Heat engine

Device that transforms heat into work.
It requires two energy reservoirs at different temperatures

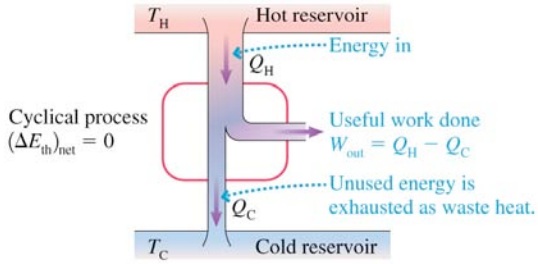
An energy reservoir is a part of the environment so large wrt the system that its temperature doesn't change as the system exchanges heat with the reservoir.

All heat engines and refrigerators operate between two energy reservoirs at different temperatures T_H and T_C.

Heat engine

Device that transforms heat into work.
It requires two energy reservoirs at different temperatures

Car, truck, jet, and rocket engines are heat engines. So are steam engines and turbines



Thermal efficiency

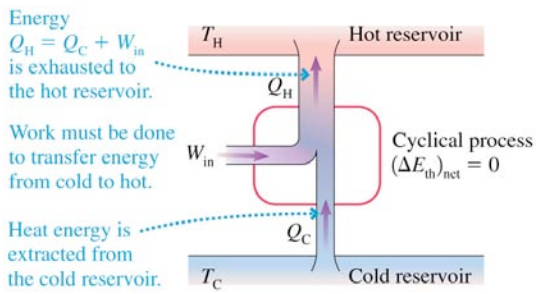
$$\eta = \frac{W_{out}}{Q_H} = \frac{what\ \ you\ \ get}{what\ \ you\ \ pay}$$

Second law limit

$$\eta \le \eta_{Carnot} = 1 - \frac{T_C}{T_H}$$

refrigerator

Device that uses work to transfer heat from a colder object to a hotter object.



Coefficient of performance

$$K = \frac{Q_C}{W_{in}} = \frac{what\ \ you\ \ get}{what\ \ you\ \ pay}$$

Second law limit

$$K \le K_{Carnot} = \frac{T_C}{T_H - T_C}$$

reversible engine

A perfectly reversible engine (a **Carnot engine**) can be operated either as a heat engine or a refrigerator between the same two energy reservoirs, by reversing the cycle and with no other changes.

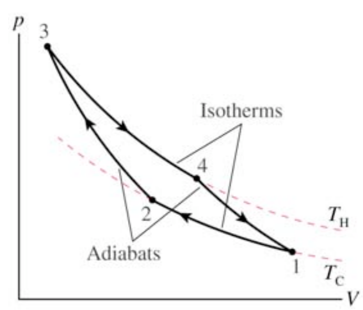
A **Carnot engine** has max. thermal efficiency, compared with any other engine operating between T_H and T_C.

$$\eta_{Carnot} = 1 - \frac{T_C}{T_H}$$

A **Carnot refrigerator** has max. coefficient of performance, compared with any other refrigerator operating between T_H and T_C.

$$K_{Carnot} = \frac{T_C}{T_H - T_C}$$

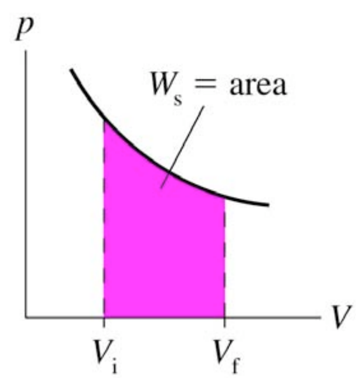
A **Carnot cycle** for a gas engine consists of two isothermal processes and two adiabatic processes.



tools

Work W_s done ***by*** the system

$W_s = -W =$ area under the pV curve

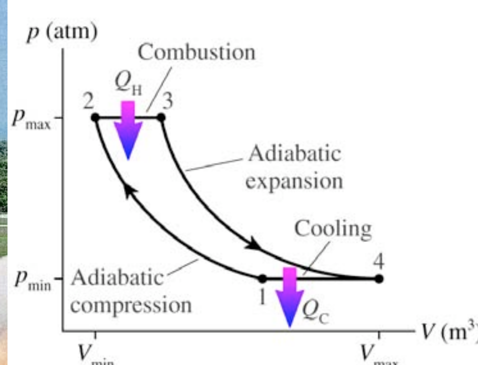


Steam turbines

A steam turbine is a mechanical device that extracts thermal energy from pressurized steam, and converts it into useful mechanical work.

90% of the world electricity is produced by steam turbines.

Steam turbines, jet engines and rocket engines use a **Brayton cycle**



Steam turbines

MG&E, the electric power plan in Madison, boils water to produce high pressure steam at 400°C. The steam spins the turbine as it expands, and the turbine spins the generator. The steam is then condensed back to water in a Monona-lake-water-cooled heat exchanger, down to 20°C.

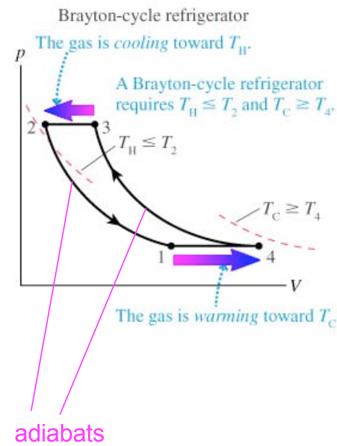
Steam turbines

MG&E, the electric power plan in Madison, boils water to produce high pressure steam at 400°C. The steam spins the turbine as it expands, and the turbine spins the generator. The steam is then condensed back to water in a Monona-lake-water-cooled heat exchanger, down to 20°C. What is the *maximum* possible efficiency with which heat energy can be converted to electrical energy?

$$\eta_{Carnot} = 1 - \frac{T_C}{T_H} = 1 - \frac{293}{673} = 0.44 = 44\%$$

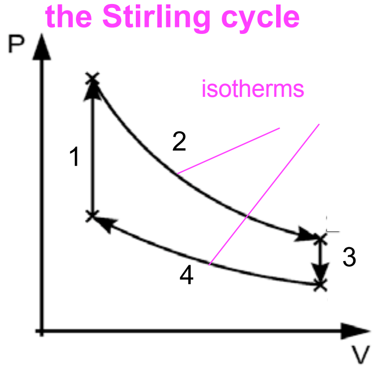
This is an upper limit: the real efficiency of MG&E is between 30-40%

Brayton-cycle refrigerator



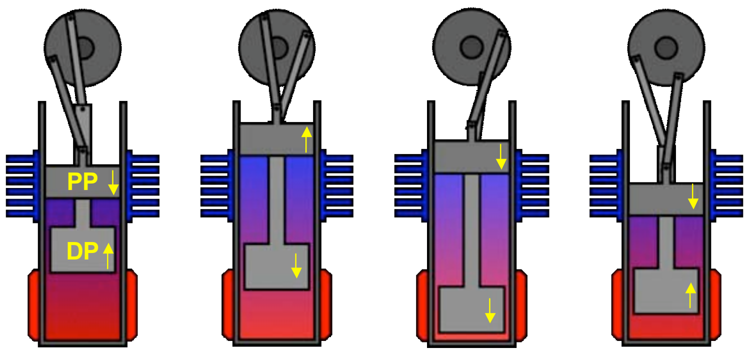
Stirling engines

the Stirling cycle

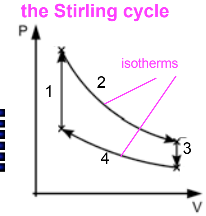


The SES solar Stirling system

Stirling Engine (Beta-type)



the Stirling cycle



Power piston (**PP**) has compressed the gas, the displacer piston (**DP**) has moved up so that most of the gas is adjacent to the hot heat exchanger.

The heated gas increases its pressure (1) and pushes the PP up along the cylinder (2). This is the $\mathbf{W_s>0}$ expansion, or **power stroke**.

The DP piston moves to shunt the gas to the cold end of the cylinder (3).

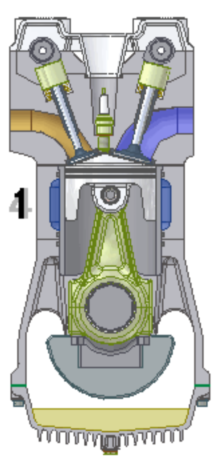
The cooled gas is now compressed by the flywheel momentum (4). This takes less work than $-\mathbf{W_s}$, because when the gas cooled its pressure also dropped.

Animated version. Note that PP lags DP by 90°. In this design the displacer piston shaft passes through the power piston in a gas proof sleeve.

In addition, and internal heat exchanger called **the regenerator** increases the efficiency, up to ~40%!

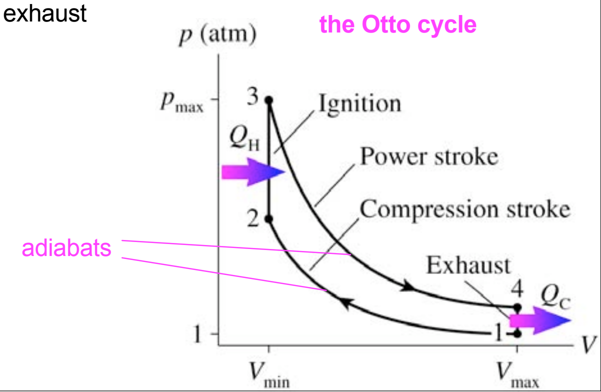
Internal combustion engine: gasoline engine

A gasoline engine utilizes the Otto cycle, in which fuel and air are mixed *before* entering the combustion chamber and are then ignited by a spark plug.



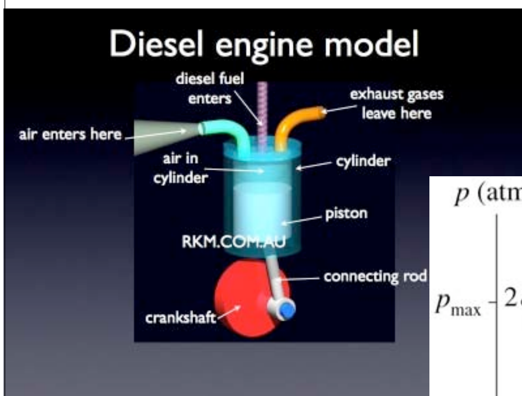
Four-stroke cycle

1. intake
2. compression
3. power stroke
4. exhaust

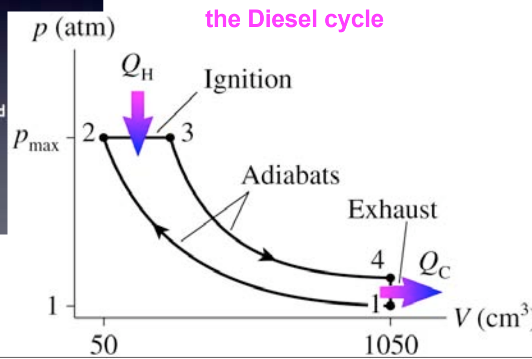


Internal combustion engine: Diesel engine

A Diesel engine uses compression ignition, a process by which fuel is injected *after* the air is compressed in the combustion chamber causing the fuel to self-ignite.



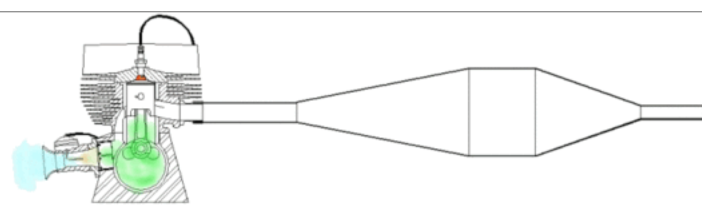
the Diesel cycle



Internal combustion engine

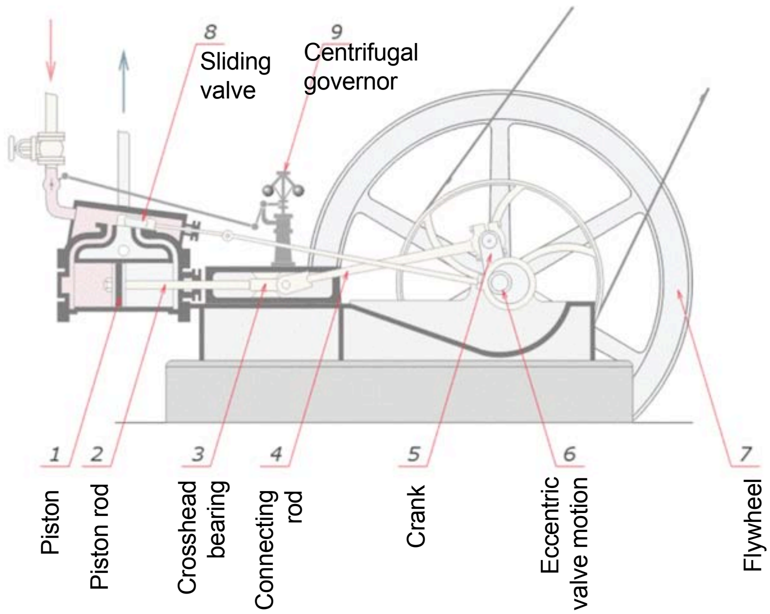
Two-stroke cycle

1. intake and compression
2. power stroke and exhaust

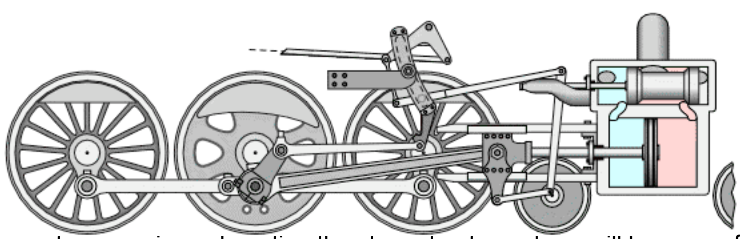


A two-stroke engine, in this case with an expansion pipe, illustrates the effect of a reflected pressure wave on the fuel charge. This feature is present in most high performance engine designs.

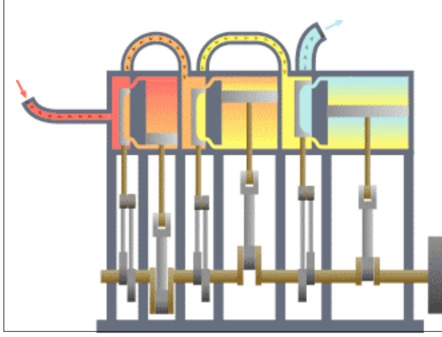
A typical single cylinder, simple expansion **steam engine**



Locomotive Steam Engine



In practice, a steam engine exhausting the steam to atmosphere will have an efficiency (including the boiler) of 1% to 8%, but with the addition of a condenser and multiple expansion engines the efficiency may be greatly improved.



A simplified triple-expansion engine. High-pressure steam (red) enters from the boiler and passes through the engine, exhausting as low-pressure steam (blue) to the condenser. Efficiency is 25% or better.