# Lecture 40 – Brayton cycle improvements

Purdue ME 200, Thermodynamics I

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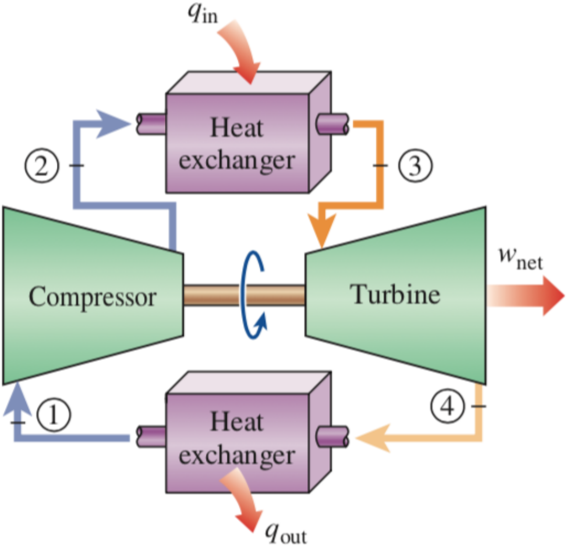
# Outline

Real vs. ideal Brayton cycles

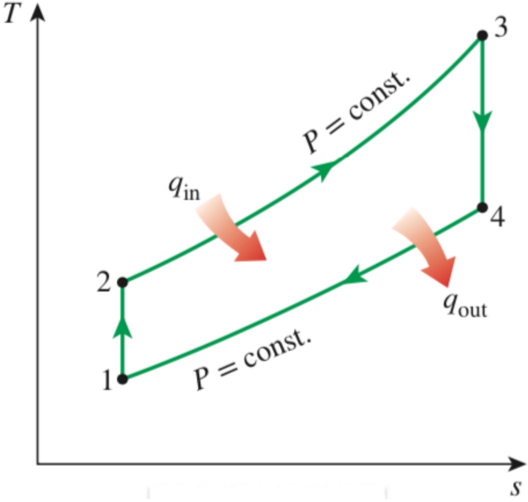
Improving Brayton cycle efficiency

# Reminder: the Brayton model of gas power cycles



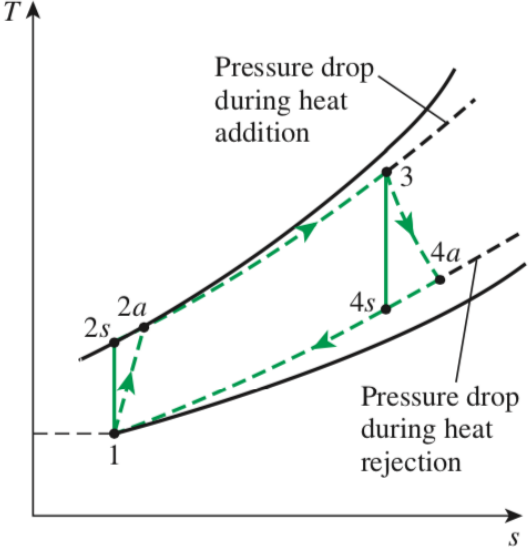

Cengel and Boles, *Thermodynamics: An Engineering Approach* (2019)

# Reminder: ideal Brayton cycle $T$-$s$ diagram




Cengel and Boles, *Thermodynamics: An Engineering Approach* (2019)

# Real Brayton cycle $T$-$s$ diagram




Cengel and Boles, *Thermodynamics: An Engineering Approach* (2019)

# Isentropic efficiencies

- pressure drops matter less than isentropic (in)efficiencies
- turbine isentropic efficiency:

$$\eta_t = \frac{\dot{W}_{34}}{\dot{W}_{34}^\star} = \frac{h_3 - h_4}{h_3 - h_4^\star}$$

- compressor isentropic efficiency:

$$\eta_c = \frac{\dot{W}_{12}^\star}{\dot{W}_{12}} = \frac{h_2^\star - h_1}{h_2 - h_1}$$

- after decades of R&D, $\eta_t$ and $\eta_c$ can now reach 85–90%
- but 'vanilla' Brayton cycle efficiencies may still be low

# Outline

Real vs. ideal Brayton cycles

Improving Brayton cycle efficiency

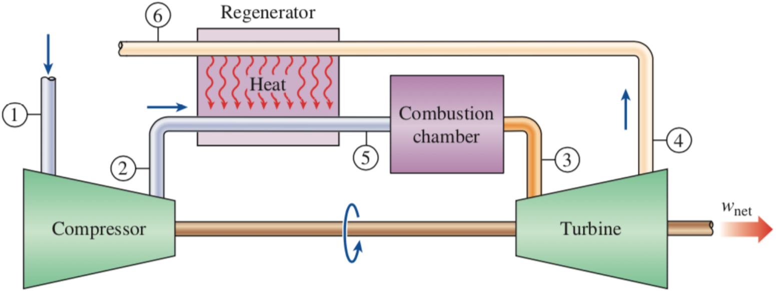
# How to improve Brayton cycle efficiency?

- reminder: the Brayton cycle efficiency is

$$\begin{aligned}\eta &= \frac{\text{useful output}}{\text{costly input}} \\ &= \frac{\text{net work output}}{\text{heat transfer input}} \\ &= \frac{\text{work output} - \text{work input}}{\text{heat transfer input}}\end{aligned}$$

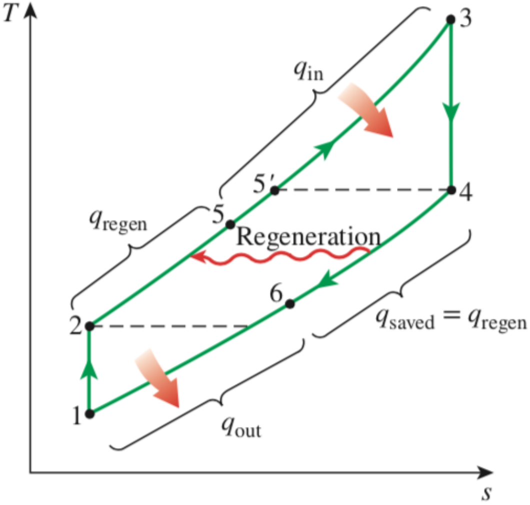
- to increase efficiency,
  - ◇ decrease (combustion) heat transfer input
  - ◇ increase (turbine) work output
  - ◇ decrease (compressor) work input

# Decreasing heat transfer input with regeneration



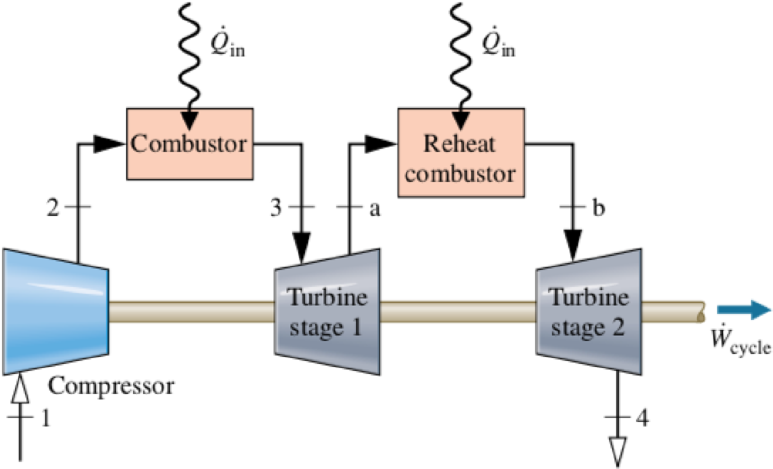

Cengel and Boles, *Thermodynamics: An Engineering Approach* (2019)

# Ideal Brayton cycle $T$-$s$ diagram with regeneration



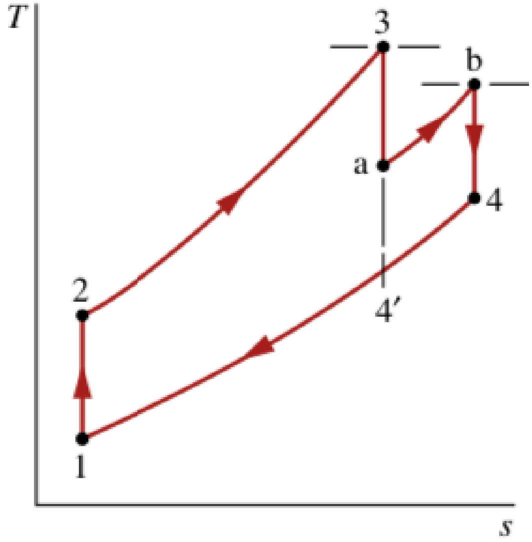

Cengel and Boles, *Thermodynamics: An Engineering Approach* (2019)

# Increasing turbine work output with reheat



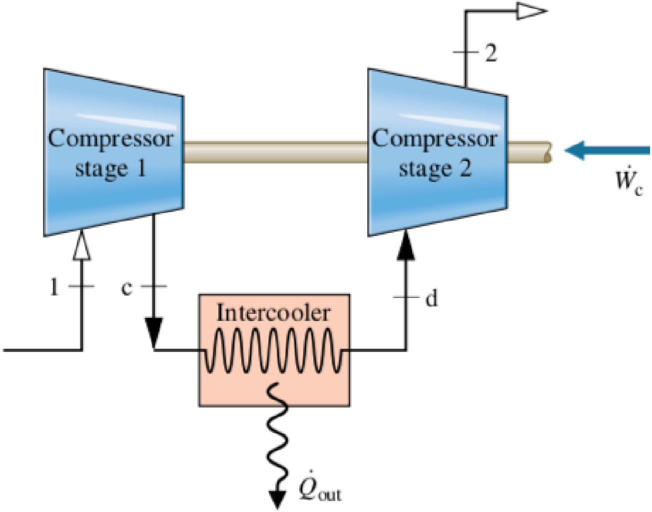

Moran et al., *Fundamentals of Engineering Thermodynamics* (2018)

# Ideal Brayton cycle *T*-*s* diagram with reheat



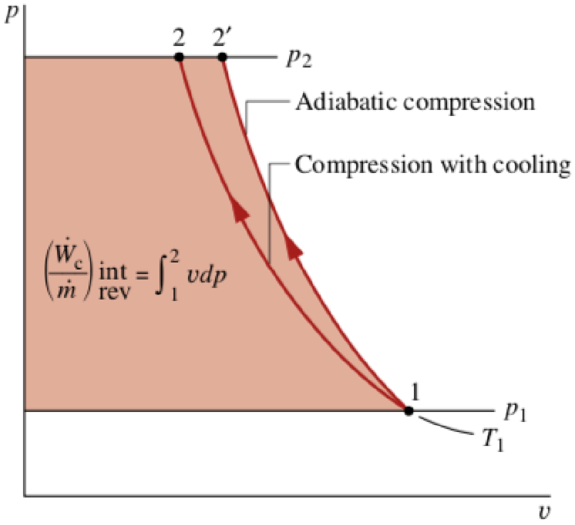

Moran et al., *Fundamentals of Engineering Thermodynamics* (2018)

# Decreasing compressor work input with intercooling



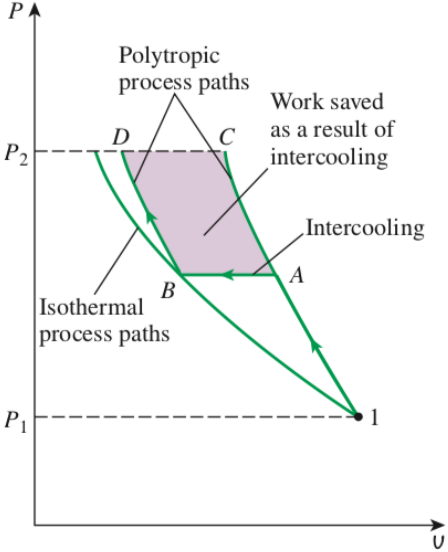

Moran et al., *Fundamentals of Engineering Thermodynamics* (2018)

# Cooling during compression decreases input work



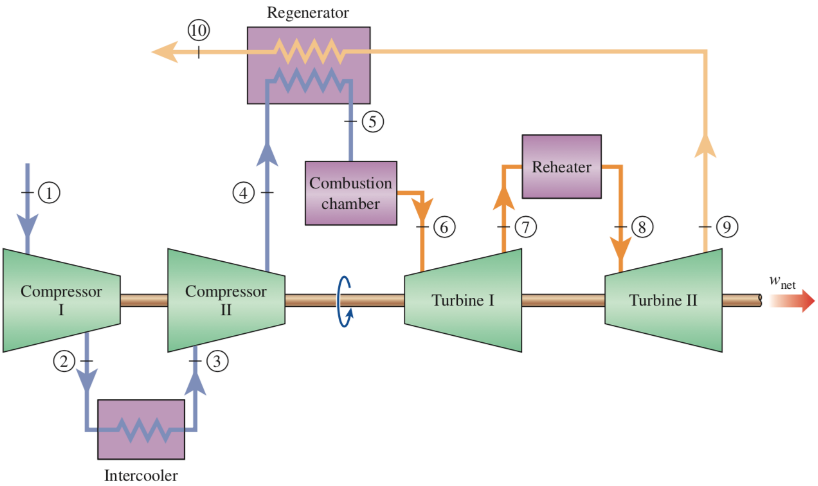

Moran et al., *Fundamentals of Engineering Thermodynamics* (2018)

# Compression $p$-$v$ diagram with intercooling



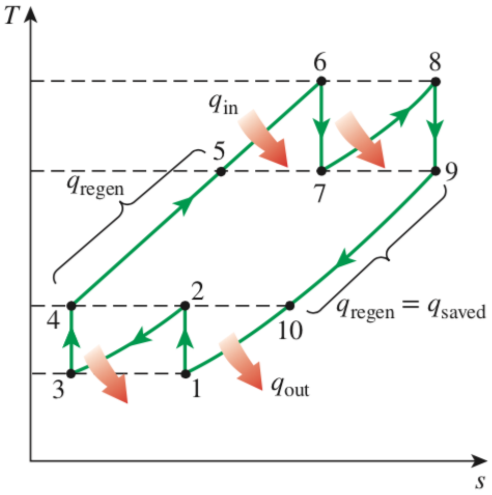

Cengel and Boles, *Thermodynamics: An Engineering Approach* (2019)

# Combining regeneration, reheat and intercooling



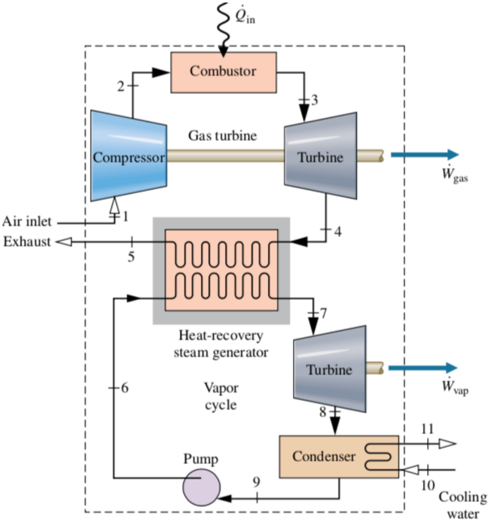

Cengel and Boles, *Thermodynamics: An Engineering Approach* (2019)

# $T$-$s$ diagram with regeneration, reheat and intercooling




Cengel and Boles, *Thermodynamics: An Engineering Approach* (2019)

# The combined (gas [Brayton] + vapor [Rankine]) cycle

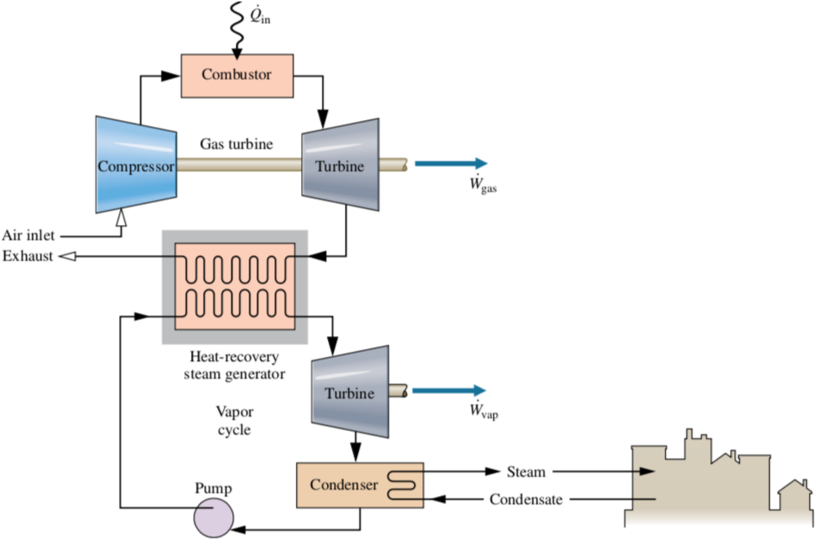



Moran et al., *Fundamentals of Engineering Thermodynamics* (2018)

# Rough efficiency comparisons

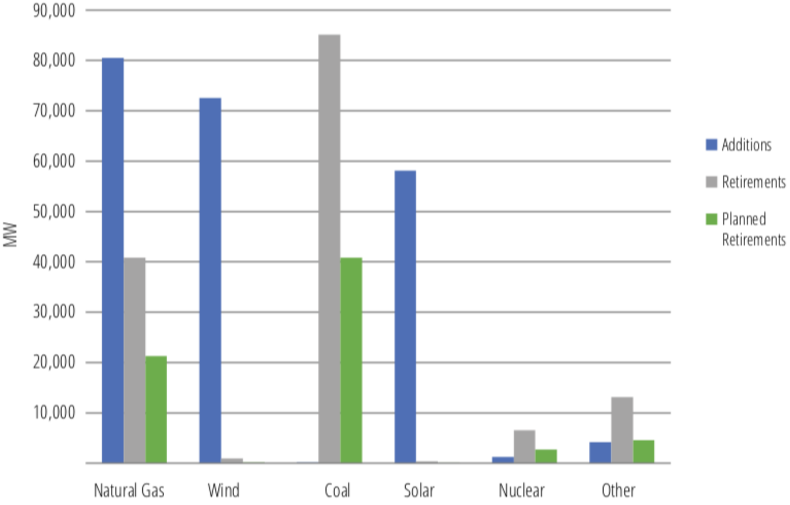
- ‘vanilla’ Brayton cycle with non-ideal components: $\sim$15–20%
- add regeneration (no reheat or intercooling): $\sim$25–30%
- add reheat and intercooling (no regeneration): $\sim$25–30%
- add regeneration, reheat and intercooling: $\sim$30–40%
- today’s simple-cycle record: 46%
- typical combined-cycle: $\sim$45–50%
- today’s combined-cycle record: 63%

# Expanding the notion of 'useful output' with cogeneration




Moran et al., *Fundamentals of Engineering Thermodynamics* (2018)

## Figure 6.2 Additions and Retirements, 2014-2021, plus Planned Retirements to 2026




American Public Power Association, *America's Electricity Generation Capacity: 2022 Update*