MODULE 1
CHAPTER 2: ANALYSIS OF WASTE HEAT AND COLD TECHNOLOGIES

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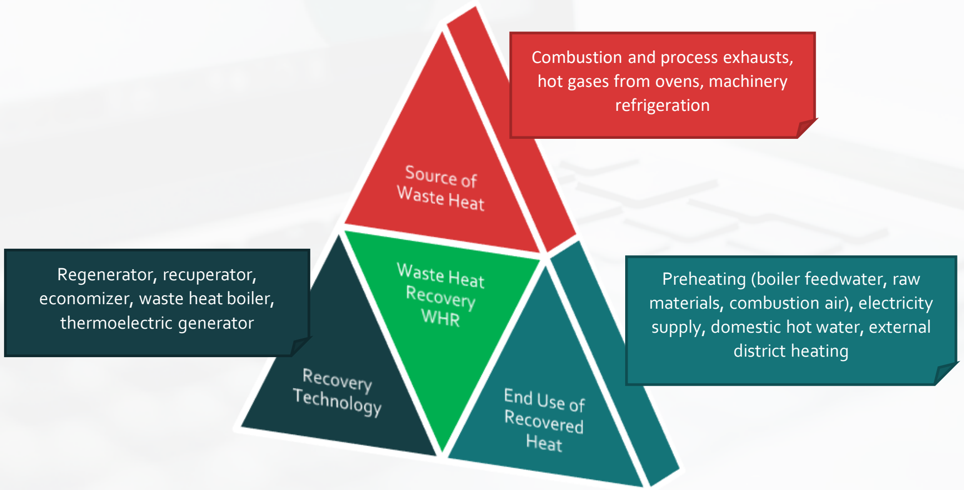
This Project has received funding from the European Union’s Horizon 2020 Research and Innovation Programme under Grant Agreement N. 847097

Preface

20-50% of the industry energy consumption ends as WH and 18-30% could be recovered

3 main components are required to accomplish it:



S. M. Gutiérrez Caballero, F. Morentin, L. Á. Bujedo Nieto, F. Peccianti, N. Purshouse, and C. Ferrando, 'Report on end-users' current status, practices and needs in waste H/C recovery and RES integration', SO WHAT H2020 Project, Deliverable 2.1, Jan. 2020. [Online]. Available: www.sowhatproject.eu.

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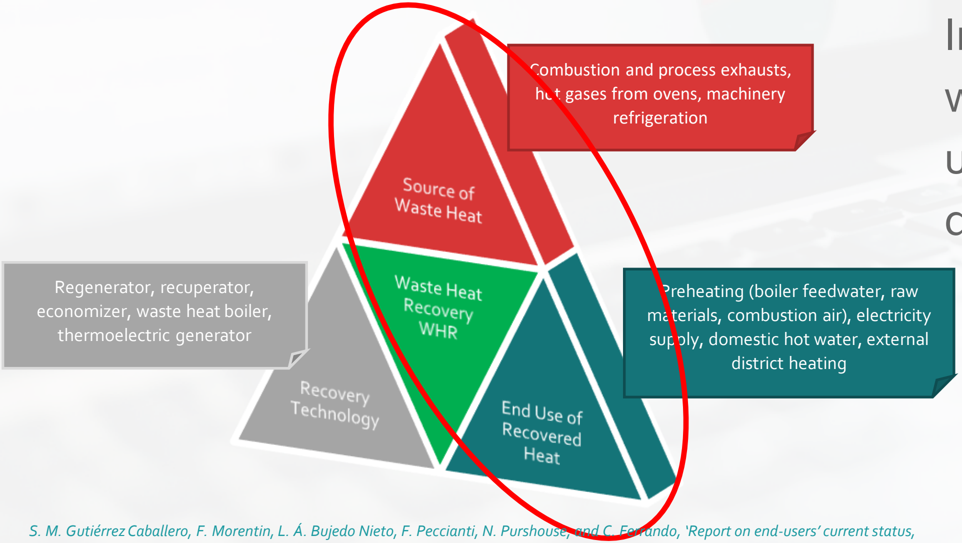
Preface

Waste heat is generated along the industrial processes as a by-product in different forms, but the key factor is a suitable "end use" for the recovered heat



In Chapter 1, the main sources of waste heat and the possible end use of the recovered heat were described

S. M. Gutiérrez Caballero, F. Morentin, L. Á. Bujedo Nieto, F. Peccianti, N. Purshouse, and C. Ferrando, 'Report on end-users' current status, practices and needs in waste H/C recovery and RES integration', SO WHAT H2020 Project, Deliverable 2.1, Jan. 2020. [Online]. Available: www.sowhatproject.eu.

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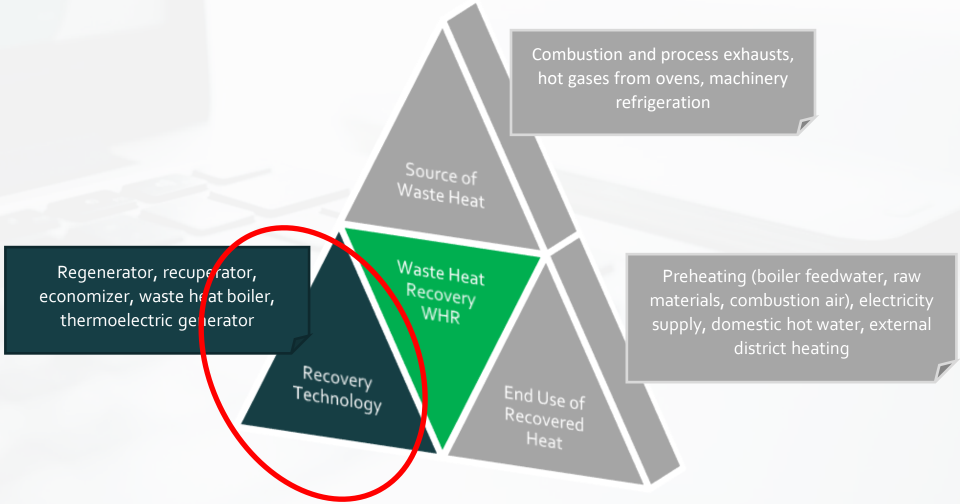
Preface

There are different technologies available depending on the type and power of the waste heat source, the temperature ranges and the final use of the energy

In Chapter 2, individual technologies will be reviewed with a focus on operating principle, performance and typical applications



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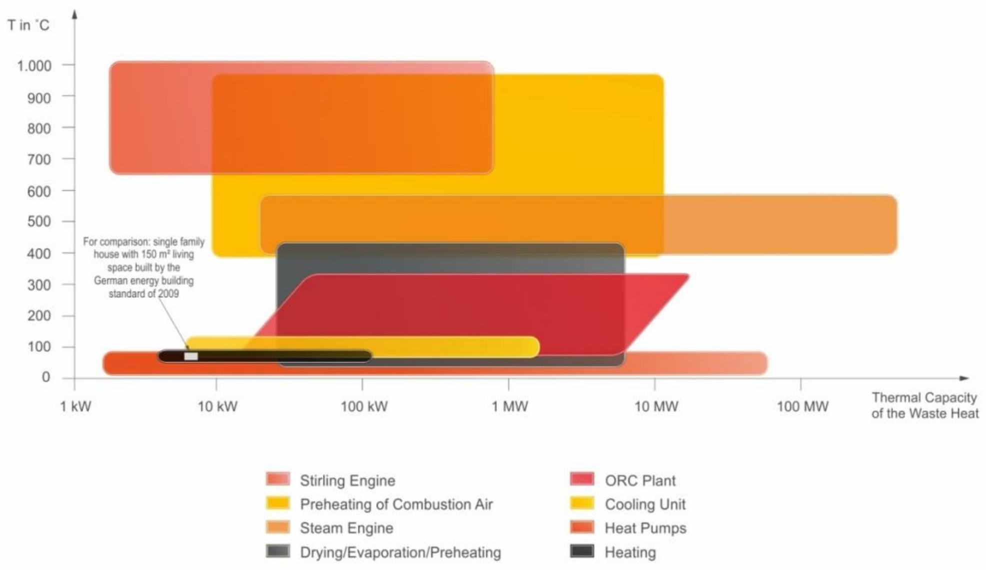
Introduction

The equipment used for waste heat recovery must take into account parameters such as pressure and temperature operation ranges, waste heat source size, carrier, purity and corrosiveness of the streams



Source: Sächsische Energieagentur GmbH

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Introduction

The Chapter is structured into five sections, each one dedicated to a category of WH/C recovery technology

- **Waste Heat-to-Heat (WHTH)**
- **Thermal Energy Storage (TES)**
- **Waste Heat-to-Cold (WHTC)**
- **Waste Heat-to-Power (WHTP)**
- **Heat Upgrade (HU) technologies**

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Introduction

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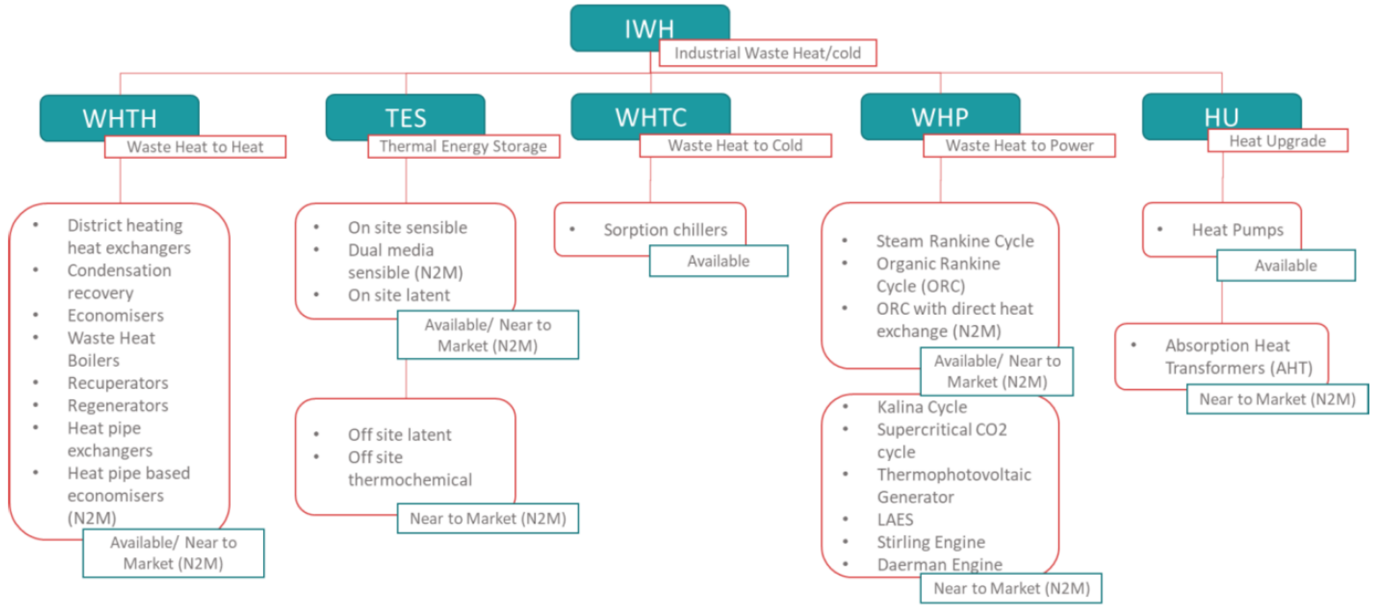

A. Sciacovelli, G. Manente, F. Morentin, G. Bonvicini, and C. Ferrando, 'Report on H/C recovery/storage technologies and renewable technologies', SO WHAT H2020 Project, Deliverable 1.6, Jan. 2020. [Online]. Available: www.sowhatproject.eu.

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Waste Heat to Heat (WHTH) Technologies

In this section, passive WH/C recovery technologies designated to transfer heat from a source to a sink are shown

District Heating Heat Exchangers (DH HE)

Technology to recover the waste heat from industrial processes and transfer it to the district heating network (DHN)

Shell and Tube heat exchanger (STHE) and Plate Heat Exchanger (PHE) are the most common.

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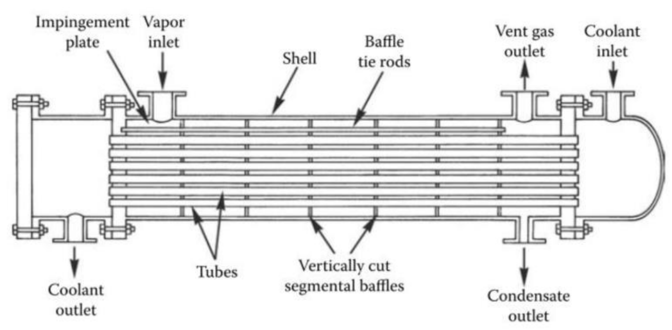
Waste Heat to Heat (WHTH) Technologies

District Heating Heat Exchangers (DH HE)

- STHEs are built of round tubes mounted in a cylindrical shell with the tubes parallel to the shell
- Easier to be cleaned
- Can be designed for high pressures

- PHEs are built of thin plates forming flow channels
- Well suited to liquid–liquid duties
- Not recommended for gas-to-gas applications



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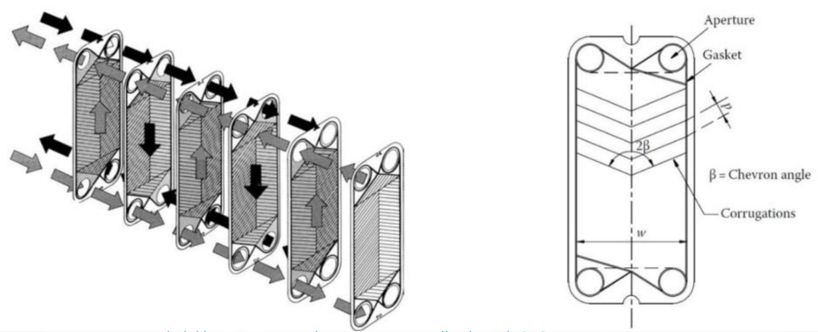

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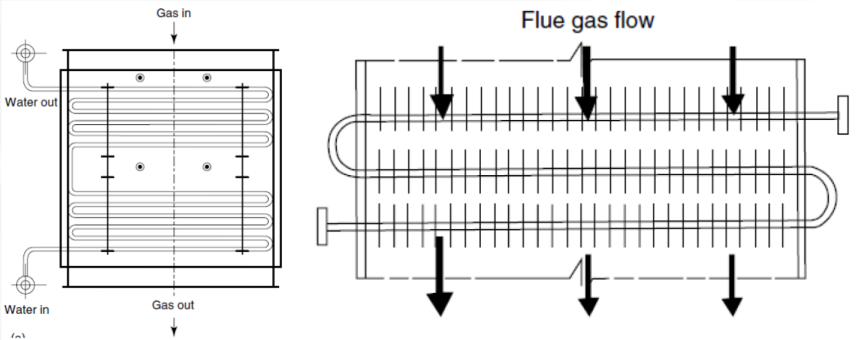
Waste Heat to Heat (WHTH) Technologies

Economizers (ECO)

- Typically used to recover the waste heat from the flue gas at the outlet of industrial boilers around 200-250°C
- Used to preheat the feed water entering the boiler up to 100-150°C
- Thermal duties in the range of hundreds kWs to a few MWs and pressures up to 60 bar



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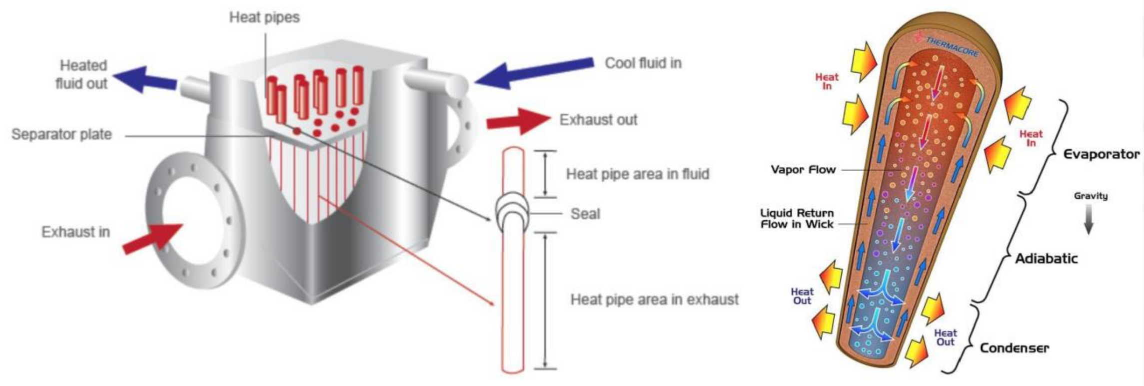
Waste Heat to Heat (WHTH) Technologies

Heat pipe heat exchangers (HPHEs)

- Designed to meet harsh operating conditions, enabling WH recovery in industrial processes where the use of traditional HEs is not viable
- The two streams exchange heat *only* via a series of components called “heat pipes”
- Sealed shell, wick structure and a certain amount of working fluid that transfers heat from the hot side to the cold side through continuous vaporization and condensation



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Thermal Energy Storage (TES)

TES are passive technologies designated to store thermal energy for subsequent use in time, bridging mismatch between thermal energy availability and thermal energy demand.

Sensible thermal energy storage (STES)

- Widely commercialized and used at scale for a broad range of temperatures
- Process: raising or lowering the temperature of a suitable storage medium (liquid or solid) to capture heat from a process (charging) or release it to a process (discharging)
- Water is commonly used up to about 120°C. Diathermic oils for temperature up to 250°C (oils) and molten salts for around 300-400°C

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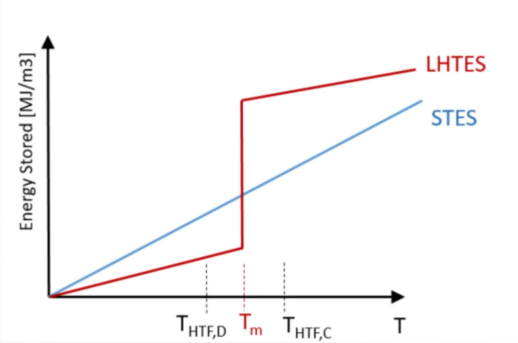
Thermal Energy Storage (TES)

Latent heat thermal energy storage (LHTES)

- Process: melting and solidification of the storage media in order to store heat or cold
- Most of the energy is stored around the melting point of the PCM and in the form of latent heat
- Low temperature (<250°C) range PCMs are mostly constituted by paraffins and fatty acids, molten salts are more common for medium/high temperature PCMs (<450°C) and metallic materials are currently explored as high temperature PCMs



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Waste Heat to Cold technologies (WHTC)

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Active technologies which transform original WH stream to produce cooling will be described in this section

- Cooling based on the gas-on-liquid absorption is widely used for cold production
- Sorption chillers are equipment, that through a sorption process (gas-on-liquid absorption or gas-on-solid adsorption), able to establish two levels of pressure through which the refrigerant can condense and evaporate and therefore produce the required cooling effect
- Water/lithium bromide absorption chiller is the most widespread technology for air conditioning applications
- The absorption chiller uses WH at low/medium temperatures in the range of 65-200°C
- Commercially available absorption cooling systems using lithium bromide-water or ammonia-water working pairs present a thermal COP in the range of 0.7-1.4

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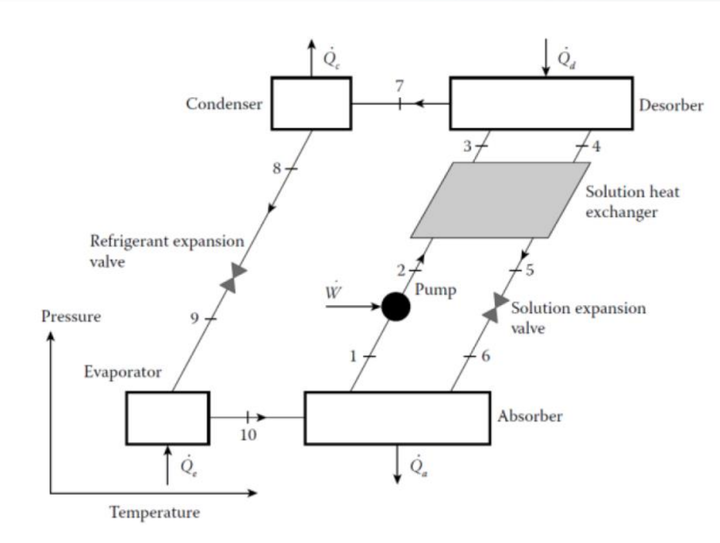
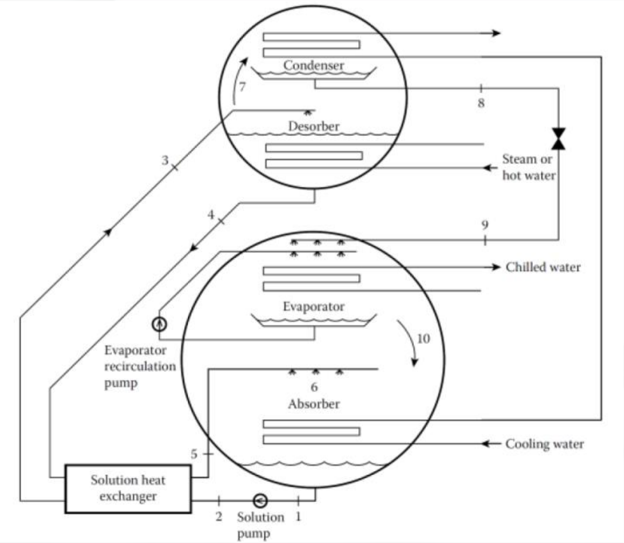
Waste Heat to Cold technologies (WHTC)





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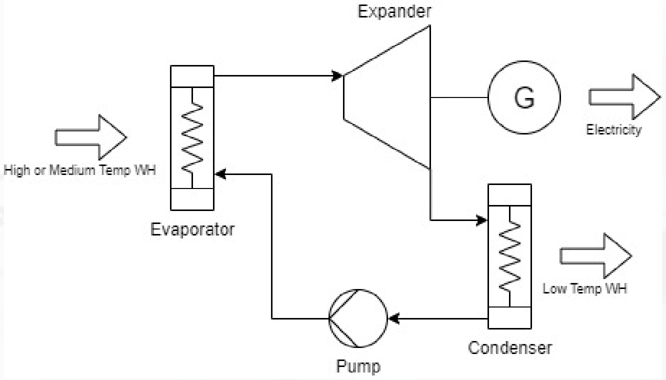
Waste Heat to Power technologies (WHTP)

In this section, active technologies which transform a WH stream to an electrical power output driving an energy conversion process will be described

Organic Rankine Cycles (ORCs)

- Identical layout to a conventional Steam Rankine Cycle and comprises pump, evaporator, expander and condenser
- ORC technology uses organic substances as working fluids with lower boiling point than water
- Enables the conversion of low/mid-grade WH in the range 80-300°C into power



Source: Own elaboration

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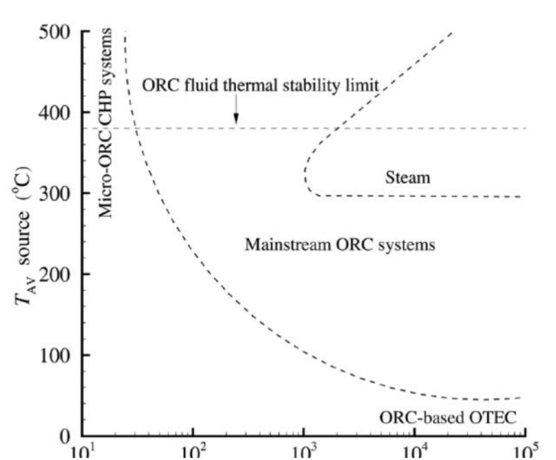
Waste Heat to Power technologies (WHTP)

Organic Rankine Cycles (ORCs)

- Thermal efficiency of ORCs varies in the range 5-25%. Relatively low due to the low temperature working conditions
- ORCs can be driven by multiple kinds of heat sources. Specifically, thermal energy from stationary ICEs, gas turbines and industrial processes
- Averaging project costs of 3414 €/kW



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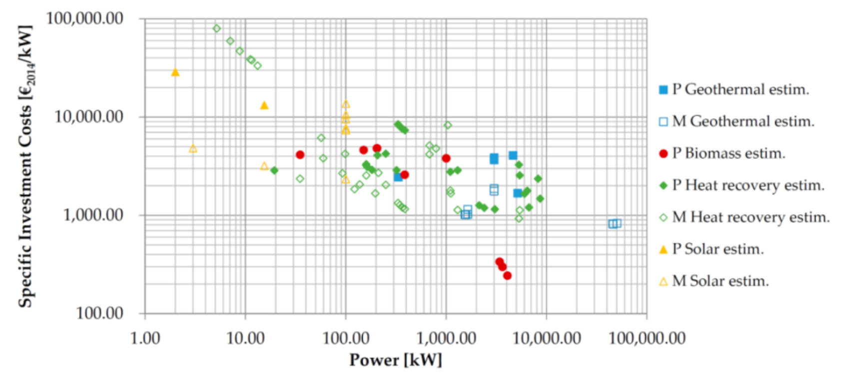

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Waste Heat to Power technologies (WHTP)

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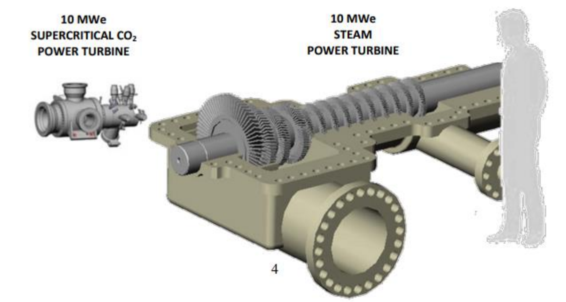
Supercritical CO2 power cycles (sCO2)

- Closed Brayton cycle operating with CO_2 as working fluid
- The compressor inlet is close to the CO_2 critical point where a marked reduction in compression work can be achieved
- Higher temperature applications (350-650°C) are of interest as they represent an alternative to the Steam Rankine Cycles
- Energy recovery with efficiencies up to 30%
- Extremely compact and highly efficient turbomachinery designs
- Installation cost is between 1800-1900 €/kW



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Waste Heat to Power technologies (WHTP)

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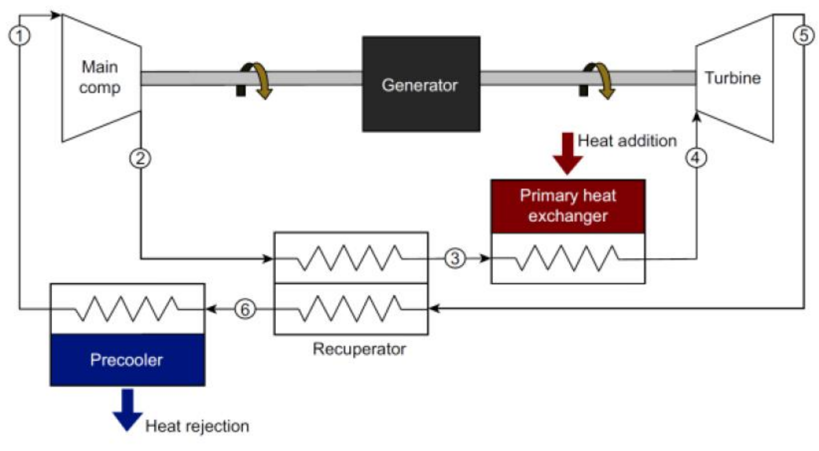
Supercritical CO2 power cycles (sCO2)



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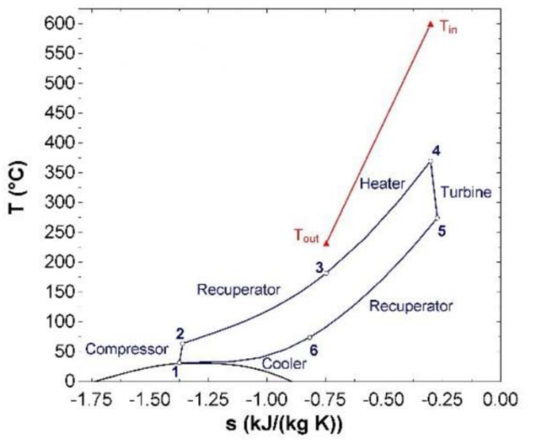

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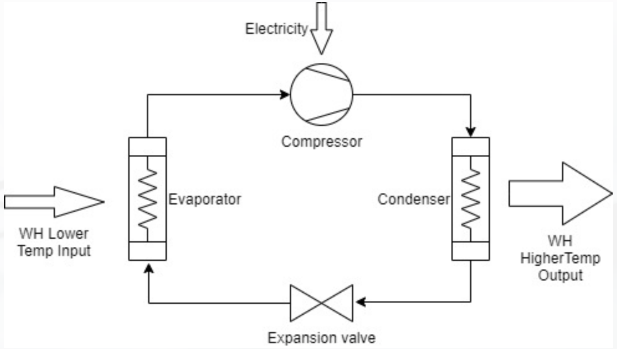
Heat Upgrade technologies (HU)

HU consist on active technologies which alter the conditions of available WH without transforming it into a different form of energy, increasing the performance or usability of the heat flow

Heat Pumps (HP)

- Primary aim: upgrading heat from a heat source to a heat sink at higher temperature
- Working principle of HPs is very similar and to refrigeration or air conditioning systems
- Employed to valorise low-grade WH and upgrade it to higher temperatures
- Crucial parameters are the heat source temperature T_L (WH temperature) and the heat sink temperature T_H (usable heat temperature) across which the HP is capable to operate across.



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Heat Upgrade technologies (HU)

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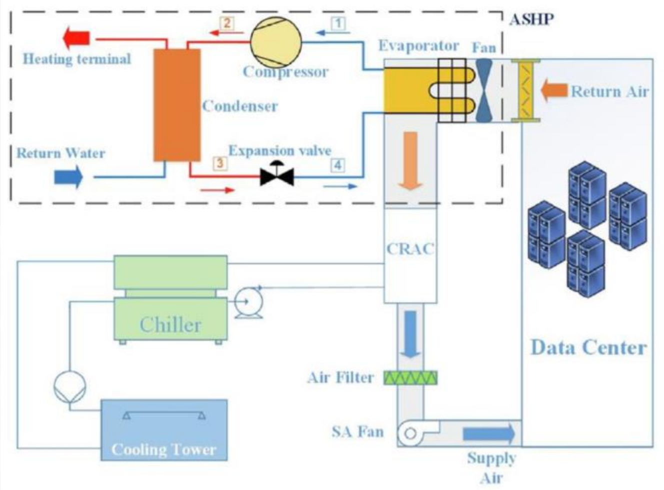
Heat Pumps (HP)

Air source heat pumps (ASHP)

- Employ the outdoor air as heat source
- Can upgrade low-grade heat around 20-40°C
- ASHP providing space heating can reach a COP of 5 in some cases



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Heat Upgrade technologies (HU)

Heat Pumps (HP)

Water source heat pumps (WSHP)

- Take advantage of heat sources in form of liquid, in most instances water, rather than outdoor air
- The temperature of the source is relatively more stable and less affected by outdoor conditions
- WSHPs reach higher COPs than ASHPs, often exceeding value of 4-5

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Heat Upgrade technologies (HU)

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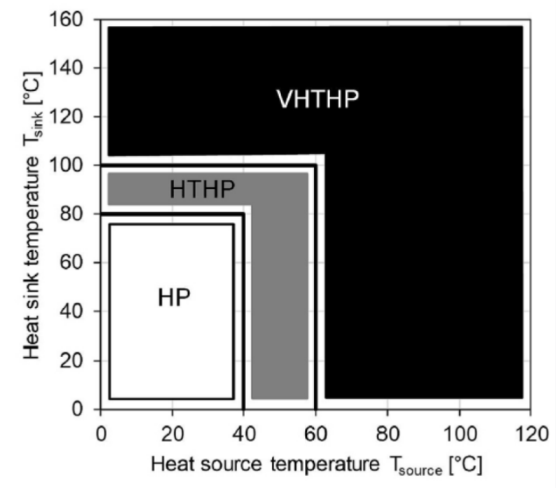
Heat Pumps (HP)

High temperature and very high temperature heat pumps

- HTHPs commonly refers to HPs capable to reach a maximum temperature of ~100°C at the condenser of the machine, while the concept of VHTHPs push the operational envelop up to ~160°C
- Products ranging from 20 kW to >1 MW
- VHTHPs for heat upgrade above 120°C currently remain subject of R&D. However, they will reach maturity in coming years



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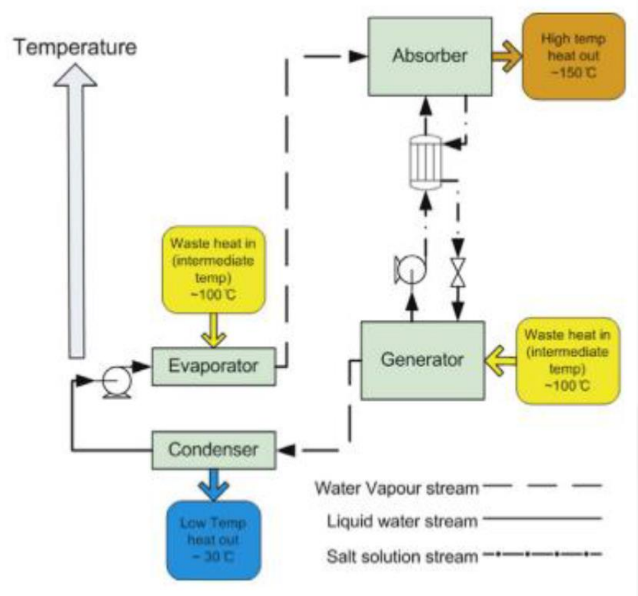
Heat Upgrade technologies (HU)

Absorption Heat Transformers

- Near-to-market technology which uses WH at low/medium temperature typically in the range 60-95°C and transforms it into two separate thermal energy streams: high temperature heat and low temperature heat
- A temperature lift in the range of 30-60°C is typically achieved
- The COP of these machines is less than 0.5
- Economic viability needs to be fully documented: In the range of 190-500 €/kW



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THANK YOU FOR YOUR PARTICIPATION

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