7th International sCO_2 Power Cycles Symposium, February 21-24, 2022

Investigation of sCO_2 Cycle Layouts for the Recovery of Low Temperature Heat Sources

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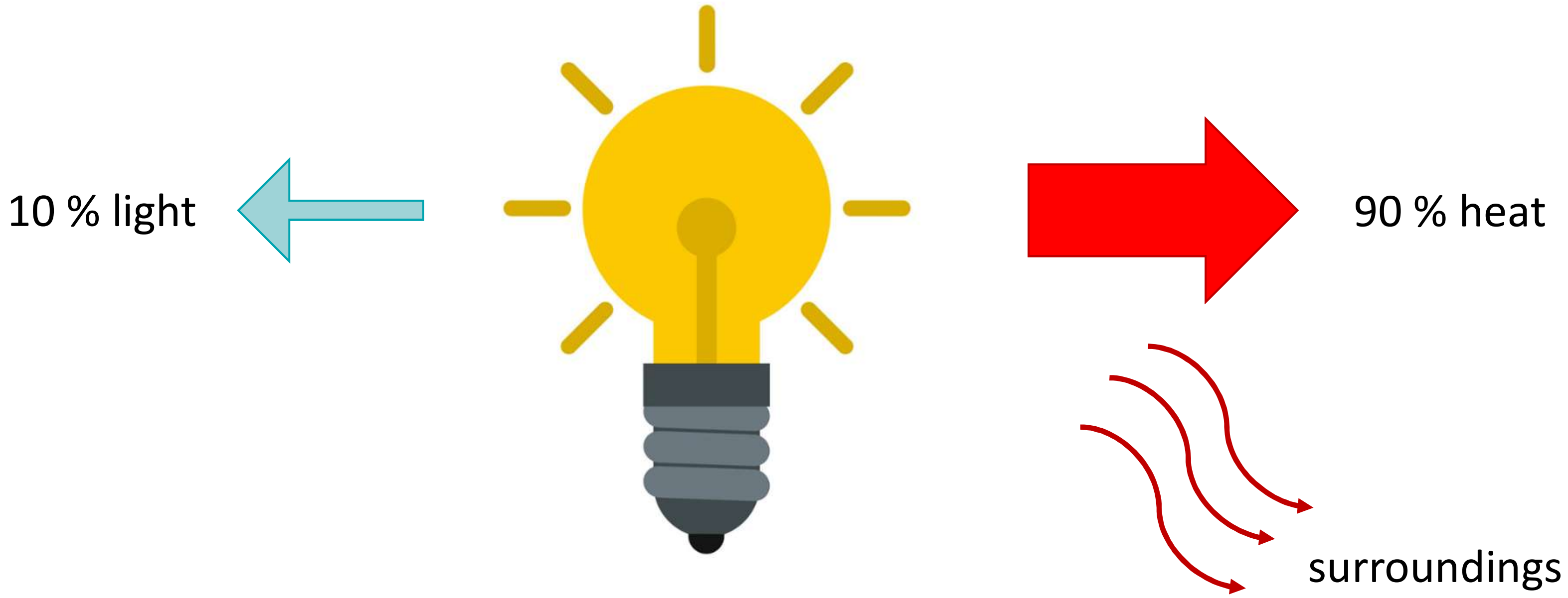
Outline

- Motivation
- Objective
- Assumptions
- Cycle comparison
- Results
- Conclusions

Motivation
Waste Heat Potential



Motivation
Waste Heat Potential

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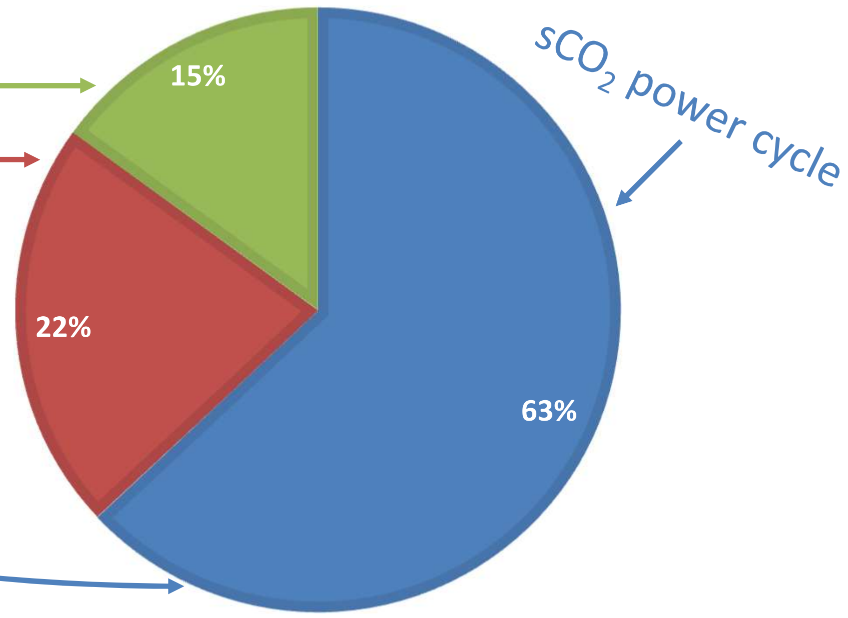
- Transformation of primary energy into secondary energy (e.g. electricity)
- Industrial processes
- Machines
- Buildings
- Transportation

Loss of heat

Large fraction of primary energy remains unused

Motivation
Classification of Waste Heat Sources

- High temperature: > 650 °C
- Medium temperature : 250-650 °C
- Low temperature: < 250 °C



Source: Forman C, Muritala IK, Pardemann R, Meyer B. Estimating the global waste heat potential. Renewable and Sustainable Energy Reviews 2016;57:1568–79.

Power cycle configurations
Literature research

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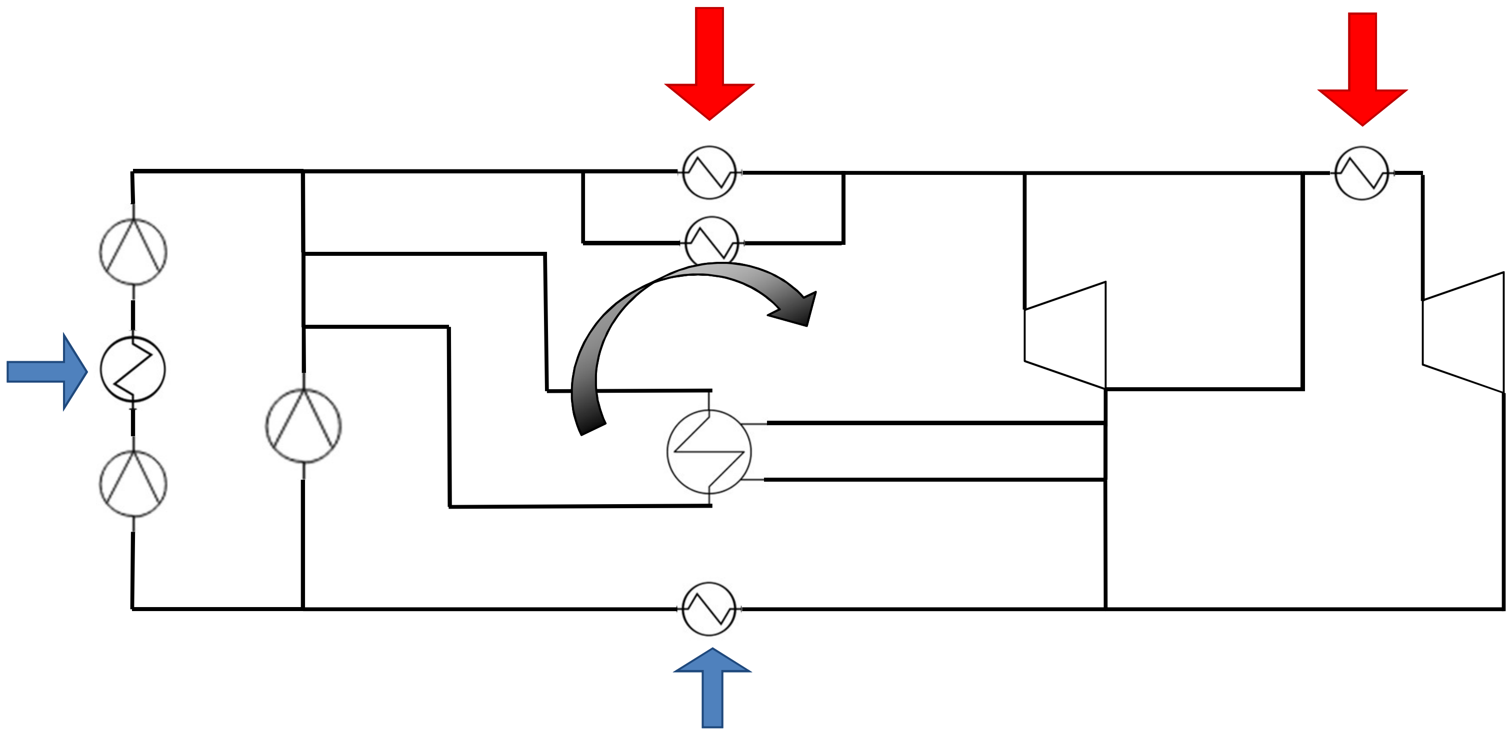
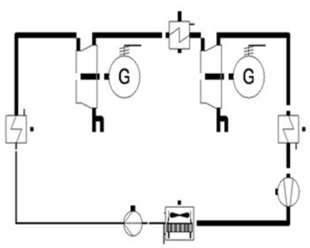
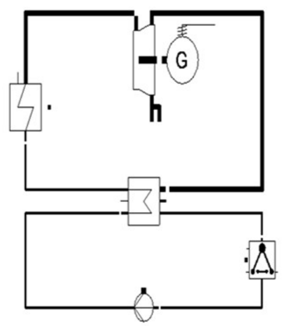
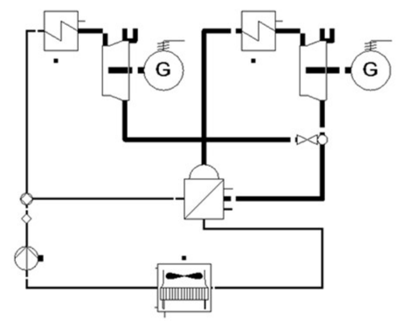


Power cycle configurations
Literature research

- Literature review: >50 different cycle configurations







- Not comparable: different boundary conditions
- Less focus on low temperatures

Objective

- Comparison of sCO2 power cycles
- Uniform boundary conditions
- Overview of efficiencies

Cycle Comparison
Boundary Conditions

- Rankine cycle based with full condensation of working fluid
- Saturated liquid exits the condenser
- Steady state condition
- No friction losses in
  - Pipes
  - Heat exchangers
- Waste heat source: air
- Heat sink: air

Cycle Comparison
Boundary Conditions

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Parameter	Value
Waste Heat Source Temperature	60-100 °C
Waste Heat Source Pressure	1.013 bar
Waste Heat Source Mass Flow	1000 kg/s
Heat Sink Temperature	20 °C
CO_2 Condensation Temperature	25.43 °C
CO_2 Condensation Pressure	65 bar
Turbine Isentropic Efficiency	80%
Pump Isentropic Efficiency	80%
Heat Exchanger Effectiveness	95%

Software:
EBSILON Professional

Cycle Comparison
Base for comparison/ Equations

- Thermodynamic first law efficiency

$$n_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{in}}$$

- Net power output of cyclic system

$$\dot{W}_{net} = \dot{W}_{Turbine(s)} - \dot{W}_{Pump(s)}$$

- Carnot efficiency

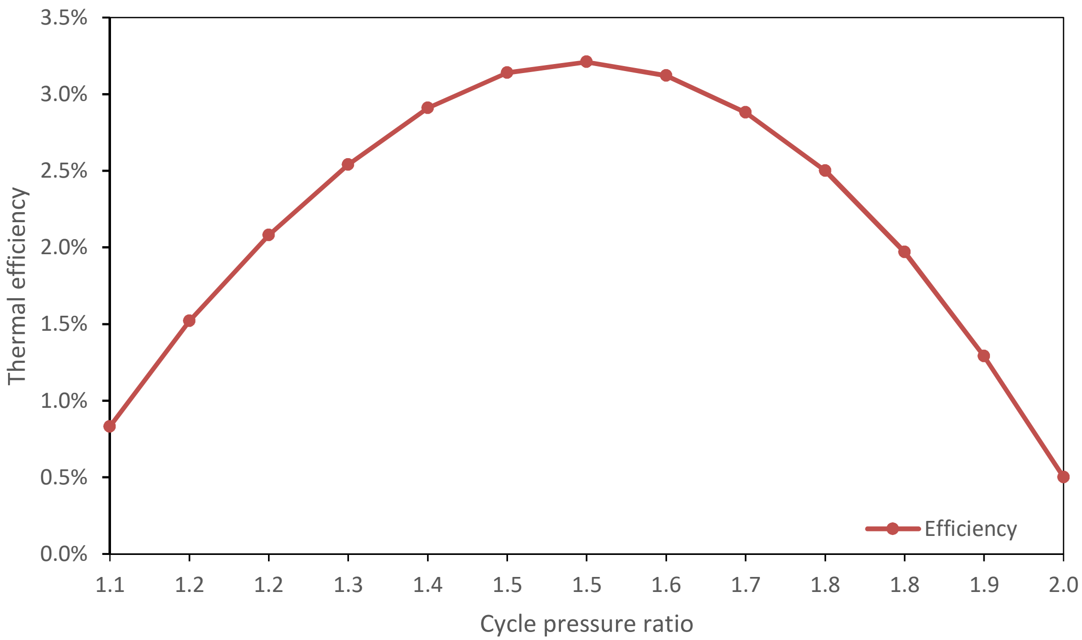
$$n_{Carnot} = 1 - \frac{T_{cold}}{T_{hot}}$$

Cycle Comparison
Validation

- Existing documented cycles from literature
- Implementation with original boundary conditions
- Resulting efficiency must agree with publication
- → only then: adaptation of boundary conditions

Results
Influence of pressure ratio

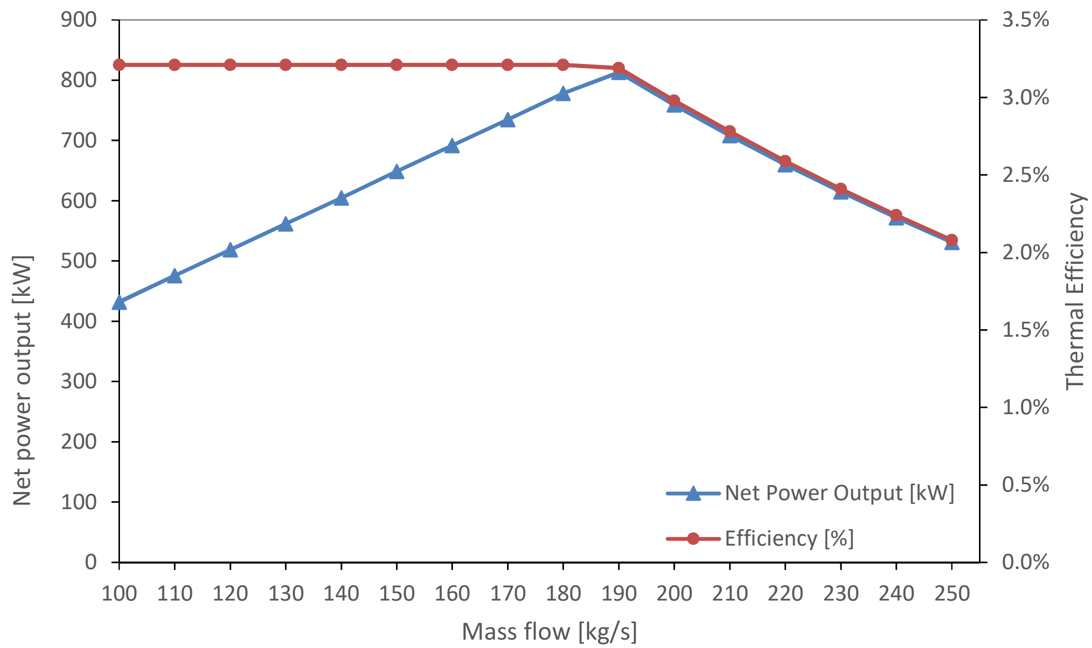
- Independent of cycle configuration
- Here: basic 4-component configuration



- Parabolic shaped efficiency
- One peak efficiency
- Value of pressure ratio dependent on cycle configuration

Results
Influence of mass flow

- Independent of cycle configuration
- Here: basic 4-component configuration



- Net power output has a peak
- Mass flow < peak mass flow: pumping power and turbine power rise at same rate
  → efficiency stays constant
- Mass flow > peak mass flow : pumping power rises at a faster rate than turbine power output
  → efficiency decreases

Results
Cycle Comparison

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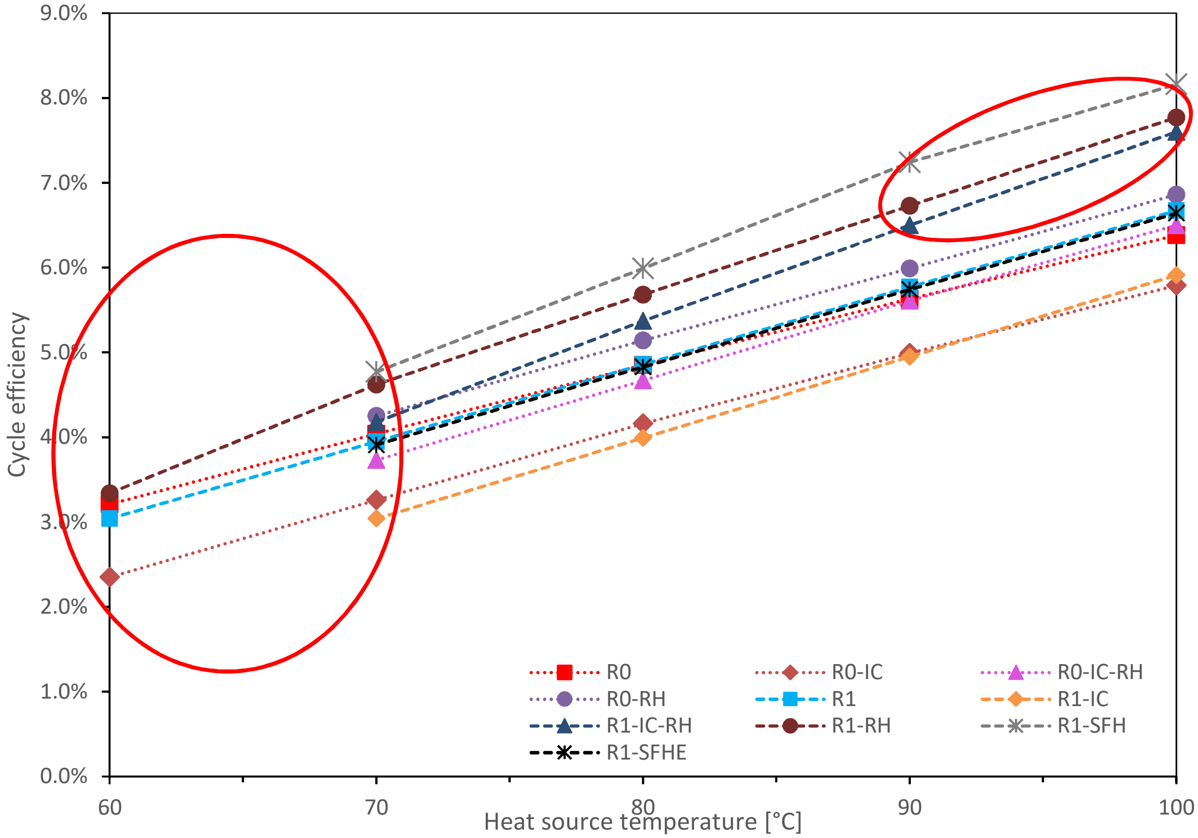
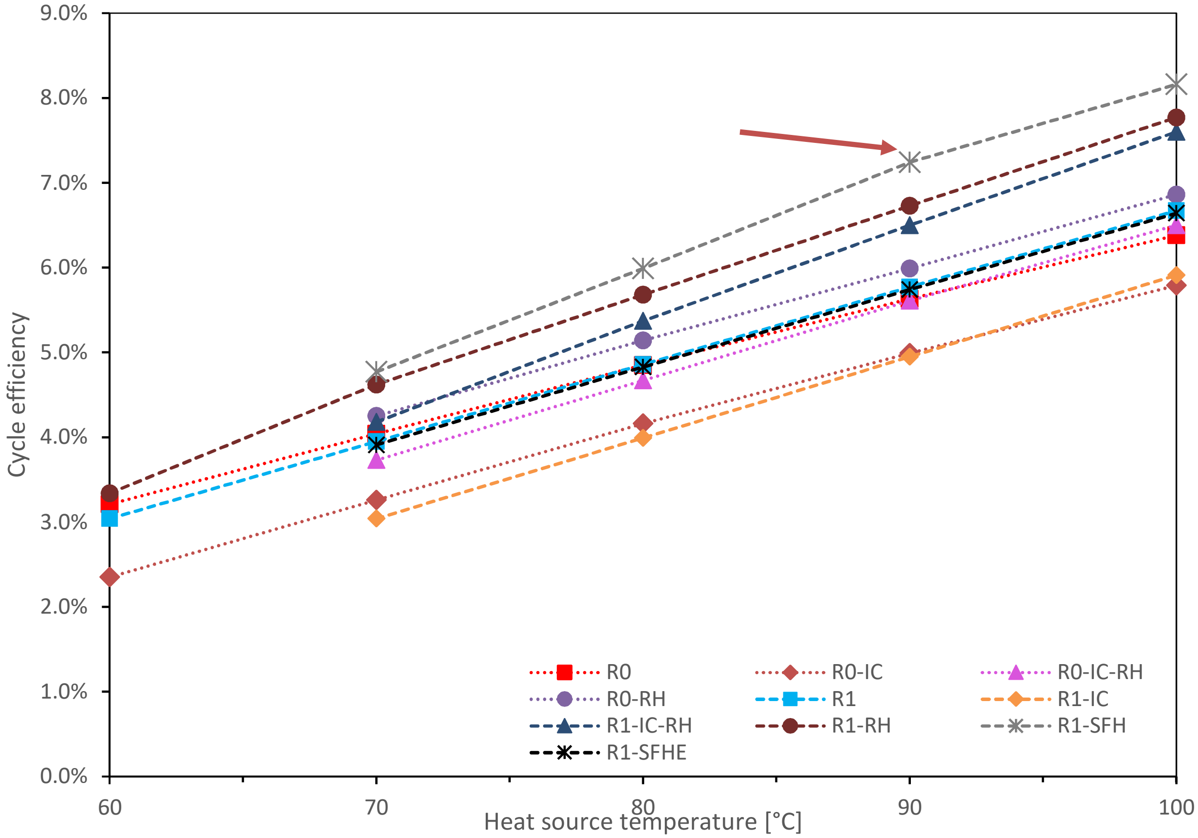


- Basic 4-component configuration performs best at lowest temperature
- Recuperator:

  With increasing heat source temperature: diverging lines

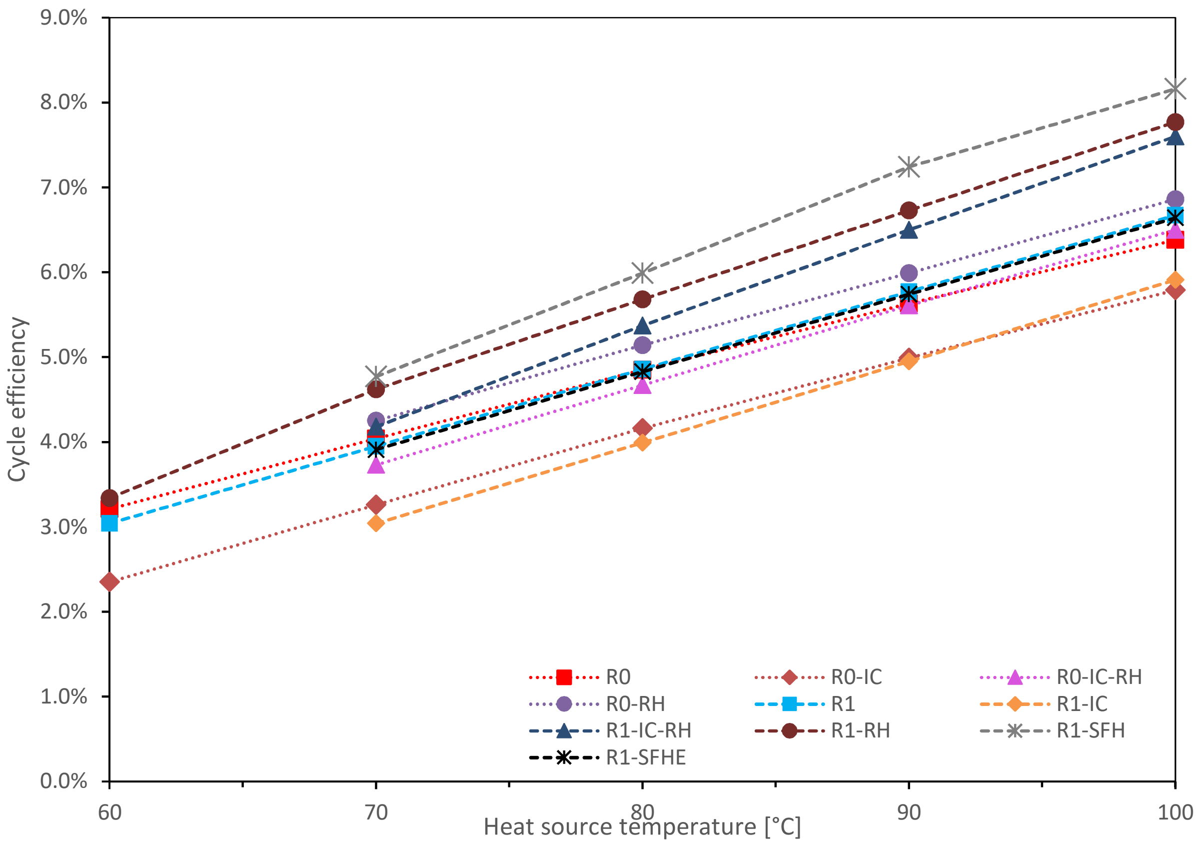
  → recuperated cycle lines rise more steeply

Results
Cycle Comparison



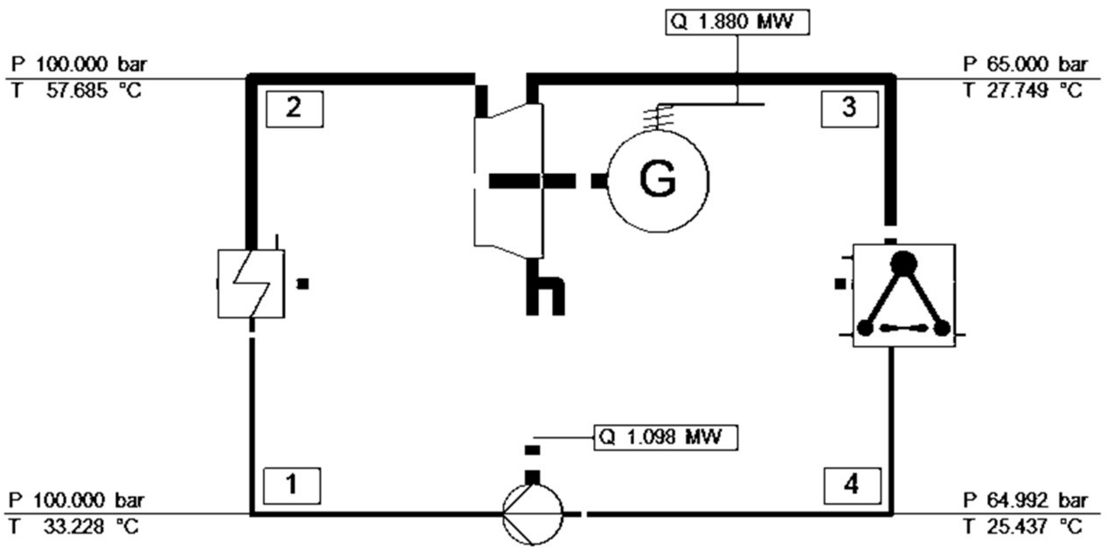
- <u>Split flow before heating:</u>
  best performance
  → good extraction of
  waste heat source
- <u>Reheated expansion:</u>
  - Beneficial from >70°C
  - More significant with higher temperatures

Results
Cycle Comparison



- Only 10 configurations lead to a result
- No configurations with two regenerators
- Several split flow configurations did not function for very low source temperatures

Results
Cycle Comparison



- Pump requires high power
- <u>Restrictive Temperatures</u>
  → make it hard to fit in further steps, e.g. regenerator

Conclusions

- **The simplest configuration is the best**: for 60-80°C heat source temperature
- Recuperator step has limited applicability, >80°C
- More HX for heat source extraction increase efficiency
- Not applicable for ultra-low temperatures:
  - Split flow before cooling
  - Intercooled compression
  - More than one recuperator
- Required pumping power is a major reason for low efficiencies

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