

# Thermodynamics - 1

## Lecture 20

### **The Second Law of Thermodynamics (Ch-6)**

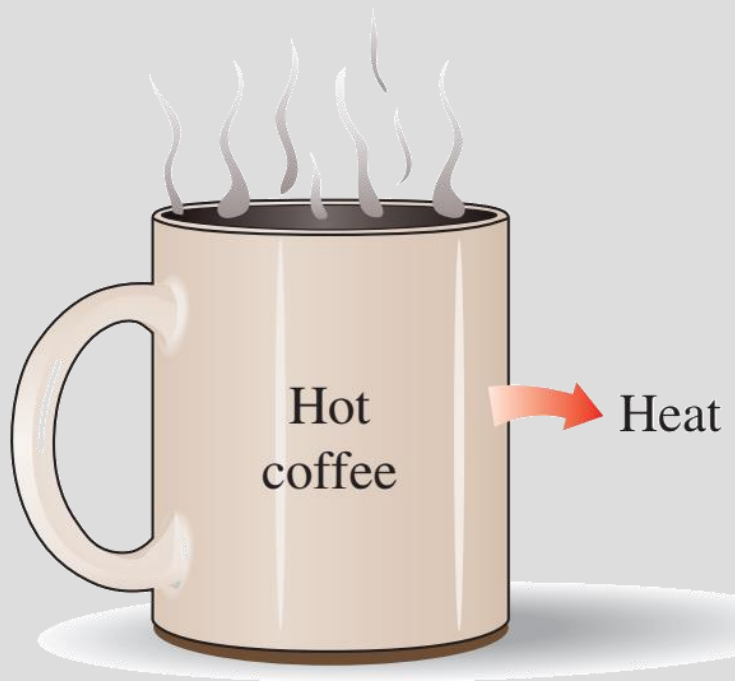
**Introduction, Heat Engines, Kelvin-Planck Statement**

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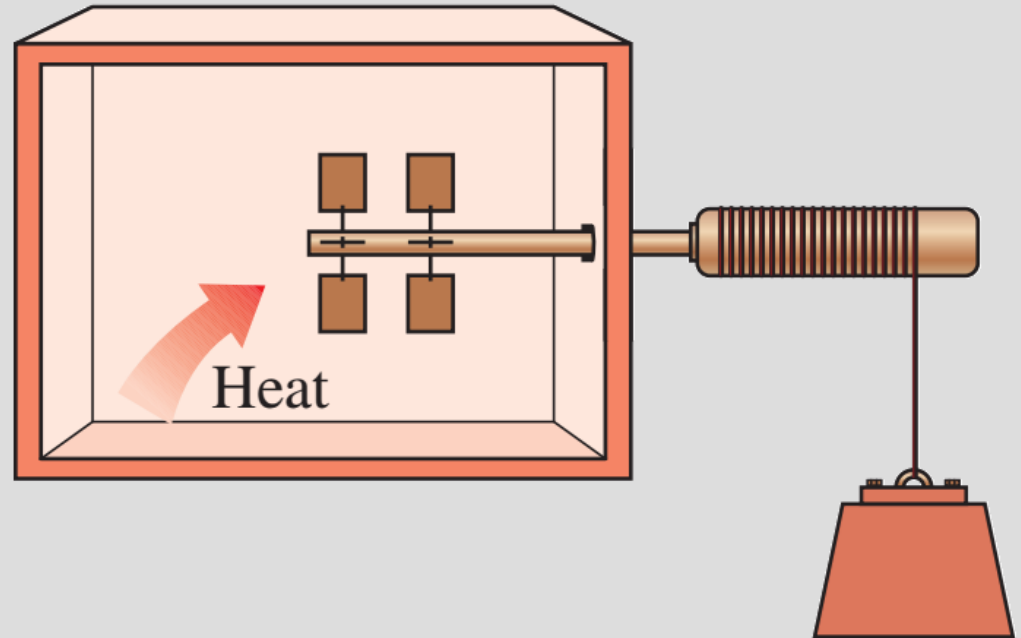
# Objectives

- Introduce the second law of thermodynamics.
- Discuss thermal energy reservoirs, reversible and irreversible processes, heat engines, refrigerators, and heat pumps.
- Describe the Kelvin–Planck and Clausius statements of the second law of thermodynamics.
- Discuss the concepts of perpetual-motion machines.
- Apply the second law of thermodynamics to cycles and cyclic devices.
- Describe the Carnot cycle.
- Examine the Carnot principles, idealized Carnot heat engines, refrigerators, and heat pumps.
- Determine the expressions for the thermal efficiencies and coefficients of performance for reversible heat engines, heat pumps, and refrigerators.

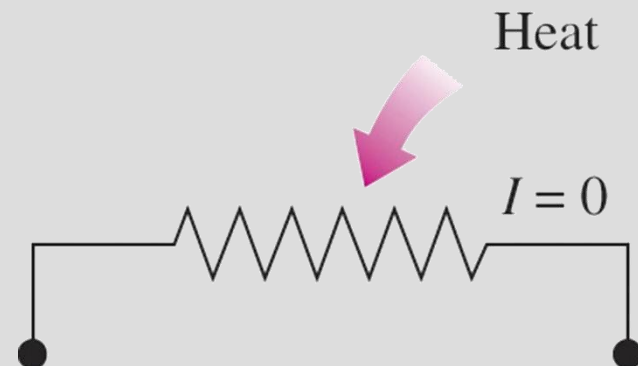
# INTRODUCTION TO THE SECOND LAW



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



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



Transferring heat to a wire will not generate electricity.

These processes cannot occur even though they are not in violation of the first law.



Processes occur in a certain direction, and not in the reverse direction.

Process

1st law

2nd law

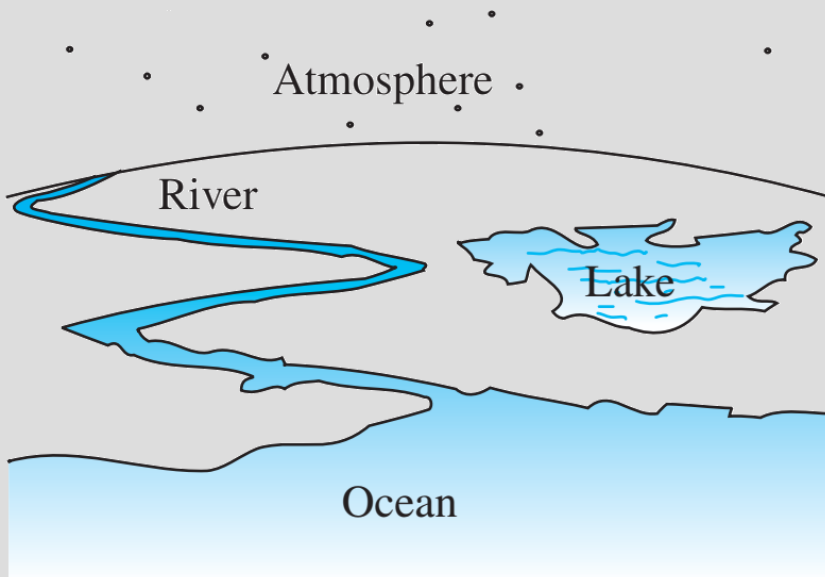
A process must satisfy both the first and second laws of thermodynamics to proceed.



## MAJOR USES OF THE SECOND LAW

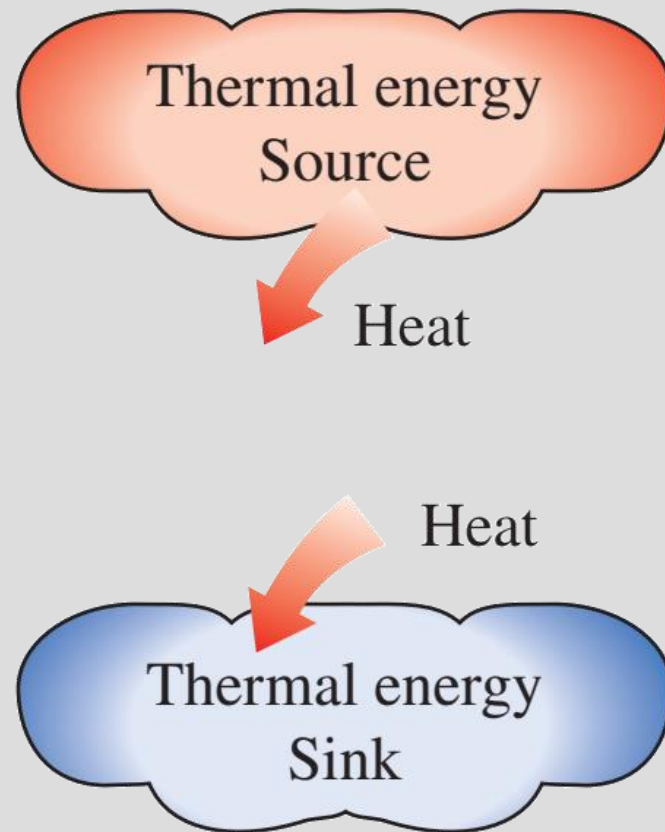
1. The second law may be used to identify the **direction** of processes.
2. The second law also asserts that energy has **quality** as well as quantity. The first law is concerned with the quantity of energy and the transformations of energy from one form to another with no regard to its quality. The second law provides the necessary means to determine the quality as well as the degree of degradation of energy during a process.
3. The second law of thermodynamics is also used in determining the **theoretical limits** for the performance of commonly used engineering systems, such as heat engines and refrigerators.

# THERMAL ENERGY RESERVOIRS

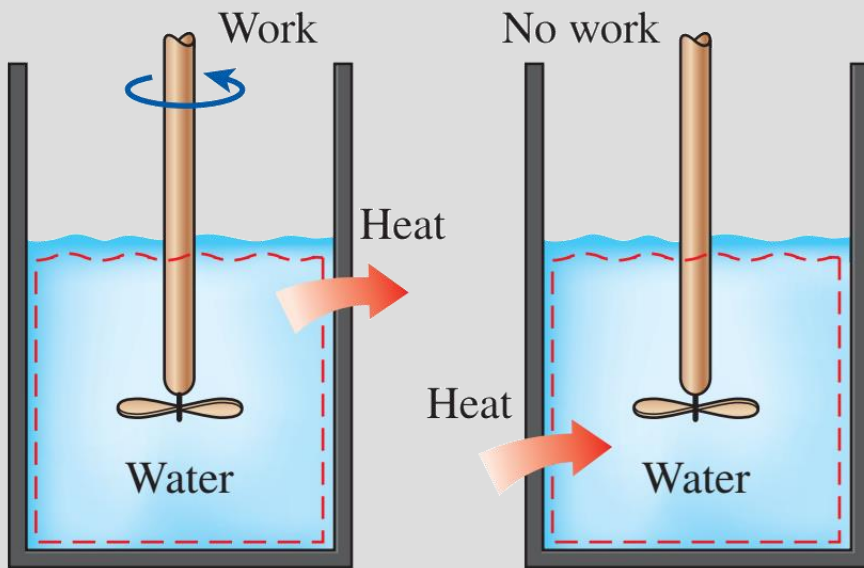


Bodies with relatively large thermal masses can be modeled as thermal energy reservoirs.

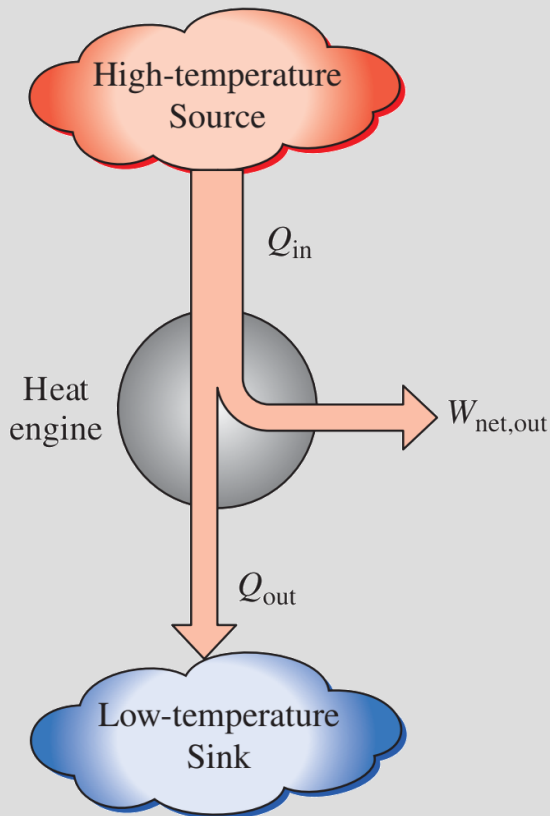
- A hypothetical body with a relatively large *thermal energy capacity* (mass  $\times$  specific heat) that can supply or absorb finite amounts of heat without undergoing any change in temperature is called a **thermal energy reservoir**, or just a reservoir.
- In practice, large bodies of water such as oceans, lakes, and rivers as well as the atmospheric air can be modeled accurately as thermal energy reservoirs because of their large thermal energy storage capabilities or thermal masses.



A source supplies energy in the form of heat, and a sink absorbs it.



Work can always be converted to heat directly and completely, but the reverse is not true.



Part of the heat received by a heat engine is converted to work, while the rest is rejected to a sink.

## HEAT ENGINES

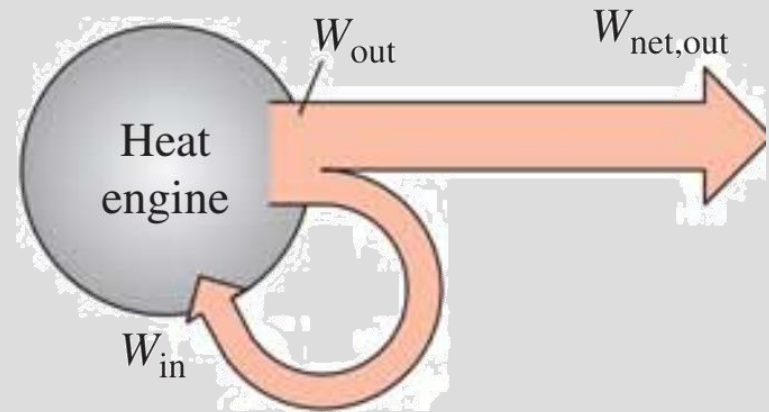
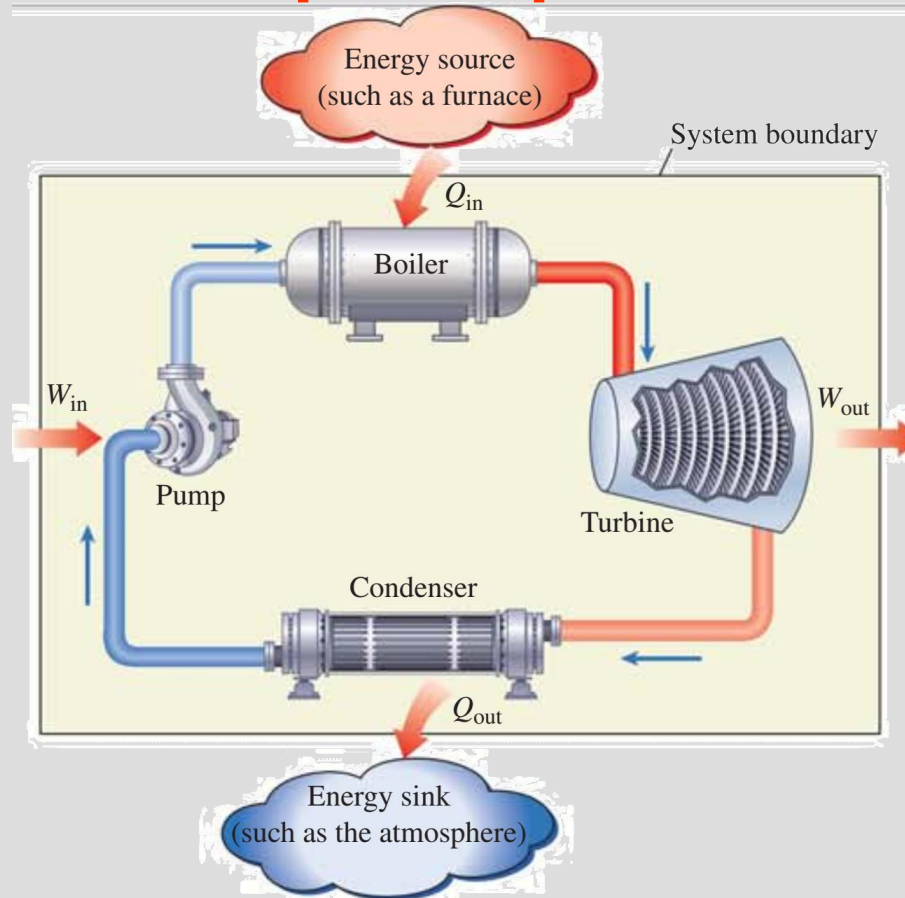
The devices that convert heat to work.

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 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**.

# Forward Heat Engine: Power Cycles

## A steam power plant



A portion of the work output of a heat engine is consumed internally to maintain continuous operation.

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

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

$Q_{in}$  = 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

# Power Cycles: Net Work Output

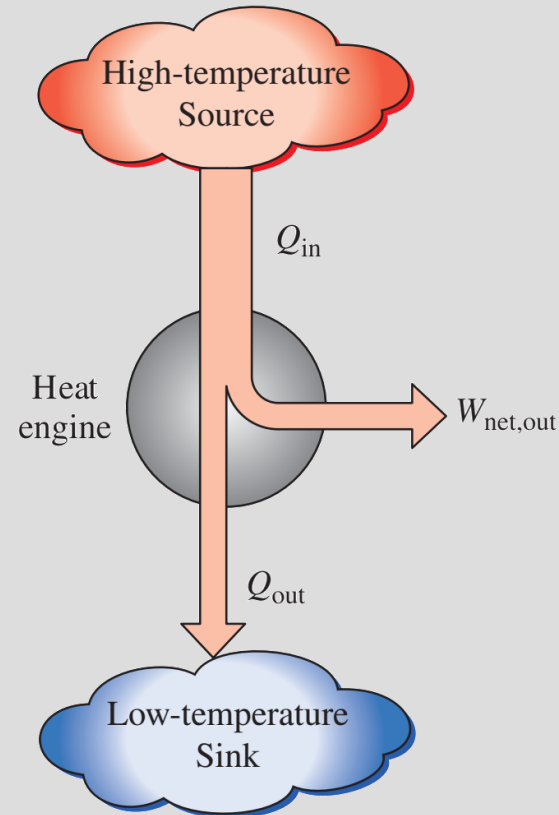
Now apply the first law to the cyclic heat engine.

$$Q_{net, in} - W_{net, out} = \Delta U \overset{0 \text{ (Cyclic)}}{\rightarrow}$$

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

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

Here the use of in and out subscripts means to use the magnitude (take positive value) of either the work or heat transfer and let the minus sign in the net expression take care of the direction





# Power Cycles: Thermal Efficiency (index of performance)

Thermal efficiency is defined by the ratio of the network output(desired result) to the heat input(required input)

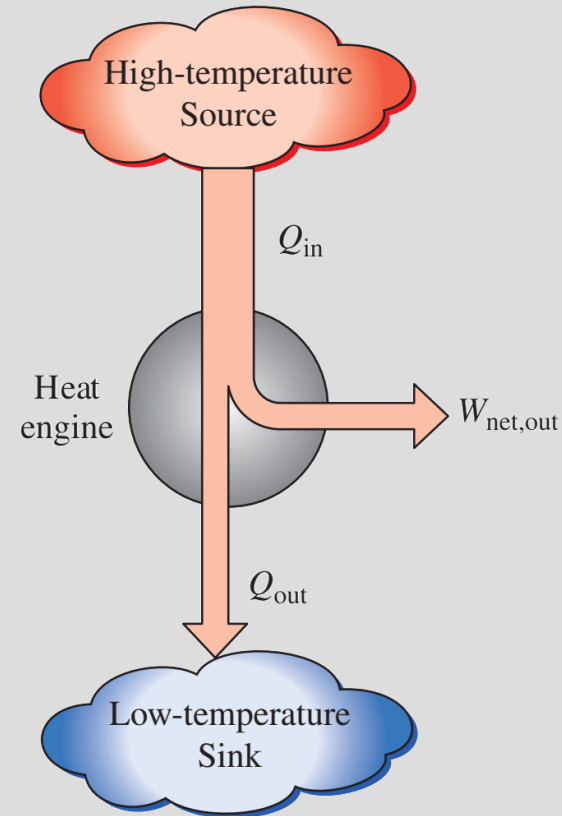
$$\eta_{th} = \frac{\text{Desired Result}}{\text{Required Input}}$$

The extent of the energy conversion from heat to work is **thermal efficiency**

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

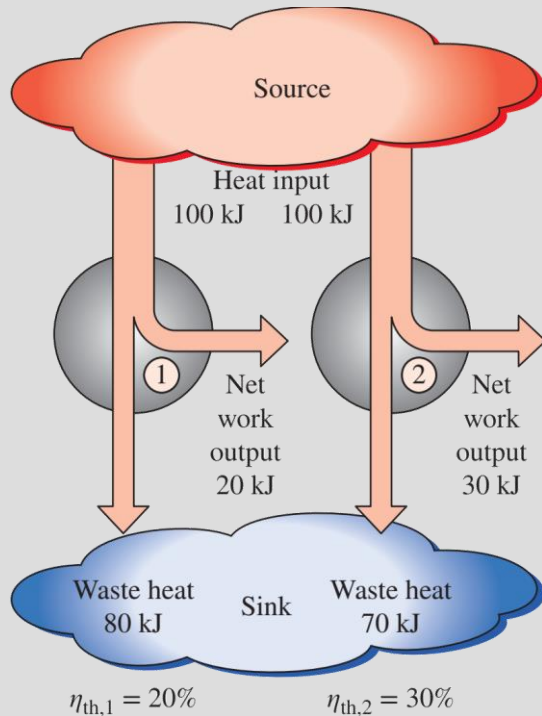
$$= \frac{Q_{in} - Q_{out}}{Q_{in}}$$

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



$$\eta < 1$$

# Thermal efficiency

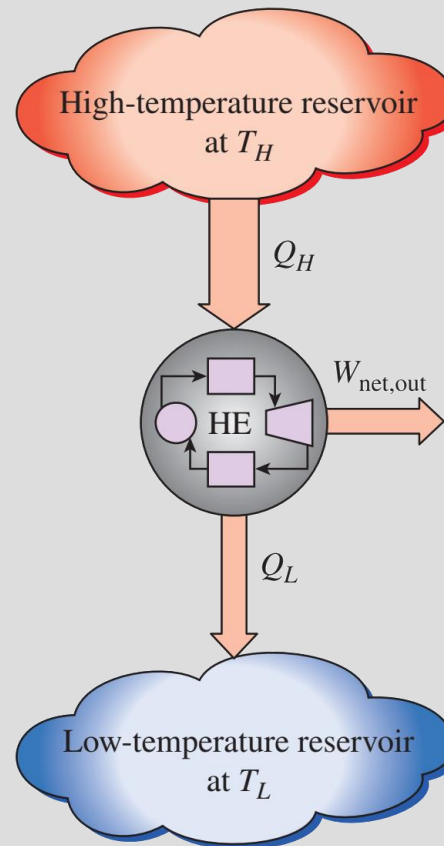


Some heat engines perform better than others (convert more of the heat they receive to work).

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

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

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



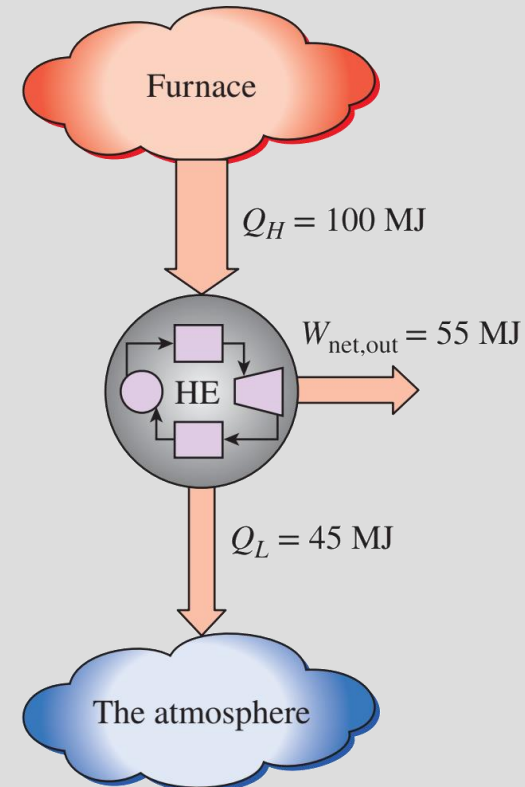
Even the most efficient heat engines reject almost one-half of the energy they receive as waste heat.

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

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

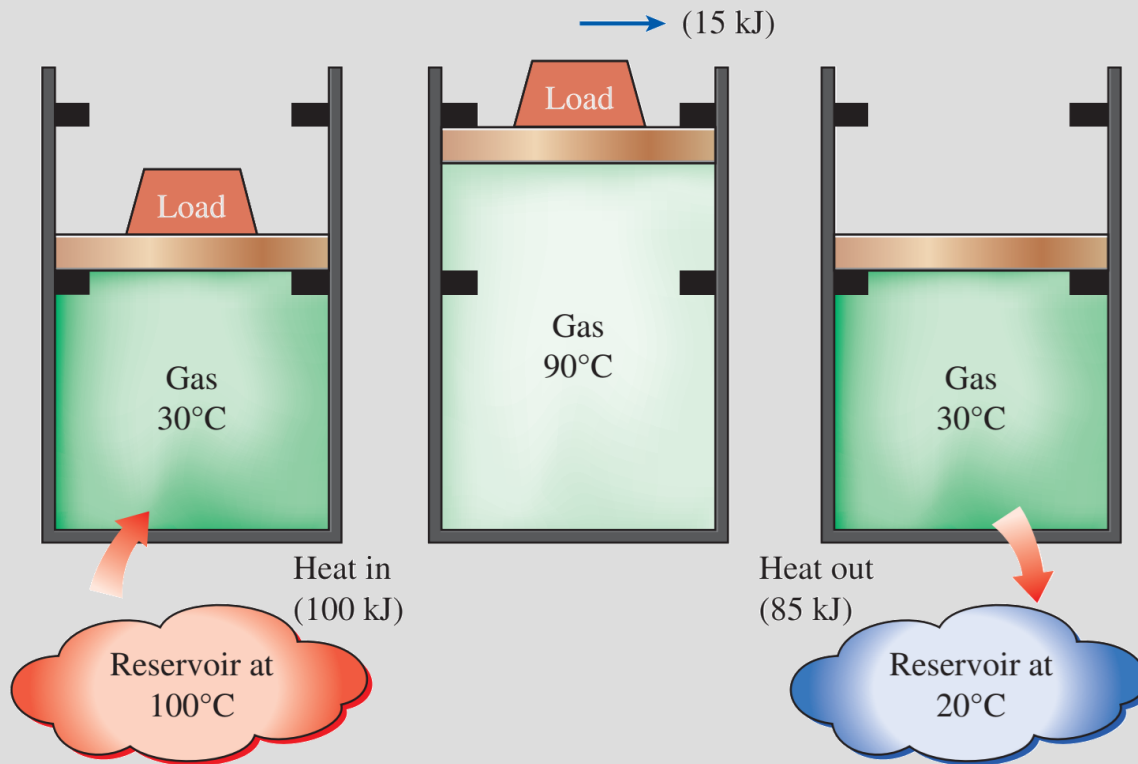
$$\eta_{th} = 1 - \frac{Q_L}{Q_H}$$

Schematic of a heat engine.



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

# Can we save $Q_{\text{out}}$ ?



A heat-engine cycle cannot be completed without rejecting some heat to a low-temperature sink.

Every heat engine must *waste* some energy by transferring it to a low-temperature reservoir in order to complete the cycle, even under idealized conditions.

In a steam power plant, the condenser is the device where large quantities of waste heat is rejected to rivers, lakes, or the atmosphere.

Can we not just take the condenser out of the plant and save all that waste energy?

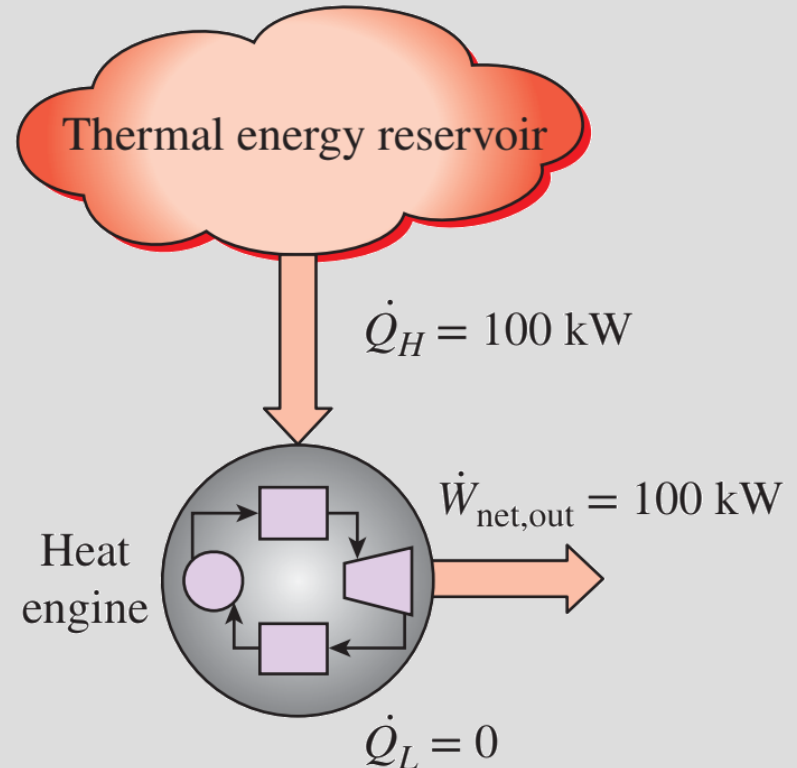
The answer is, unfortunately, a firm **NO** for the simple reason that without a heat rejection process in a condenser, the cycle cannot be completed.

# The Second Law of Thermodynamics: Kelvin–Planck Statement

It is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work.

*No heat engine can have a thermal efficiency of 100 percent, or as for a power plant to operate, the working fluid must exchange heat with the environment as well as the furnace.*

The impossibility of having a 100% efficient heat engine is not due to friction or other dissipative effects. It is a limitation that applies to both the idealized and the actual heat engines.



A heat engine that violates the Kelvin–Planck statement of the second law.

# Example 6-1

## EXAMPLE 6-1 Net Power Production of a Heat Engine

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.

$$\dot{Q}_H = 80 \text{ MW} \quad \text{and} \quad \dot{Q}_L = 50 \text{ MW}$$

The net power output of this heat engine is

$$\dot{W}_{\text{net,out}} = \dot{Q}_H - \dot{Q}_L = (80 - 50) \text{ MW} = \mathbf{30 \text{ MW}}$$

Then the thermal efficiency is easily determined to be

$$\eta_{\text{th}} = \frac{\dot{W}_{\text{net,out}}}{\dot{Q}_H} = \frac{30 \text{ MW}}{80 \text{ MW}} = \mathbf{0.375} \text{ (or 37.5\%)}$$

