Chemical Engineering (Thermodynamics I) (UCH305)

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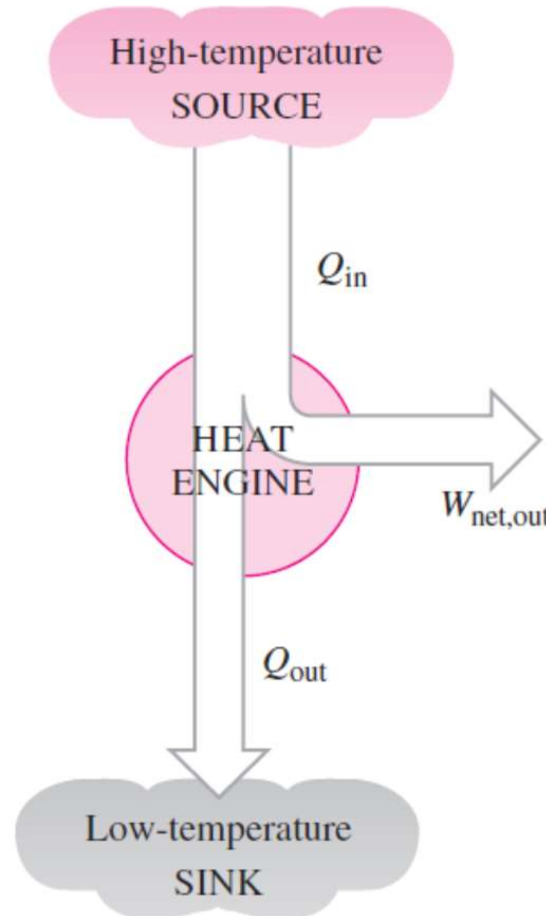
Lecture 18

Heat engines

Heat engines

- The **heat engine** is a ***device*** which converts heat into work.

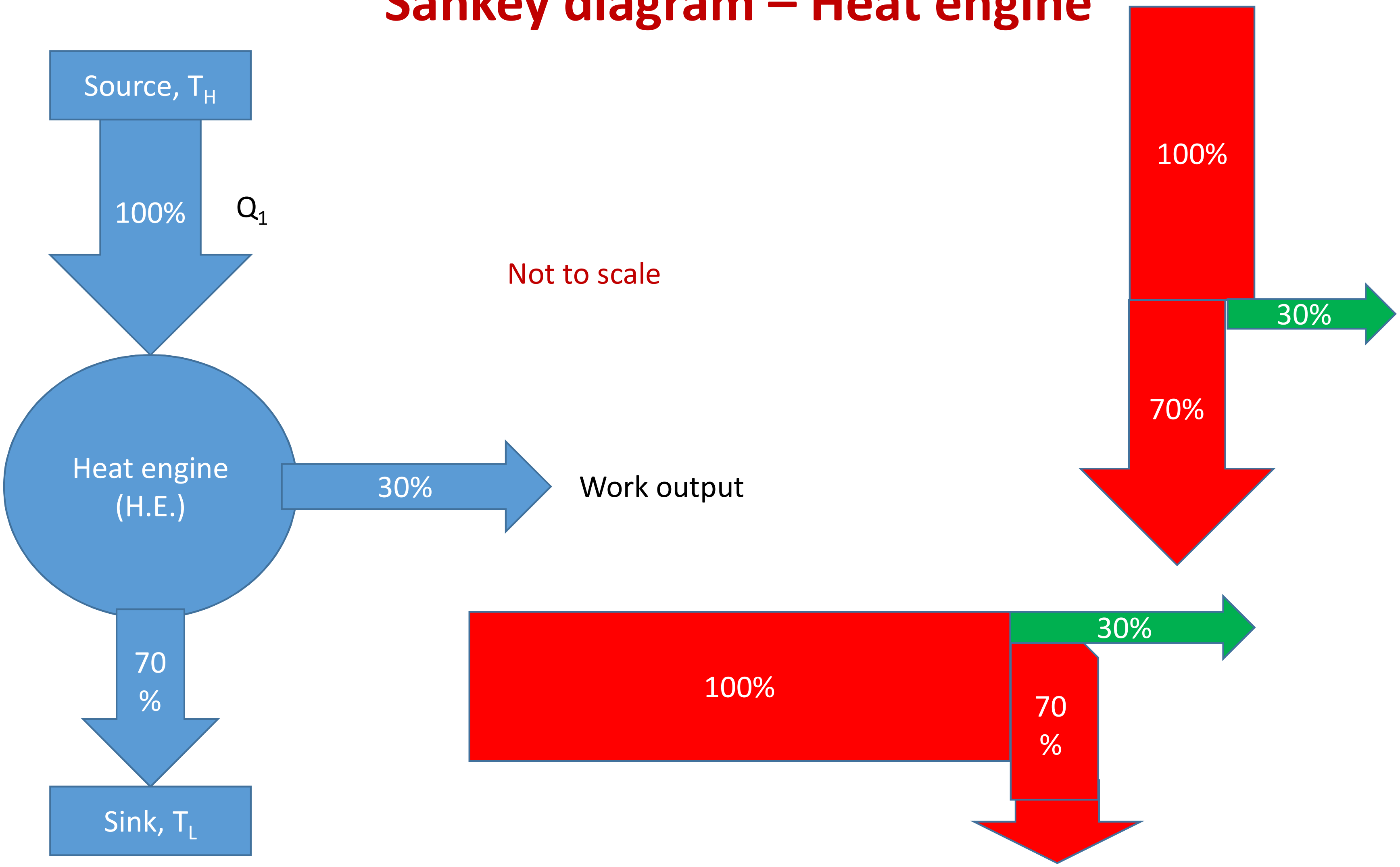
- Heat engines differ considerably from one to another, but all can be characterized by the following:
  1) They receive heat from a high-temperature source (solar energy, fuel, oil furnace, nuclear reactor, etc.).
  2) They convert part of this heat to work (usually in the form of a rotating shaft).
  3) They reject the remaining waste heat to a low-temperature sink (the atmosphere, rivers, etc.).
  4) They operate on a cycle.



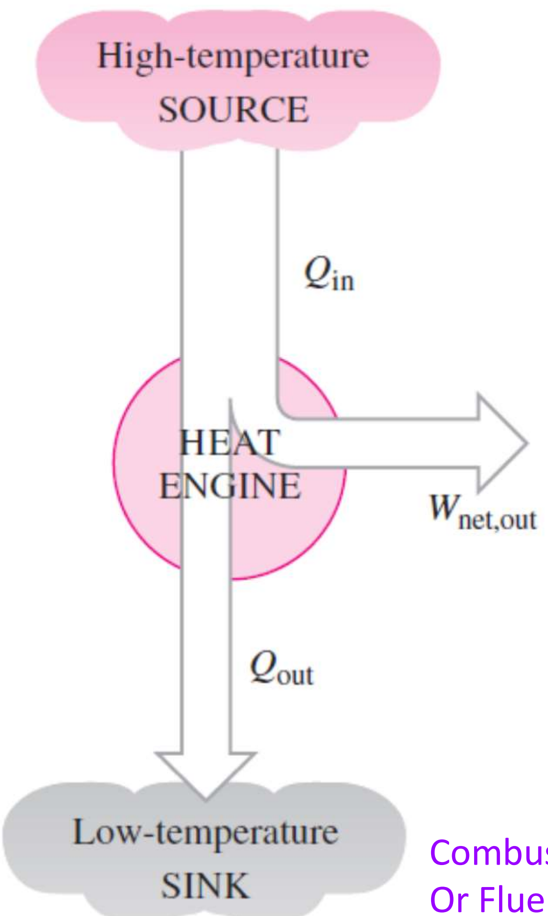
- Heat engines and other cyclic devices usually involve a fluid to and from which heat is transferred while undergoing a cycle.

- This fluid is called the **working fluid**.

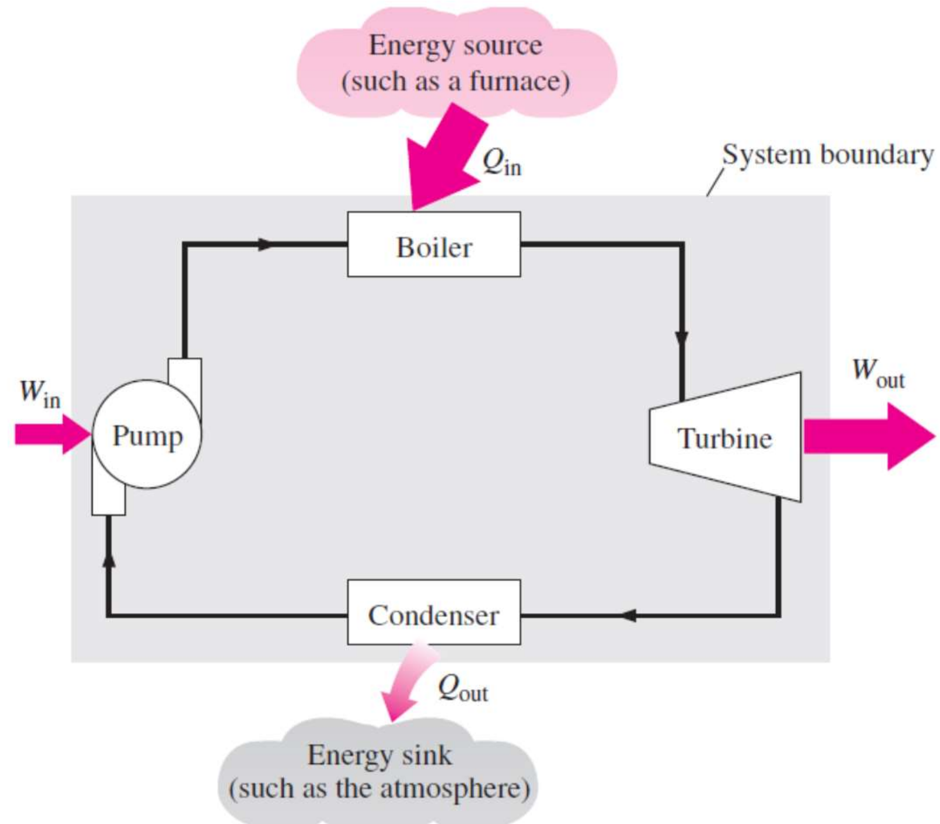
Sankey diagram – Heat engine



Heat engines



Combustion gases
Or Flue gases is working fluid
In automobiles



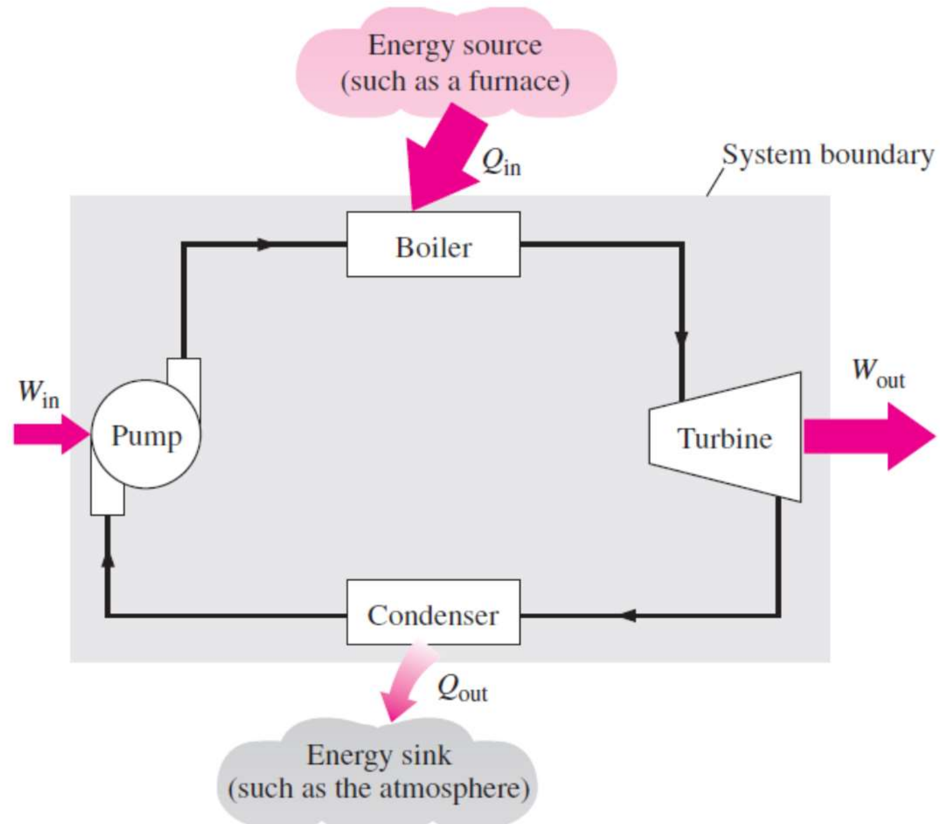
Working fluid is water

Heat engine

- The various quantities shown on this figure are as follows:
  - Q_{in} = amount of heat supplied to steam in boiler from high-temperature source (furnace)
  - Q_{out} = amount of heat rejected from steam in condens to a low temperature sink (the atmosphere, a river, etc.
  - W_{out} = amount of work delivered by steam as it expan in turbine
  - W_{in} = amount of work required to compress water (pump) to boiler pressure

- Notice that the directions of the heat and work interactions indicated by the subscripts *in* and *out*.

- Therefore, all four of the described quantities are always *positive*.



- The net work output of the system is equal to the net heat transfer to the system:

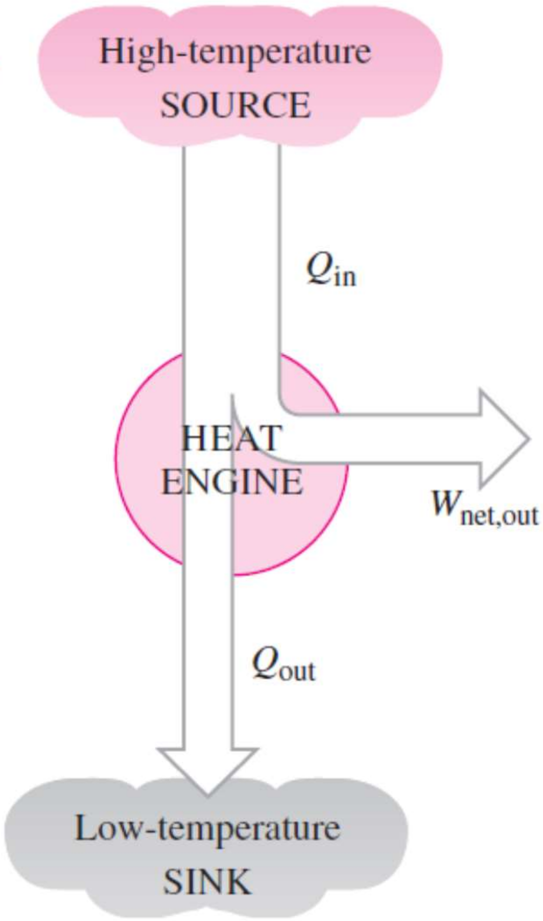
    - Energy input = Energy output

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

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

$$Q_{net,in} = Q_{in} - Q_{out}$$

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



Thermal Efficiency

- *The* Q_{out} represents the magnitude of the energy wasted in order to complete the cycle.
- But Q_{out} is never zero; thus, the net work output of a heat engine is always less than the amount of heat input.
- That is, only part of the heat transferred to the heat engine is converted to work.
- The fraction of the heat input that is converted to net work output is a measure of the performance of a heat engine and is called the thermal efficiency, η_{th}.

- For heat engines, the desired output is the net work output, and the required input is the amount of heat supplied to the working fluid.

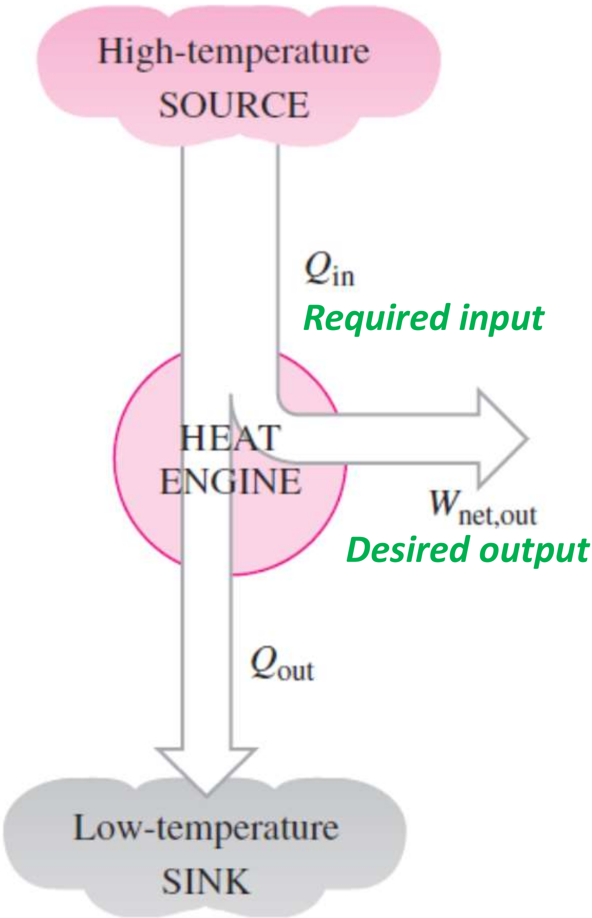
- Then the thermal efficiency of a heat engine can be expressed as:

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

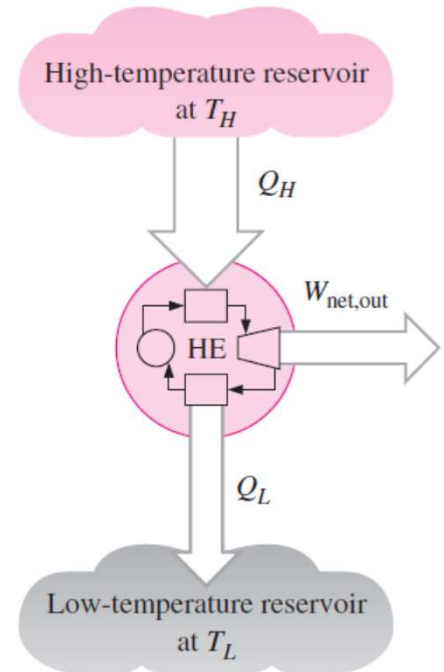
$$\eta_{th} = \frac{W_{net,out}}{Q_{in}}$$

$$\eta_{th} = \frac{(Q_{in} - Q_{out})}{Q_{in}} \qquad \because W_{net,out} = (Q_{in} - Q_{out})$$

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



- Cyclic devices of practical interest such as heat engines, refrigerators, and heat pumps operate between
  - a high-temperature medium (or reservoir) at temperature $T_{H,}$ and
  - a low-temperature medium (or reservoir) at temperature T_L.



- To bring uniformity to the treatment of heat engines, refrigerators, and heat pumps, we define these two quantities:
  - Q_H magnitude of heat transfer between the cyclic device and the high temperature medium at temperature T_H.
  - Q_L magnitude of heat transfer between the cyclic device and the low temperature medium at temperature T_L.

- Both Q_H and Q_L are defined as *magnitudes* and therefore are positive quantities.
- The direction of Q_H and Q_L is easily determined by inspection.
- Then the net work output and thermal efficiency relations for any heat engine can also be expressed as:

$$W_{net,out} = (Q_H - Q_L)$$

$$\eta_{th} = \frac{W_{net,out}}{Q_H} = \frac{(Q_H - Q_L)}{Q_H} = \frac{(T_H - T_L)}{T_H}$$

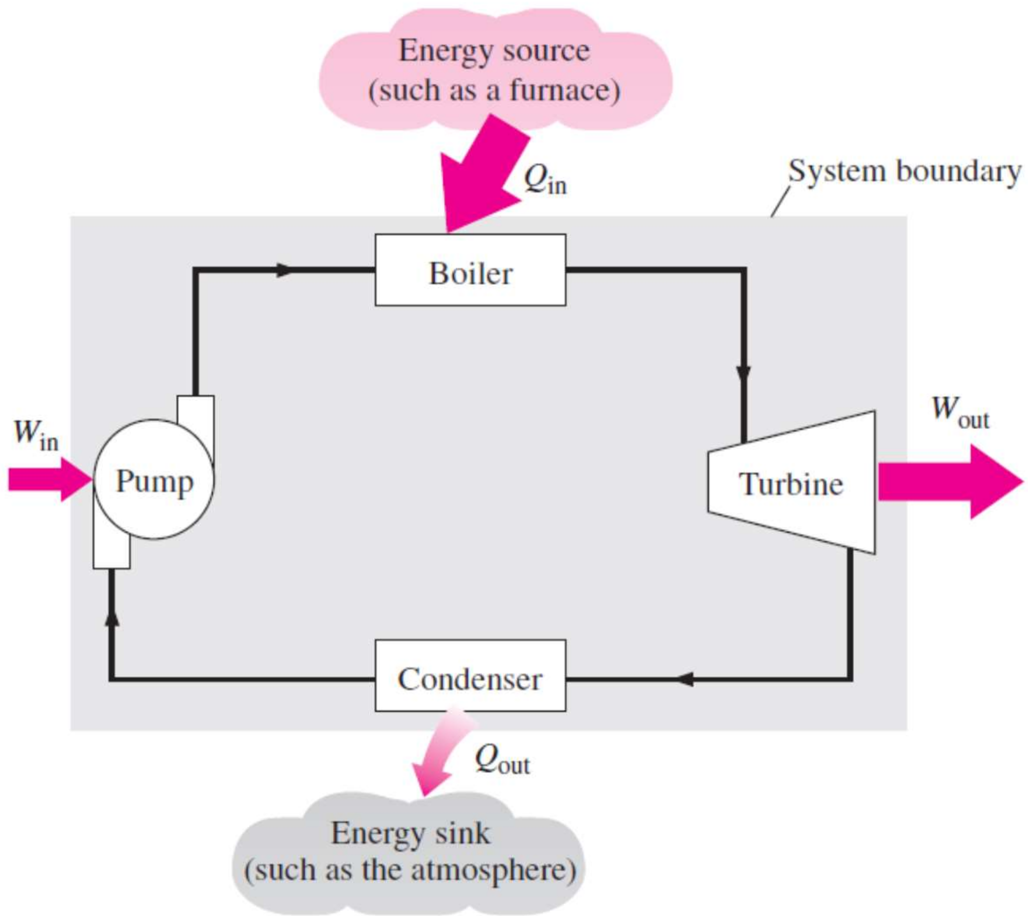
$$\eta_{th} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H}$$

- The thermal efficiency of a heat engine is always less than unity since both Q_L and Q_H are defined as positive quantities.

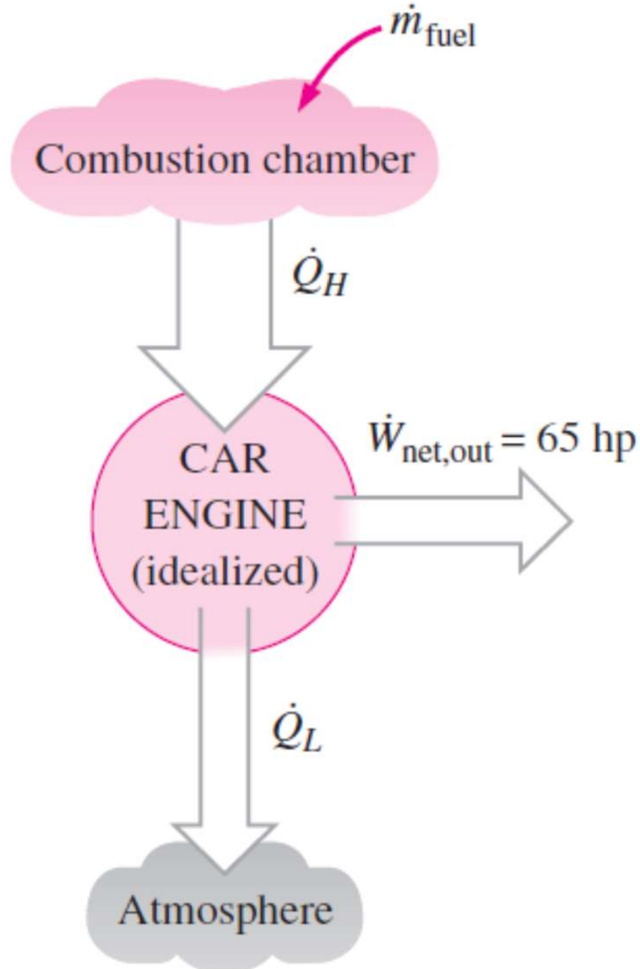
- Thermal efficiency is a measure of how efficiently a heat engine converts the heat that it receives to work.
- The thermal efficiencies of work-producing devices are relatively low.
- Ordinary spark-ignition automobile engines have a thermal efficiency of about 25 percent.
  - That is, an automobile engine converts about 25 percent of the chemical energy of the gasoline to mechanical work.
- This number is as high as 40 percent for diesel engines and large gas-turbine plants, and as high as 60 percent for large combined gas-steam power plants.

Can we save Q_{out}

- In a steam power plant, the condenser is the device where large quantities of waste heat is rejected to rivers, lakes, or the atmosphere.
- Then one may ask, can we not just take the condenser out of the plant and save all that waste energy?
- The answer to this question is, unfortunately, a firm ***no*** for the simple reason that without a heat rejection process in a condenser, the cycle cannot be completed.
- Cyclic devices such as steam power plants cannot run continuously unless the cycle is completed.



Steam power plant



Fuel Consumption Rate of a Car

Heat Engines

$$\eta_{th} = \frac{W_{net,out}}{Q_H} = \frac{(Q_H - Q_L)}{Q_H} = \frac{(T_H - T_L)}{T_H}$$

$$\eta_{th} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H}$$

References

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Thank you for your Patience