Efficient Brayton Batteries: Powering Integrated Electricity, Heat, and Cooling Solutions

Dr.-Ing. Michael Krüger
German Aerospace Center (DLR), Institute of Engineering Thermodynamics, Stuttgart, Germany
Michael.Krueger@dlr.de

Motivation

- Integrating Carnot batteries enhances sector coupling by linking electricity, heating, and cooling, optimizing renewable energy use.
- Innovative Brayton battery systems enable CO_2-free heat generation for industrial and residential applications, aiding decarbonization.
- Utilizing waste heat in combined systems boosts energy efficiency, reducing losses and maximizing performance.

Objectives

Conduct extensive design calculations, including topological analysis, to:

- optimize system parameters and configurations, enhancing efficiency and reducing costs,
- explore additional benefits beyond electricity only, including integrated systems for combined heat, power, and cooling.

Approach & Methods

- A concept study[1-3] evaluated Brayton batteries using air, CO_2, and Ar, with or without recuperators, considering various points for heat integration or extraction.
- Compressor outlet temperature COT=450°C (state of the art) and COT=625°C (under development) were assessed.
- Over 200,000 concepts were analyzed, driven by the combinatorial possibilities of placing one or more heaters and coolers at different points, supported by the development of a universal tool for topological analysis (see Fig 1).
- Lead concepts were defined for each application with or without **W**aste **H**eat **I**ntegration (@90°C):
  - **E**lectricity only;
  - **C**ombined **H**eat (@250°C) and **P**ower;
  - **C**ombined **C**ooling (@6°C) and **P**ower;
  - **C**ombined **H**eat (@250°C), **C**ooling (@6°C), and **P**ower.

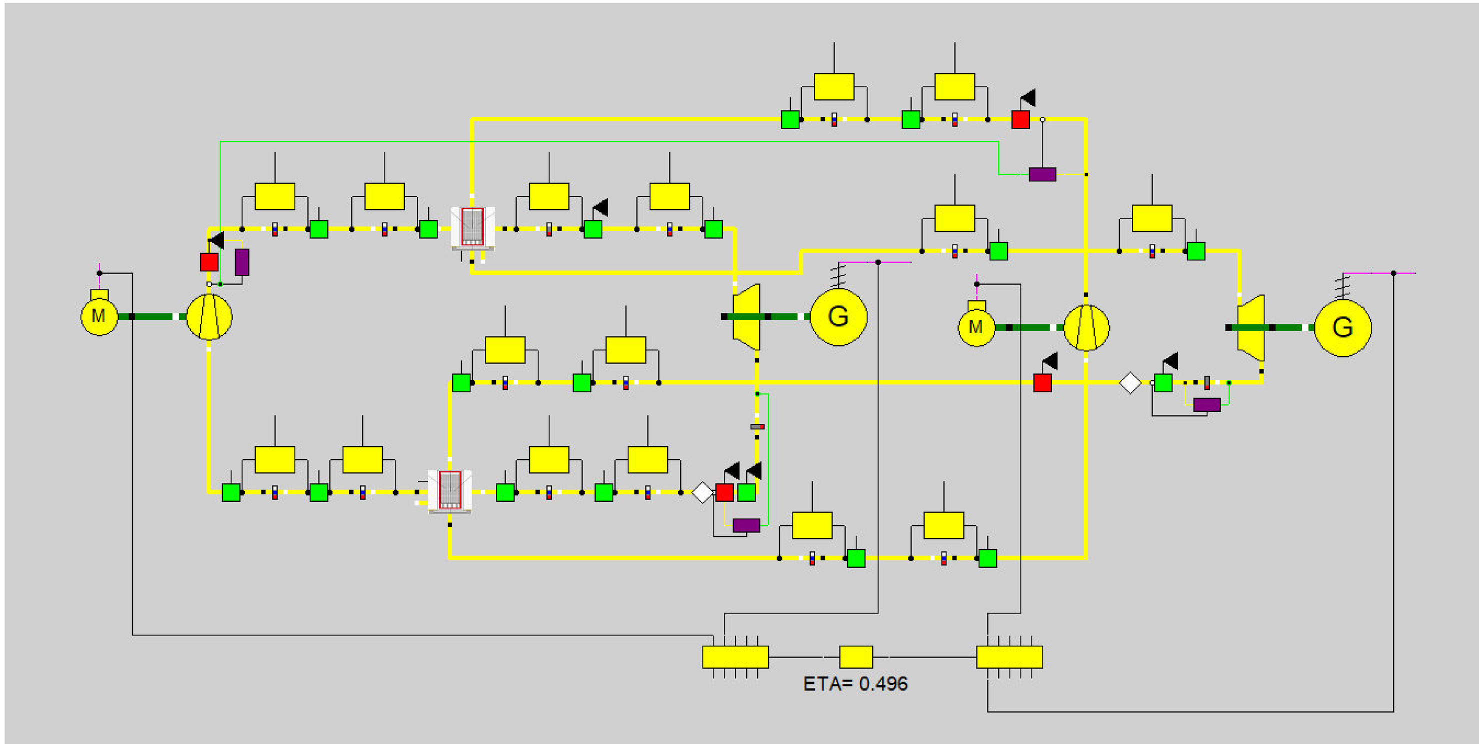

Fig. 1: Universal simulation tool for topological analyses using in Ebsilon Professional®

Results

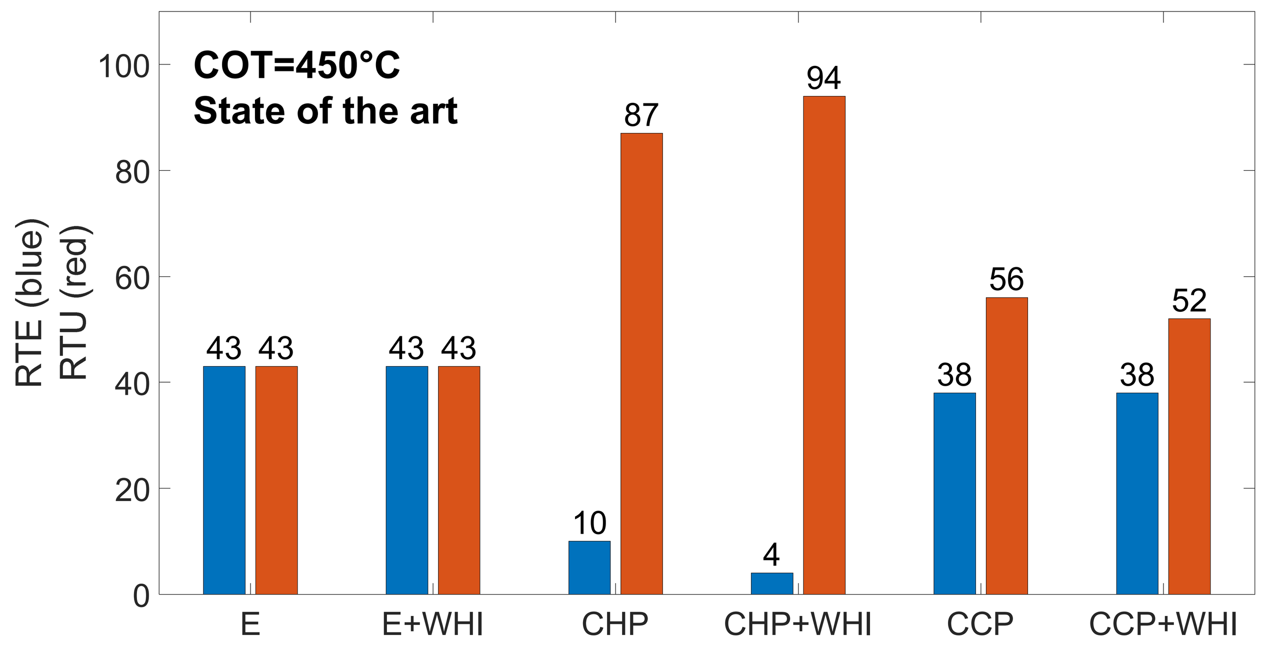

Fig. 2: Summarized results: Maximum values for round trip efficiency (RTE) and round trip utilization (RTU) at compressor outlet temperature COT=450°C

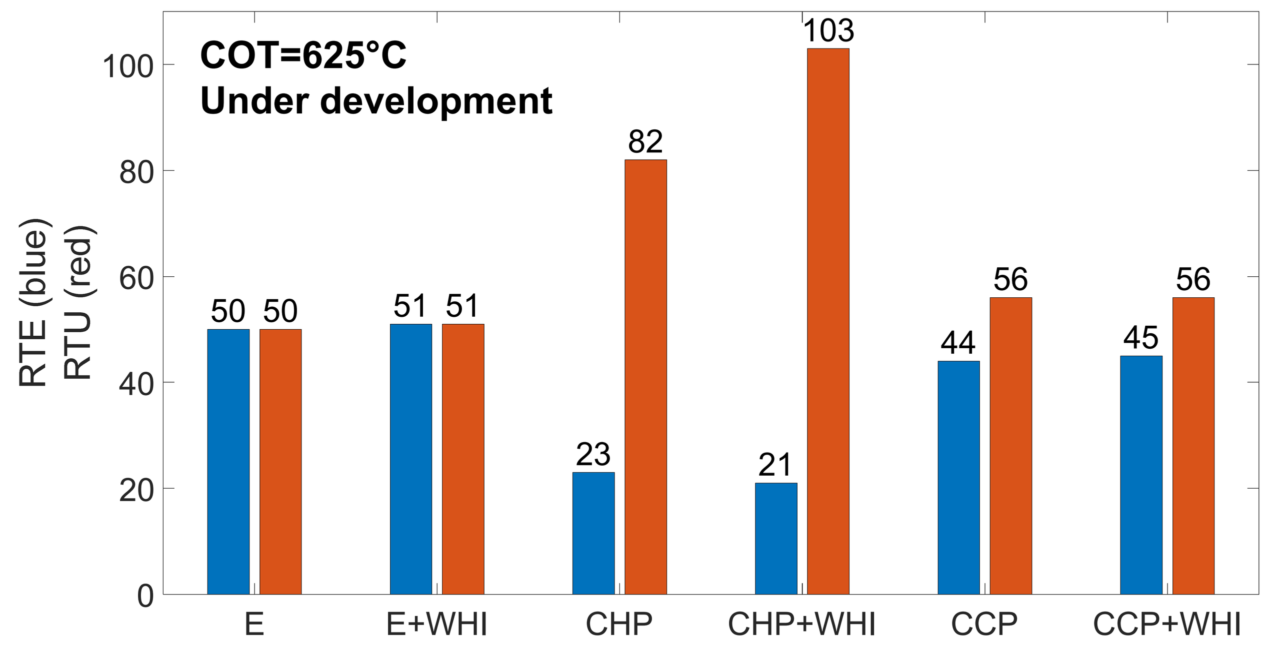

Fig. 3: Summarized results: Maximum values for round trip efficiency (RTE) and round trip utilization (RTU) at compressor outlet temperature COT=625°C

- Promising lead concepts with above-average efficiency were identified (see Fig. 2-3).
- Round trip efficiency (RTE) for electricity ranges from 20-50%, improving with higher compressor outlet temperatures. This considers every loss-inducing element in the conversion chain.
- Combined generation improves round trip utilization (RTU) but lowers electric RTE.
- Waste heat integration boosts RTU for combined heat and power (see Fig. 4), but this does not apply to cooling.
- Recuperators shift heat, enabling efficiency gains in combined electricity generation, particularly at lower compressor outlet temperatures.
- No viable conceptual solution was found for combined heat, cooling, and power.
- Dynamic system simulations [4]:
  - Part load operation of turbomachinery is adequately reflected.
  - A variation in turbine outlet pressure found an optimum when both turbines operated with equal pressure at their outlets.
- Future work will aim to develop flexible systems capable of providing both heat and cooling, either simultaneously or in alternating cycles, to meet diverse application needs.

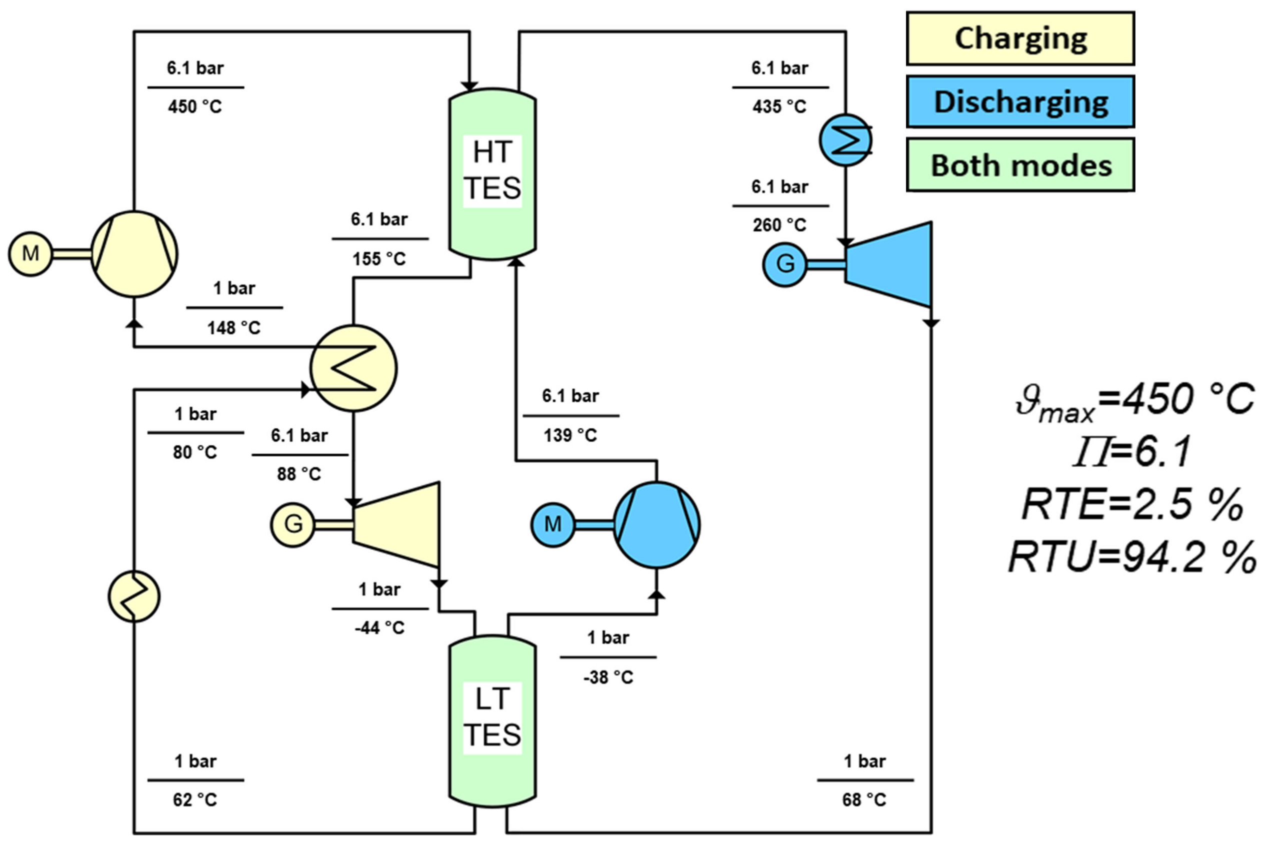

Fig. 4: Exemplary lead concept combined heat and power with waste heat integration

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References

(1) Krüger, M. Appl. Sci. 2024, 14, 6073
(2) Krüger, M. IRES Conference 2023
(3) Krüger, M. IWCB 2022
(4) Krüger, M. Appl. Sci. 2024 (in preparation)

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