = \frac{W}{Q_H} = 1 + \frac{Q_C}{Q_H} = 1 - \left|\frac{Q_C}{Q_H}\right|}$$ efficiency of an engine

1. efficiency is defined as the ratio of the net work done by an engine during one cycle divided by the energy absorbed at the higher temperature during the cycle.

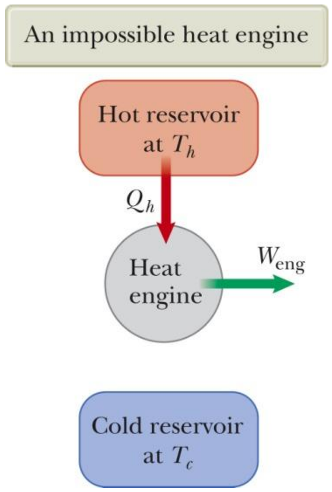
2. The ratio of what you gain (work) to what you give (energy transfer at the higher temperature).

In practice all real engine only convert a fraction of the input energy Q_H as mechanical work and thus their efficiency is less than 100%.

Car gas engine – 20%
Diesel engine – 35 %

Thus, it's impossible to have a 100% efficiency engine with Q_C = 0.

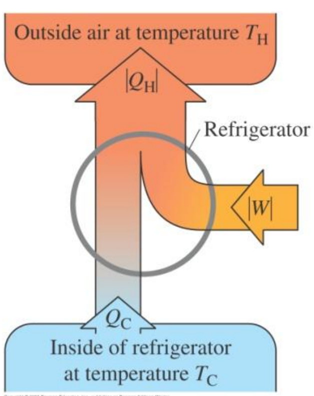
2nd Law of Thermodynamics (Engine Statement)
It is impossible for any system to undergo a process in which it absorbs heat from a reservoir at a single temperature and converts the heat completely into mechanical work, with the system ending in the same state in which it began.



Refrigerator – A heat engine operating in reverse.

1. It takes heat from a cold place (inside the refrigerator) and gives it off to a warmer place (the air in the room where the refrigerator is kept).

2. A heat engine has a net output of mechanical work; the refrigerator requires a net input of mechanical energy (work).

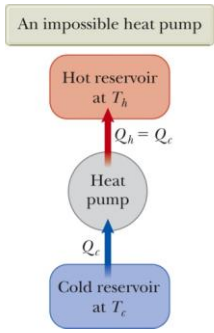


$$\Delta U = Q - W$$
$$0 = Q_H + Q_C - W$$
$$|Q_H| = Q_C + |W|$$

Why does a refrigerator require a net input of mechanical energy (work)?

1. Heat flows spontaneously from a hotter to colder body.
2. Work is needed to transfer heat from a colder to a hotter body.
3. Experiments show that it is impossible to make a refrigerator that transports heat from a colder body to a hotter body without the addition of work!

2^{nd} Law of Thermodynamics (Refrigerator Statement)
It is impossible for any process to have as its sole result the transfer of heat from a cooler to a hotter body.



The two versions of the 2^{nd} Law are equivalent. If one is true, then so is the other and if one is false, then so is the other.