Brayton batteries for combined electricity and heat and cooling production: Systematic concept and parameter study

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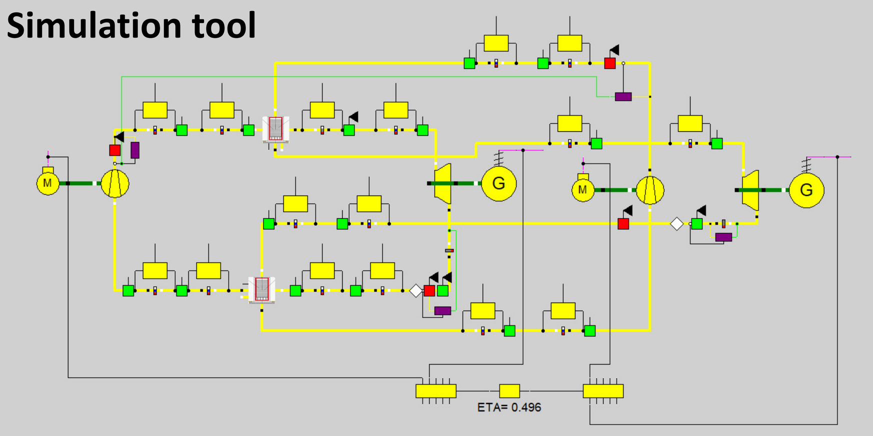
Introduction

- Carnot batteries can have potentially very high power-to-power efficiency.
- However, with respect to Brayton batteries, the gap between theoretically and realistically achievable efficiency is quite high.
- During both the charging and discharging cycles, a significant portion of the energy is converted into heat, which cannot be used or can only be used partly in the case of pure electricity generation.

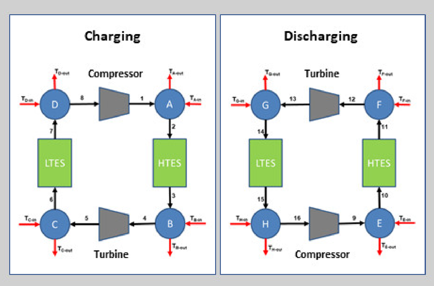
→ Therefore, in this concept study, the topology and parameter selection are varied with the main objective of achieving the highest energy efficiency.

Simulation tool



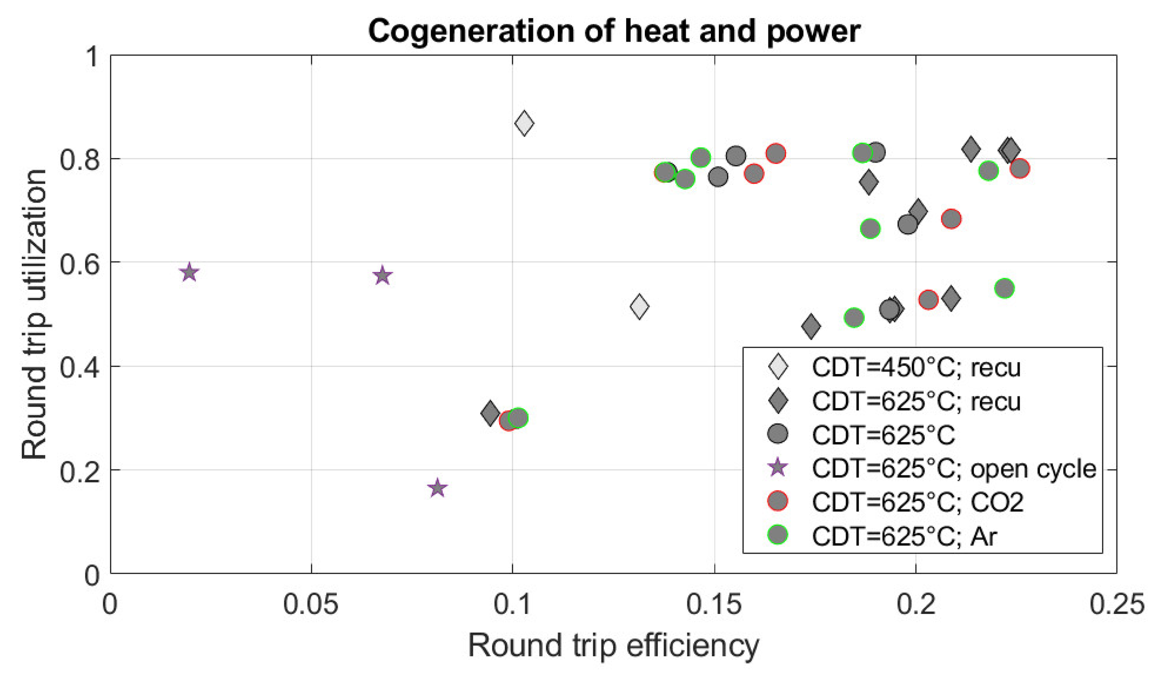
Boundary conditions and topology

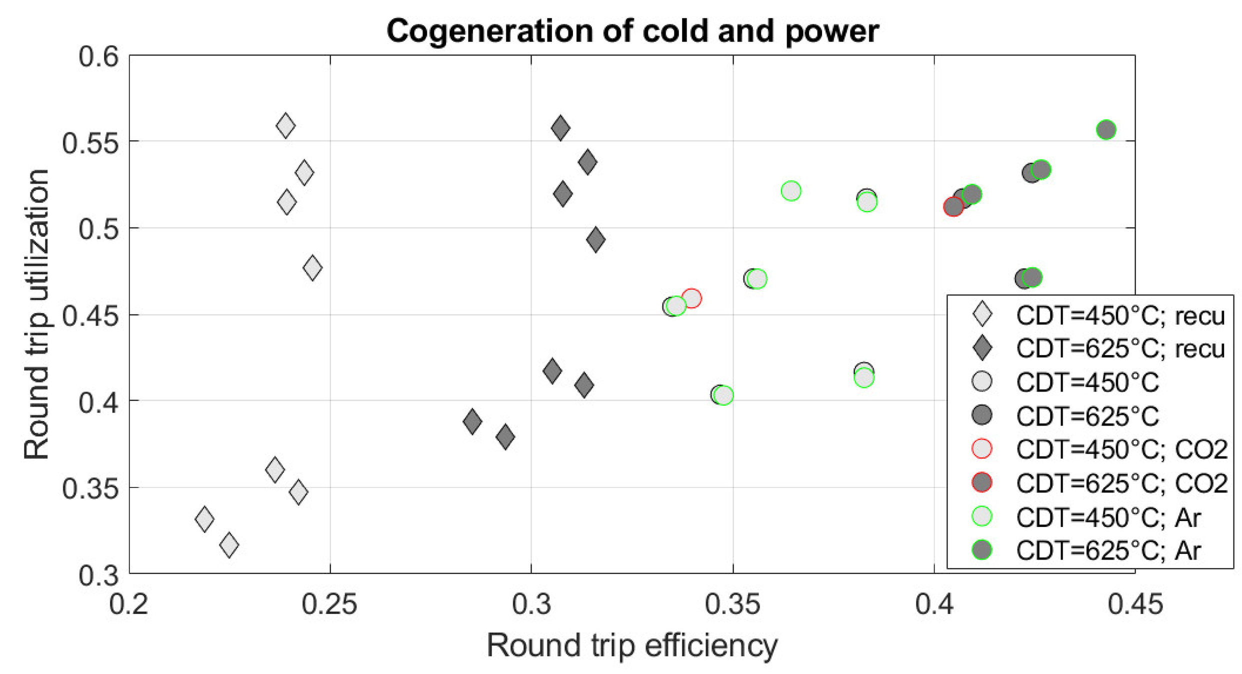
- Temperature after compressor (controlled variable): 450 °C / 625 °C
- Pressure after compressor / turbine: manipulated variable / 1 bar
- Isentropic efficiency TM: 0.9
- Mechanical. Efficiency TM: 0.99
- Electrical efficiency motor: 0.97
- Mechanical efficiency motor: 0.998
- Generator electrical efficiency: 0.99
- Thermal energy storage efficiency: 0.95
- Recuperator efficiency: 0.9
- Ambient temperature: 15 °C
- Heat exchanger gradient: 10 K
- Temperature level of heat integration: 5 °C or depending on the purpose (80 °C in case of waste heat integration, -4 °C in case of cold generation)
- Cooling temperature level: 25 °C or depending on purpose (260 °C in case of heat generation)

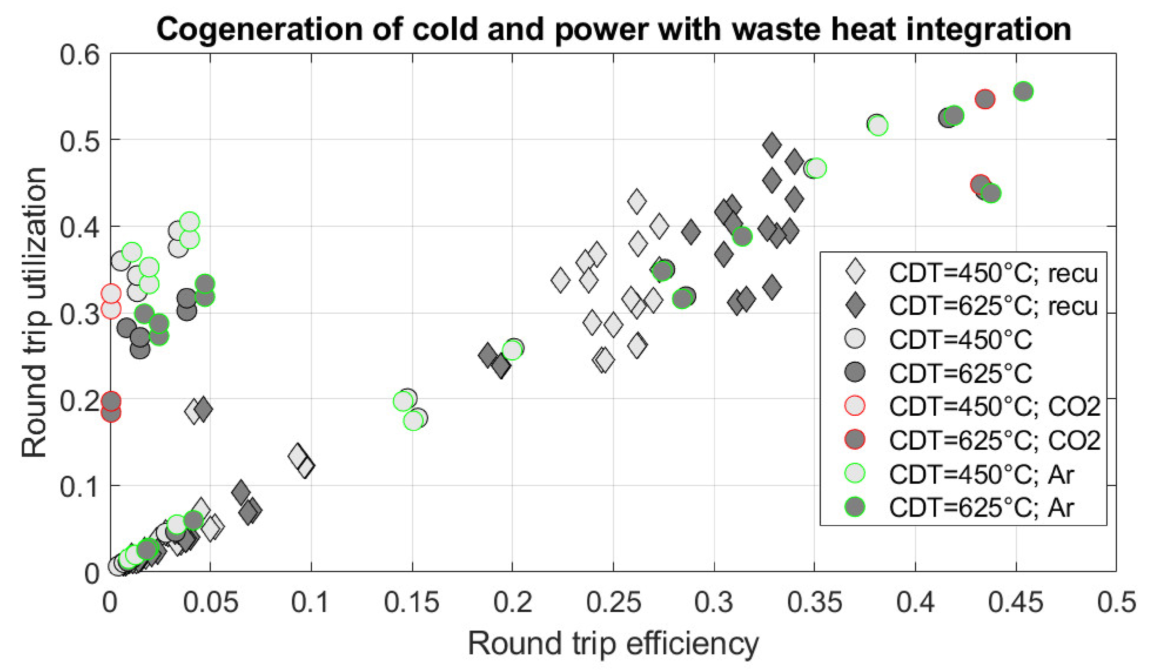


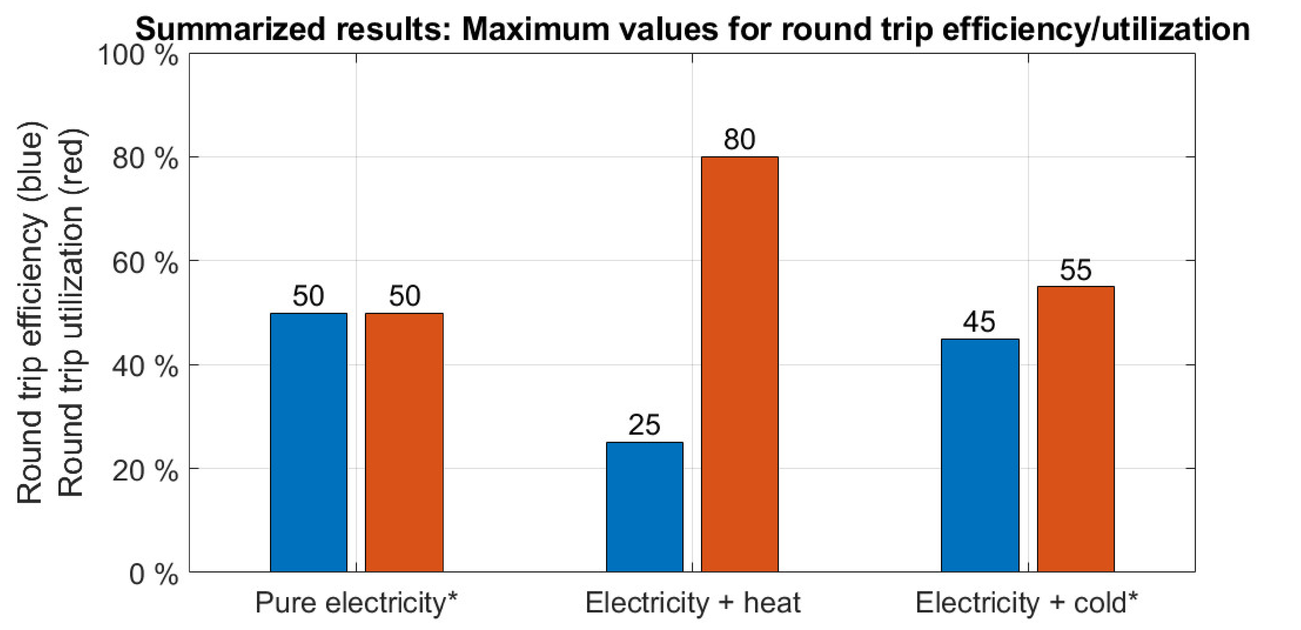
Methods

- To extend the plant benefits, the following coupled generation options are considered in addition to pure electricity generation with or w/o heat integration:
  - electricity/heat,
  - electricity/cooling,
  - electricity/heat/cooling and
  - electricity/cooling with waste heat integration.
- All theoretically possible integration points for heat exchangers for the input or output of heat into the plant were systematically investigated by system simulations (software Ebsilon Professional®).
- Closed and open circuits were considered.
- The compressor discharge temperature CDT of the charging line was set to 450 °C or 625 °C as a manipulated variable with the compressor discharge pressure as a controlled variable.
- For the closed concepts, CO_2 and argon were considered as working fluids in addition to air.
- For the air-driven system, variants with a recuperator to shift heat from the hot to the cold side of the charging line were also looked at.
- Almost 100,000 concepts were calculated.









*even with the waste heat integration

Results

- Not even 1% of the calculated concepts come to physically possible results (858 solutions).
- For pure electricity generation, round trip efficiencies in the range of 20 to 50 % are obtained.
- Additional waste heat integration didn't result in significantly higher values.
- Efficiency increase can only be achieved with coupled generation, but this is in relation to the degree of utilization, see diagrams above.
- Concepts at 450 °C have lower round trip efficiencies than at 625 °C, although the round trip utilization rates do not necessarily have to be lower.
- No clear trend can be observed with regard to the working fluids. The same applies to the use or omission of a recuperator.
- With regard to open concepts, very few solutions were achieved, moreover with low efficiencies.

Conclusions and Outlook

- While the concepts with pure electricity generation achieve rather modest results, the concepts with coupled generation are quite promising. Here, the results have to be compared with the requirement profiles of the respective application and an appropriate concept has to be selected. In particular, the ratio of electricity to heating or cooling capacity must be taken into account, as well as the exact demand profile for the product in question.
- In order to achieve the maximum possible efficiencies, sensitivity analyses will be carried out with regard to the compressor discharge pressure in the discharging line. In the present results, this was set equal to the compressor discharge pressure in the charging line. The same applies to the turbine discharge pressure.
- From the findings obtained, lead concepts for the respective purposes are to be selected, which will be further elaborated in the course of the project. This includes the creation of more detailed component models as well as the technology selection and subsequent design of the thermal energy storage. In the end, the investigations should provide requirement profiles for component development.

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