CÁTEDRA DE TRANSICIÓN ENERGÉTICA
COMILLAS ICAI
REPSOL Fundación

CÁTEDRA RAFAEL MARIÑO DE NUEVAS TECNOLOGÍAS ENERGÉTICAS
COMILLAS ICAI

ExCo MEETING - WORKSHOP

OVERVIEW OF INDUSTRIAL ENERGY TECHNOLOGIES IN SPAIN

High-Temperature Heat Pump based on reverse Brayton cycle

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18/11/2024

Industrial Energy-Related Technologies and Systems iets

Technology Collaboration Programme by iea

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Industrial heat pumps

- Expected to play a major role in the **industry decarbonization**.
- Allow to recover excess heat (typically 50-100°C) and increase its temperature, using **renewable electricity**.
- **Mature and solidly implemented technology in the industry**, for supply temperatures below 100°C.
- Challenge for implementation **above 100°C**:
  - High **operating temperatures and pressures.**
  - A thorough analysis of **working fluids**, **cycle types**, and **key components** (turbomachinery, heat exchangers) is required.

CURRENT TECHNOLOGY:

TRL between 4 and 9

Supply temperature: **100-280°C**

Thermal power: **30 kW to 70 MW**

Specific cost: **200-1500 €/kW**

Commercially available:

2024-25 ----- 120°C

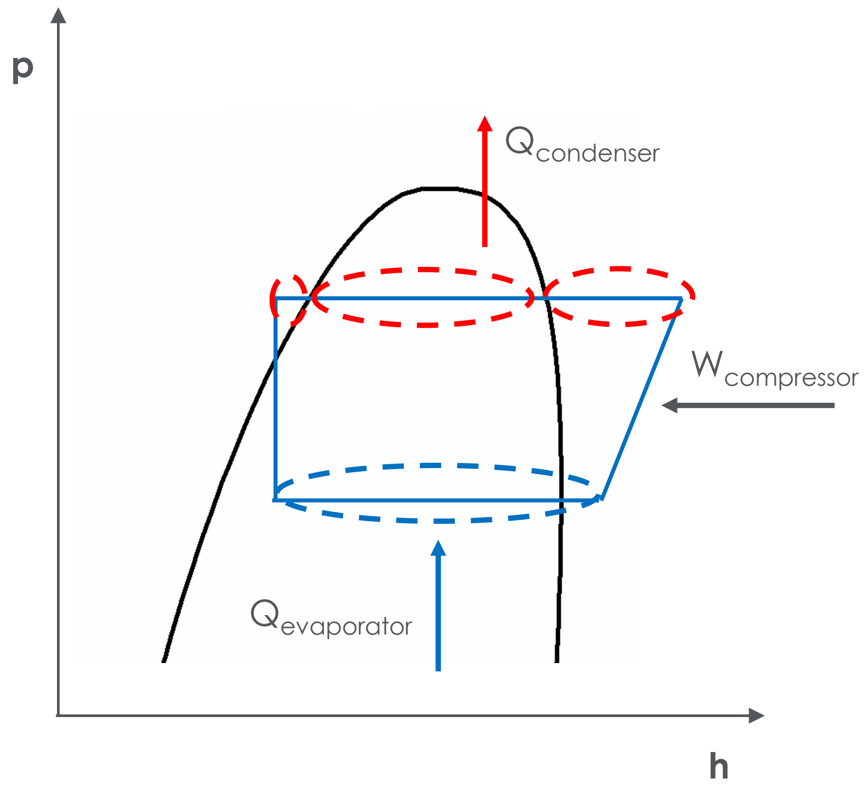
2025-26 ------160°C

Overcoming that barrier in 2026-27

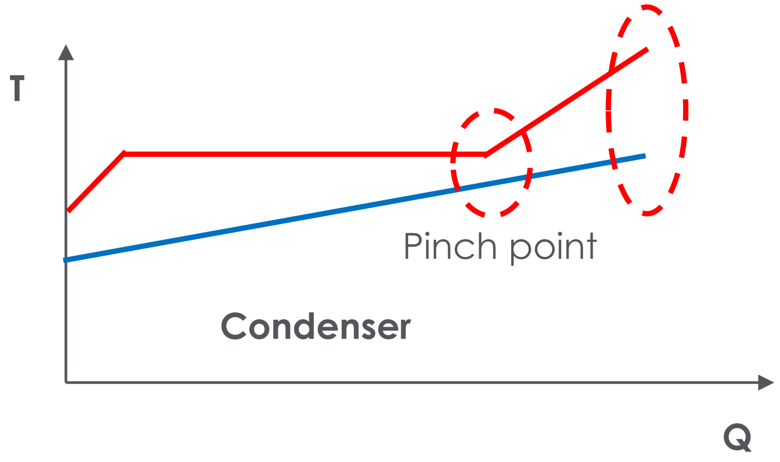
[Source: TCP-IEA Annex 58 Task 1]

TYPE OF CYCLES FOR HIGH TEMPERATURE HEAT PUMPS

Conventional heat pumps (Rankine)

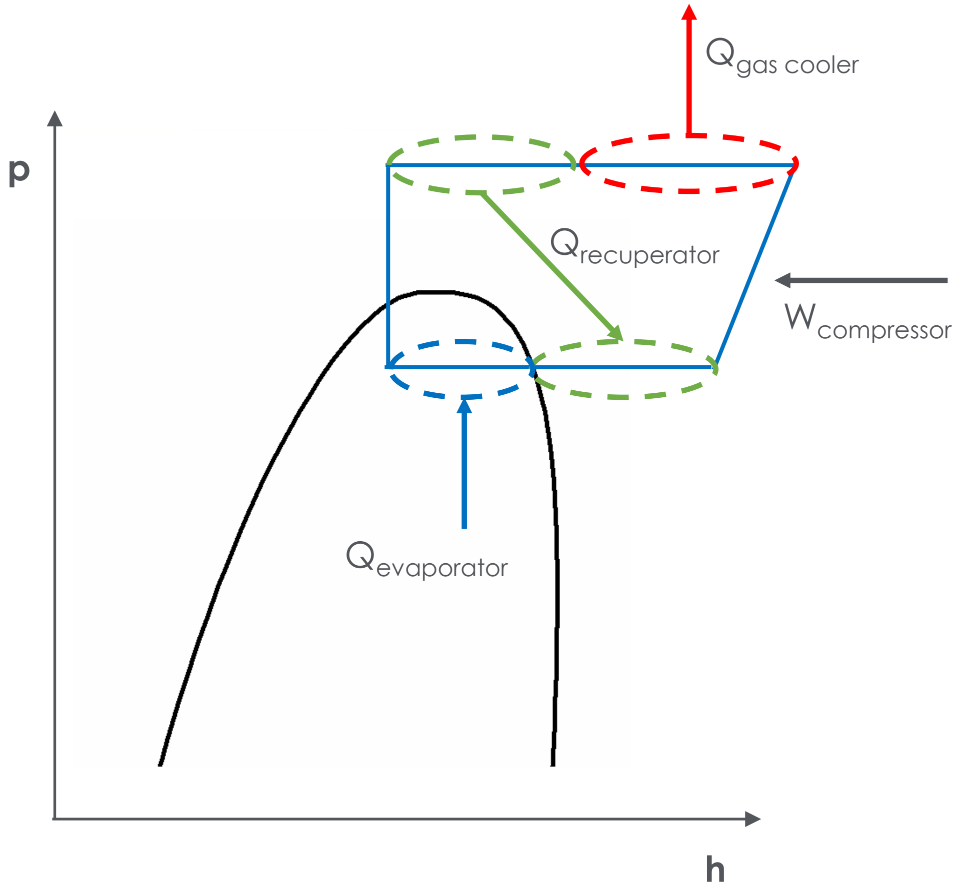


- Heat transfer to the demand (condenser):
  - Temperature change (sensible) zones: desuperheating and subcooling
  - Phase-change zone (latent): constant temperature limits the heat release
- Working fluid limits the operation temperatures

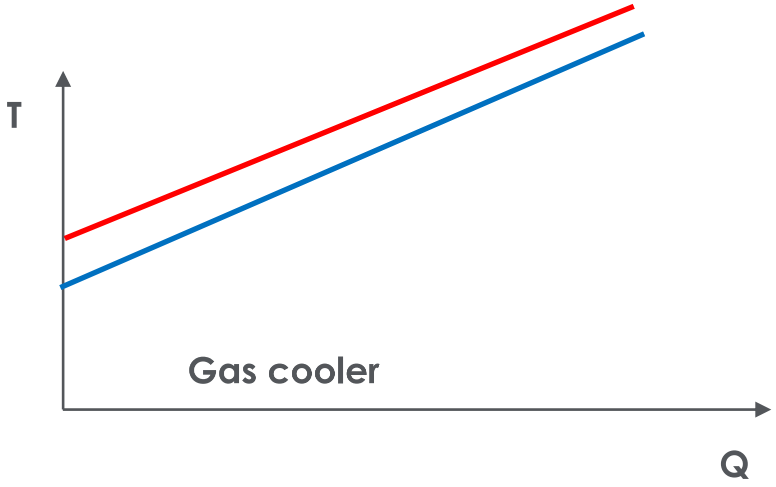


The demand does not take advantage of the maximum temperature of the working fluid

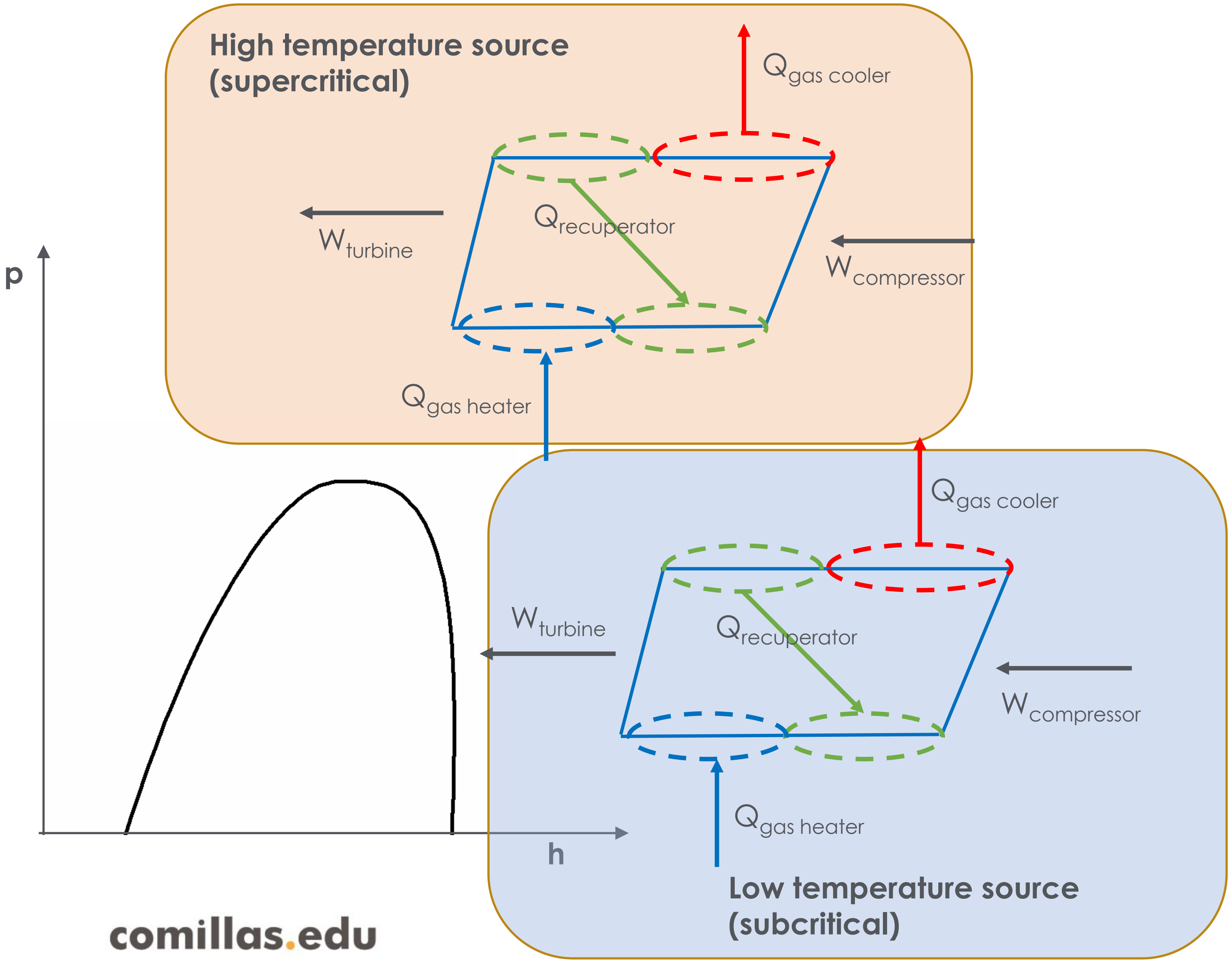
Transcritical Rankine heat pumps



- Refrigerant is a gas throughout the cycle. No phase-change in heat release (gas cooler).
- The recuperator allows high temperature in the sink, preheating the compressor suction
- An expander might be used in the one-phase zone
- CO_2 appropriate as working fluid

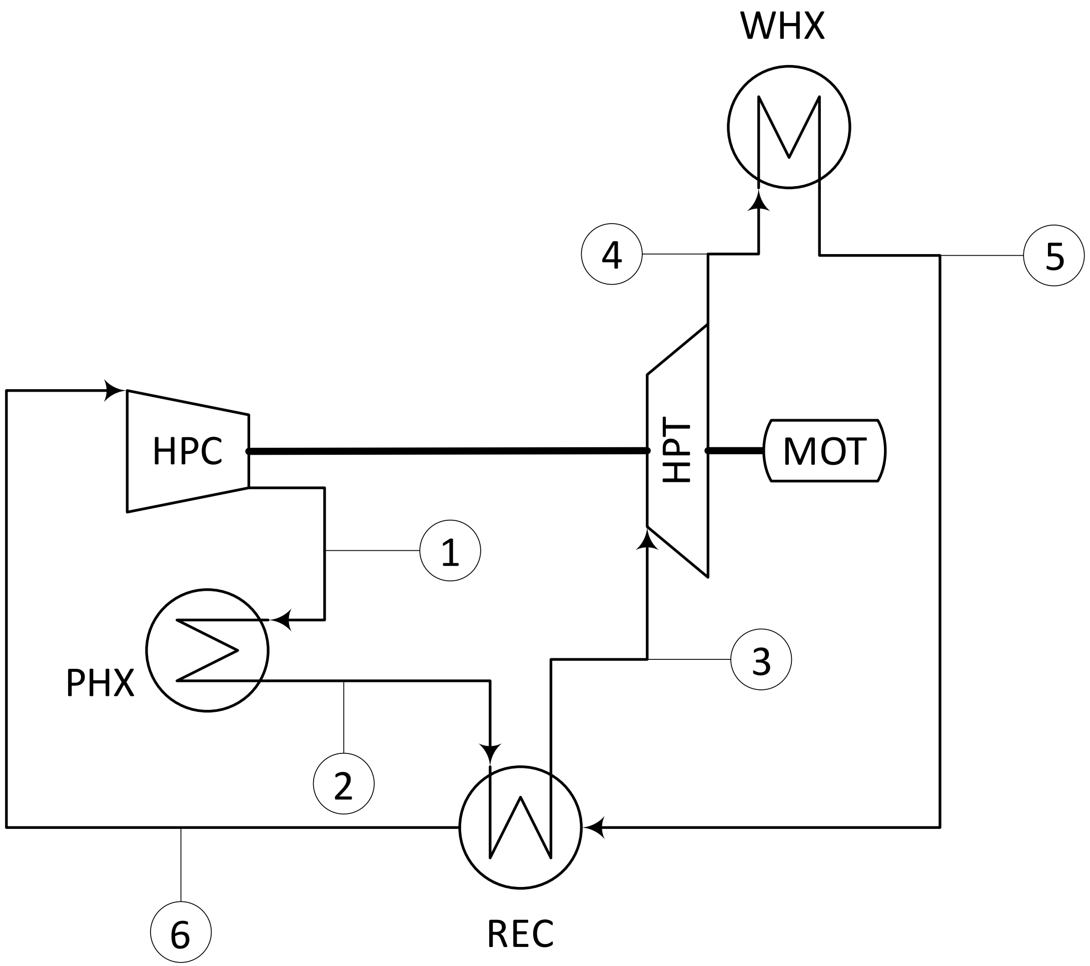


Reverse Brayton heat pumps



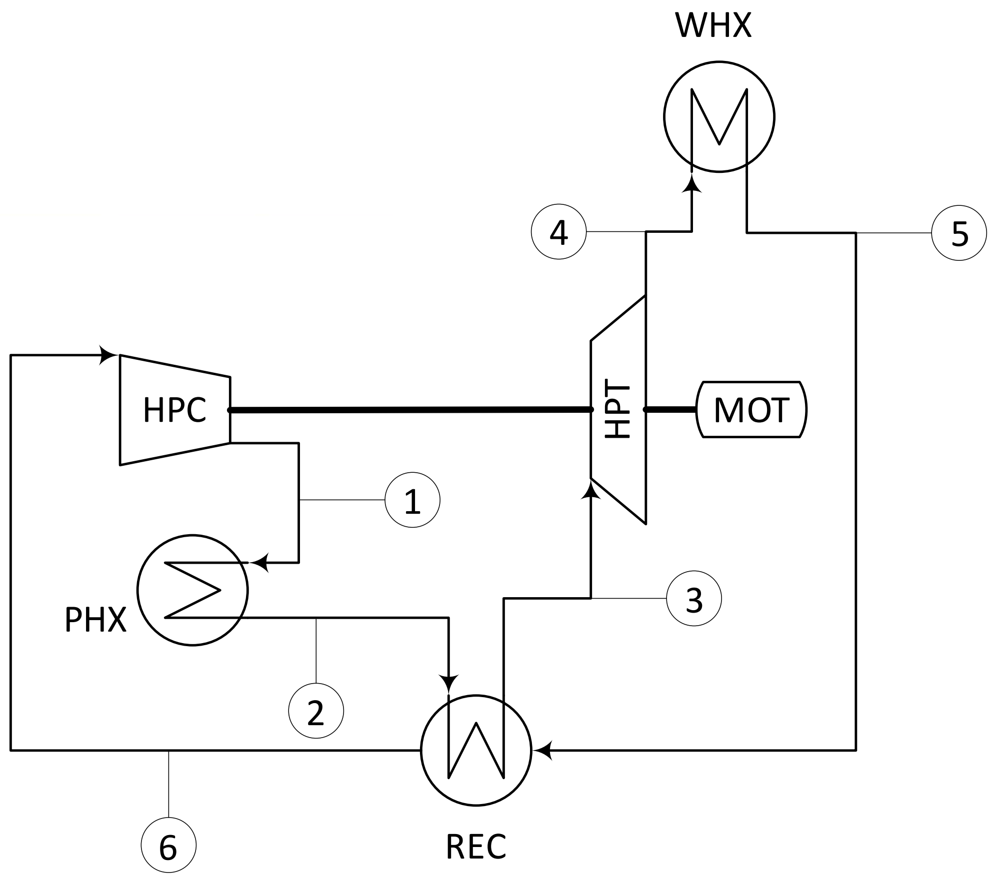
- The opposite to a closed-cycle gas turbine, but without combustión
- Turbine (expander) replaces the valve of typical reverse Rankine cycles
- Compressor and turbine are turbomachines
- CO_2 as working fluid allows to reduce the footprint

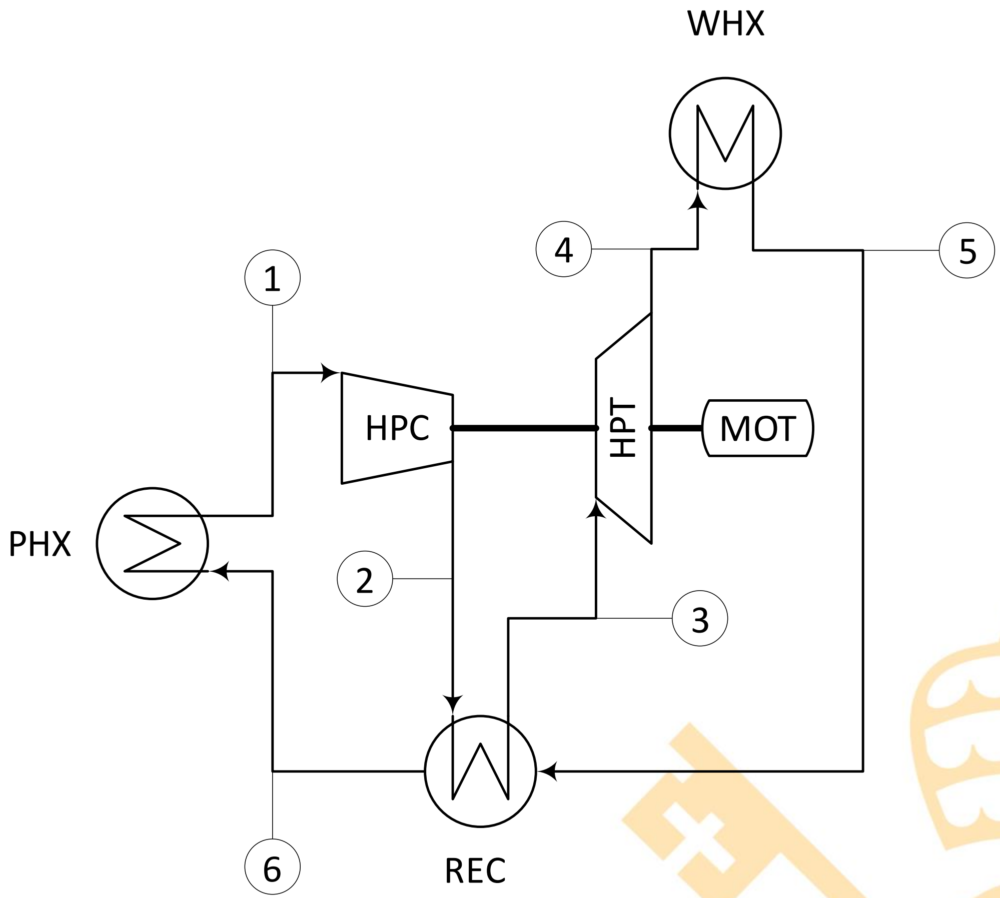
Reverse Brayton heat pumps



- PHX (gas cooler) is in the high pressure side
- WHX (gas heater) is in the low pressure side

Reverse Brayton heat pumps





- PHX is in the high pressure side
- Best option if no thermal storage is needed

- PHX is in the low pressure side
- Best option if thermal storage is needed

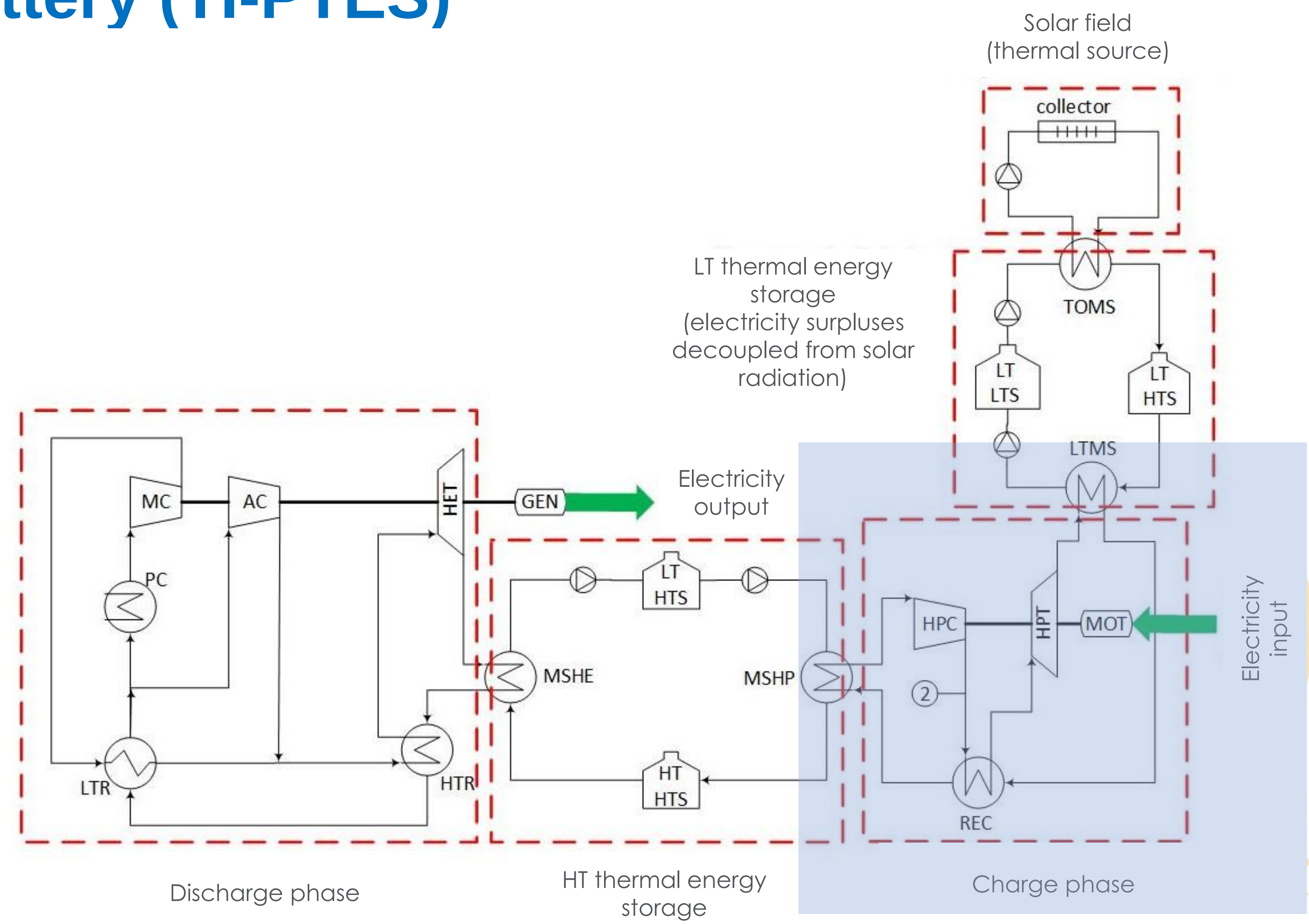
HIGH TEMPERATURE

INDUSTRIAL APPLICATIONS

Very high temperature application
Carnot battery (TI-PTES)

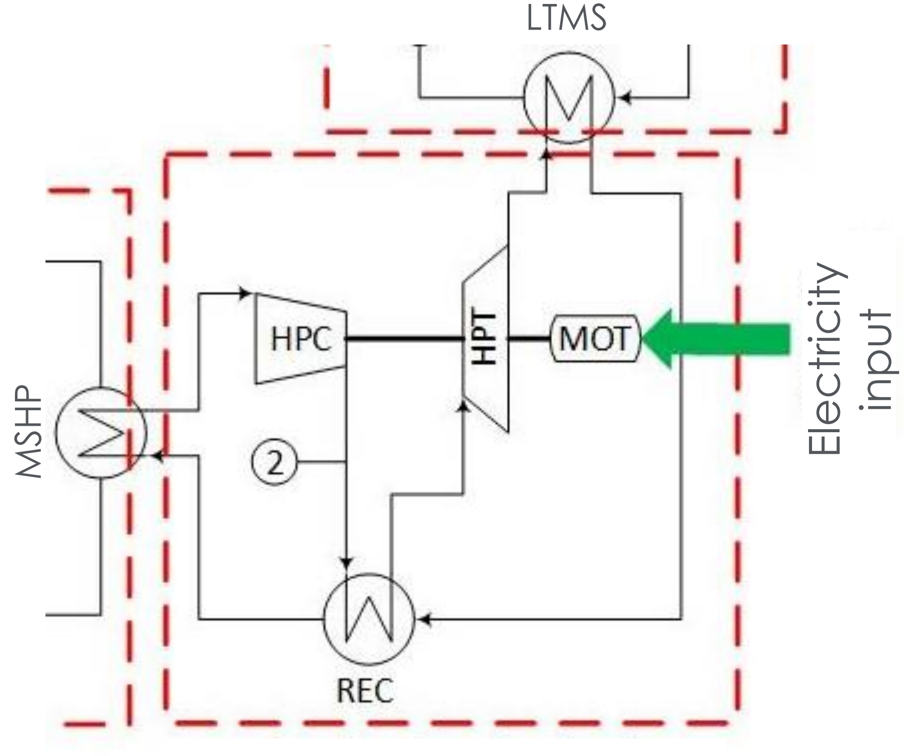
- Heat pump is fed from a PTC solar field (400 °C/300 °C), supplying useful heat at (600 °C/400 °C)

- HT thermal energy storage works as if a heliostat field is feeding, whereas the heat comes from a PTC field

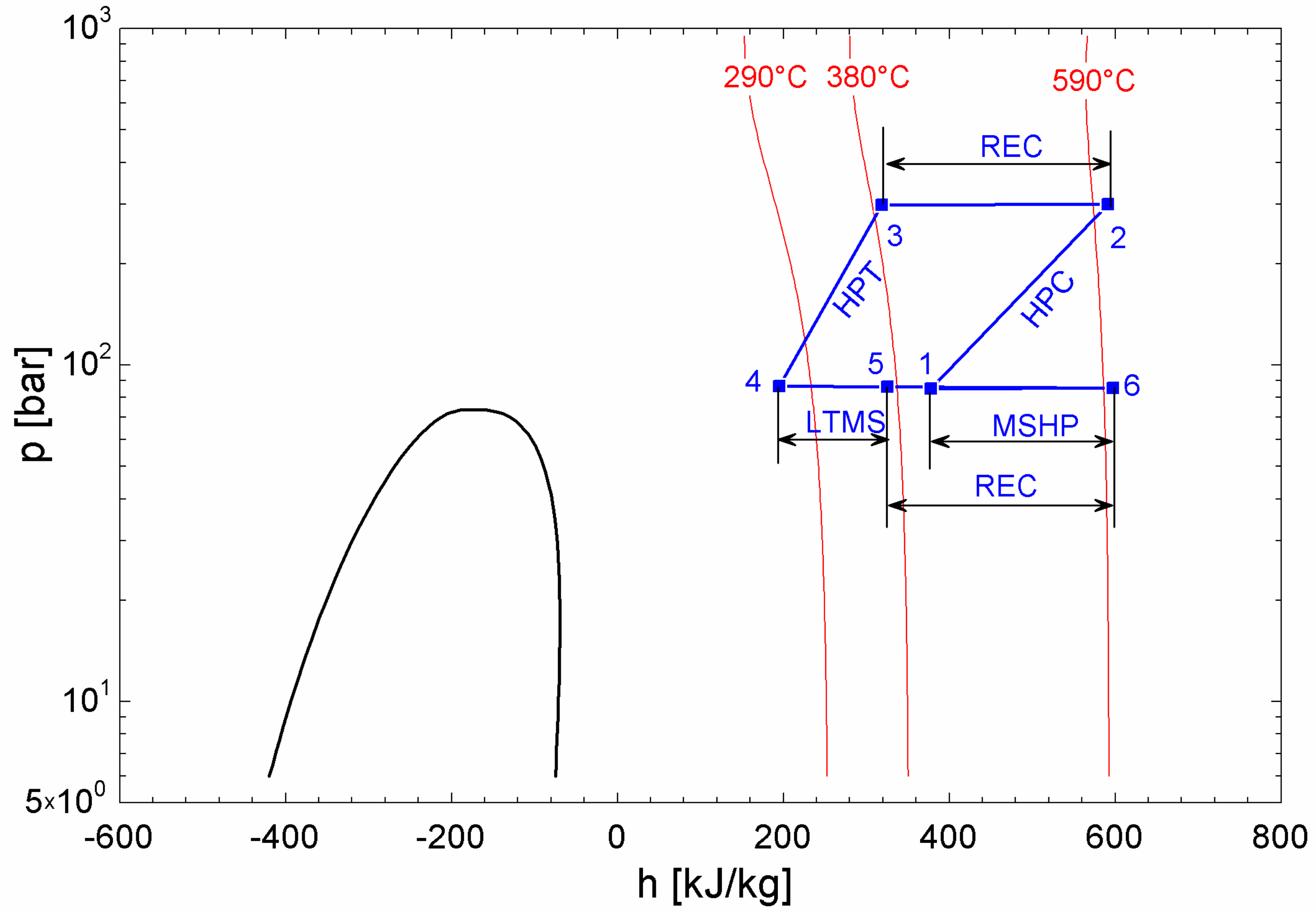


[Linares et al., Energies 16(9) 2023, 3871]

Very high temperature application
Carnot battery (TI-PTES)



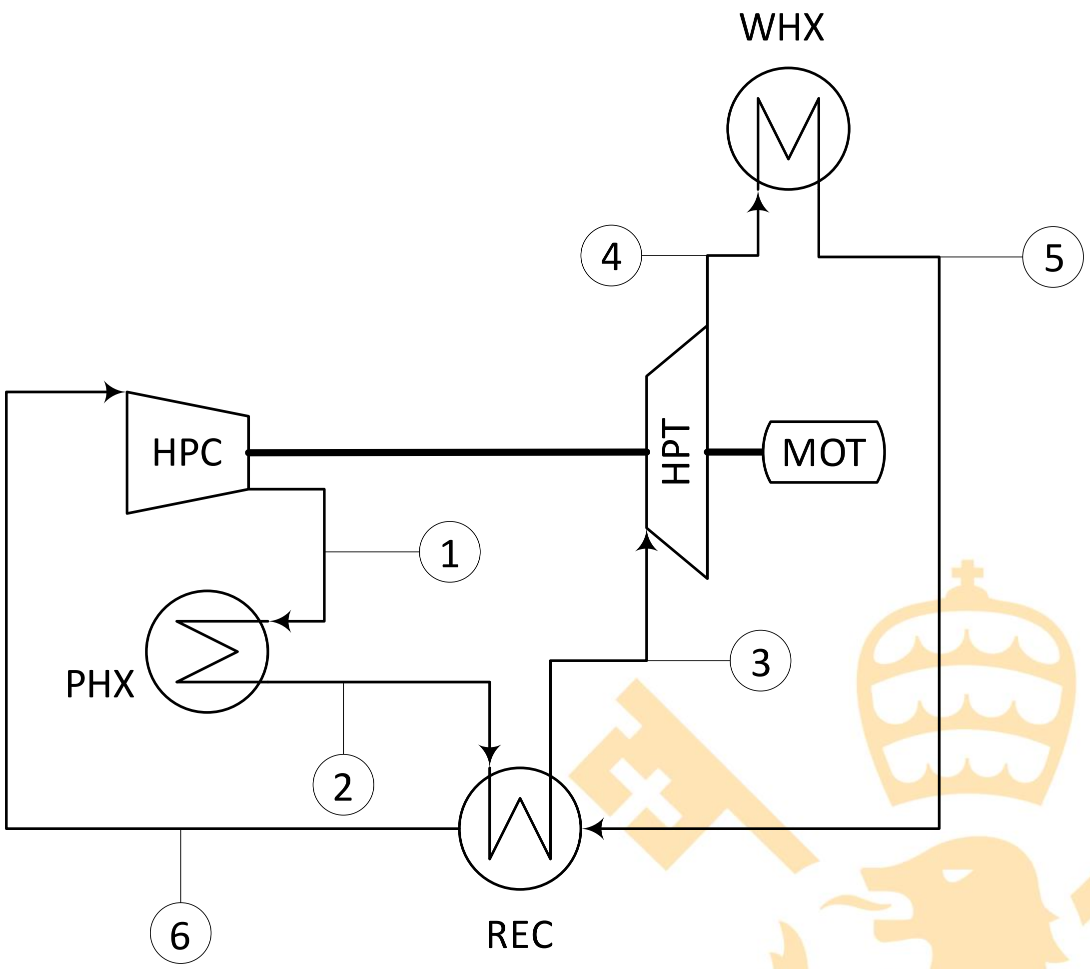
Charge phase



[Linares et al., Energies 16(9) 2023, 3871]

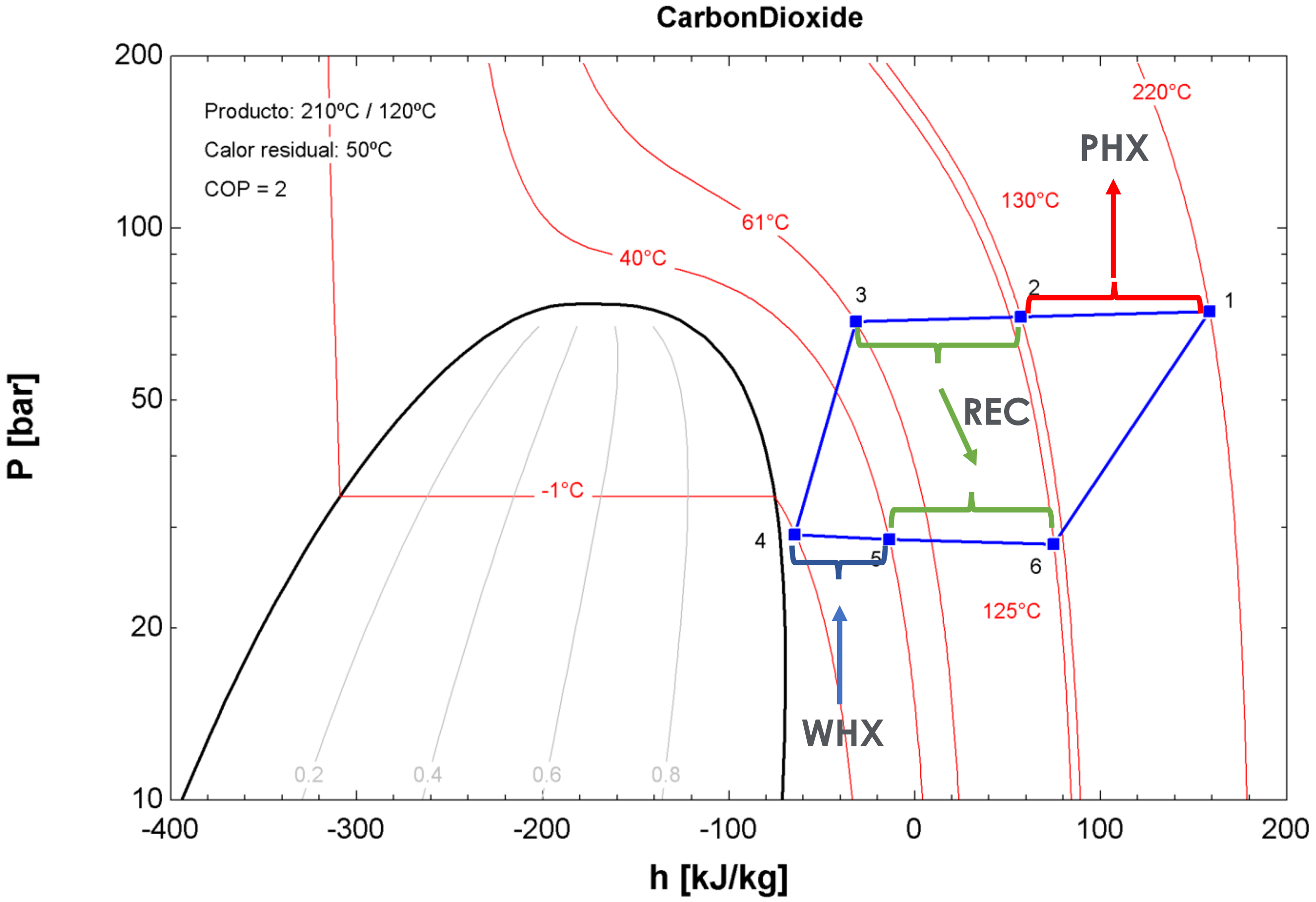
Industrial application
Compressed water production

- Application to beverage sector
- Product: compressed water 210 °C/ 120 °C
- Source: waste heat arriving at the WHX at 100 °C or 50 °C (two cases)
- No thermal storage is required



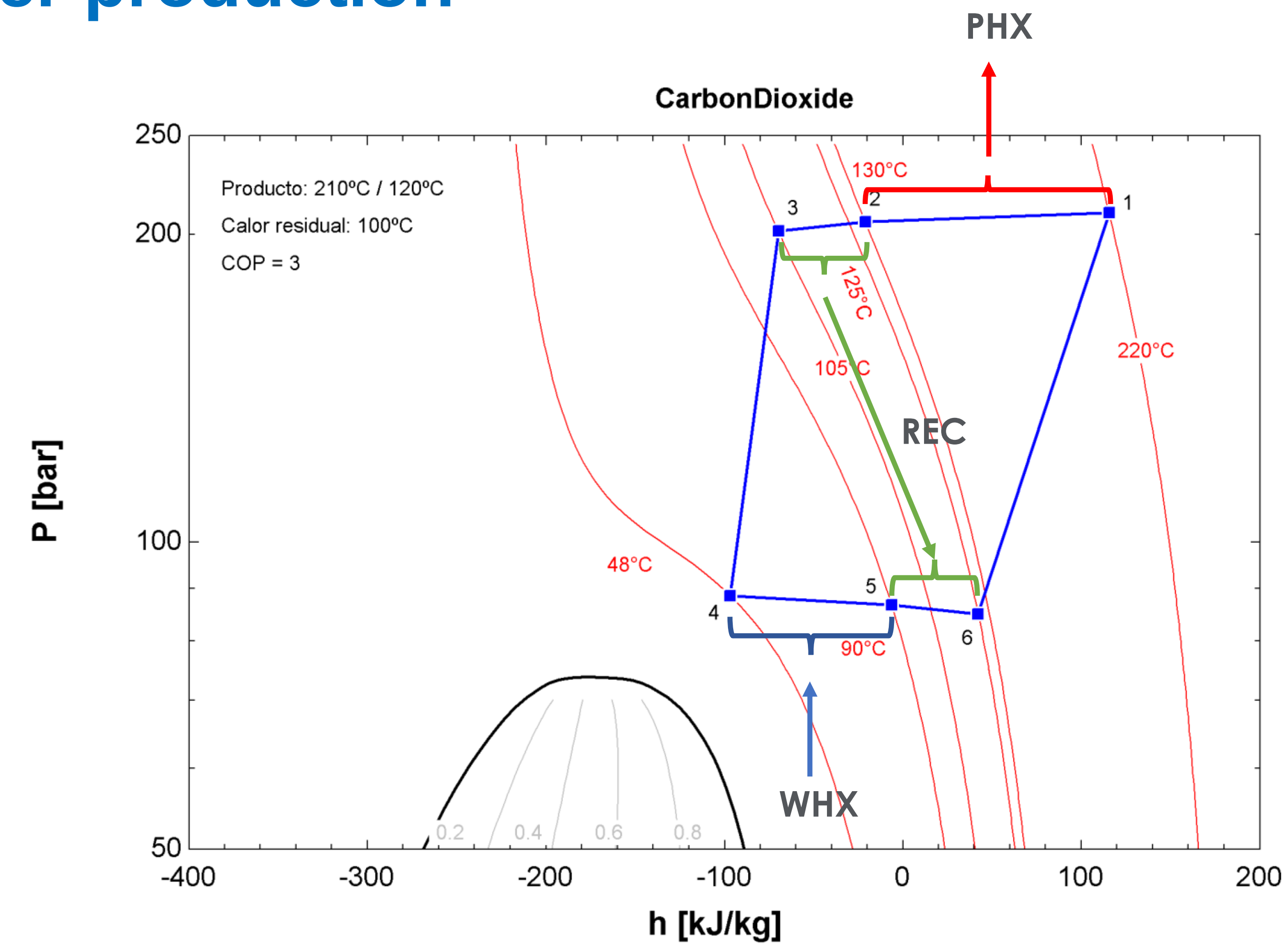
Industrial application
Compressed water production

- **Waste heat arriving at the WHX at 50 °C**
- Product (PHX)
  - Liquid water inlet at 120 °C
  - Liquid water outlet at 210 °C
- COP = 2
- Waste heat (WHX)
  - Liquid water inlet at 50 °C
  - Liquid water outlet at 9 °C
  - Water leaving WHX might be used as heat sink of chillers

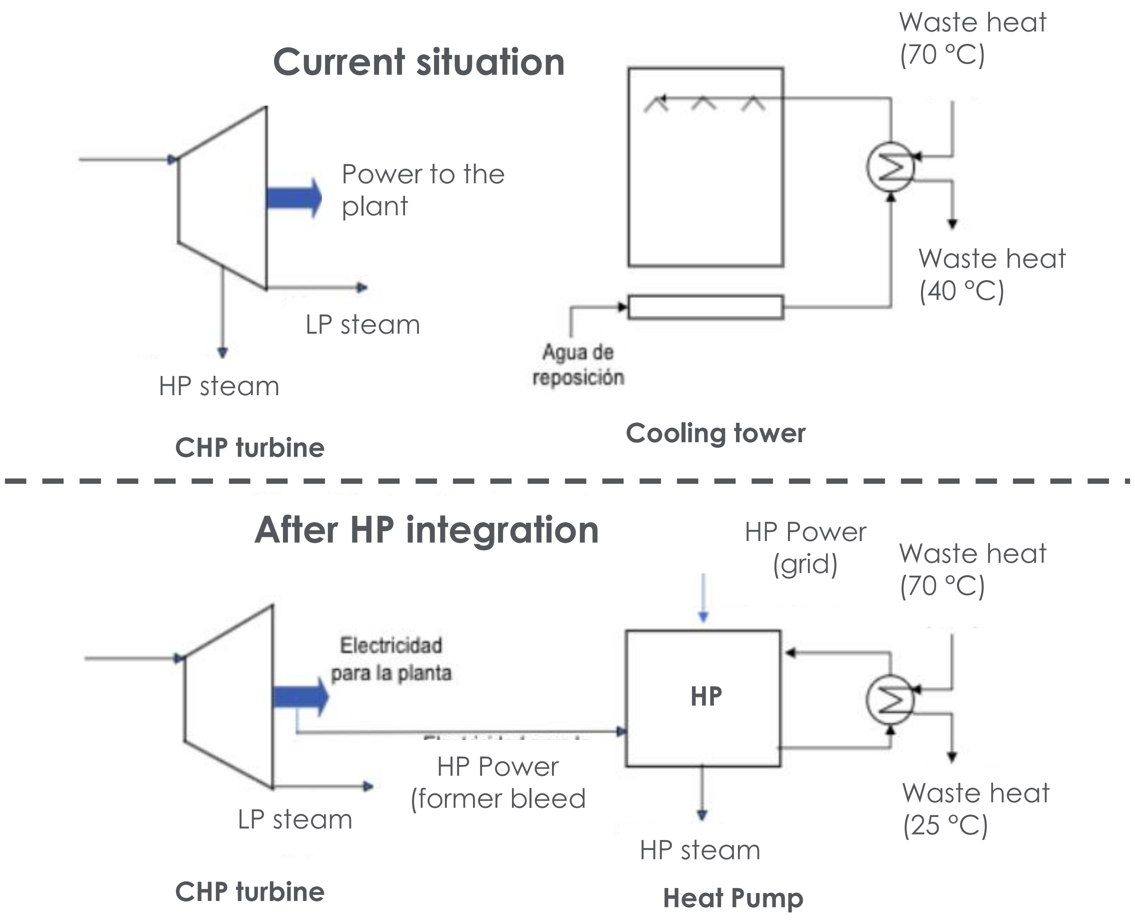


Industrial application
Compressed water production

- **Waste heat arriving at the WHX at 100 °C**
- Product (PHX)
  - Liquid water inlet at 120 °C
  - Liquid water outlet at 210 °C
- COP = 3
- Waste heat (WHX)
  - Liquid water inlet at 100 °C
  - Liquid water outlet at 58 °C
  - Water leaving WHX might be used for warming purposes or as source for the previous arrangement



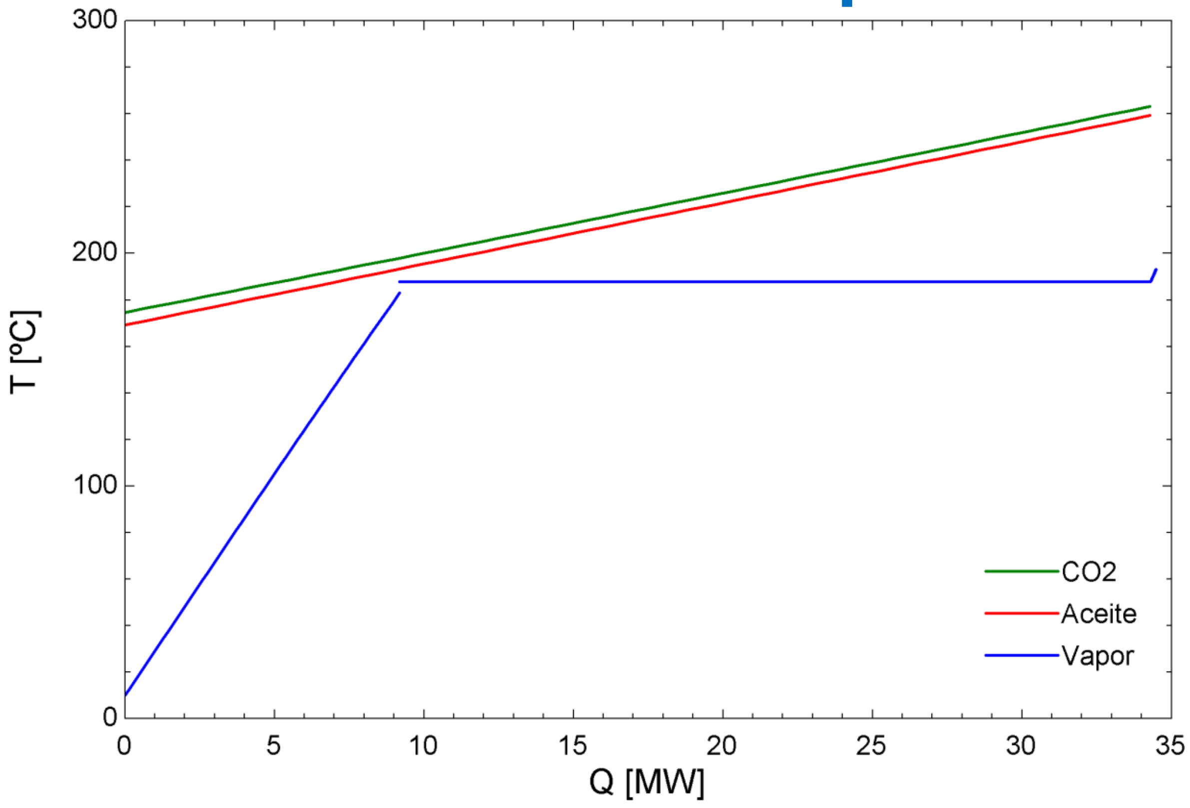
Industrial application
Steam production (10 – 12 bara)

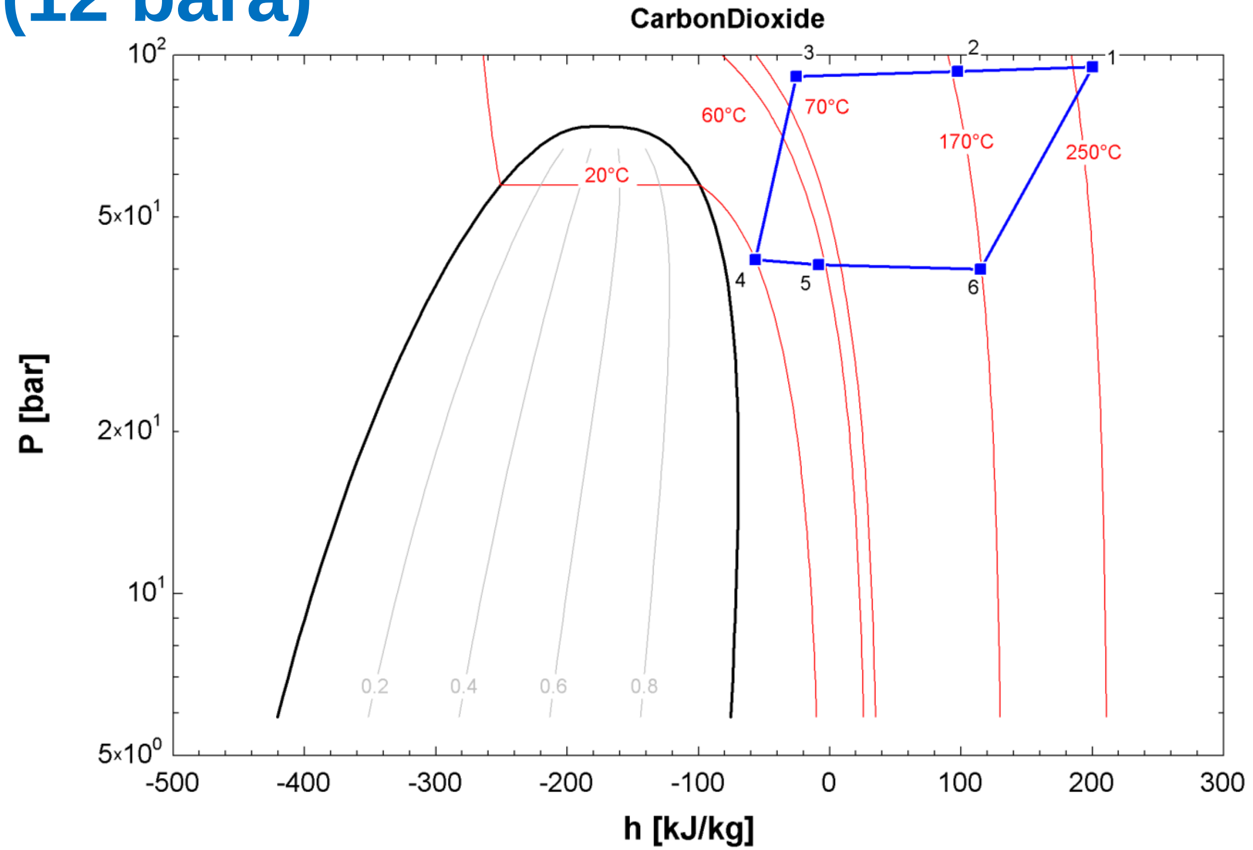


- The HP is intended to replace the existing cooling towers by using the incoming process water for cooling as a source for the heat pump. The aim is to eliminate make-up water and further cool the process water for better operation of the treatment plant.
- The HP will produce process steam, which replaces the steam currently extracted from the CHP steam turbine. The electricity produced by the steam that now is not extracted from the turbine, partly offsets the electricity consumption of the pump.
- The HP would be placed next to the cooling towers, to take advantage of the existing process water piping connections. A thermal oil loop is required to transfer the heat from the PHX to the steam production system (ECO-EV-SH).
- Two designs have been proposed, one for low process flow rate (12 bara) and another one for high process flow rate (10 bara). The sizing is done for the highest mass flow rate.

[A. González-Alonso, Master Thesis, 2024]

Industrial application.
Steam production (12 bara)

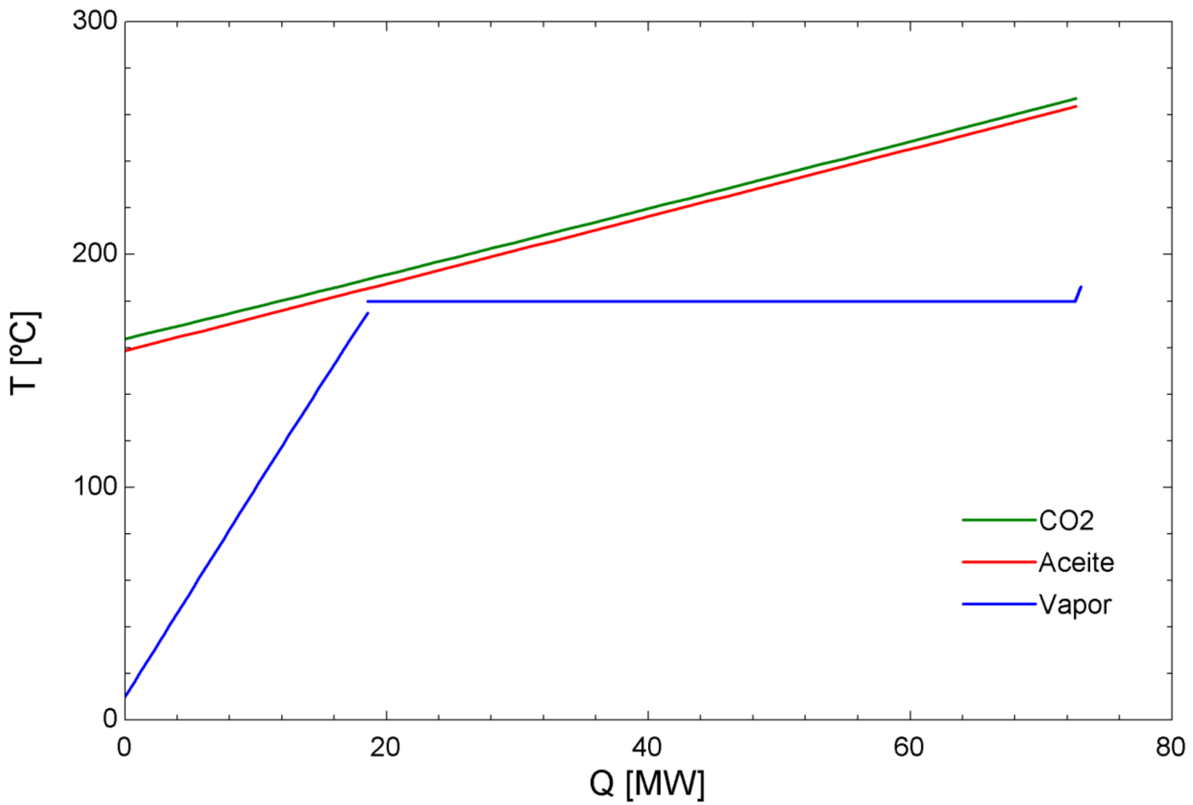


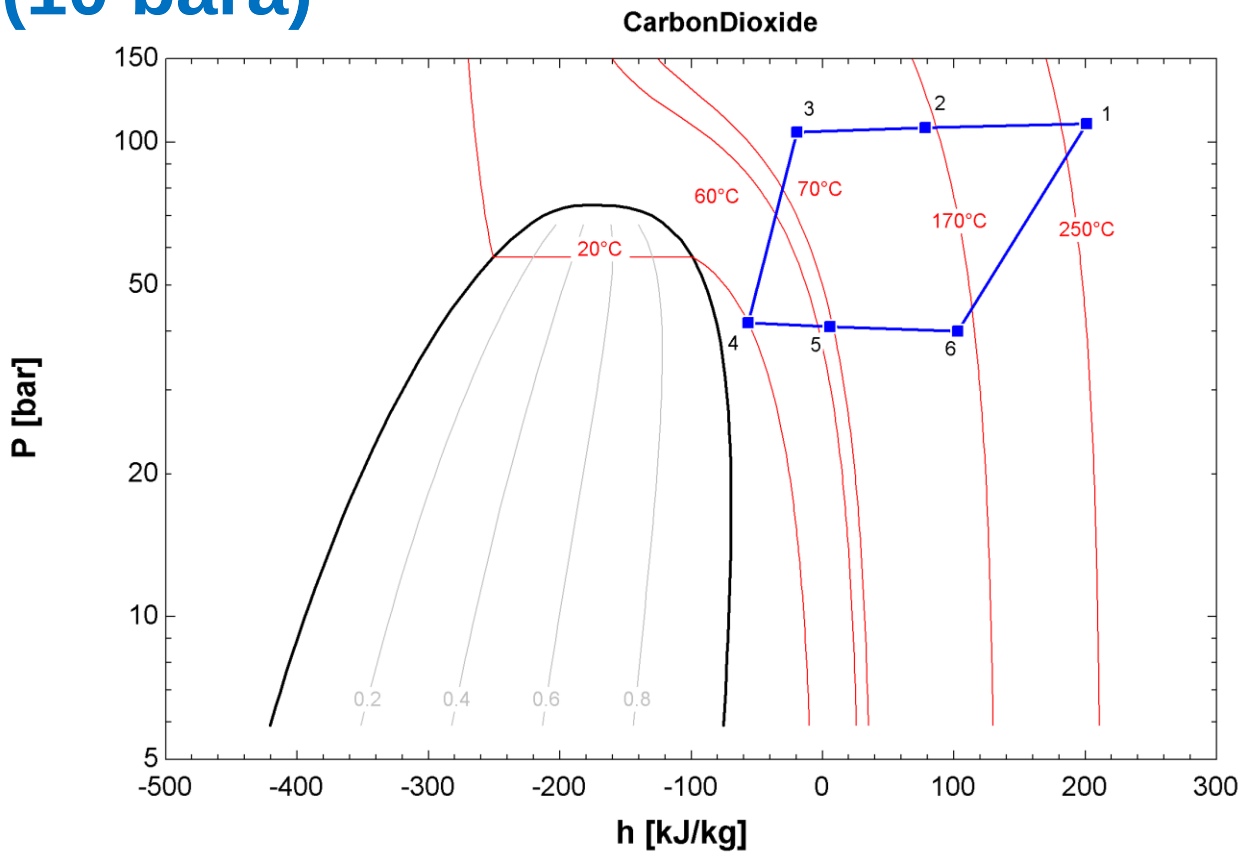


- Process effluent: 70 °C → 25 °C
- Steam: 10 °C (river) → 193 °C (12 bara); 45 t/h

- HP consumption: 18 MWe
- Waste heat: 16 MWth
- Steam heat: 34 MWth (COP = 1.89)

Industrial application. Steam production (10 bara)

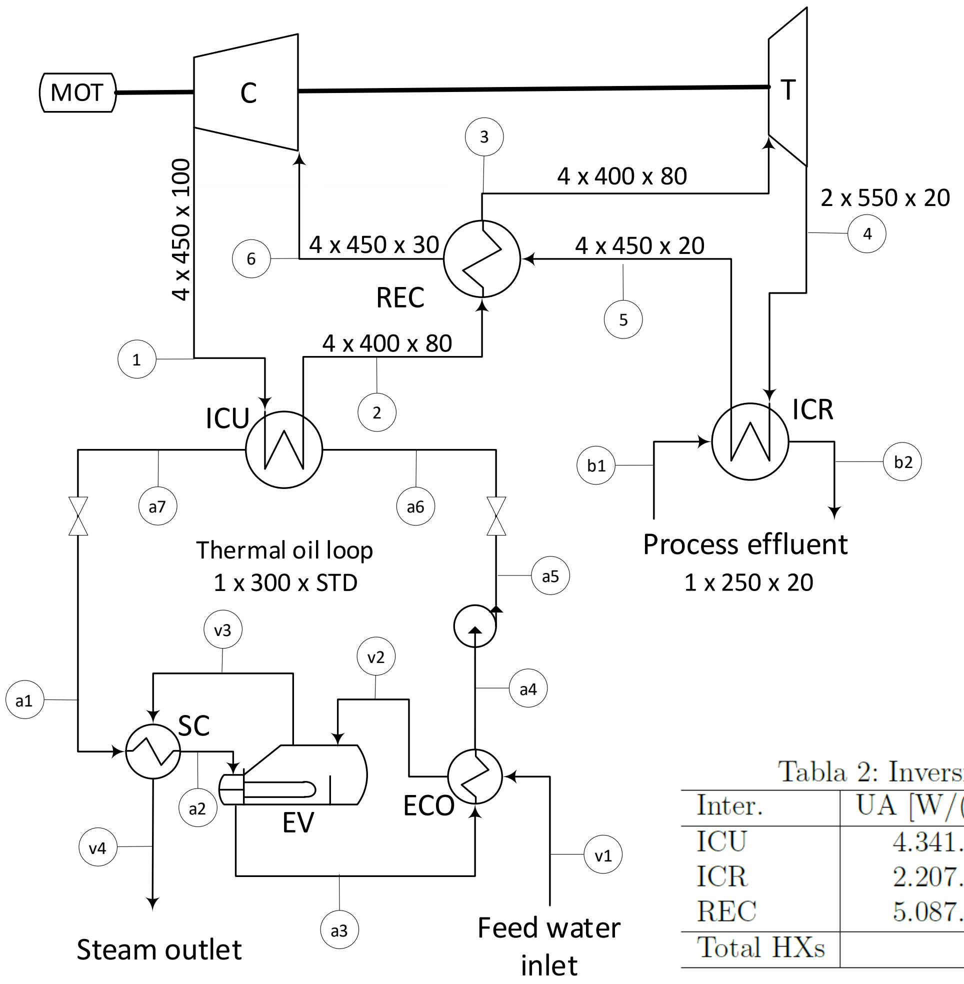




- Process effluent: 70 °C → 25 °C
- Steam: 10 °C (river) → 186 °C (10 bara); 96 t/h

- HP consumption: 36 MWe
- Waste heat: 37 MWth
- Steam heat: 73 MWth (COP = 2.03)

Industrial application. Steam production



HP sizing

- No. of pipes x DN x Schedule
- Heat exchangers: Width (m) x Depth (m) x Height (m)
  - REC: 2 units: 0.6 x 6 x 2.5
  - ICU: 0.6 x 8 x 5
  - ICR: 0.6 x 7 x 2
  - Theorical dimensions (no connection ports)

Tabla 2: Inversión requerida por los intercambiadores

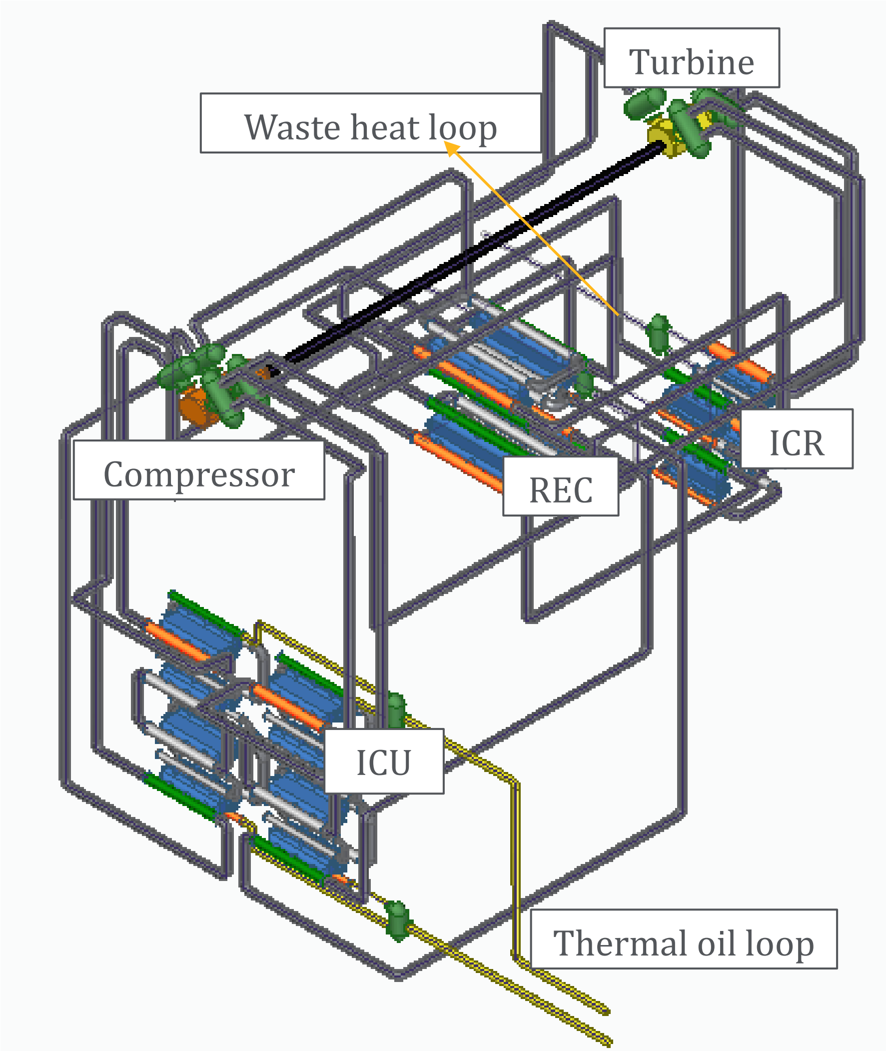
Inter.	UA [W/(m²K)]	PEC [€]	ONSC [€]	FCI [€]
ICU	4.341.593	5.030.473	6.539.614	8.174.518
ICR	2.207.637	3.020.128	3.926.166	4.907.708
REC	5.087.890	5.669.939	7.370.920	9.213.651
Total HXs		13.720.539	17.836.701	22.295.876

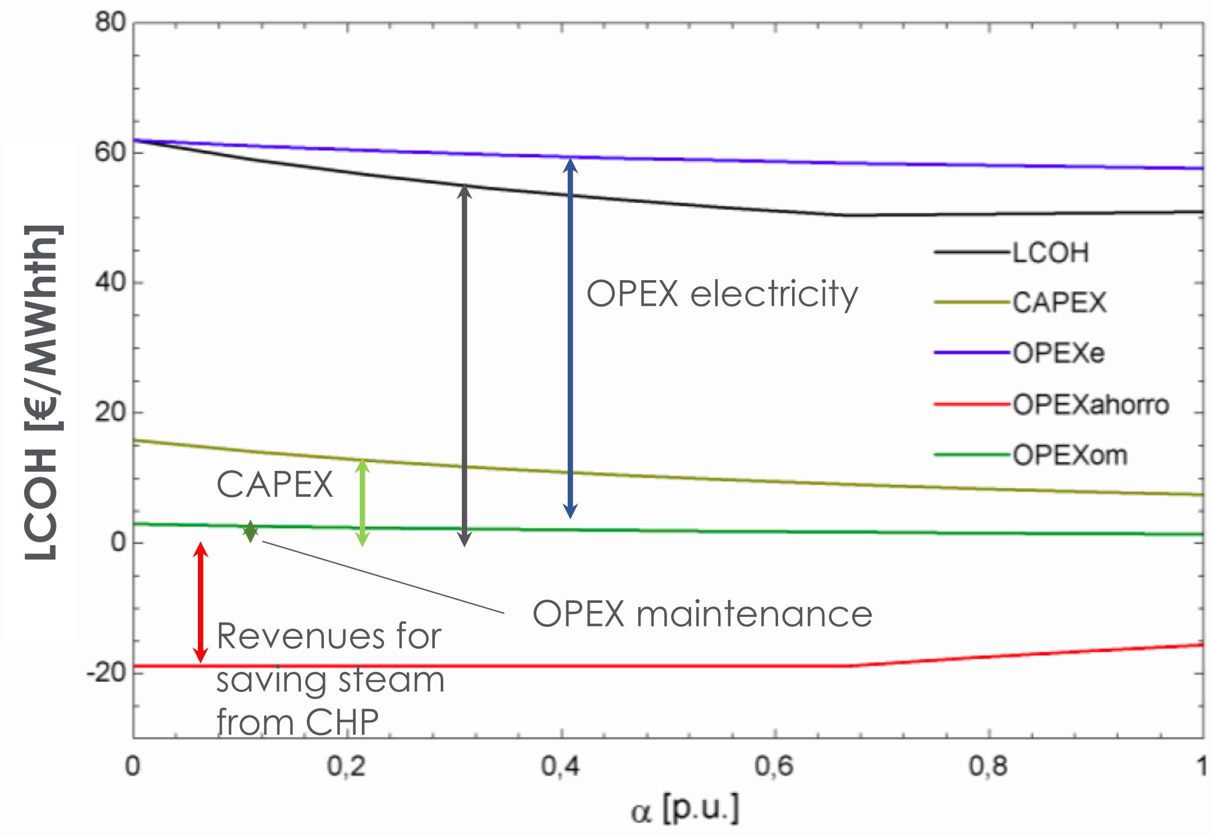
Tabla 3: Inversión requerida por equipos rotativos

	Potencia [MW]	PEC [€]	ONSC [€]	FCI [€]
Compresor	57,851	6.214.692	8.079.100	10.098.875
Turbina	22,067	1.020.367	1.326.477	1.658.096
Motor	35,784	3.493.448	4.541.482	5.676.853
Total		10.728.507	13.947.059	17.433.824

Total investment: 608 €/kWth

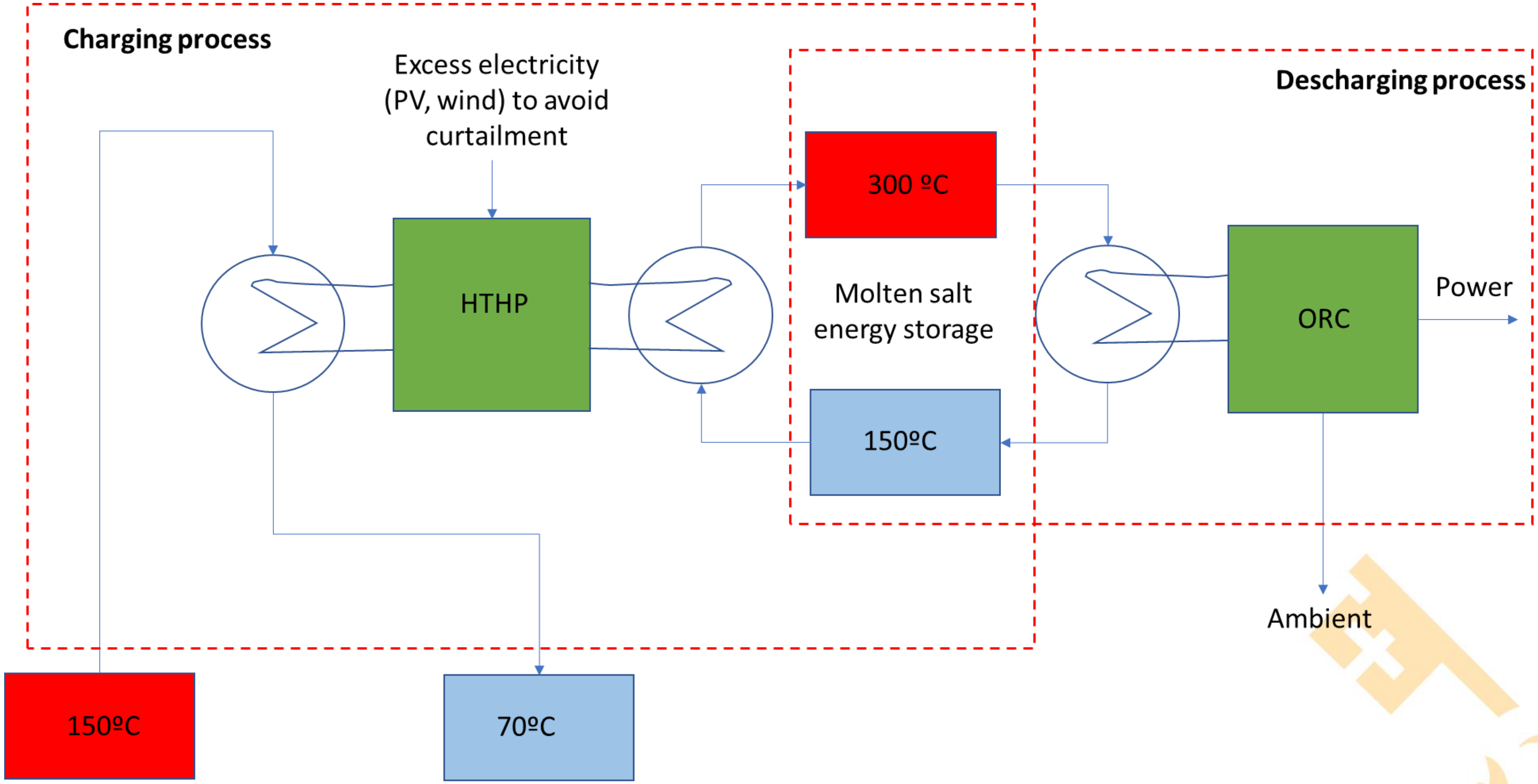
Industrial application. Steam production





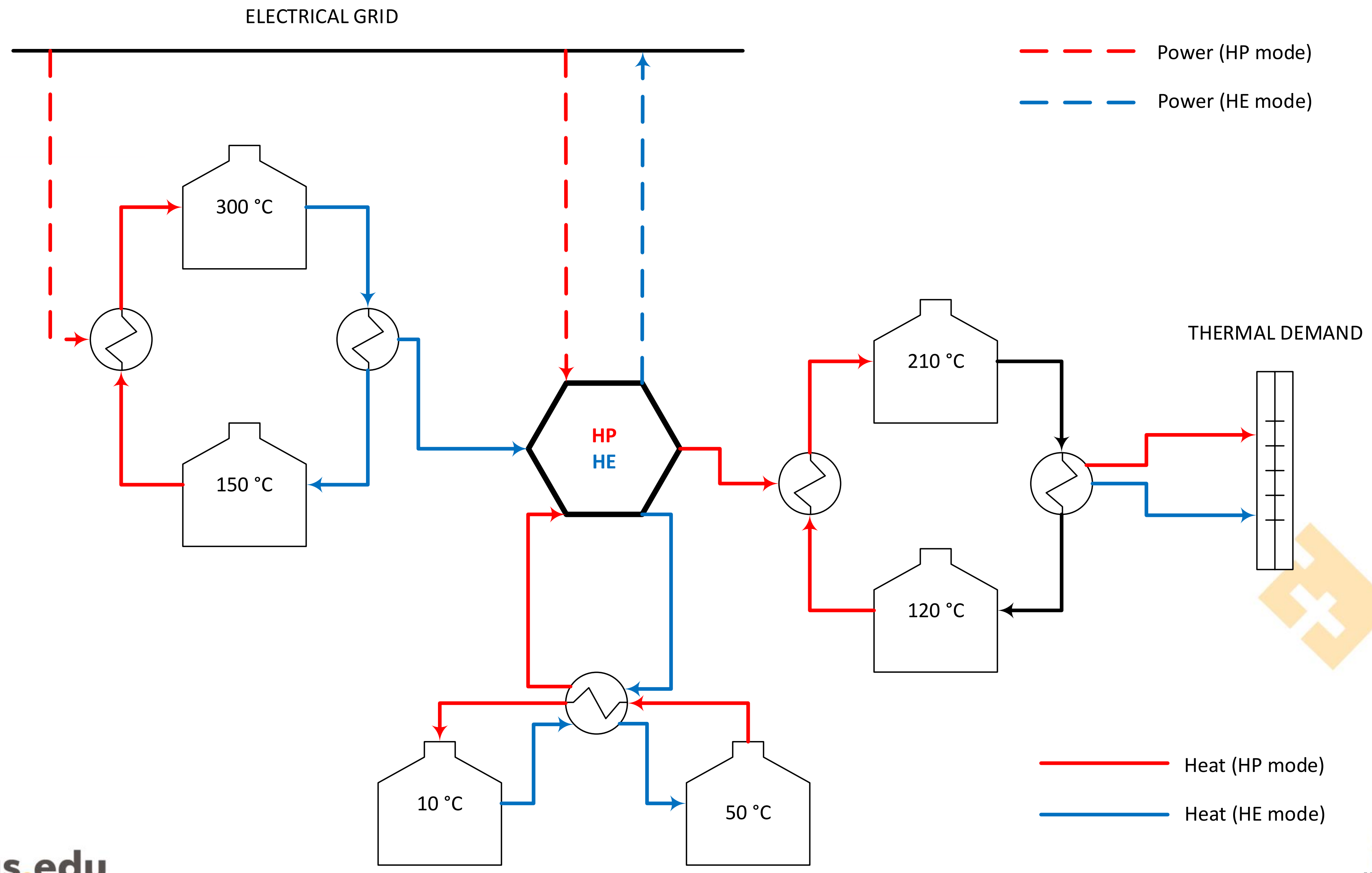
LCOH vs. time fraction at maximum steam production

Exploring other applications



EGS (Enhanced Geothermal System) coupled with HTHP

Exploring other applications



Conclusions

- Conventional technology does not allow to reach temperatures higher than 150 °C

- Reverse Brayton HP has revealed as a flexible system:

  - ✓ Overcomes working fluid decomposition issues associated with high temperatures
  - ✓ Uses CO_2, with ODP = 0 and GWP = 1
  - ✓ Overcomes high temperature issues of reciprocating compressors
  - ✓ Suitable temperature profile (both source and sink) for fluids with temperature change:
    - Very low outlet temperatures from the waste HX, allowing the use of waste water for chilling
    - Excellent approach to maximum working fluid temperature

Conclusions

- Integration with thermal energy storage is possible moving the PHX to the low pressure side, enabling the use of tube/fin heat exchangers, S&T, or hybrid PCHE, able to work with molten salts or air (solid material as storage medium).

- Issues detected:

  ✓ No commercial units with this technology
  ✓ Only few manufacturers: Echogen, MAN (Pasch)
  ✓ Problems with scale:

    - Small units (< 2 MWth) require high speeds turbomachines
    - Large units (> 30 MWth) require large investments

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THANK YOU FOR YOUR ATTENTION

Questions?

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