Parametric Evaluation of S-CO2 Brayton Cycles for Waste Heat Recovery Applications

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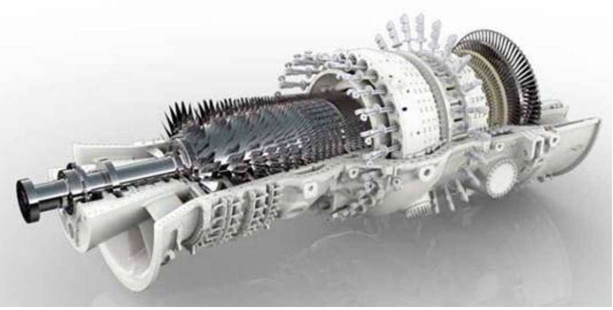
Agenda

- Objectives study
- Cycles
- Methodology
- Results
- Conclusions

s-CO$_2$ heat recovery cycles

Objectives

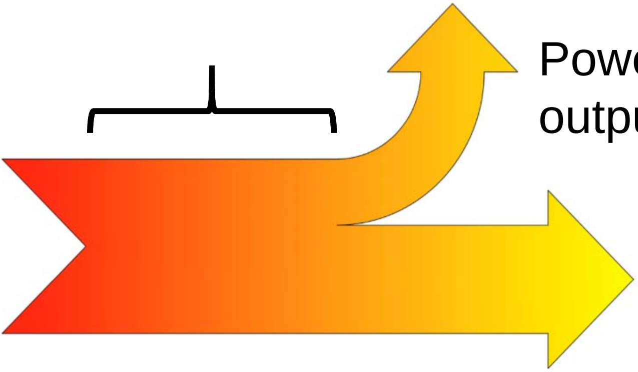
Gas turbine



Ansaldo GT26 Source: www.turbomachinerymag.com/

Heat recovery cycle

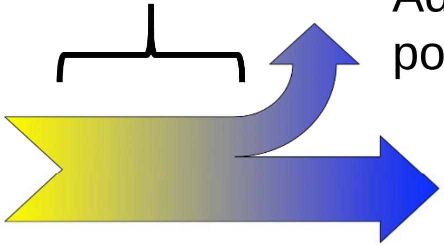
Source: http://www.echogen.com



Chemical energy

Power output

Exhaust heat ~ 750 K



Additional power output

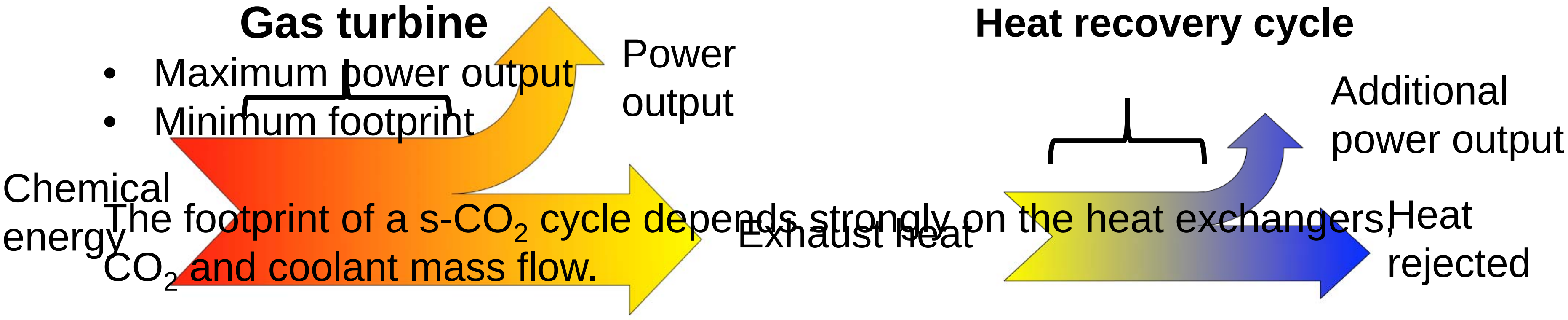
Heat rejected

s-CO_2 heat recovery cycles

Objectives

For retrofitting existing gas turbine power plants there two contrasting objectives for the bottoming cycle:

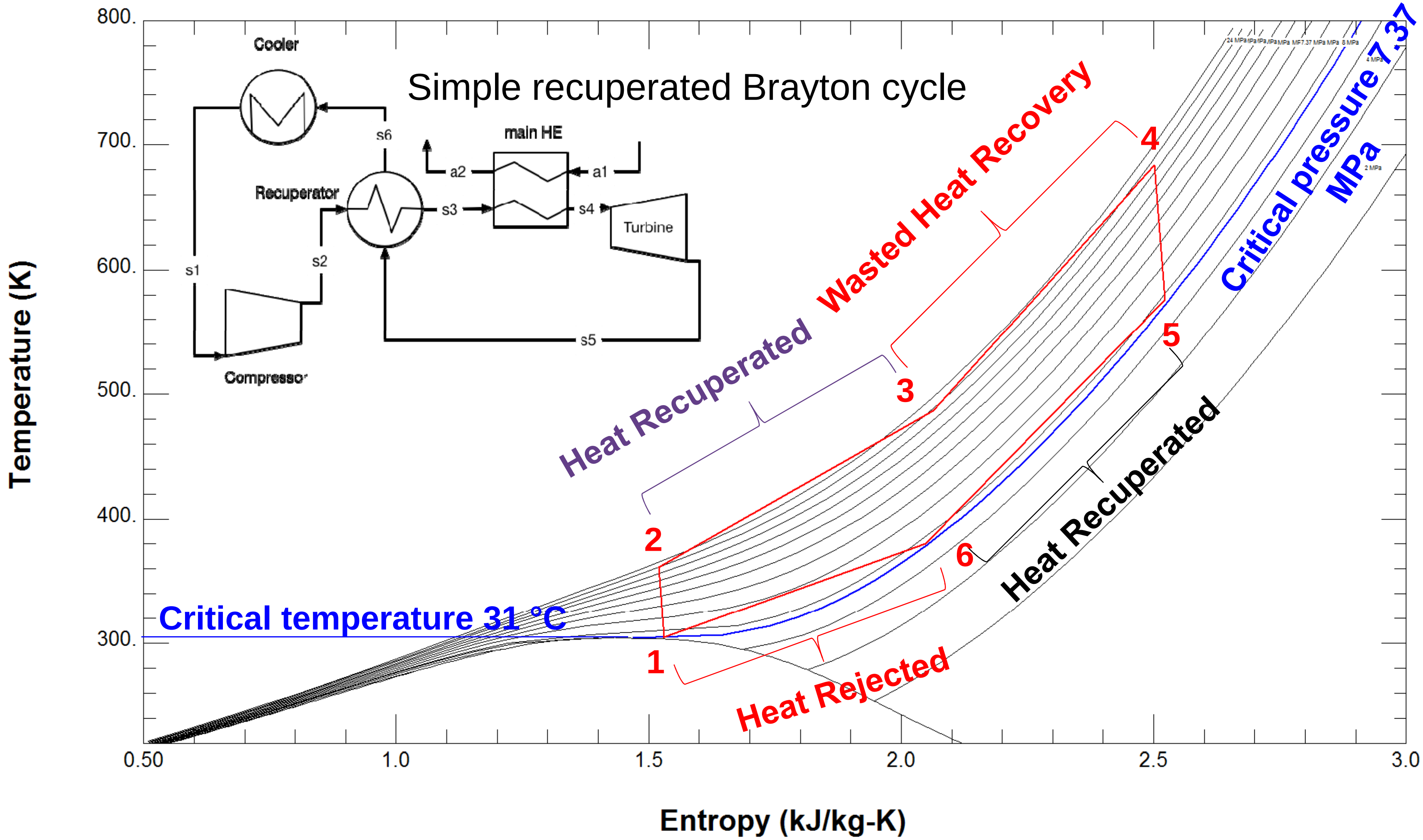
- Maximum power output
- Minimum footprint



The footprint of a s-CO_2 cycle depends strongly on the heat exchangers, CO_2 and coolant mass flow.

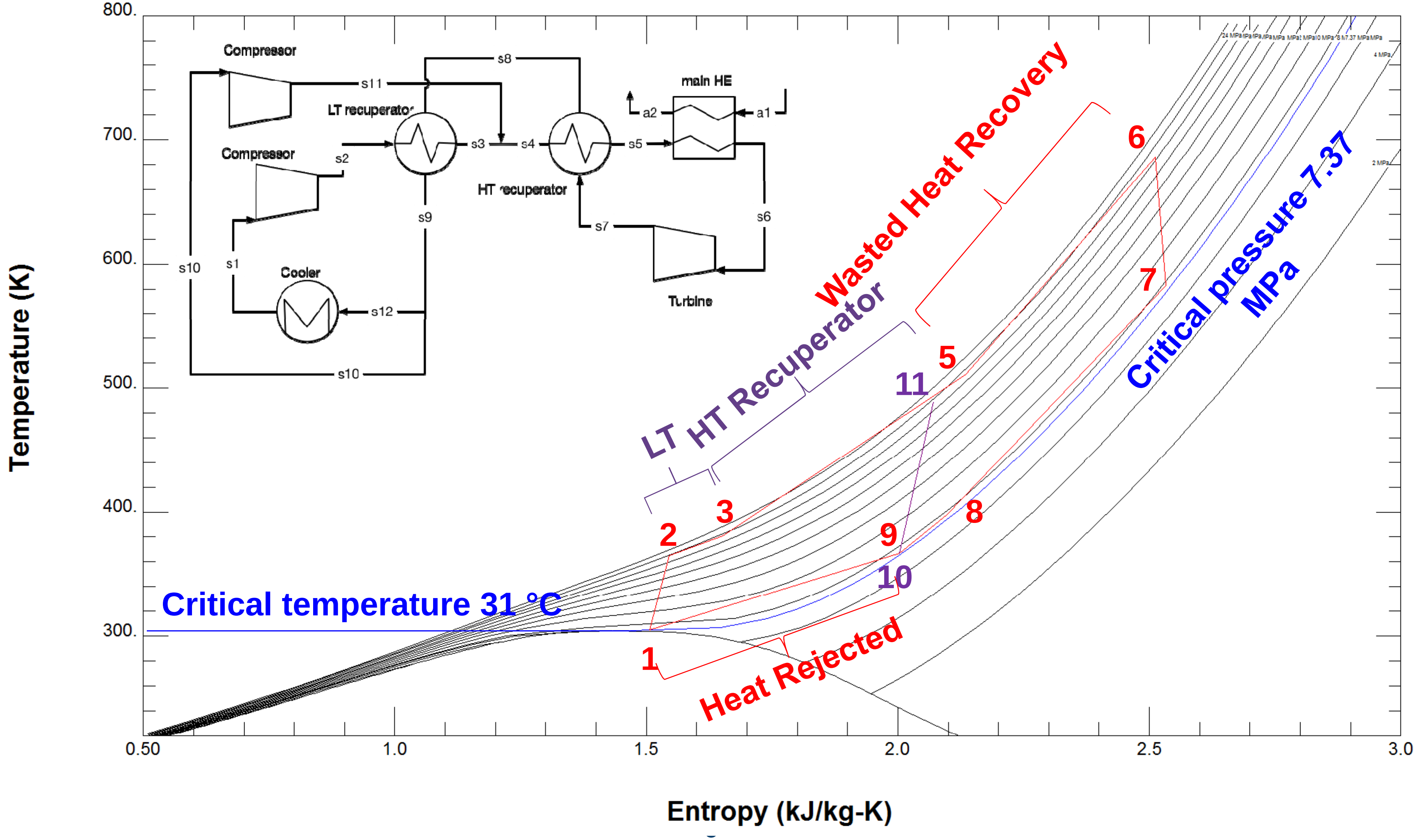
This study therefore focuses on the comparison of established s-CO_2 cycles on the base of the heat exchanger UA and the power output.

s-CO_2 cycles
Simple Brayton



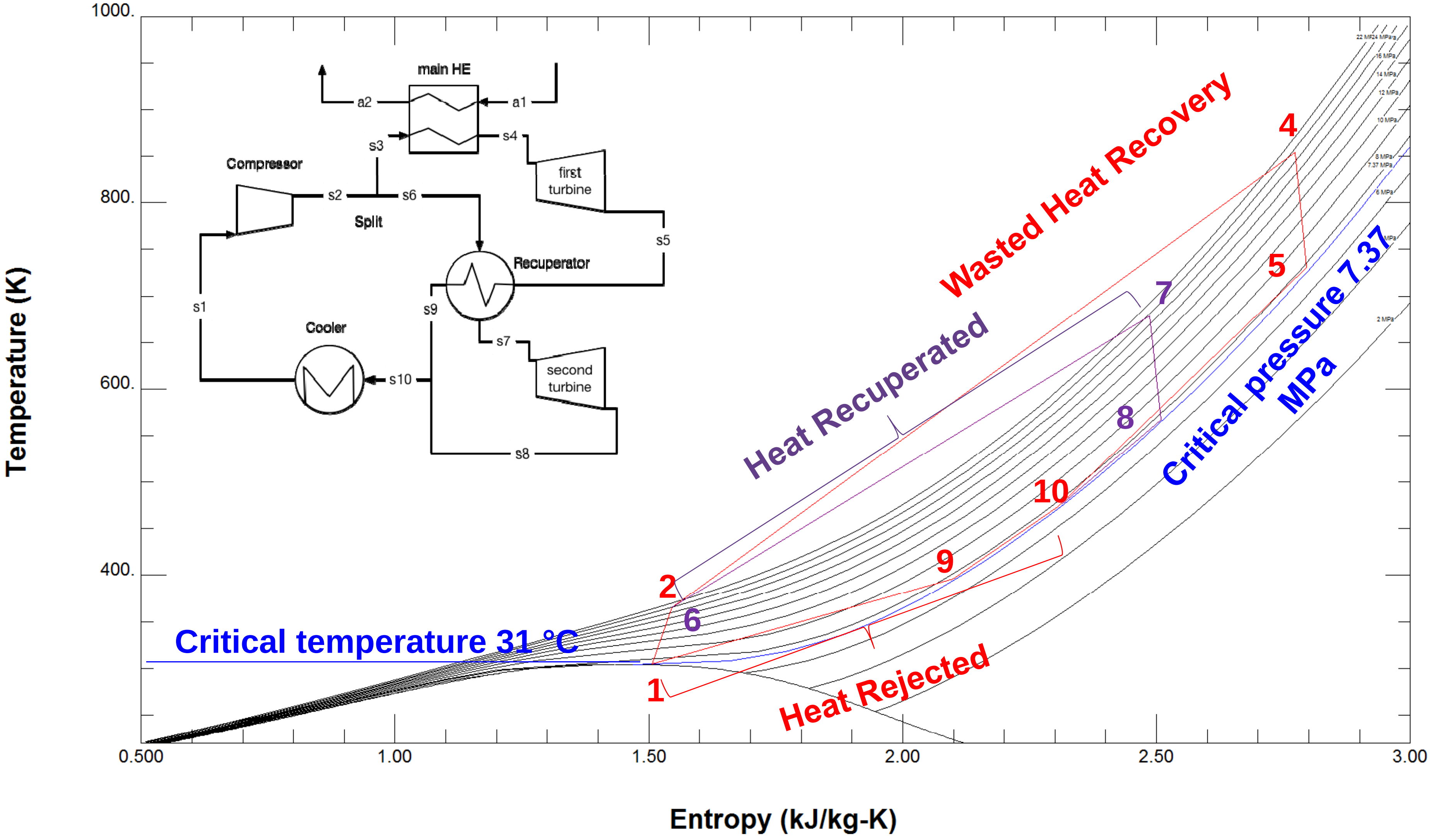
s-CO_2 cycles

Recompressed Brayton cycle



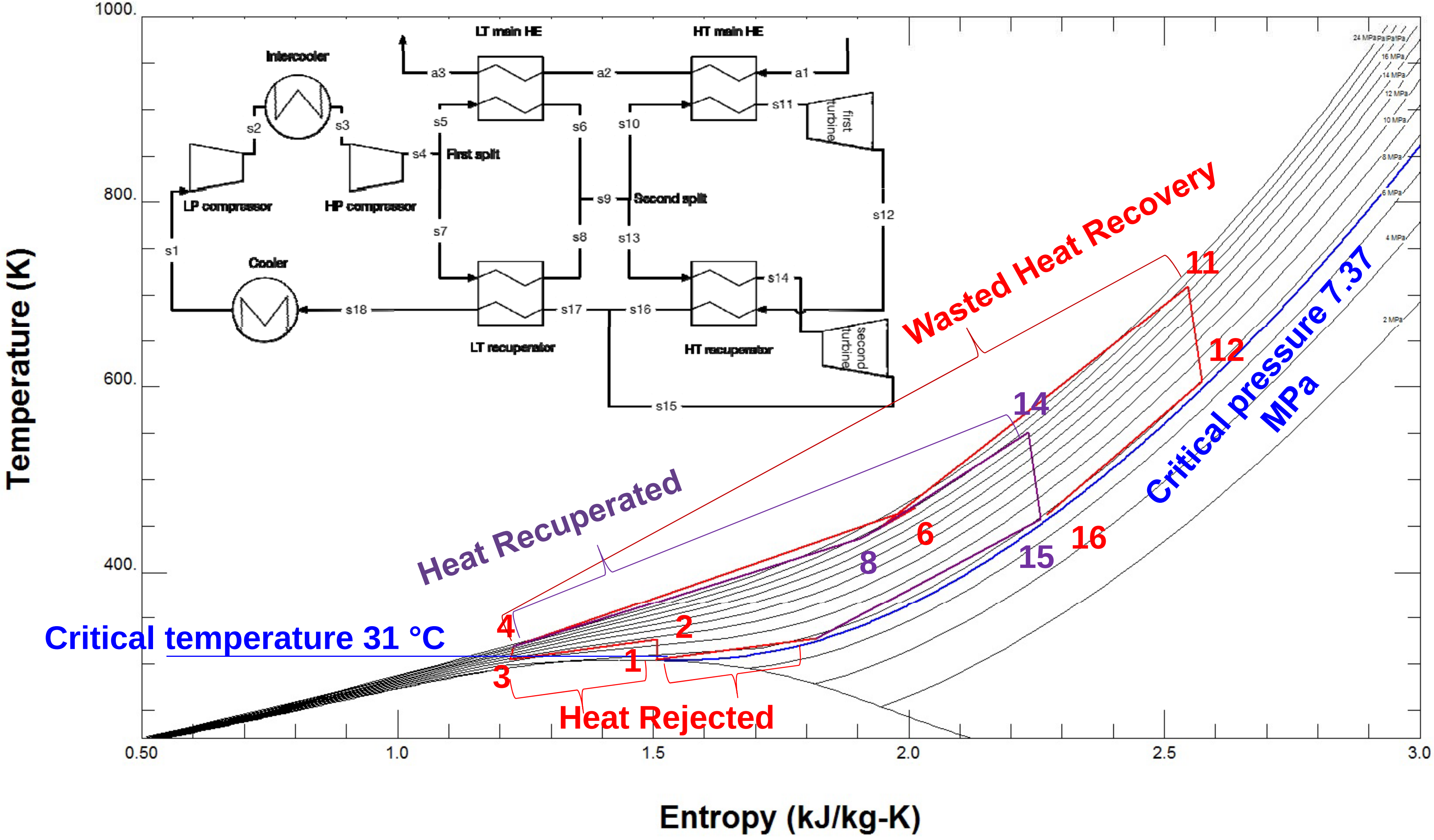
s-CO$_2$ cycles

Nested Brayton cycle



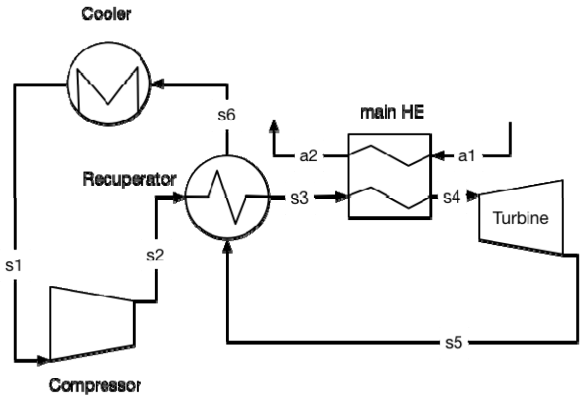
s-CO$_2$ cycles

Dual split nested Brayton cycle

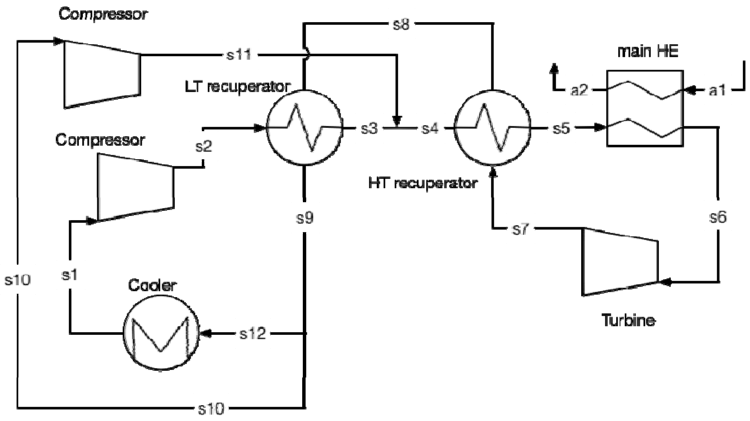


s-CO_2 cycles

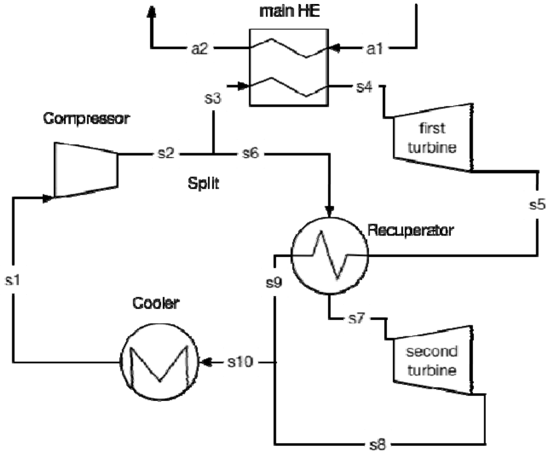
Simple recuperated Brayton cycle



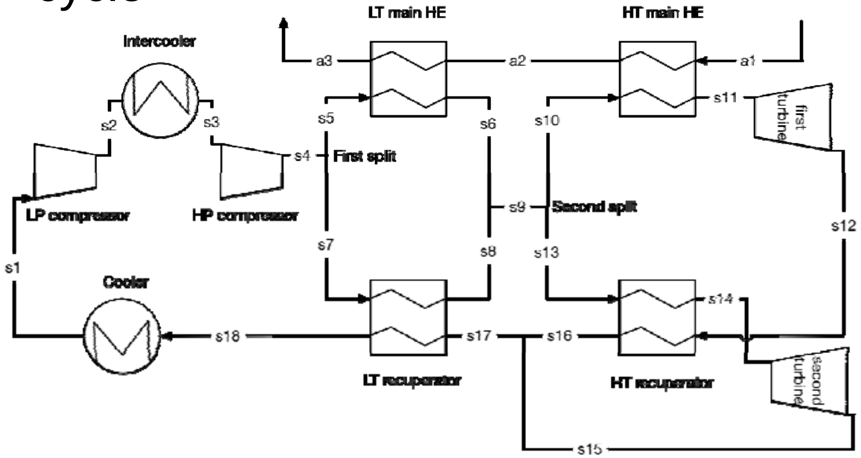
Recompressed Brayton cycle



Nested Brayton cycle

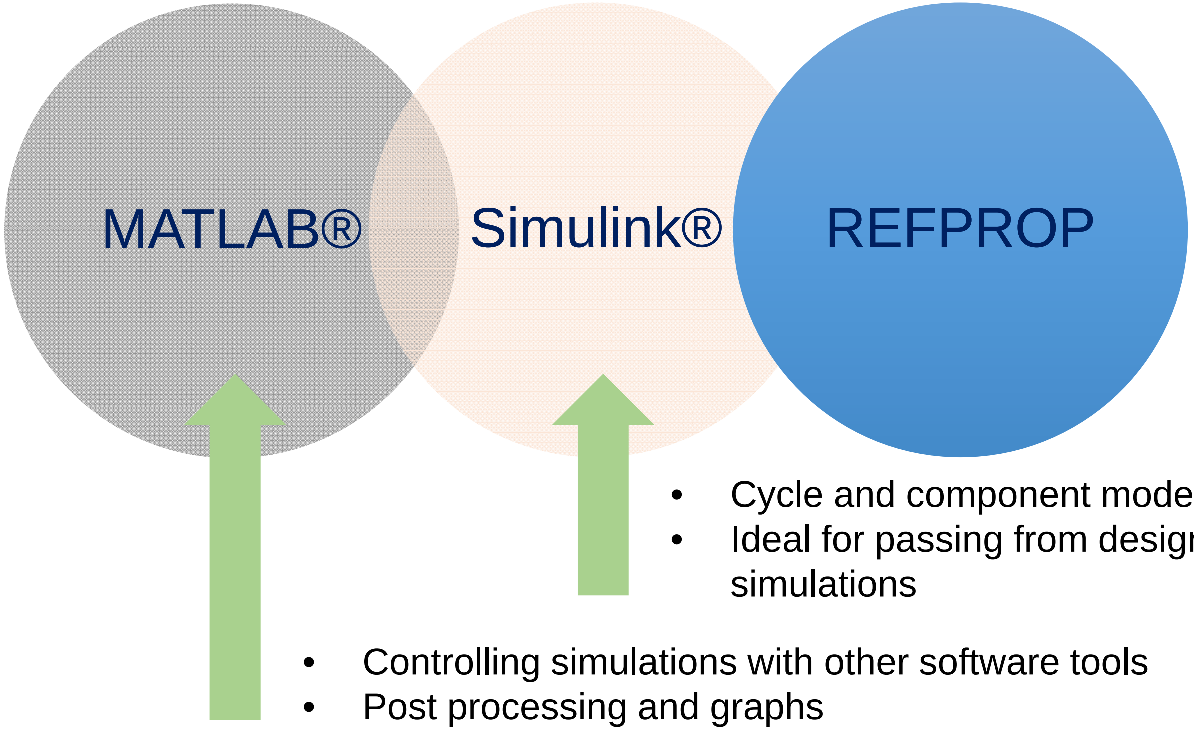


Dual split nested Brayton cycle



Methodology

Cycle simulation platform



MATLAB®

Simulink®

REFPROP

- Fluid Thermodynamic and Transport Properties Database and Includes a thermo-physical properties database for CO_2
    - Span and Wagner equation of state[1]

- Cycle and component models
- Ideal for passing from design point simulations to part load simulations

- Controlling simulations with other software tools
- Post processing and graphs

UA calculations for the heat exchangers are *first order backward difference discretization of the energy equation*

[1] Span, R., and Wagner, W., “A New Equation of State for Carbon Dioxide Covering the Fluid Region from the Triple-Point Temperature to 1100 K at Pressures up to 800 MPa,” Journal of Physical and Chemical Reference Data, vol. 25, Nov. 1996, pp. 1509–1596.

Methodology

Assumptions & design space exploration

When comparing the cycles the following assumptions are made:

- No mechanical losses are accounted for
- Coolant circulation pumping power is not accounted for in performance calculations

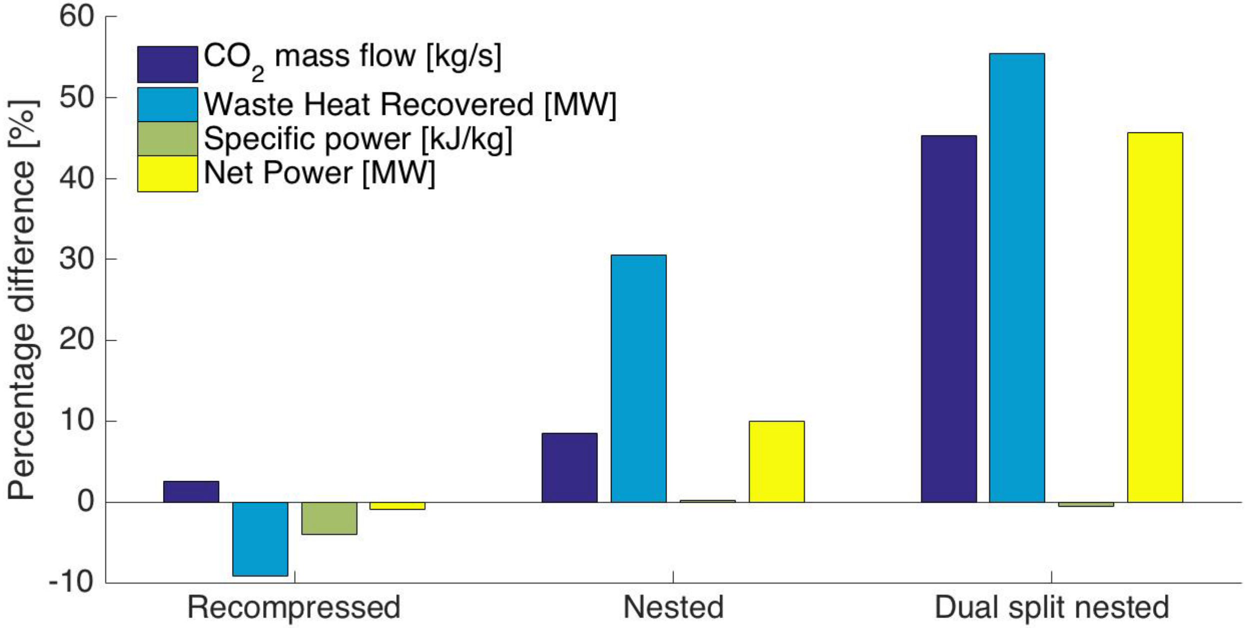
Variable [Unit]	Value
Gas turbine exhaust gas temperature [K]	740
Gas turbine exhaust gas mass flow [kg/s]	100
Inlet compressor pressure [MPa]	7.5
Inlet compressor temperature [K]	305
Compressor isentropic efficiency [-]	0.87
Compressor delivery pressure (Max cycle pressure) [MPa]	22
Turbine isentropic efficiency [-]	0.85
Heat exchanger effectiveness [-]	0.9
Coolant inlet temperature [K]	300
MHEX pressure loss coefficient [-]	0.02
High/low pressure recuperator pressure loss coefficient [-]	0.01
Cooler pressure loss coefficient [-]	0.02

Design space exploration across a range of:

- CO_2 mass flow [80-200] kg/s
- CO_2 mass flow splits for the recompressed, nested and dual split nested cycle [0.1-0.9]

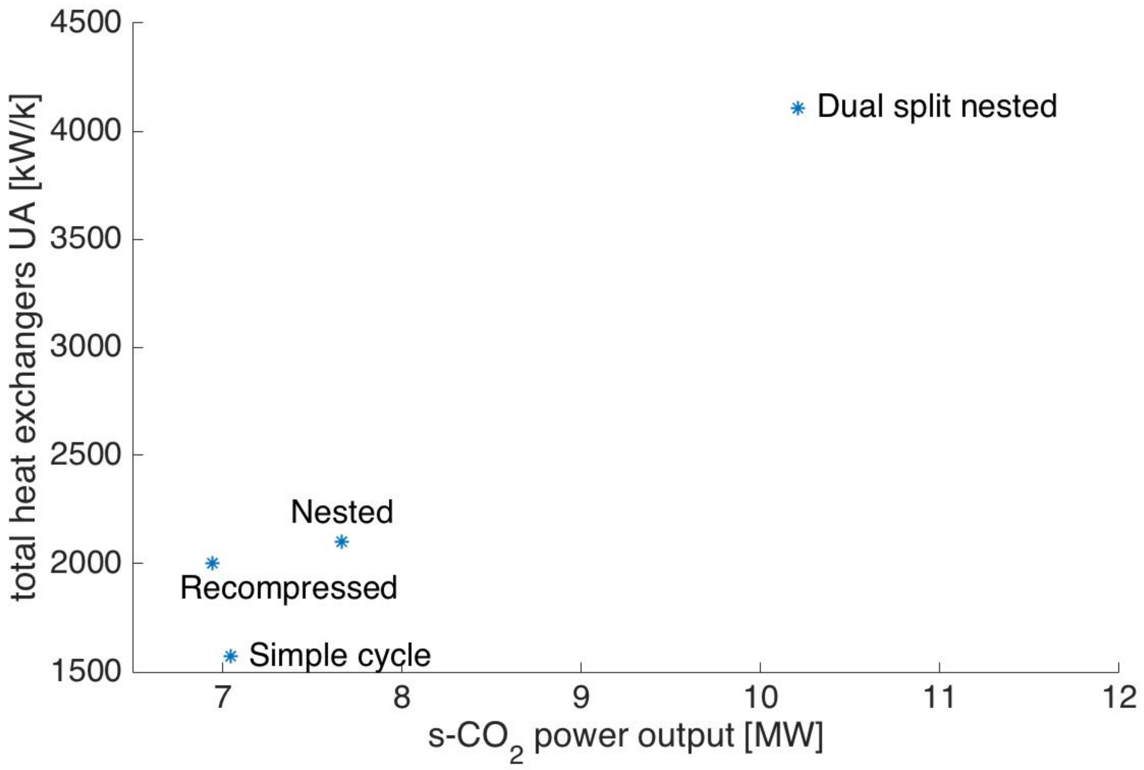
Cycle performance against the simple recuperated cycle

Cycle Layout	CO_2 mass flow rate	Waste Heat Recovered	Specific power	Net power
Simple Recuperated	117 kg/s (reference)	27.2 MW (reference)	60.3 kJ/kg (reference)	7.0 MW (reference)



- Dual split nested cycle achieves 45% higher Net power with 57% higher waste waste heat recovery compared to the simple recuperated cycle
- The recompressed cycle under performs the simple cycle

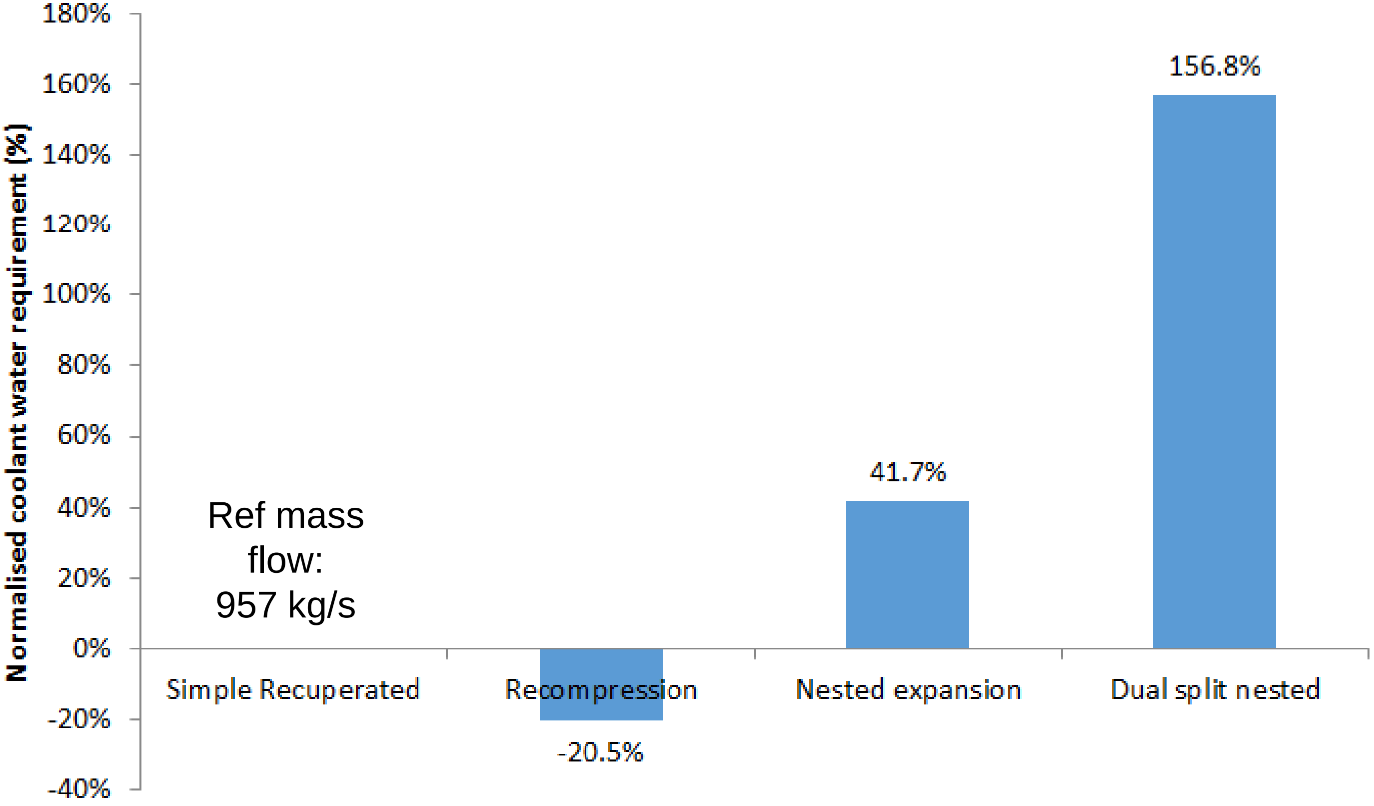
Thermodynamic dimension comparison



- The UA in the dual split nested cycle increases by **109.5% for the main HE, 313.5% for the recuperator and 78% for the cooler** devices compared to the simple cycle, the main increase in UA is in the recuperation process
- The UA in the nested cycle increases by **47.3% for the main HE, 1% for the recuperator and 50.2% for the cooler** device compared to the simple cycle, the main increase in UA is in the cooling process

Coolant mass flow requirement comparison

Coolant inlet (288.15 K) and outlet temperature (293.15 K) are fixed, the coolant mass flow requirement is calculated, to comply environmental limitations for water cooled power plants



Conclusions

The **dual split nested cycle**:

- Achieves the higher power output (10 MW)
- Need very high UA (161% higher than the simple cycle) and coolant mass flow therefore the expected highest footprint.

The **recompressed cycle** for heat recovery applications is outcompeted for both total UA and power output by all cycles.

The **nested cycle**:

- Achieves 10% higher power output than the simple cycle
- 33% higher total UA than the simple cycle

The **simple recuperated cycle** was found to require physically more compact heat exchanger configurations at modest net power output

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$$(h_{c,n})^{i} = (h_{c,n-1})^{i-1} + \frac{UA}{m_c} * (T_{h,n} - T_{c,n})^{i-1}$$

n=node
i=iteration
h= hot stream
c= cold stream

Water inlet

CO2 inlet

Water inlet