# Sustainable Energy

Alternatives for the Future

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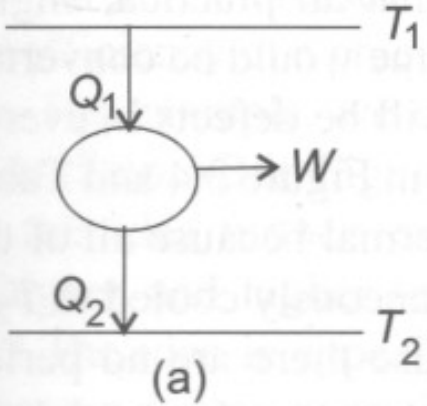
# Heat Engines

- A heat engine is an energy conversion machine that absorbs heat from a suitable source and converts a portion of that heat into useful work.
- The source is usually a fluid (gas, liquid or gas-liquid mixture).
- Common fluids used are water and steam (also pentane, ammonia, chloropentafluoroethane).
- Heat engines are devices or machines that convert heat into work by a cyclic process.

# Types of Heat Engines

- Carnot heat engine – the "ideal" engine.
- Carnot heat pump



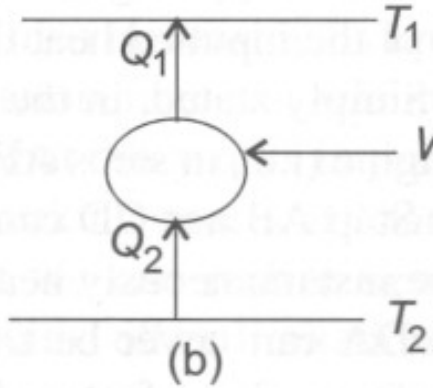



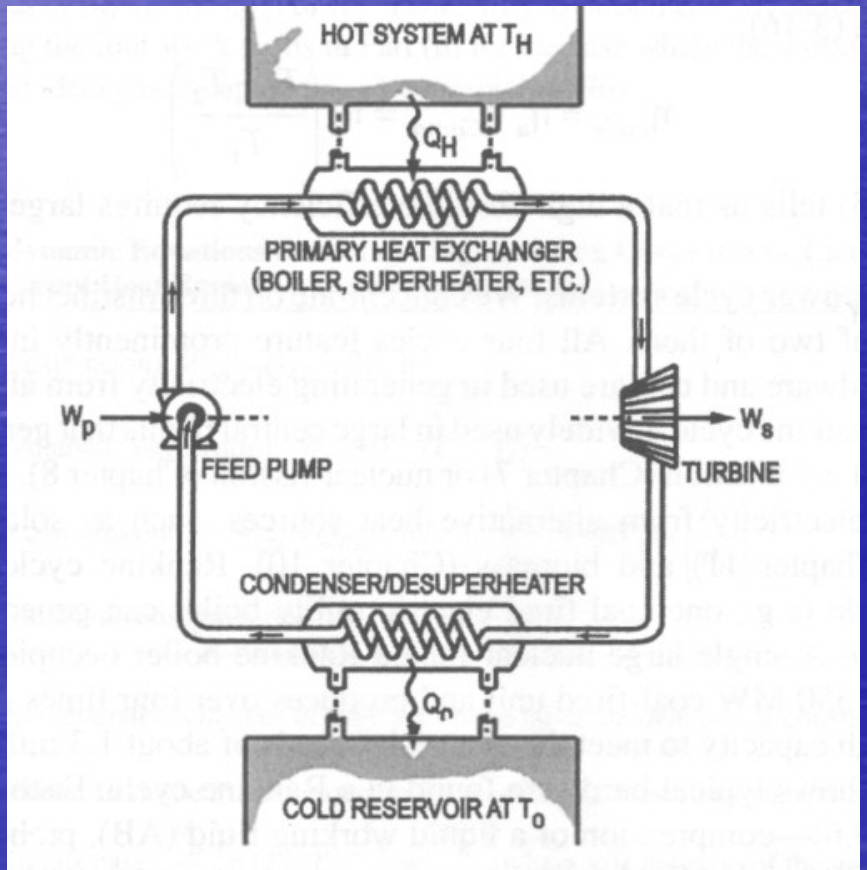

Figure 3.3. Two combinations of continuous heat and work flows between a high temperature ($T_1$) and a low temperature ($T_2$) heat reservoir, allowed by the First and Second Laws of Thermodynamics. The ellipse represents a device that can produce work from heat or utilize work to move heat from a lower to a higher temperature. For reversible systems (see text), Case (a) is a Carnot heat engine and Case (b) is a Carnot heat pump. Adapted from Levenspiel (1996).

# Heat Engines…continued

- Carnot proved 3 important theorems about heat engines:
  - All reversible heat engines operating between the same two temperatures must have the same efficiency.
  - Reversible heat engines have the highest efficiency at the same temperatures.
  - The reversible heat engine that has the larger temperature difference has the highest efficiency (i.e, it produces more work)

# Stationary Power Cycle Systems

- Rankine cycle engine



# Rankine ….continued

- Rankine cycle engines have some characteristics that restrict efficiency:
  - Boiler tube materials cannot tolerate high pressure steam above 600 degrees C.
  - Combustion temperatures are much higher; 1000-1500 degrees C.

# Stationary power systems..continued

- Brayton cycle
  - Working fluid is always in the vapor phase
  - Heat loss in the conversion from liquid to gas (vaporization) phase is avoided as well as during condensation in the cycle.
  - Total cycle efficiencies approach 28%!

# Stationary power ….continued

- Integrated or combined power cycle
  - Brayton turbine heat is used as a heat source for a Rankine cycle system.
  - Natural gas fueled Brayton cycle turbine linked to a steam (Rankine) cycle system has very high overall efficiencies; 60% or better.

# Internal Combustion Engines

- Two types are commonly used:
  - SI or spark ignition (Otto cycle)
  - CI or compression ignition (Diesel)
  - Which is more efficient?
    - Technically, the gasoline engine produces more energy at the same compression ratio.
    - Typical compression ratios for SI engines are 8-12; 12-24 for CI engines.
    - Diesel engines are more efficient as a result.

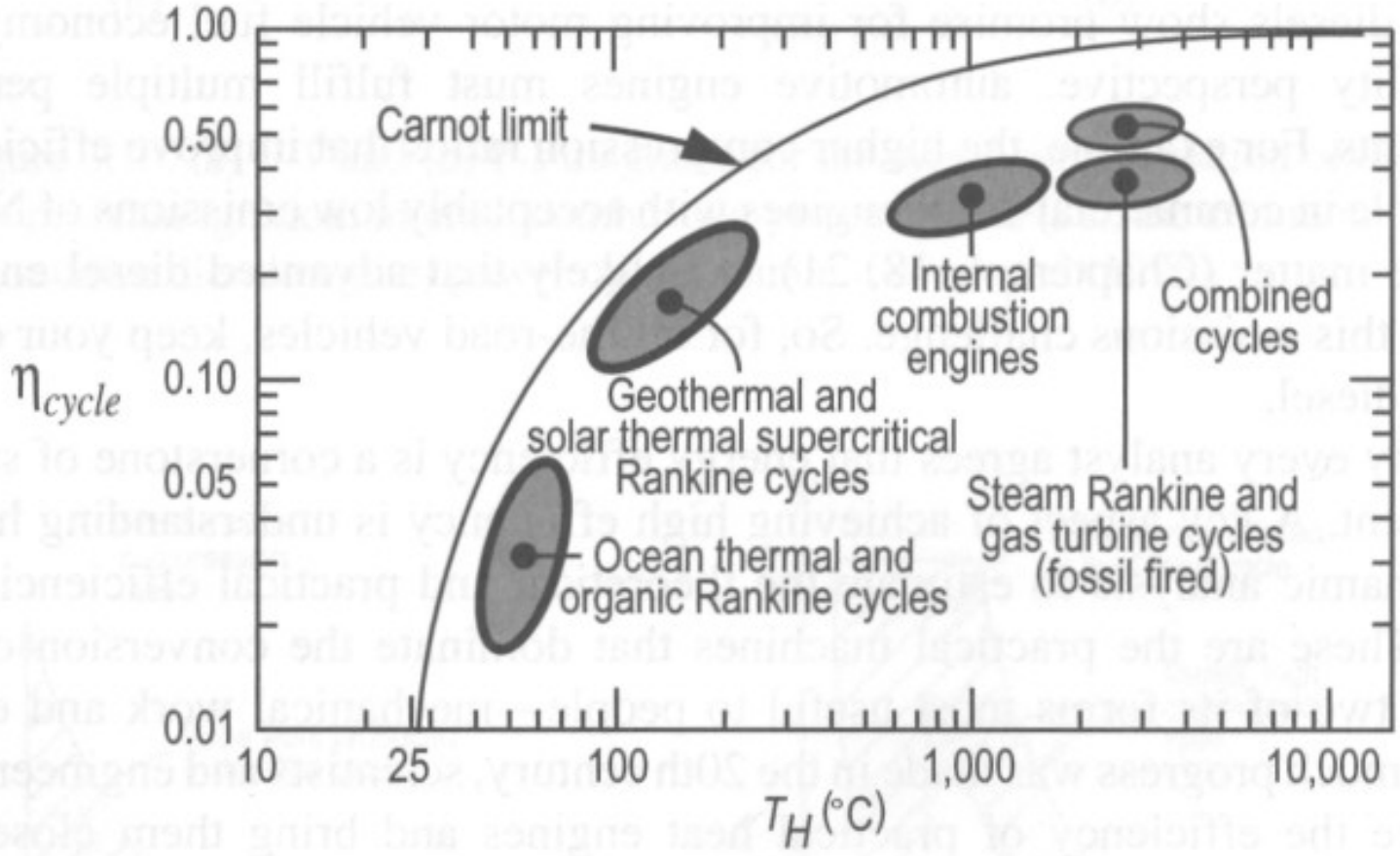


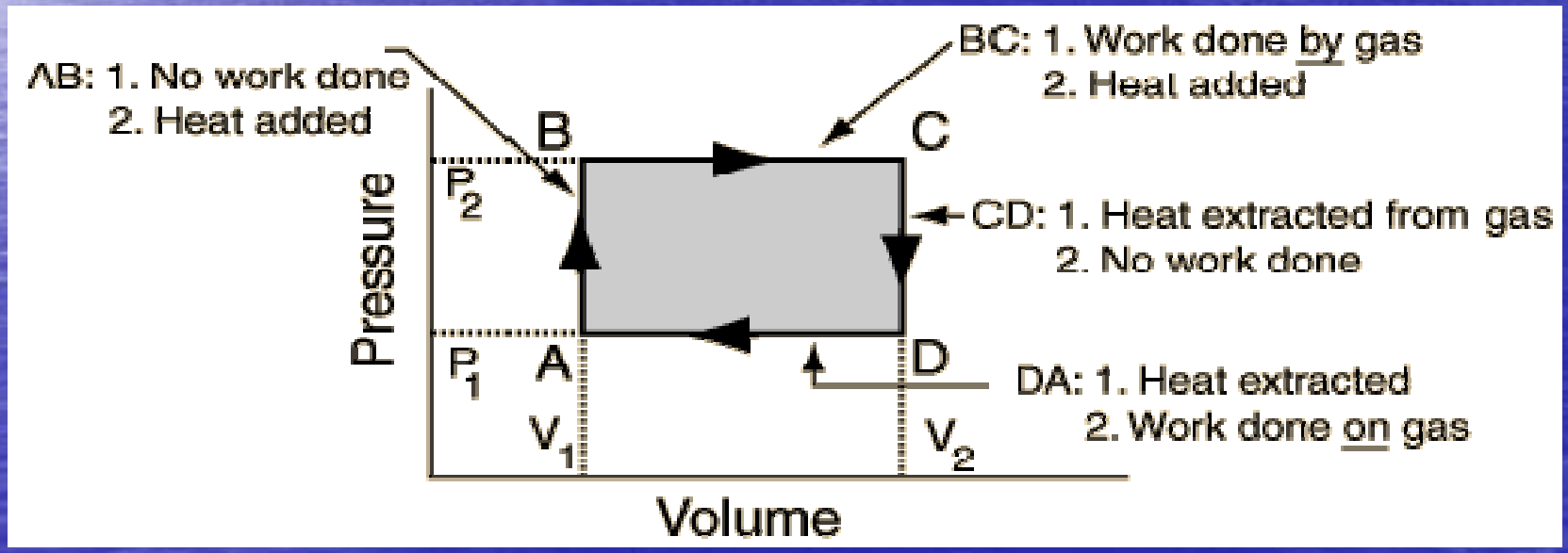

Figure 3.12. Practical efficiencies for heat-to-work conversion in various heat engine cycles of interest in sustainable energy applications and corresponding Carnot limits, as affected by heat source temperature. Heat is assumed to be rejected at average ambient conditions, i.e., 25°C and 1 bar pressure. Source: Tester and Modell (1997). Reprinted with permission of Pearson Education, Inc.

# Engine Cycles

- **Engine Cycles**
- For a constant mass of gas, the operation of a heat engine is a repeating cycle and its PV diagram will be a closed figure. The idea of an engine cycle is illustrated below for one of the simplest kinds of cycles. If the cycle is operated clockwise on the diagram, the engine uses heat to do net work. If operated counterclockwise, it uses work to transport heat and is therefore acting as a refrigerator or a heat pump

# Engine Cycles continued….

- Engine Cycles



# Heat Pumps

- **Air Conditioners and Heat Pumps**
- Air conditioners and heat pumps are heat engines like the refrigerator. They make good use of the high quality and flexibility of electric energy in that they can use one unit of electric energy to transfer more than one unit of energy from a cold area to a hot area. For example, an electric resistance heater using one kilowatt-hour of electric energy can transfer only 1 kWh of energy to heat your house at 100% efficiency. But 1 kWh of energy used in an electric heat pump could "pump" 3 kWh of energy from the cooler outside environment into your house for heating. The ratio of the energy transferred to the electric energy used in the process is called its coefficient of performance (CP). A typical CP for a commercial heat pump is between 3 and 4 units transferred per unit of electric energy supplied

# Conclusions

- The efficiency of our engines is limited by the Laws of Thermodynamics.
- Practical constraints (materials, engineering) decrease the efficiency of our working engines compared to the "Ideal" Carnot engine.
- There are 3 common types of engines used today in our systems.
- Traditional fossil fuel powered engines vary in their efficiencies.
- Modern engineering practice has attempted to increase the efficiency of our energy production systems.