HEAT PUMPS IN SPAIN

NATIONAL WORKSHOP

11TH NOVEMBER 2024

CIEMAT / Madrid

Ongoing Spanish Team activity on HPT

High temperature heat pumps for industry decarbonisation

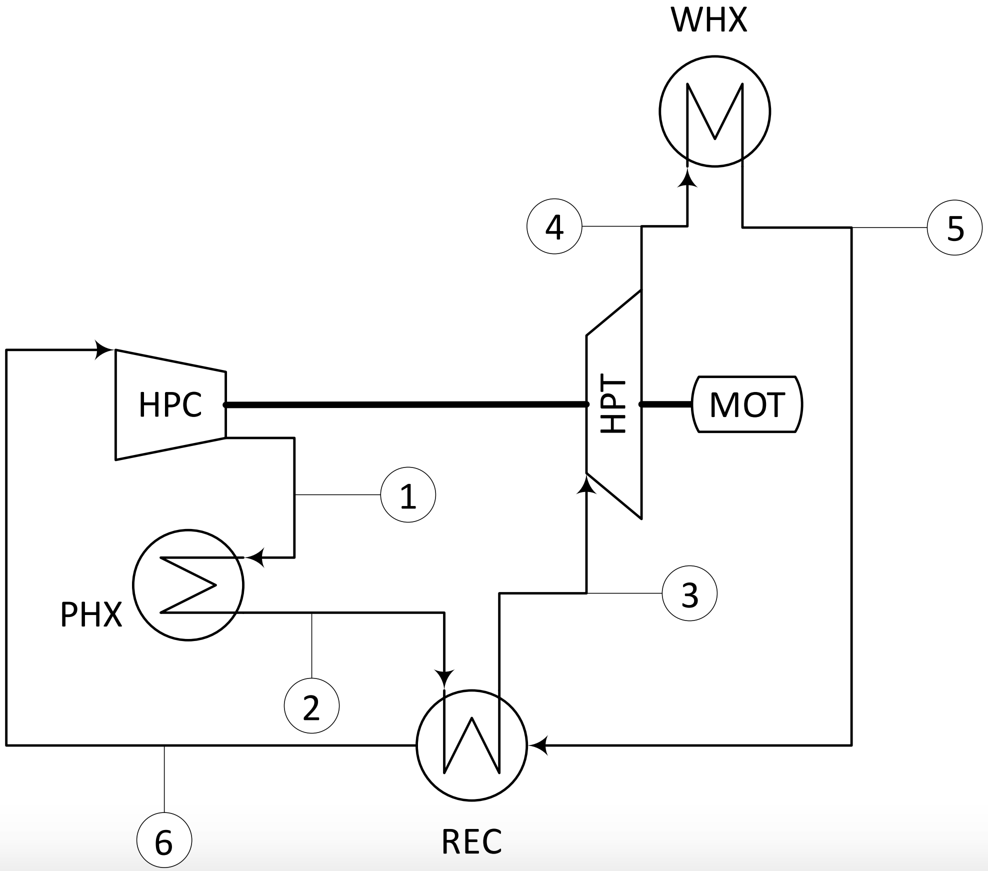
José Ignacio Linares // ICAI – Comillas Pontifical University

Madrid, 11th November 2024

IEA HPT TCP Technology Collaboration Programme | SPAIN NATIONAL TEAM

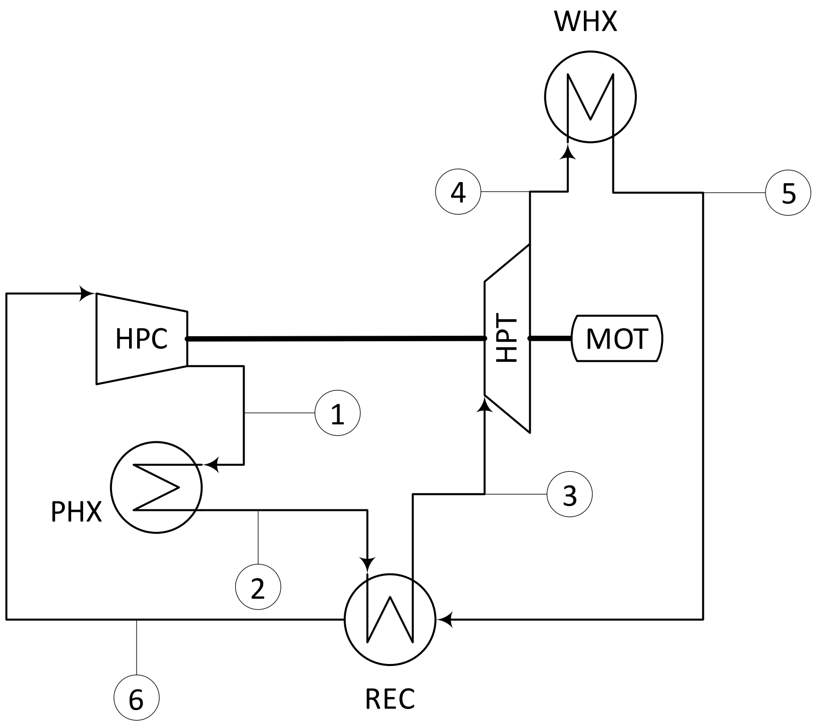
Ministerio de Ciencia, Innovación y Universidades · Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas · Vicepresidencia Tercera del Gobierno, Ministerio para la Transición Ecológica y el Reto Demográfico · IDAE

Reverse Brayton cycle for heat pumps

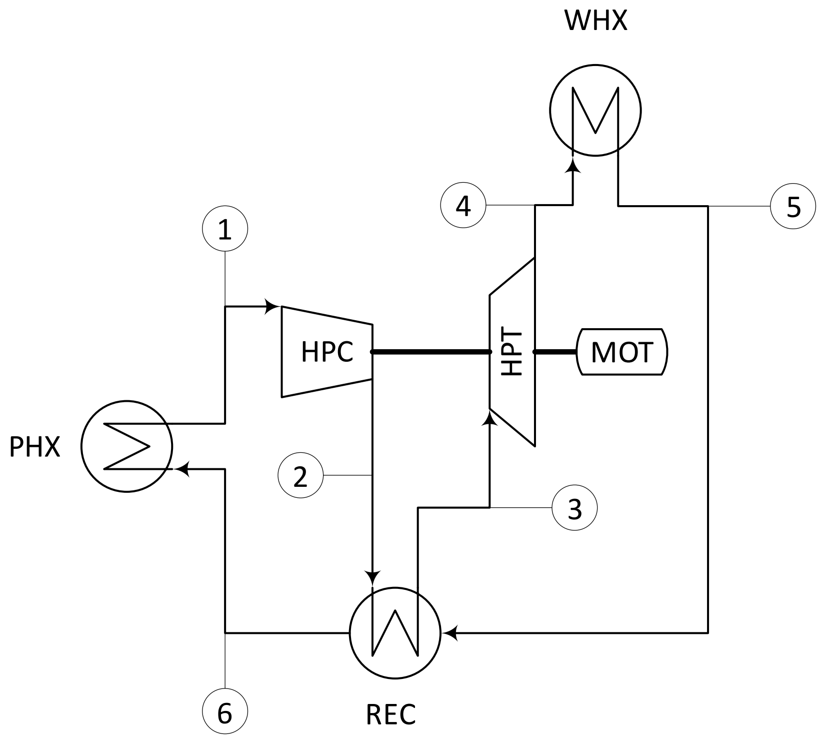


- Reverse Brayton cycle (the opposite to a closed-cycle gas turbine)
- Turbine replaces the valve of typical reverse Rankine cycles
- Turbocompressors are already used in large Rankine cycles
- PHX (gas cooler) is in the high pressure side
- WHX (gas heater) is in the low pressure side
- CO_2 is chosen as working fluid

Reverse Brayton cycle for heat pumps



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



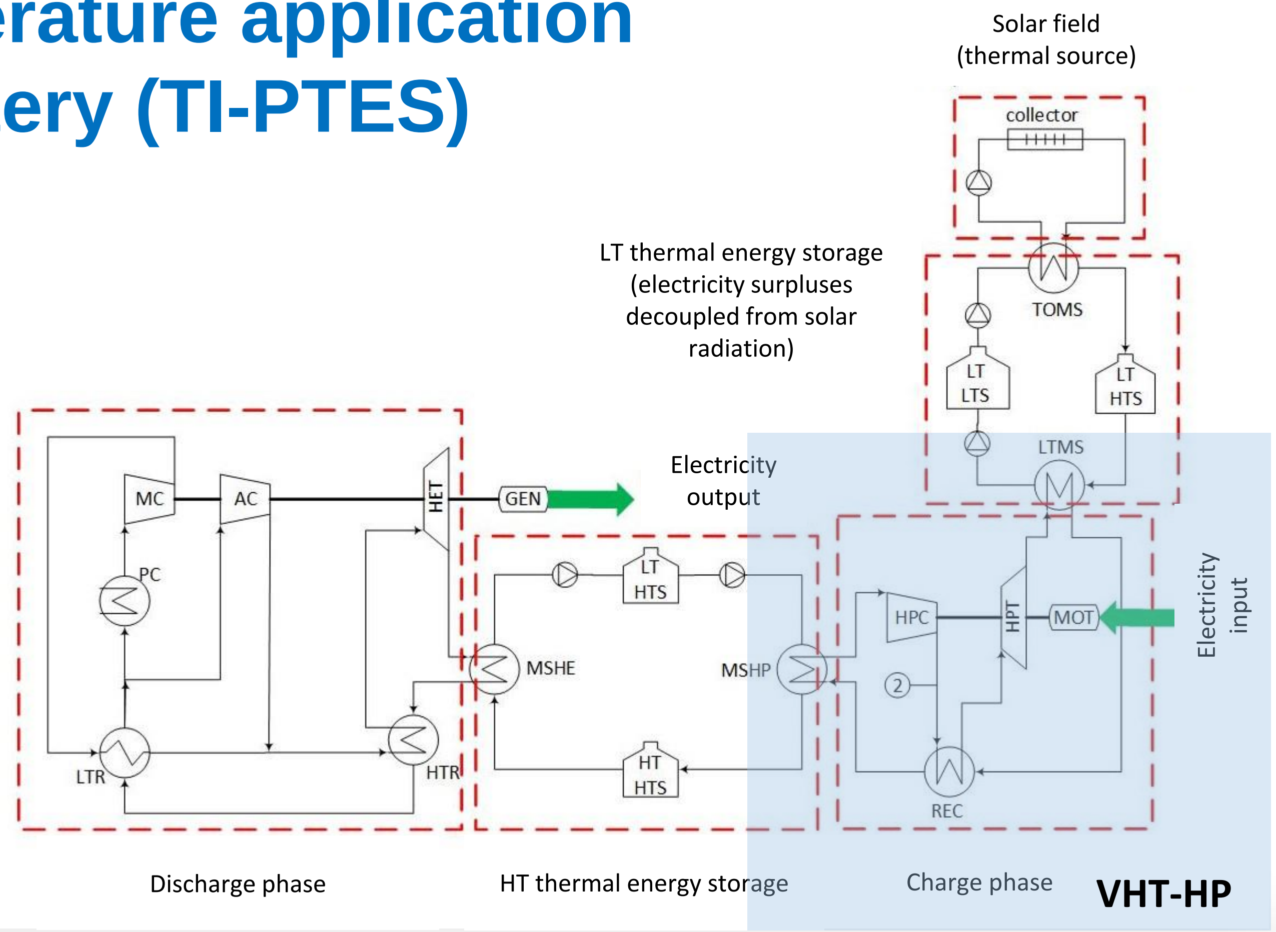
- PHX is in the low pressure side
- **Best option if thermal storage is needed**

Very high temperature application
Carnot battery (TI-PTES)

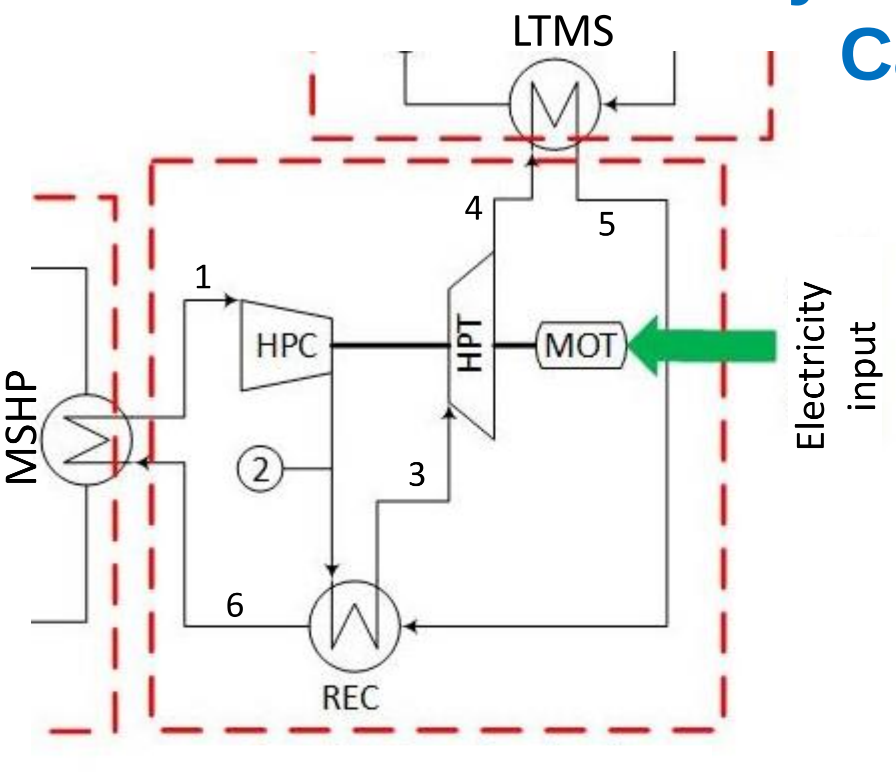
- Heat pump is fed from a PTC solar field (400 ºC/300 ºC), supplying useful heat at (600 ºC/400 ºC)

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

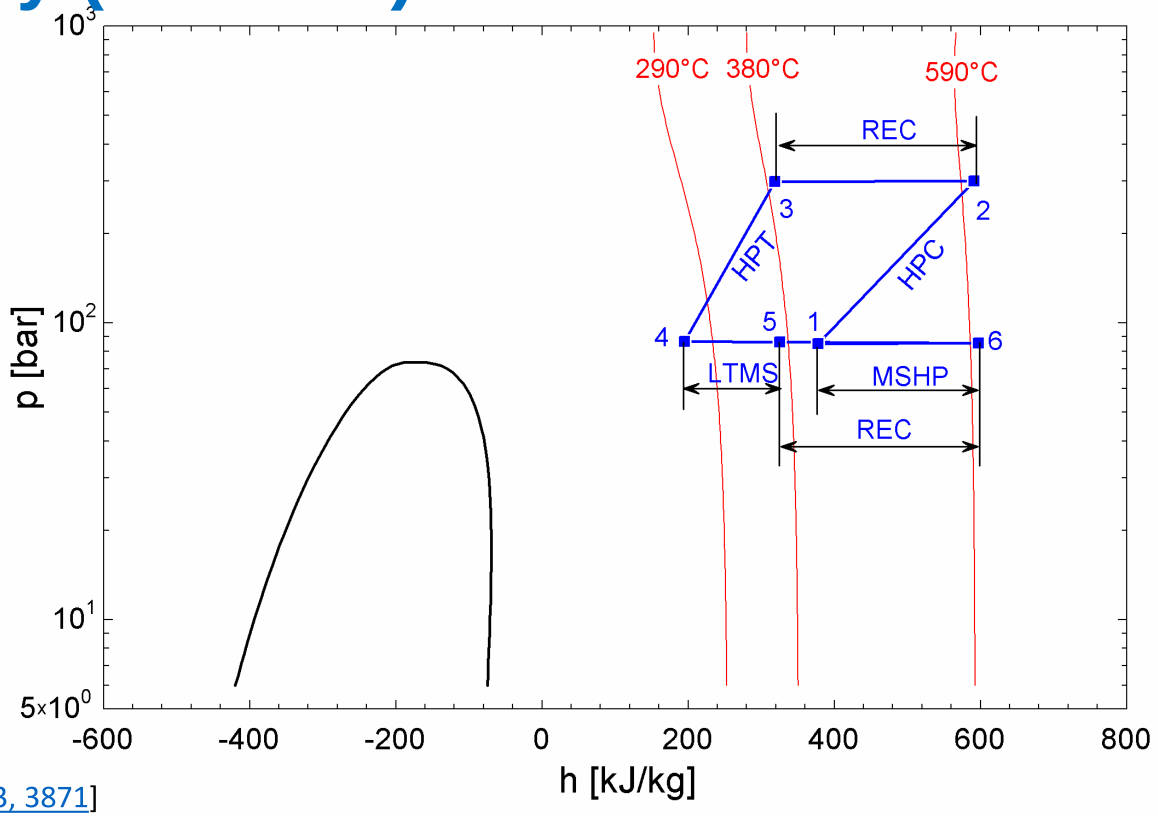
[Linares et al., Energies 16(9) 2023, 3871]



Very high temperature application
Carnot battery (TI-PTES)



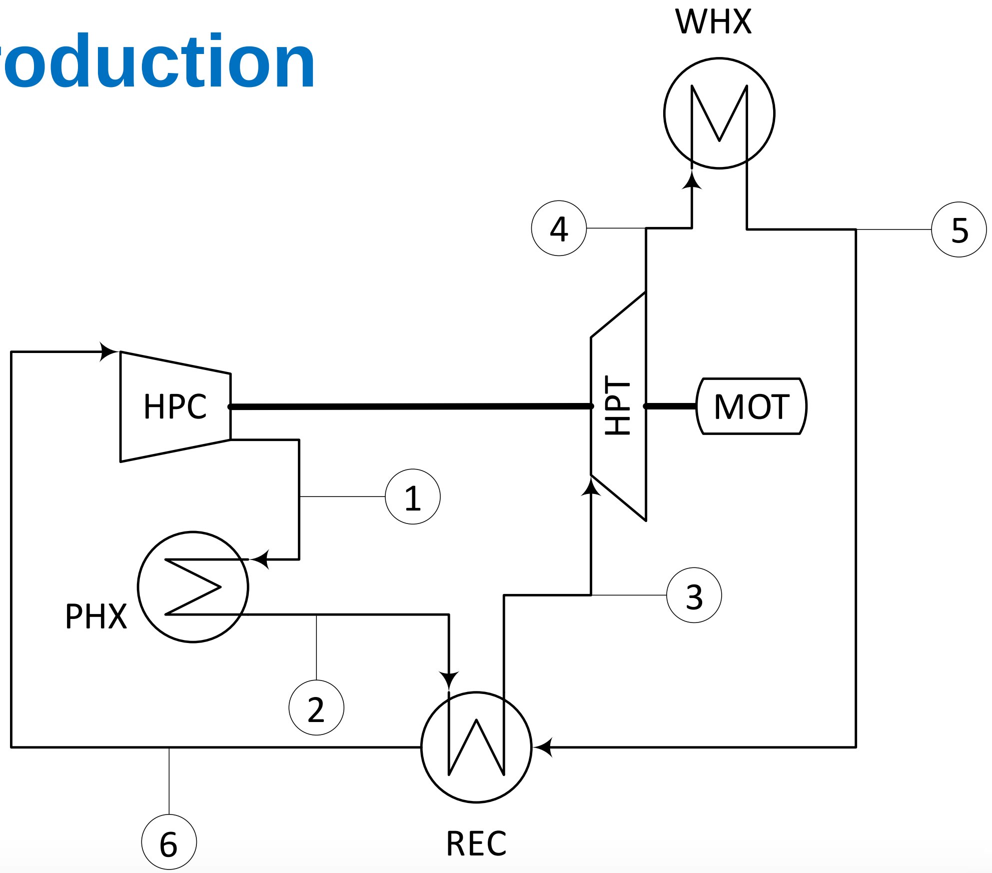
Charge phase



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

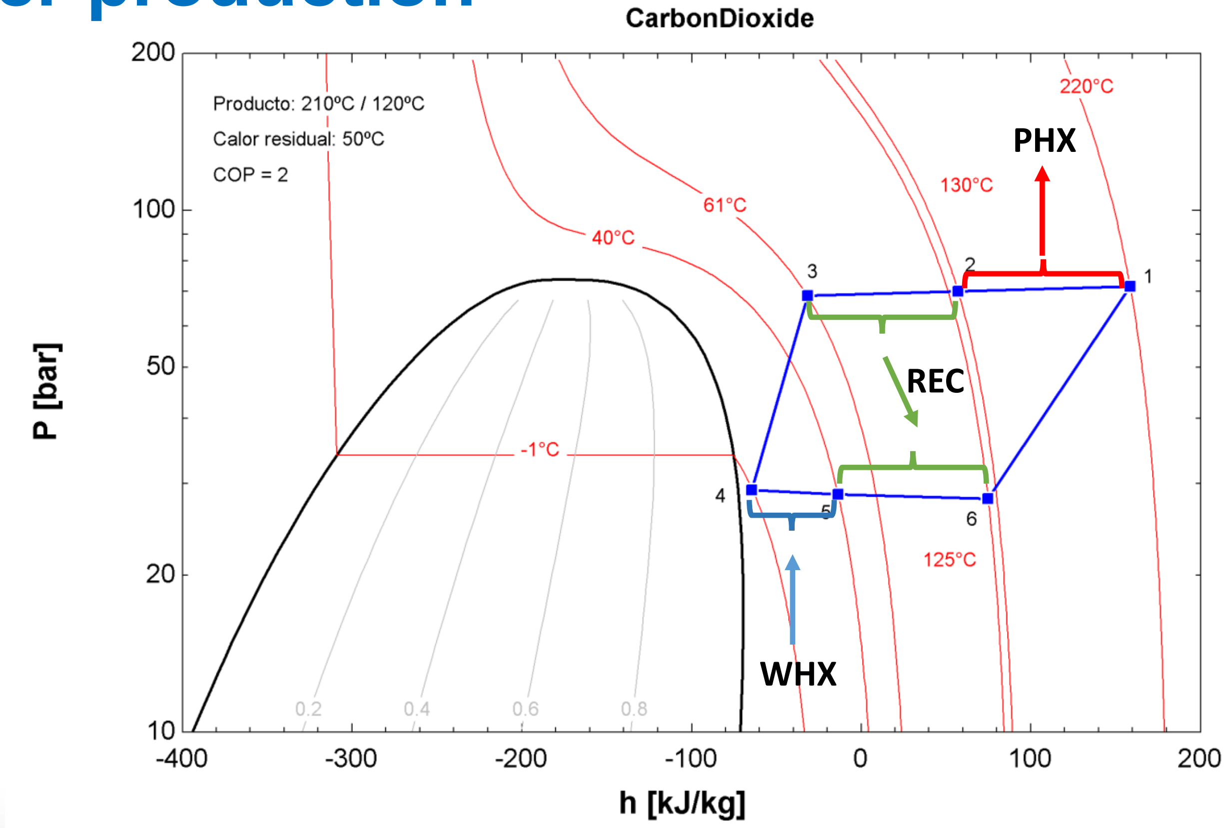
Industrial application
Compressed water production

- 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



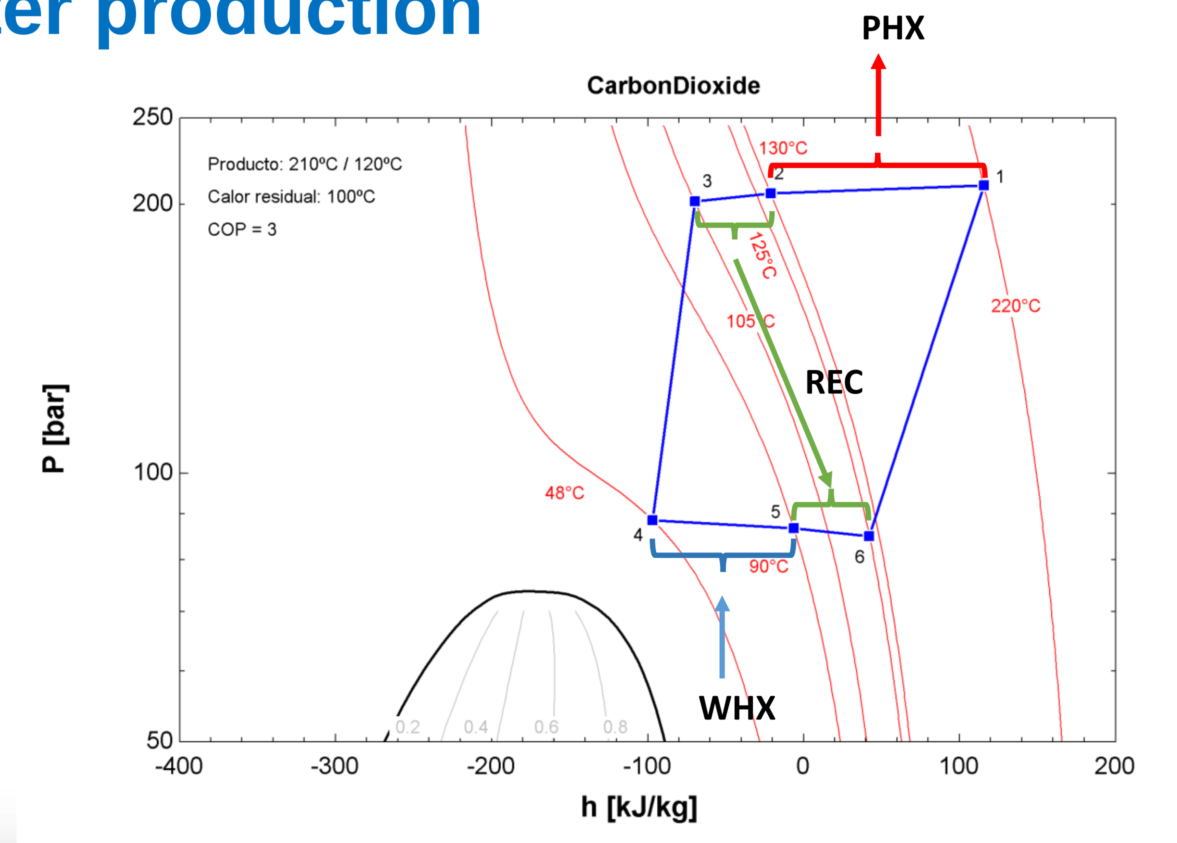
Industrial application
Compressed water production

- **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**



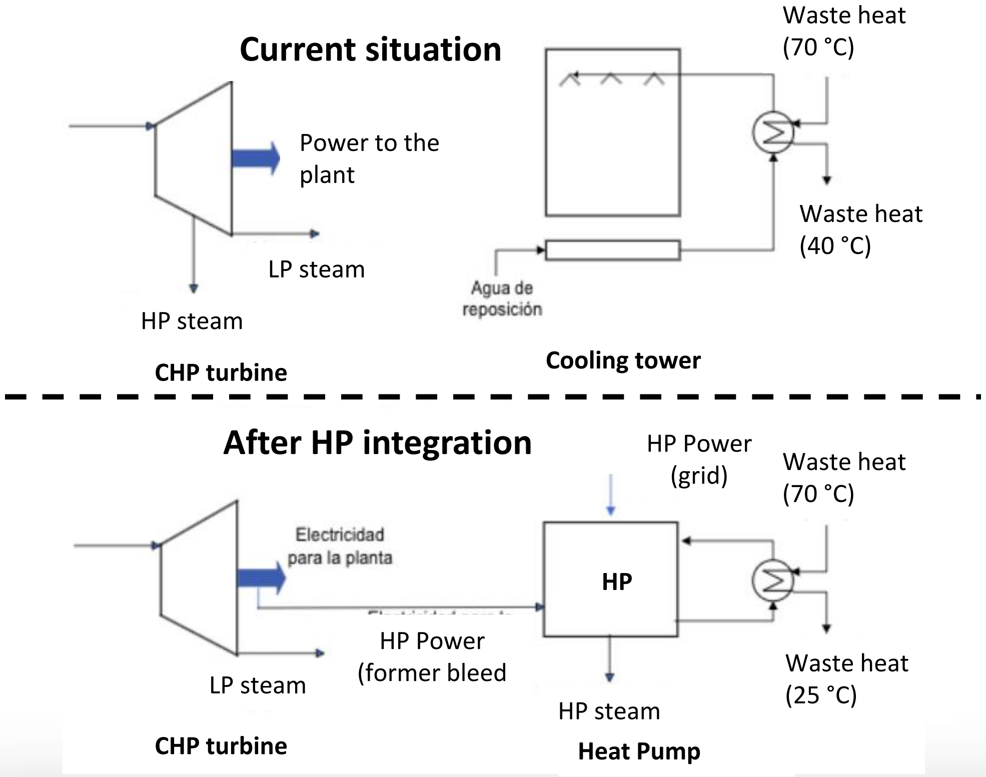
Industrial application
Compressed water production

- **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**



Industrial application

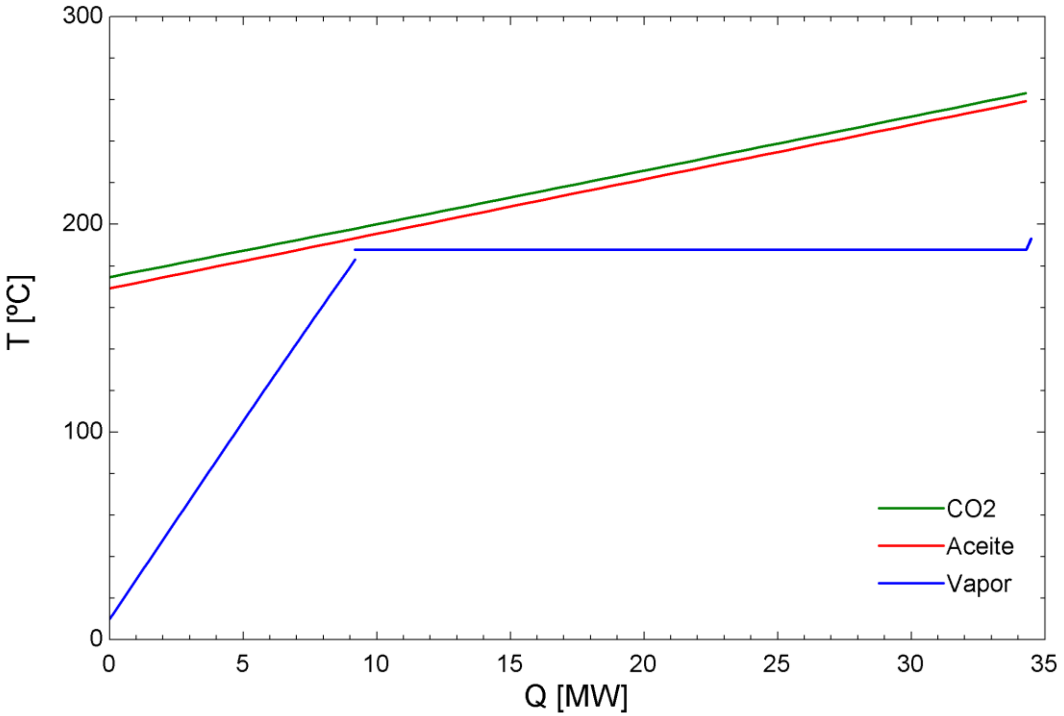
Steam production (10 – 12 bara)

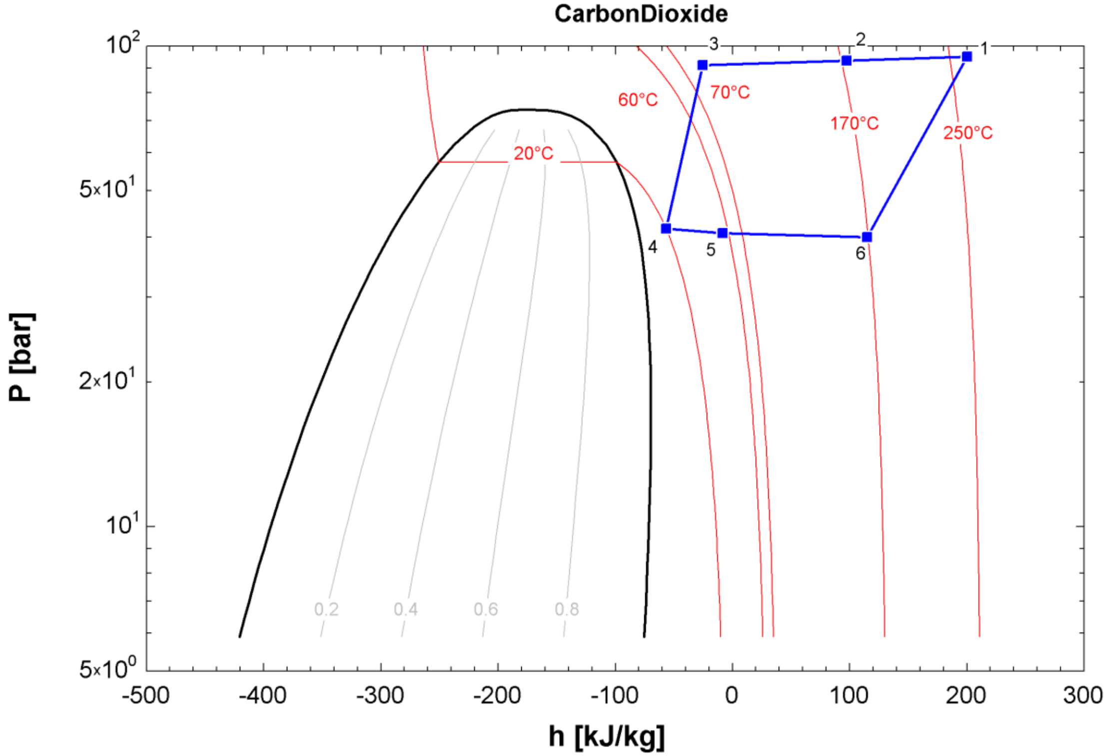


- The HP is intended to replace the existing cooling towers by using the incoming process water for cooling as a source for the heat pump. The aim is to eliminate make-up water and further cool the process water for better operation of the treatment plant.
- The HP will produce process steam, which replaces 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, Mater Thesis Dissertation, 2024]

Industrial application. Steam production (12 bara)



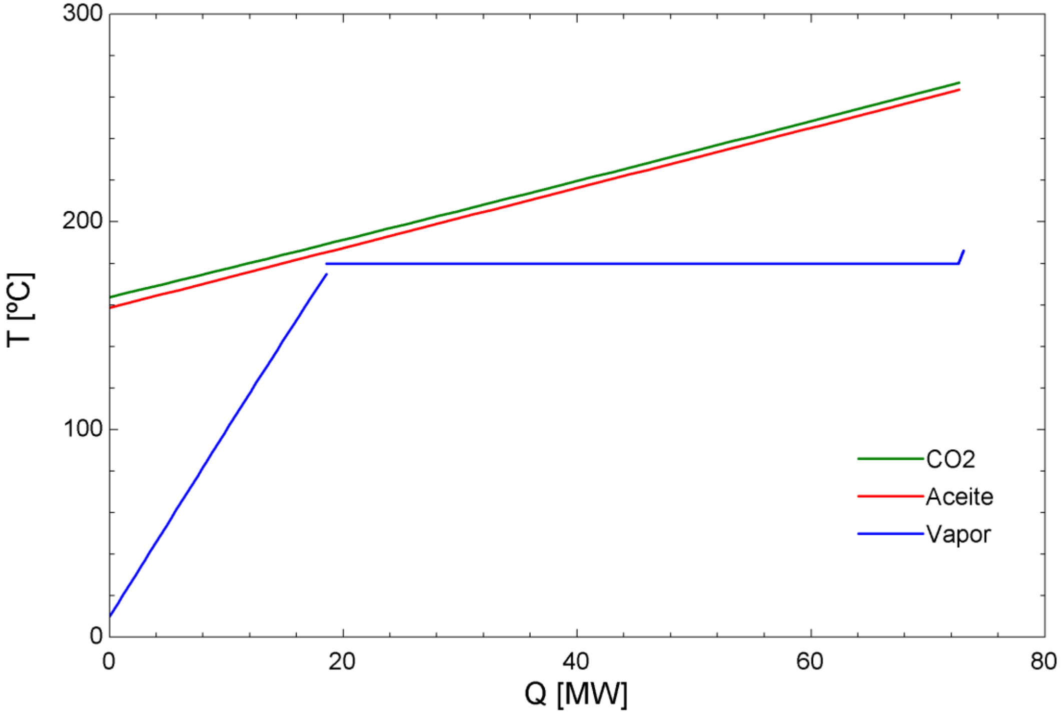


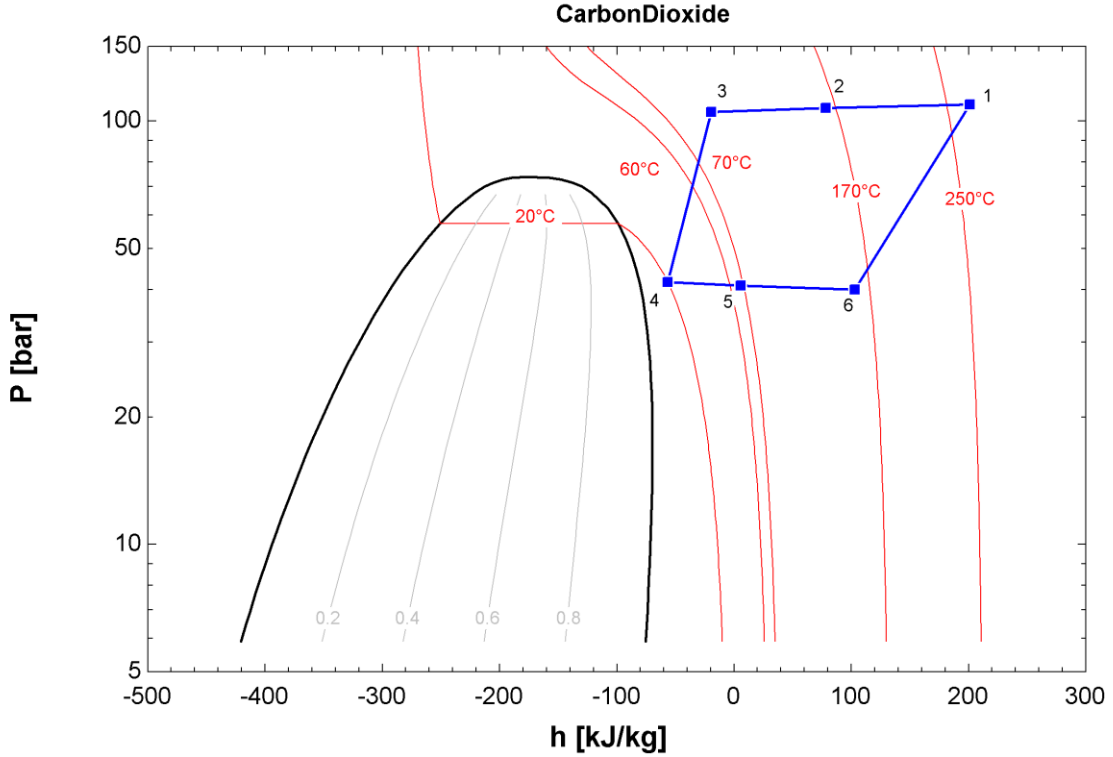
- Process effluent: 70 ºC → 25 ºC
- Steam: 10 ºC (river) → 193 ºC (12 bara); 45 t/h

[A. González-Alonso, Mater Thesis Dissertation, 2024]

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

Industrial application. Steam production (10 bara)





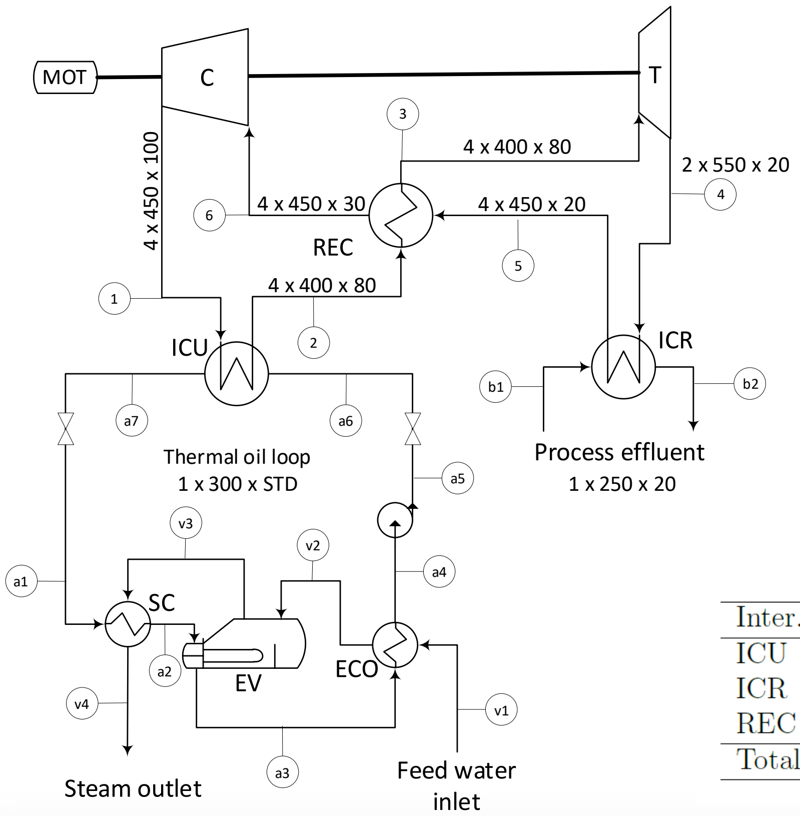
- Process effluent: 70 ºC → 25 ºC
- Steam: 10 ºC (river) → 186 ºC (10 bara); 96 t/h

[A. González-Alonso, Mater Thesis Dissertation, 2024]

- 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

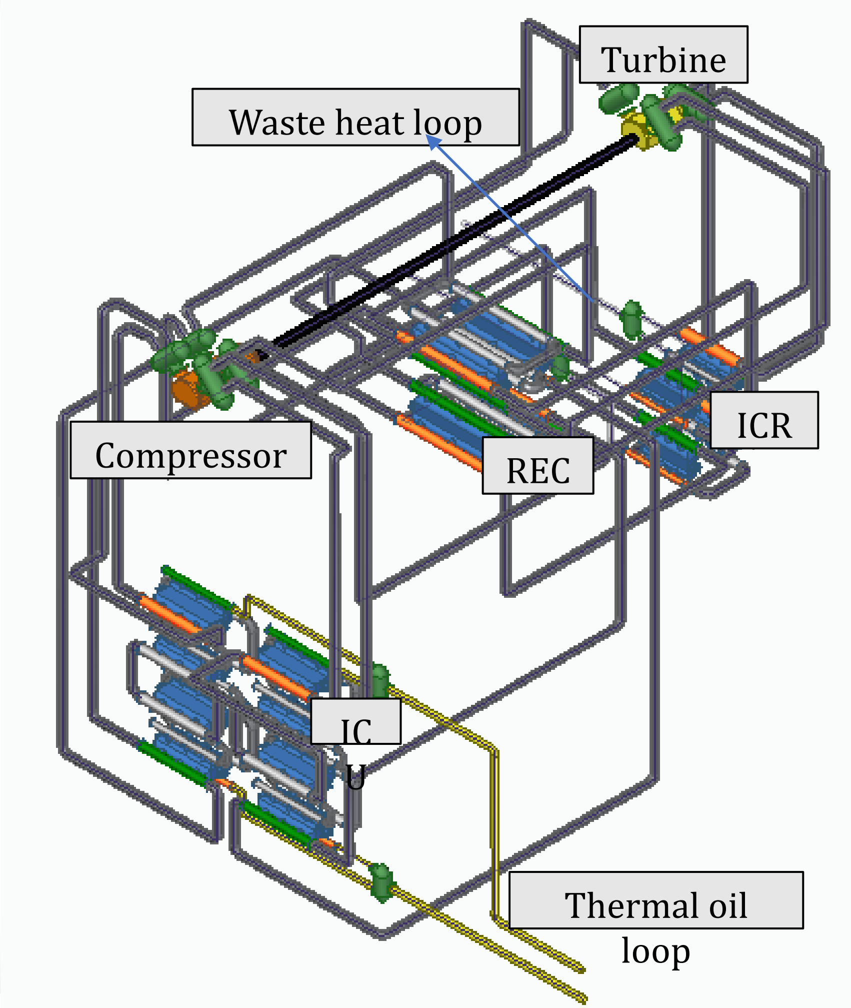
Tabla 3: Inversión requerida por equipos rotativos

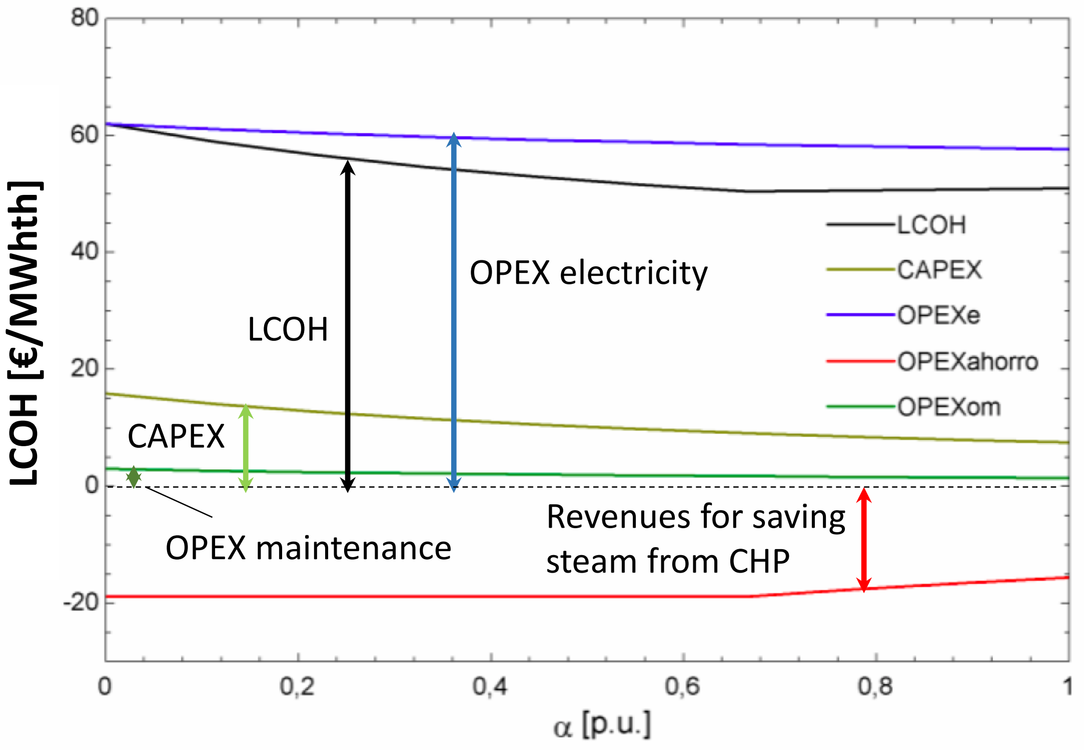
	Potencia [MW]	PEC [€]	ONSC [€]	FCI [€]
Compresor	57,851	6.214.692	8.079.100	10.098.875
Turbina	22,067	1.020.367	1.326.477	1.658.096
Motor	35,784	3.493.448	4.541.482	5.676.853
Total		10.728.507	13.947.059	17.433.824

Total investment: 608 €/kWth

[A. González-Alonso, Mater Thesis Dissertation, 2024]

Industrial application. Steam production





LCOH vs. time fraction at maximum steam production

[A. González-Alonso, Mater Thesis Dissertation, 2024]

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

- 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. Micro-gas turbine manufacturers?
    - Large units (> 30 MWth) require large investments, but turbomachineries are commercial

Thank you for your attention

linares@comillas.edu

CÁTEDRA DE TRANSICIÓN ENERGÉTICA
COMILLAS ICAI
REPSOL Fundación

CÁTEDRA RAFAEL MARIÑO DE NUEVAS TECNOLOGÍAS ENERGÉTICAS
COMILLAS ICAI