Thermal Energy Storage with
Transcritical Recuperative Two-Phase Cycles

Benedikt G. Bederna (benedikt.bederna@tu-dresden.de) // Christiane Thomas (christiane.thomas@tu-dresden.de)

Motivation
Cycle efficiency as the key aspect

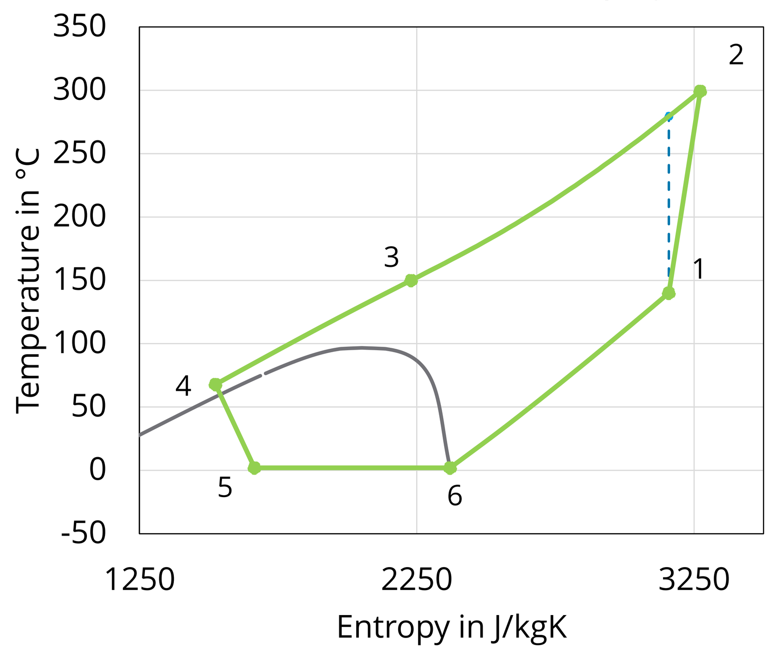
Transcritical Rankine cycle are discussed for Pumped Thermal Energy Storage (PTES) systems with the ambient or a latent storage as low-temperature heat reservoir and a sensible storage as high temperature reservoir [1]. But transcritical Rankine cycles have significant disadvantages:

— Exergy losses due to mismatch of the heat capacity flows of subcooled liquid (3 → 4) and superheated vapor (6 → 1) in the recuperator

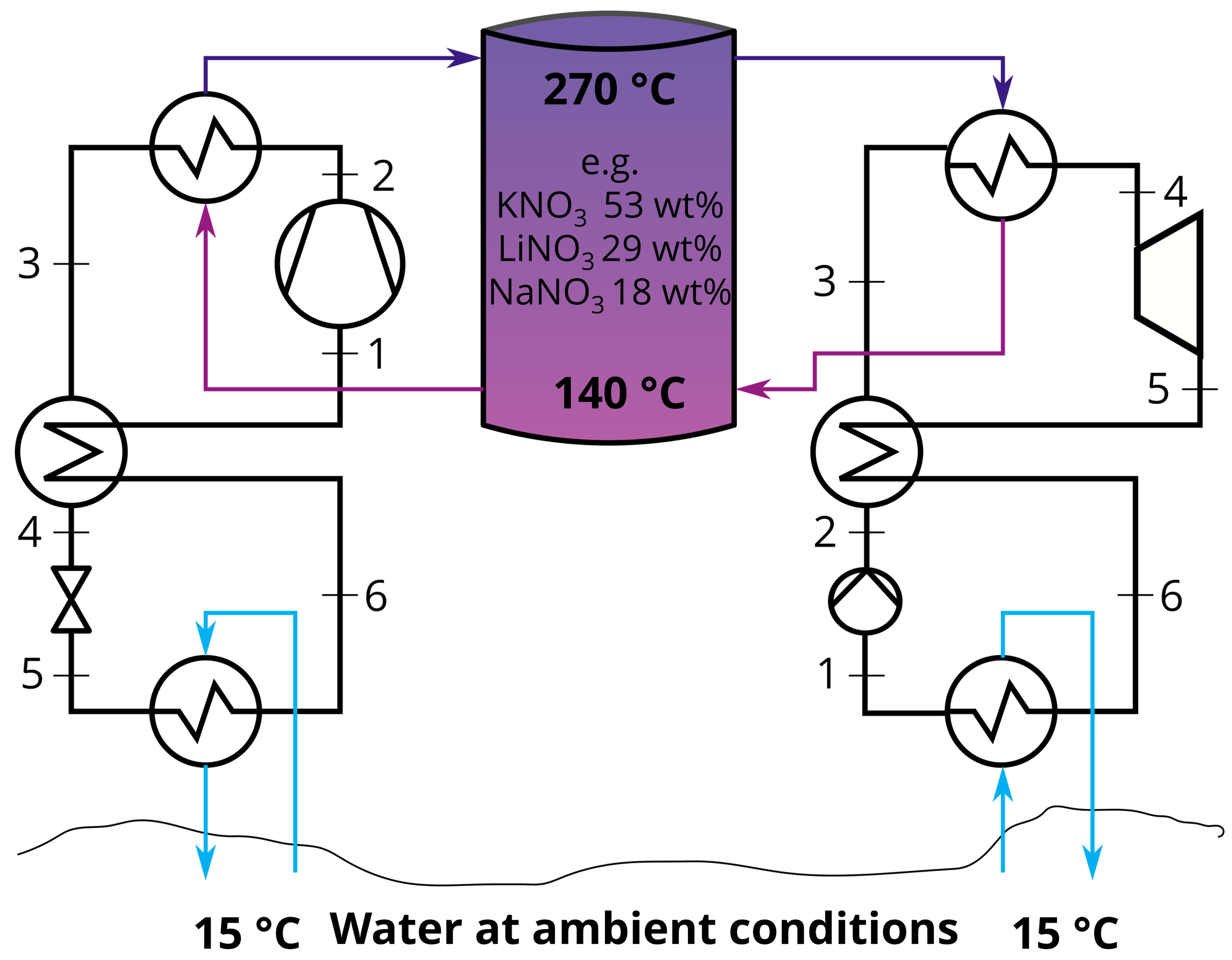
— Exergy losses in heat pump cycles due to the isenthalpic throttling process (4 → 5), which can only be overcome by using a two-phase expander

Due to the importance of the cycle efficiency for the round trip efficiency [2], advanced measures for the improvement of the cycle are required.

Transcritical Rankine Heat Pump cycle



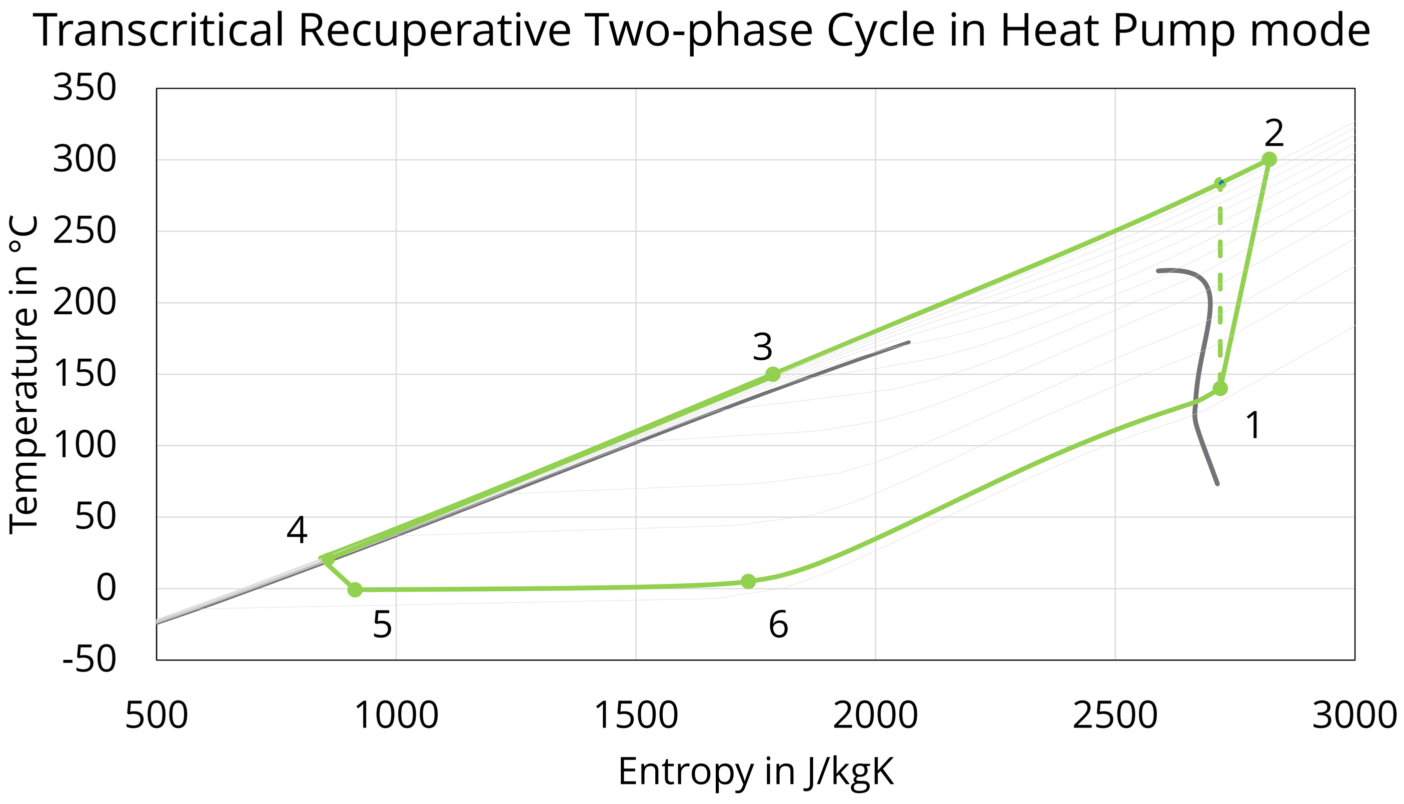
Application
PTES with sensible Storage



Method
Thermodynamic concept of a transcritical cycle

A novel transcritical cycle [3] is used to increase the heat pump (HP) and power cycle (PC) efficiency. It is based on a former subcritical version of the Recuperative Two-Phase Cycle (RTPC) [4]. The key aspects is the introduction of an asymmetric mixture composed out of a main fluid (e.g. isobutane) with a high fraction (around 95 mole%) and an auxiliary fluid (e.g. dodecane), which leads to a phase change instead of a pure superheating of the working fluid on the low-pressure side of the recuperator (6 → 1). Thereby the capacity flows in the recuperator are equalized and the exergy losses decrease. Furthermore, this leads in a heat pump cycle to lower throttling losses and in a power cycle to lower preheating losses.

Transcritical Recuperative Two-phase Cycle in Heat Pump mode

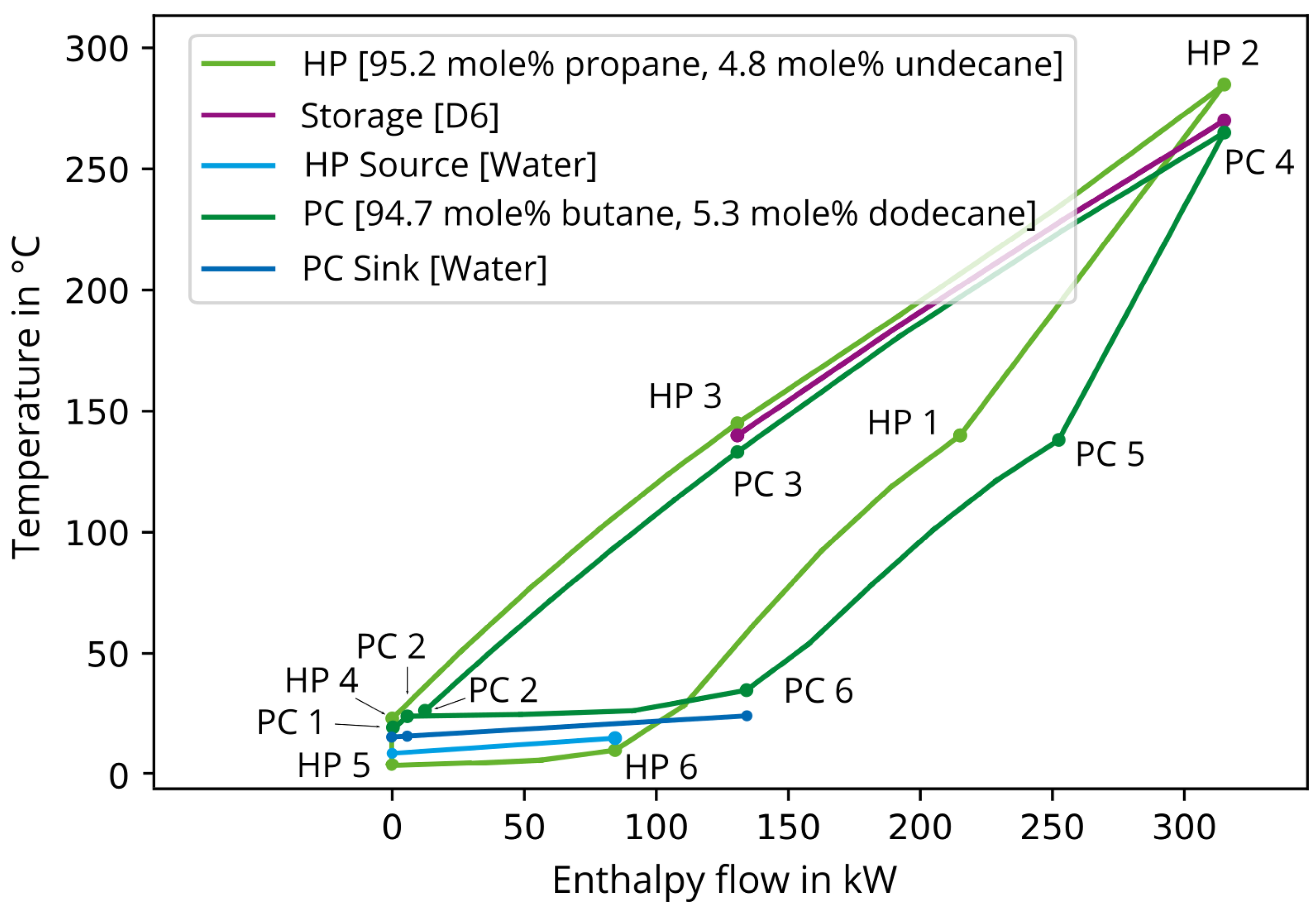


As a consequence, these cycles are more efficient than transcritical Rankine cycles with hydrocarbons and even more with CO_2 as the working fluid. Furthermore, the maximum pressure in the cycle is slightly lower.

Results
Fluid selection and cycle design

With two different asymmetric hydrocarbon mixtures for each cycle second law efficiencies of over 70 % can be reached, thus the round trip efficiency is 51,9 %. However, these must be taken as preliminary results, due to high variability of the non-linear optimization problem and due to the uncertainty of the thermodynamic properties of the asymmetric mixtures.

Assumptions	
P_{el} compressor HP	100 kW
ΔT_{min} of HXs	5 K
η_{is} of all machines	0,8
Pressure drop	0 Pa
Heat losses	0 kW
Electrical losses	0 kW



Figures:

Fig. 1: Example of a conventional transcritical Rankine heat pump cycle with the working fluid isobutane for a low temperature level of 15 °C and a high temperature level between 150 °C and 300 °C.

Fig. 2: Example of the novel transcritical Recuperative Two-phase Cycle in heat pump mode (HP-RTPC-TC) with the working fluid mixture composed out of 95 mole% isobuane and 5 mole% dodecane for a low temperature level of 15 °C and a high temperature level between 150 °C and 300 °C. The shown isobars are 1 bar, 5 bars and 10 bars up to 100 bars.

Fig. 3: Concept of a Pumped Thermal Energy Storage (PTES) system based on two transcritical Recuperative Two-phase Cycles, one in heat pump mode and one in power cycle mode and a thermocline storage system filed with molten salt.

Fig. 4: $T, \dot{H}$ diagram for the entire PTES system: heat pump and power cycle connected by the temperature profile of a storage. As an approximation the siloxane D6 is used for the calculation of the profile.

Literature:

1 *Rabi, A. M., Radulovic, J., Buick, J. M (2023) Pumped Thermal Energy Storage Technology (PTES): Review. https://doi.org/10.3390/thermo3030024.*

2 *Atakan, B. (2024). Thermodynamic Analysis of Carnot Batteries: Storage Temperatures, Sensitivities, and Optimal Parameters. http://dx.doi.org/10.2139/ssrn.4775278.*

3 *Bederna, Benedikt G. (2023). Vorrichtungen und Verfahren zum Betreiben eines transkritischen Kreisprozesses: DE 10 2023 113 884.*

4 *Bederna, B. G., Barta, R. B., Thomas, Ch. (2023). Thermodynamic concept of a novel recuperative two-phase heat pump cycle. ICR Paris. http://dx.doi.org/10.18462/iir.icr.2023.0588*

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Schaufler-Professur für Kälte-, Kryo- und Kompressorentechnik