Exergy, Reversible Work & Irreversibility

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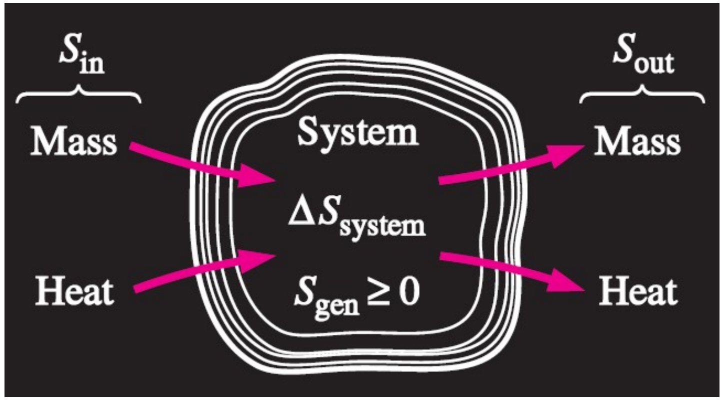
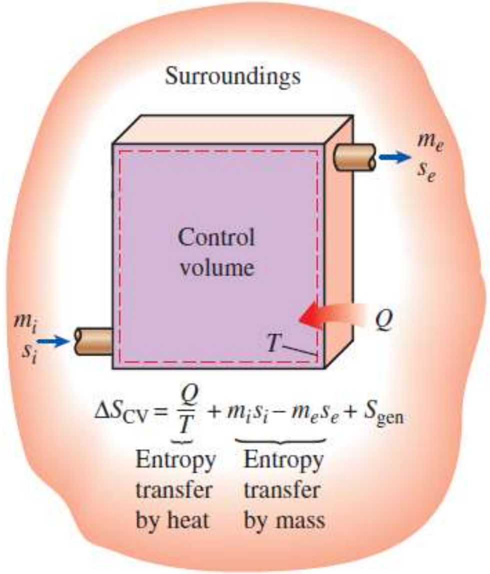
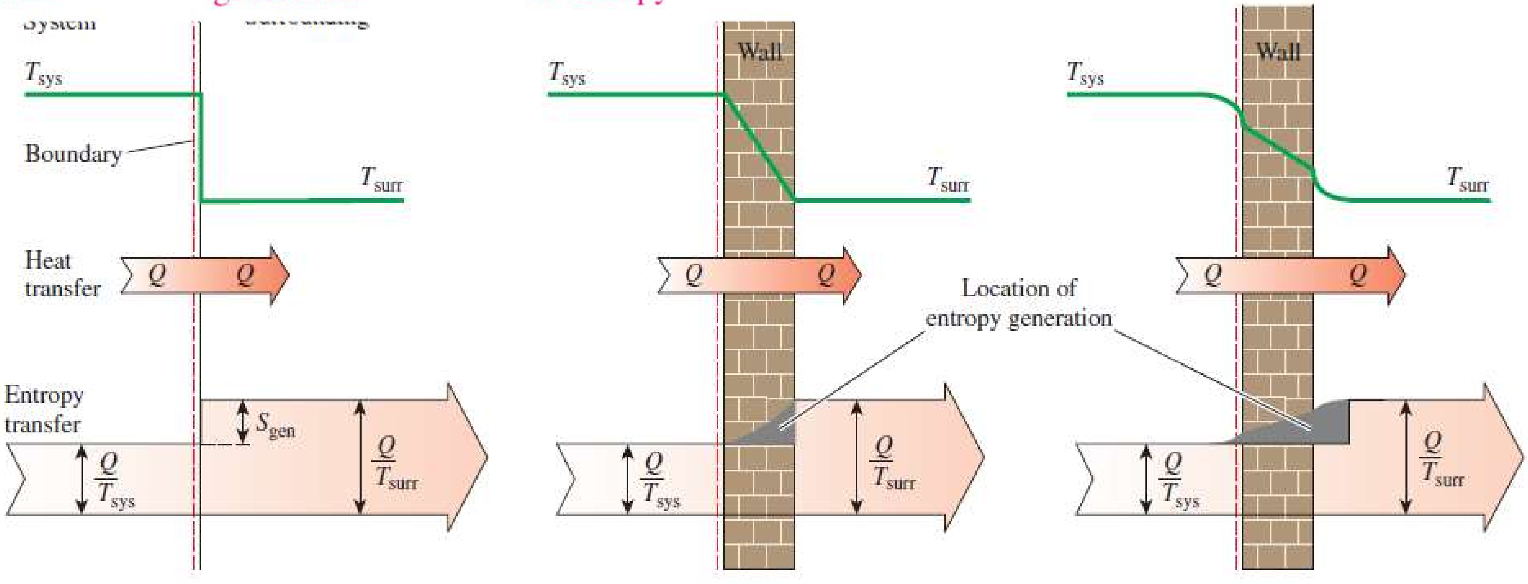
Previously: Entropy generation & Balance





$$\underbrace{S_{in} - S_{out}}_{\substack{\text{Net entropy transfer} \\ \text{by heat and mass}}} + \underbrace{S_{gen}}_{\substack{\text{Entropy} \\ \text{generation}}} = \underbrace{\Delta S_{system}}_{\substack{\text{Change} \\ \text{in entropy}}} \qquad \text{(kJ/K)}$$



(*a*) The wall is ignored

(*b*) The wall is considered

(*c*) The wall as well as the variations of temperature in the system and the surroundings are considered

Fig-TD: Cengel & Boles

Exergy Analysis: Overall objective

- How to utilize energy resources towards a specific *engineering* objective?
- Dead state: No exergy/Availability/Available energy
- Exergy provides bound on work a device deliver within thermodynamic constrains

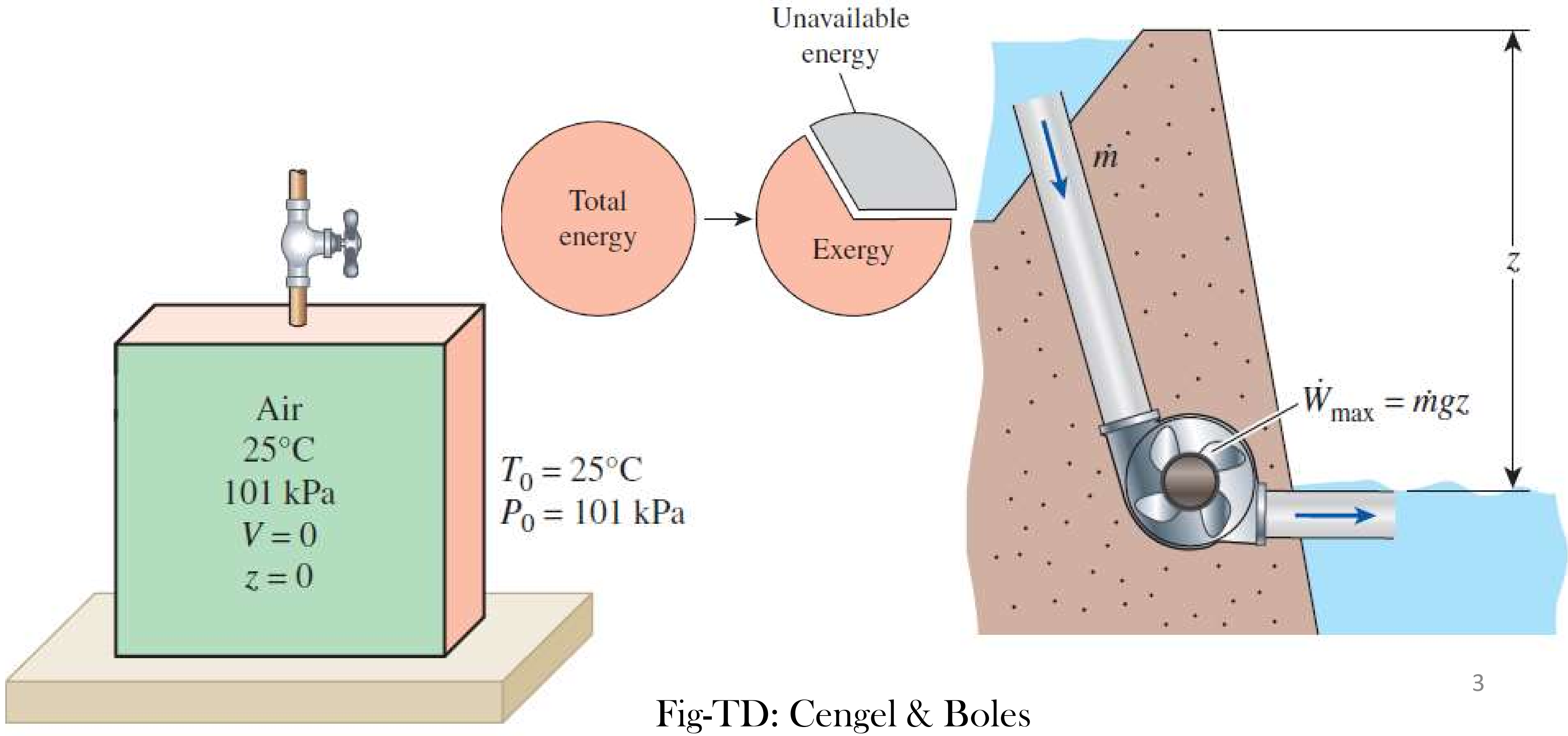
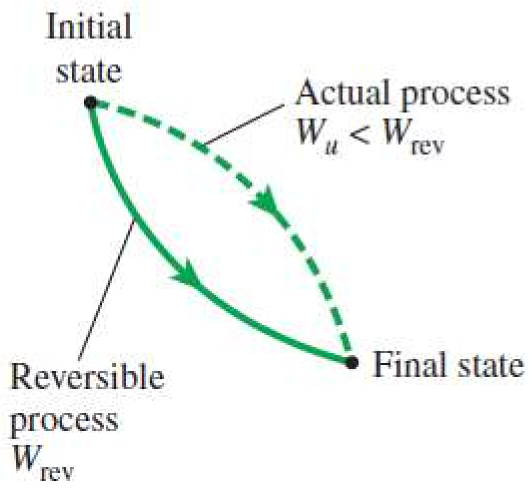
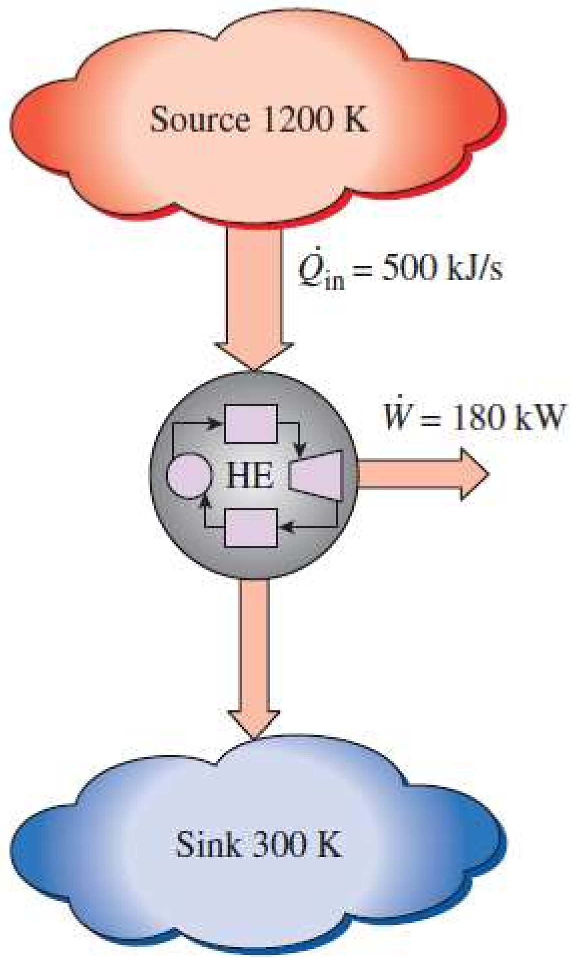


Fig-TD: Cengel & Boles

Reversible work & irreversibility



$$I = W_{rev} - W_u$$



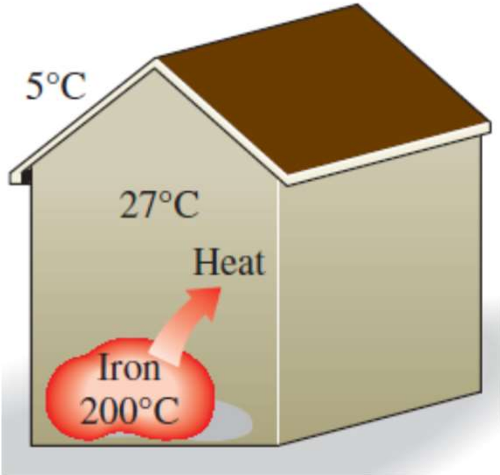
$$\dot{W}_{rev,out} = \eta_{th,rev}\,\dot{Q}_{in} = \left(1 - \frac{T_{sink}}{T_{source}}\right)\dot{Q}_{in}$$

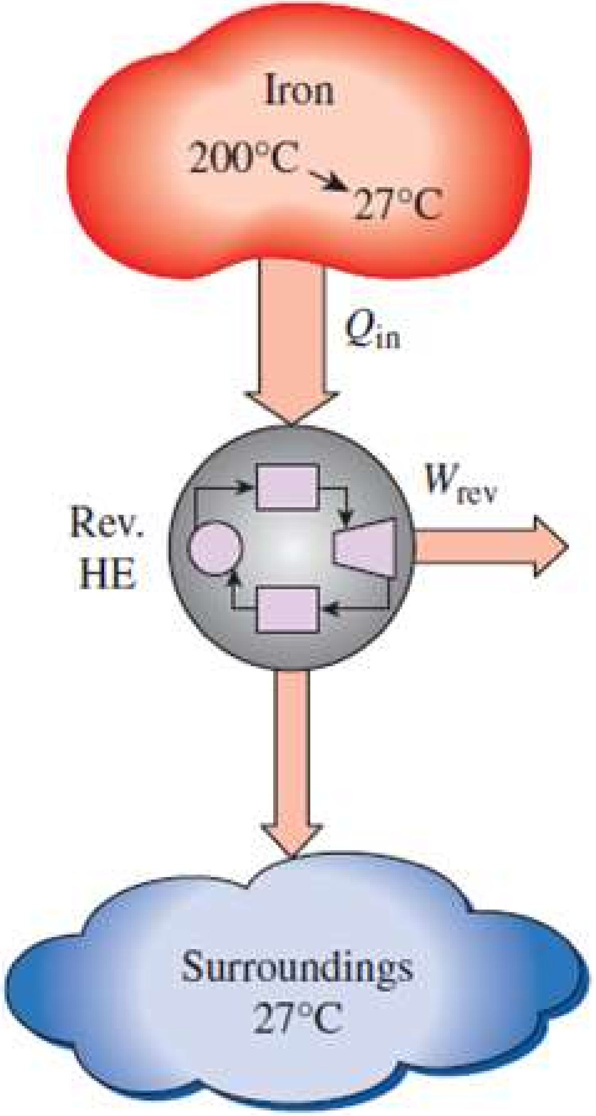
$$= \left(1 - \frac{300\text{ K}}{1200\text{ K}}\right)(500\text{ kW}) = \mathbf{375\ kW}$$

$$\dot{I} = \dot{W}_{rev,out} - \dot{W}_{u,out} = 375 - 180 = \mathbf{195\ kW}$$

Fig-TD: Cengel & Boles

What is the best way to utilize heat?





- Work obtained can be utilized for running a heat pump to transfer heat from ambient@5°C to the room
- Engineering objective: Heating the room

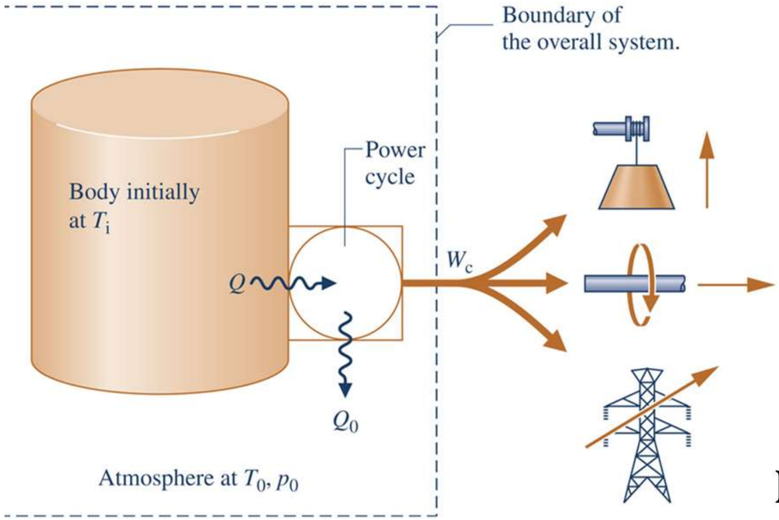
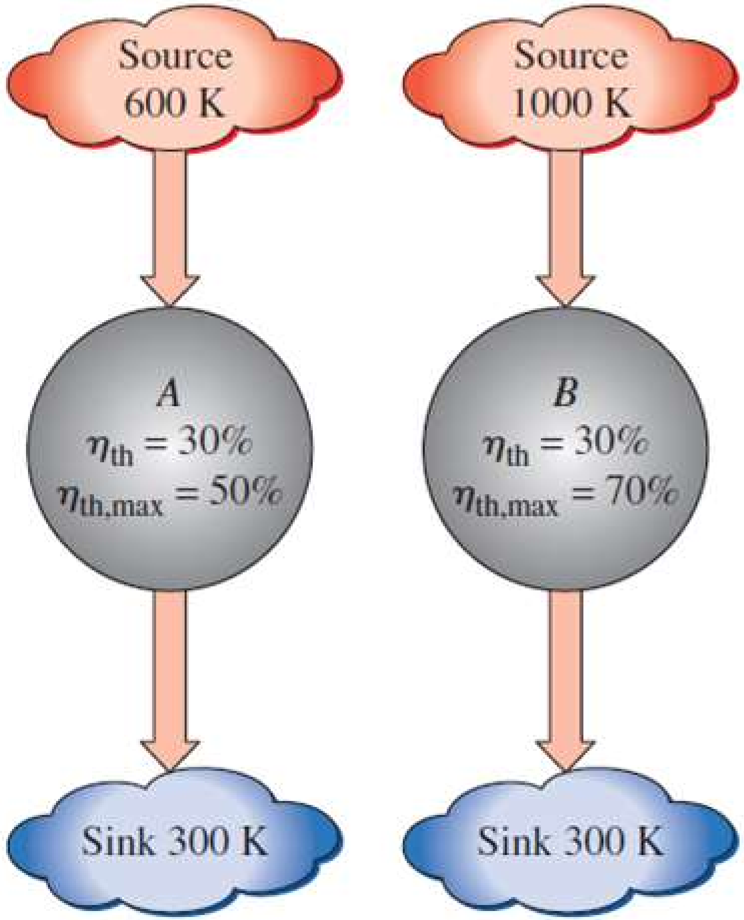


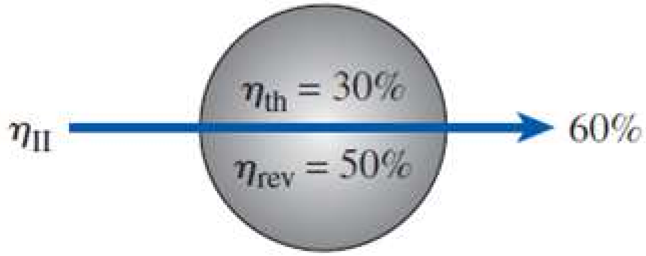
Fig-TD: Cengel & Boles; Moran, Shapiro, Boettner & Bailey

Decrease in efficiency due to irreversibilities



$$\eta_{II} = \frac{\eta_{th}}{\eta_{th,rev}} \qquad \text{(heat engines)}$$

$$\eta_{II} = \frac{W_u}{W_{rev}} \qquad \text{(work-producing devices)}$$



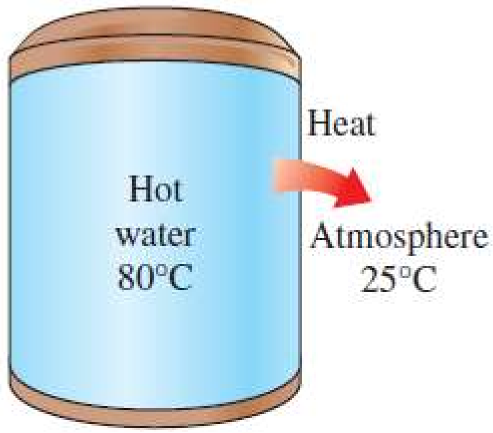
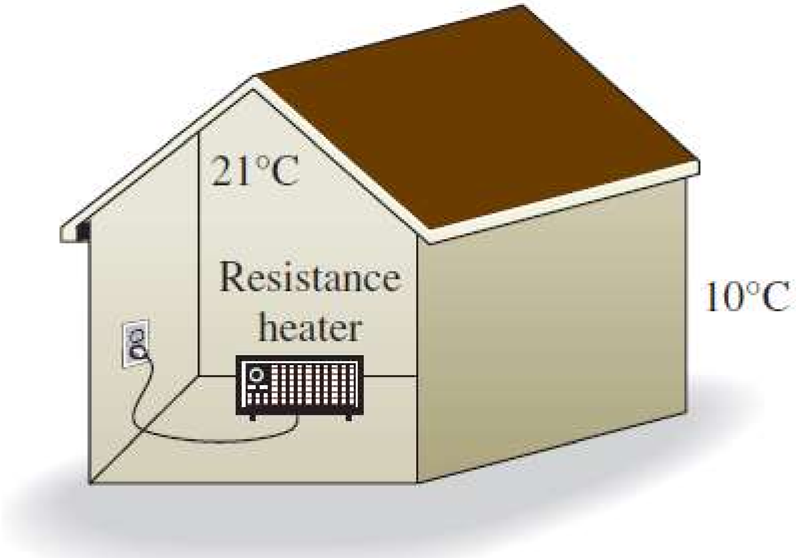


Fig-TD: Cengel & Boles

Efficiency Metrics for Work Consuming Devices



- 1 unit of electrical energy generates 1 unit of heat; "COP"=1

$$\dot{Q}_e = \dot{W}_e$$

$$\eta_{\text{II,electric heater}} = \frac{\dot{X}_{\text{recovered}}}{\dot{X}_{\text{expended}}} = \frac{\dot{X}_{\text{heat}}}{\dot{W}_e}$$

$$\eta_{\text{II}} = \frac{\text{Exergy recovered}}{\text{Exergy expended}} = 1 - \frac{\text{Exergy destroyed}}{\text{Exergy expended}}$$

$$= \frac{\dot{Q}_e(1 - T_0/T_H)}{\dot{W}_e} = 1 - \frac{T_0}{T_H}$$

$$\text{COP}_{\text{HP,rev}} = \frac{1}{1 - T_L/T_H} = \frac{1}{1 - (10 + 273\text{ K})/(21 + 273\text{ K})} = 26.7$$

$$\eta_{\text{II}} = \frac{\text{COP}}{\text{COP}_{\text{rev}}} = \frac{1.0}{26.7} = \mathbf{0.037} \text{ or } \mathbf{3.7\%}$$

$$\eta_{\text{II,electric heater}} = 1 - \frac{T_0}{T_H} = 1 - \frac{(10 + 273)\text{K}}{(21 + 273)\text{K}} = 0.037 \text{ or } 3.7\%$$

Fig-TD: Cengel & Boles

What's next?

- Quantifying exergy changes & balances in different systems