Pivotal role for heat pumps and thermal energy storage in the decarbonization of the industrial sector

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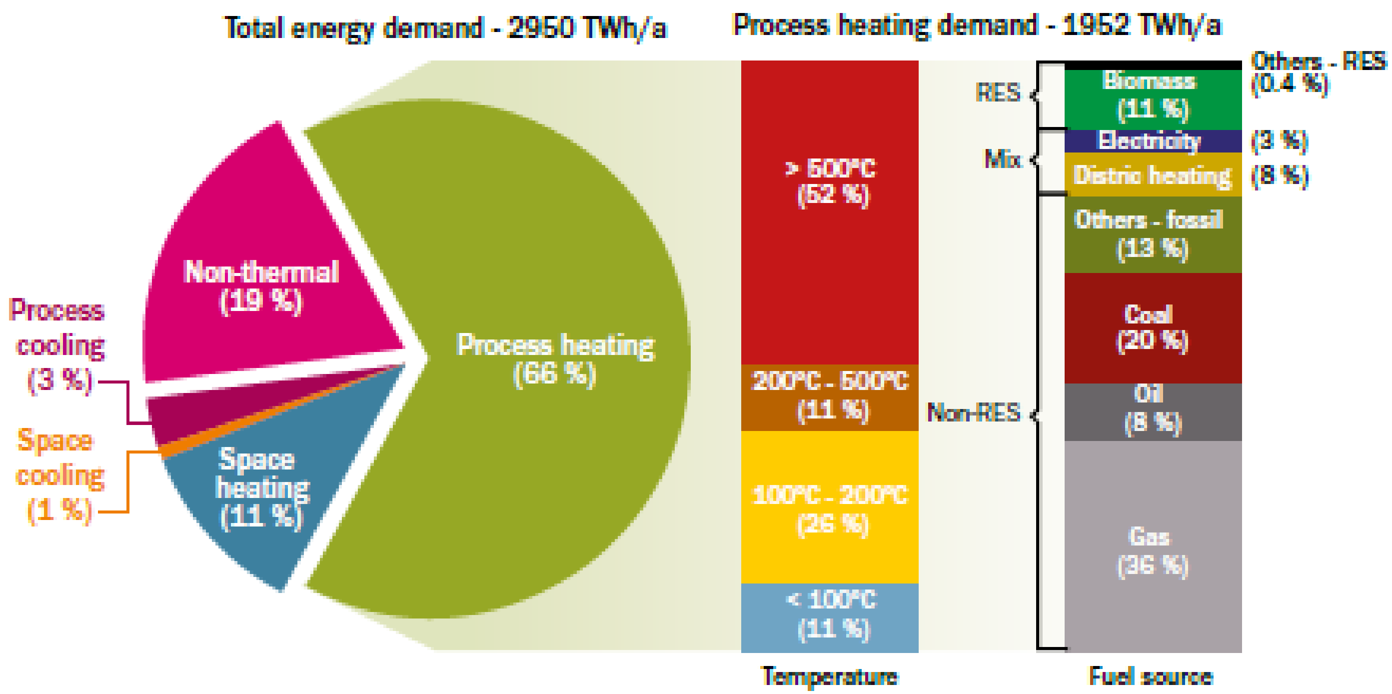
> INDUSTRIAL ENERGY USE

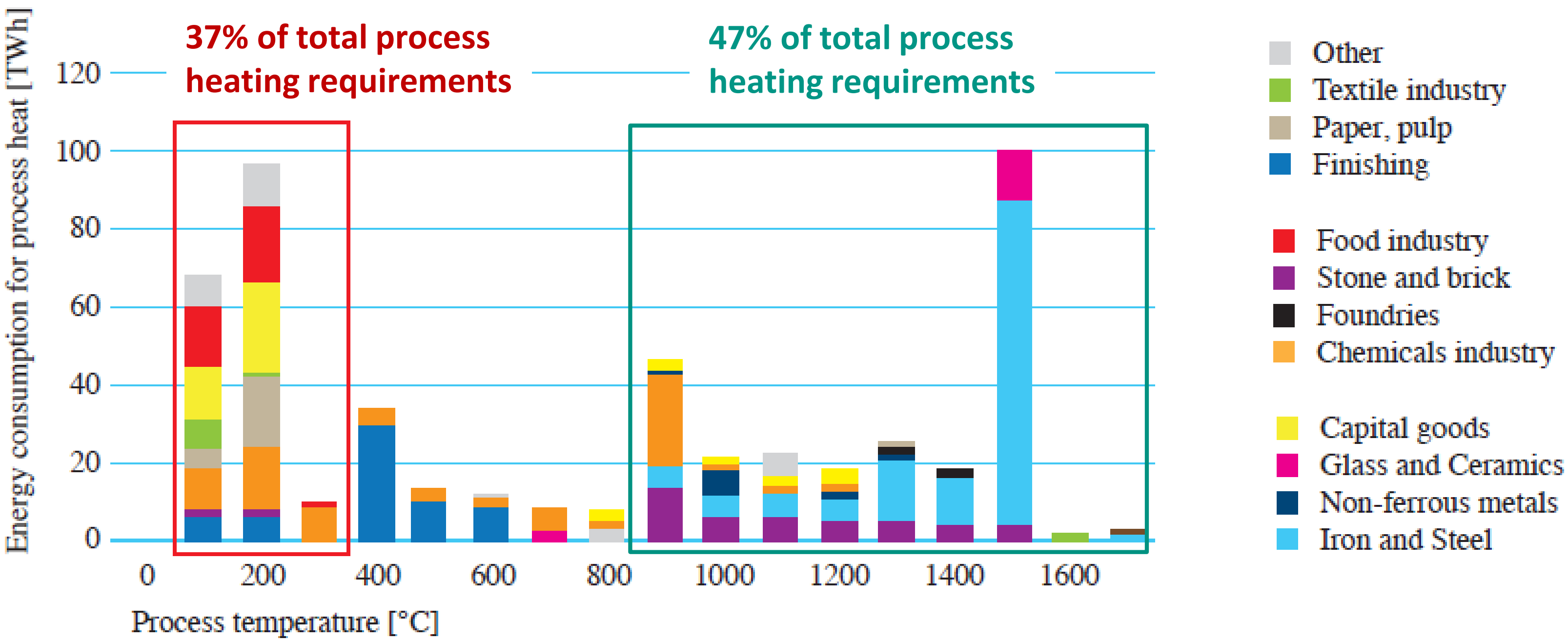
INDUSTRIAL PROCESSES ARE CURRENTLY RESPONSIBLE FOR 25% OF FINAL ENERGY CONSUMPTION AND 20% OF TOTAL GAS EMISSIONS IN EUROPE

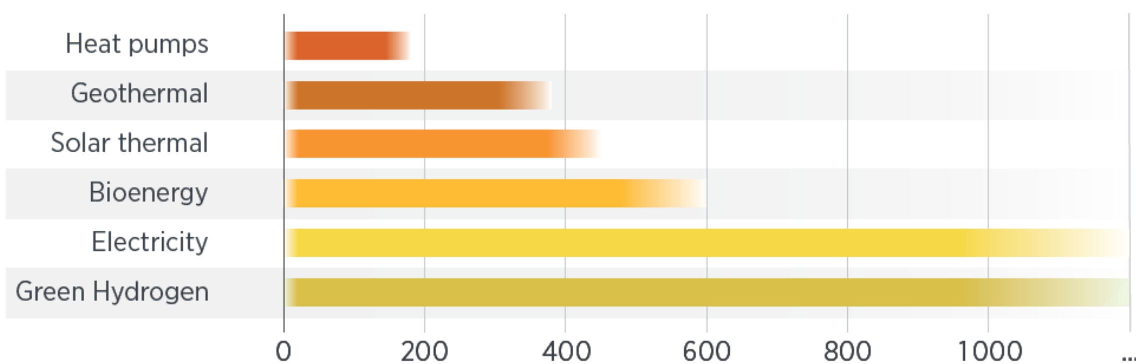


- Thermal energy accounts for 81% of the total energy demand, 66% consumed in process heating
- Low temperature (< 200 C) process heat represents 37% of total process heating requirements, whereas high temperature (> 200 C) process heat accounts for 63%
- The current industrial process heat demand is primarily (78 %) covered by fossil fuel sources. Relatively small shares are covered by more sustainable sources such as biomass (11 %) or electricity (3 %).

> INDUSTRIAL ENERGY USE

PROCESS HEAT USE BY SECTORS AND TEMPERATURE LEVEL

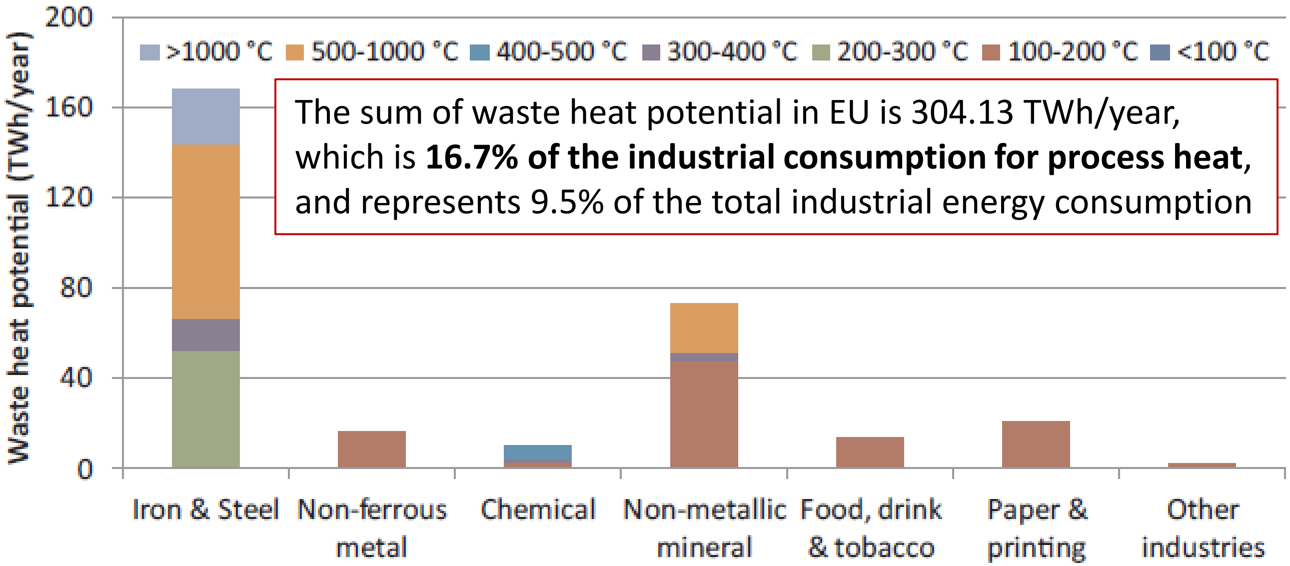




Working temperatures for various renewable heat technologies

INDUSTRIAL ENERGY USE

WASTE HEAT POTENTIAL BY SECTORS AND TEMPERATURE LEVEL



The sum of waste heat potential in EU is 304.13 TWh/year, which is **16.7% of the industrial consumption for process heat**, and represents 9.5% of the total industrial energy consumption

EU industry

https://doi.org/10.1016/j.applthermaleng.2018.04.043

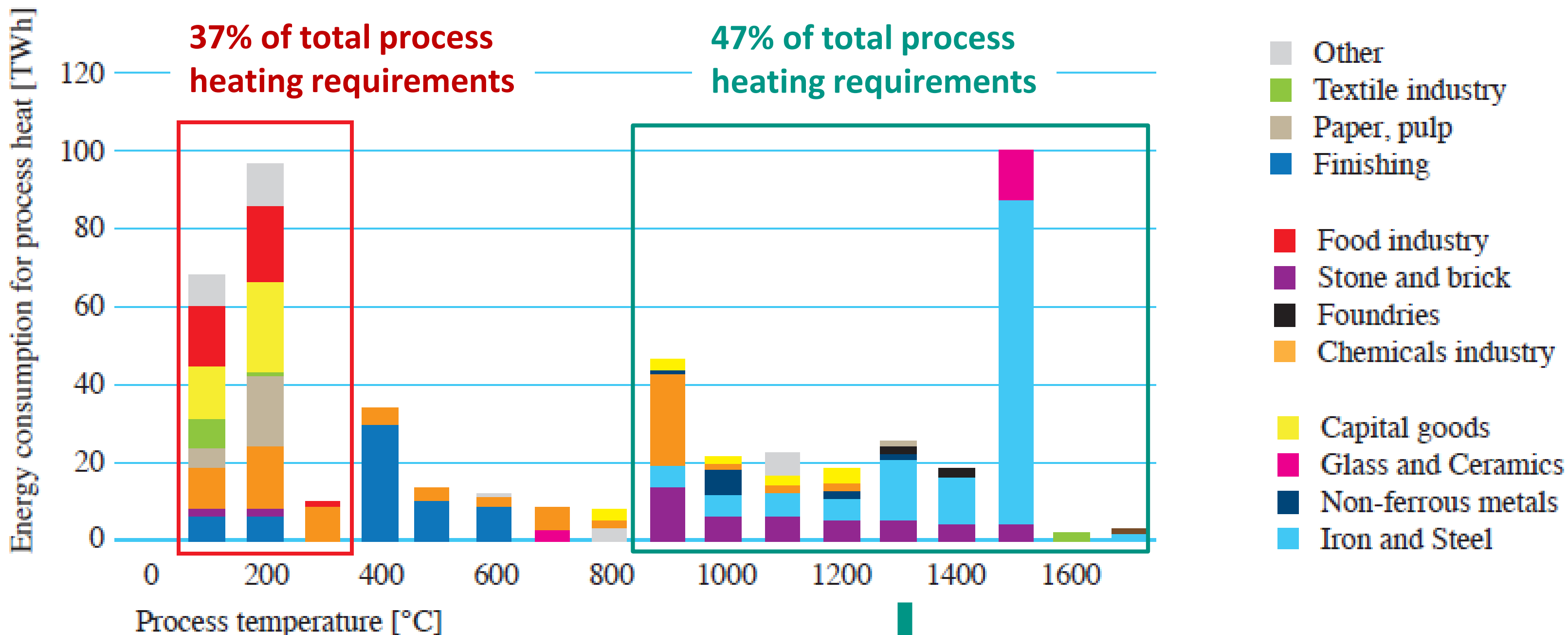
Temperature level	Waste heat potential
< 100 C	1.25 TWh/year
100 – 200 C	100 TWh/year
200 – 500 C	78 TWh/year
> 500 C	124 TWh/year

It is available in a large variety of industries, such as chemical, non-metallic minerals, food, and paper industries.

Only industries that use high temperature process heat, like the steel industry

> INDUSTRIAL ENERGY USE

SUMMARY



Almost all renewable heat technologies could contribute to the decarbonization

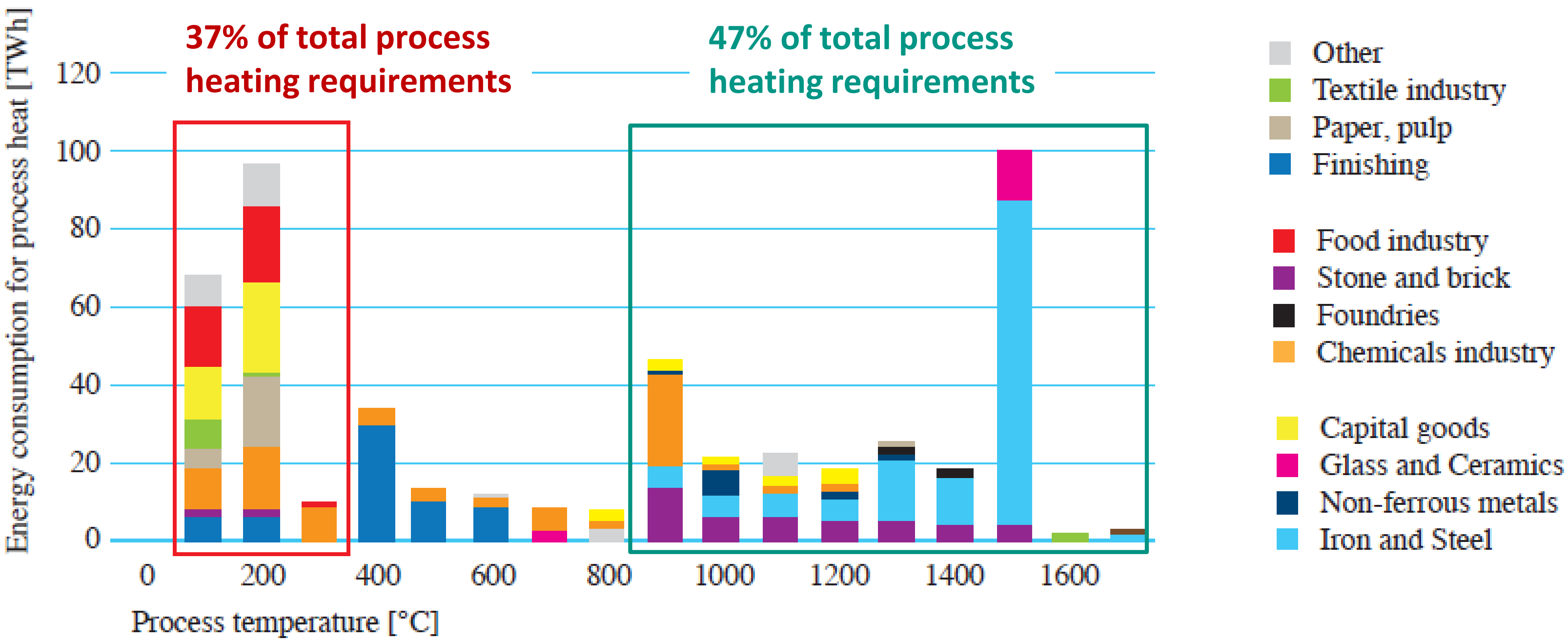
Electrification and green hydrogen are the main pathways toward decarbonization

High waste heat potential

High waste heat potential

INDUSTRIAL ENERGY USE

SUMMARY



Almost all renewable heat technologies could contribute to the decarbonization

High waste heat potential

Favorable to the electrification of heat through the combined use of heat pumps and thermal energy storage technologies

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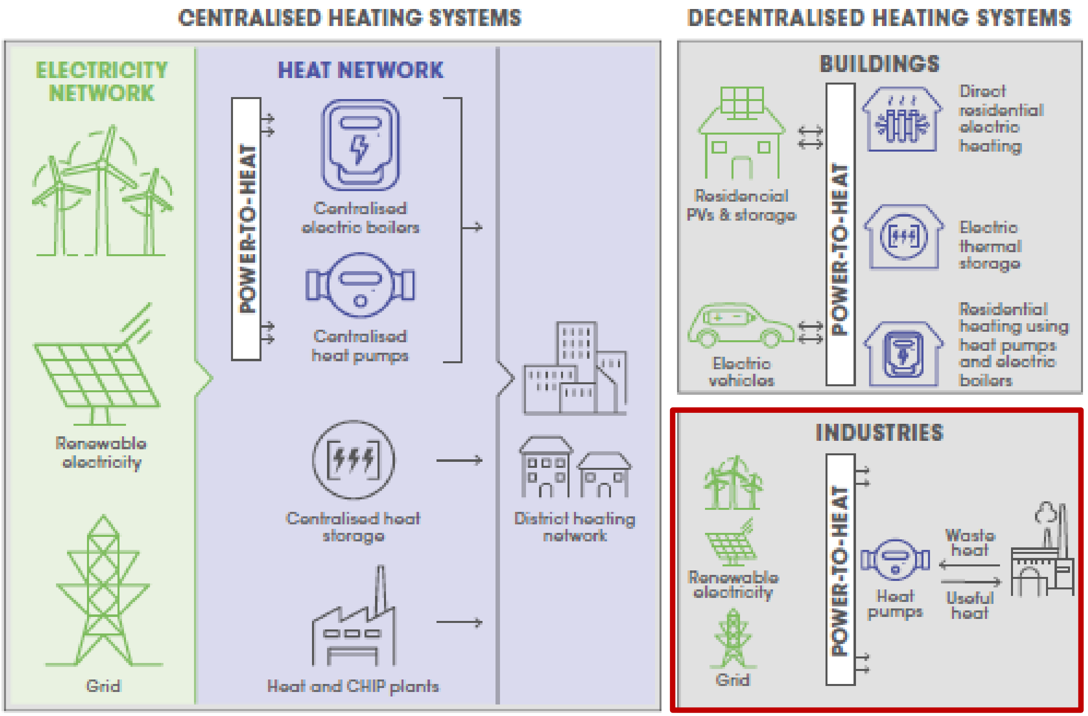
ELECTRIFICATION OF PROCESS HEAT

RENEWABLE POWER-TO-HEAT - Contribution to heat sector decarbonization and power sector transformation



CHP = combined heat and power; PV = photovoltaic.
Based on: Bloess et al. (2018).

The share of renewable energy in global annual electricity generation is expected to be increased from 25% today to 86% in 2050

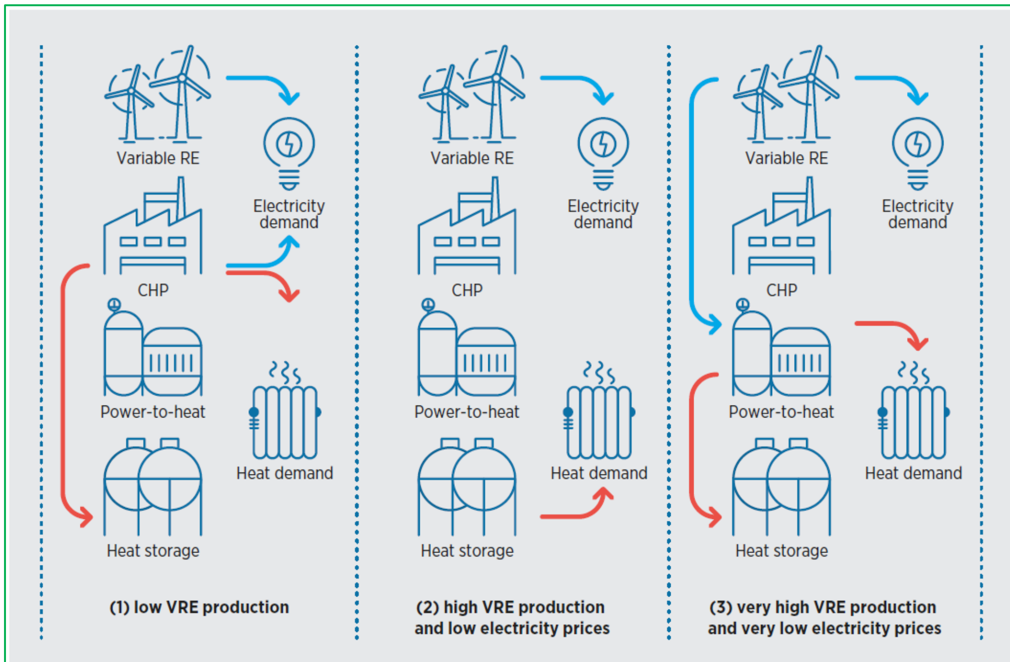
Electrification of end-use sectors is seen as a key solution to decarbonisation given the efficiency gain achieved by electrifying these sectors.

Main renewable power-to-heat technologies → **Heat pumps** or electric boilers combined with **thermal energy storage** → **Decarbonization** of process heat while providing **demand-side flexibility**

> ELECTRIFICATION OF PROCESS HEAT

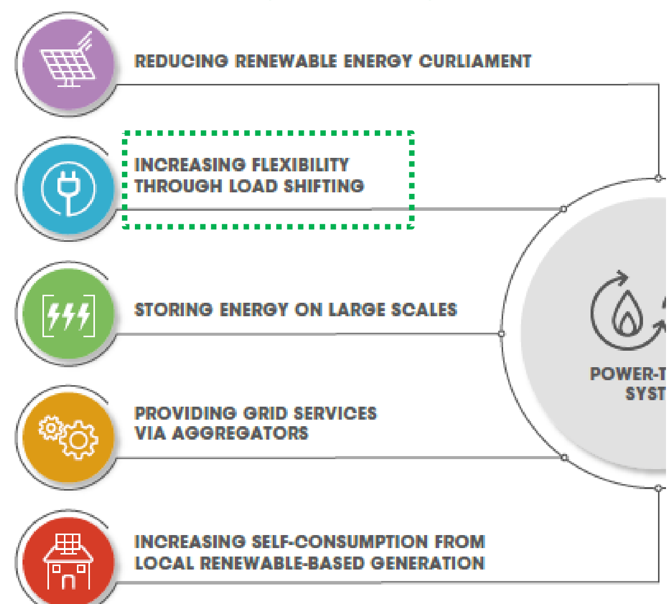
UNLOCKING THE FLEXIBILITY OF THE HEATING SYSTEM
Pivotal role of Thermal Energy Storage

Large-scale increase in electricity demand due to the production of heat from electricity, could creates challenges in covering peaks and increasing ramping requirements



Integrating power and heat sectors in smart way

DEMAND-SIDE FLEXIBILITY for the power system



Enhanced global energy efficiency and process heat cost reduction

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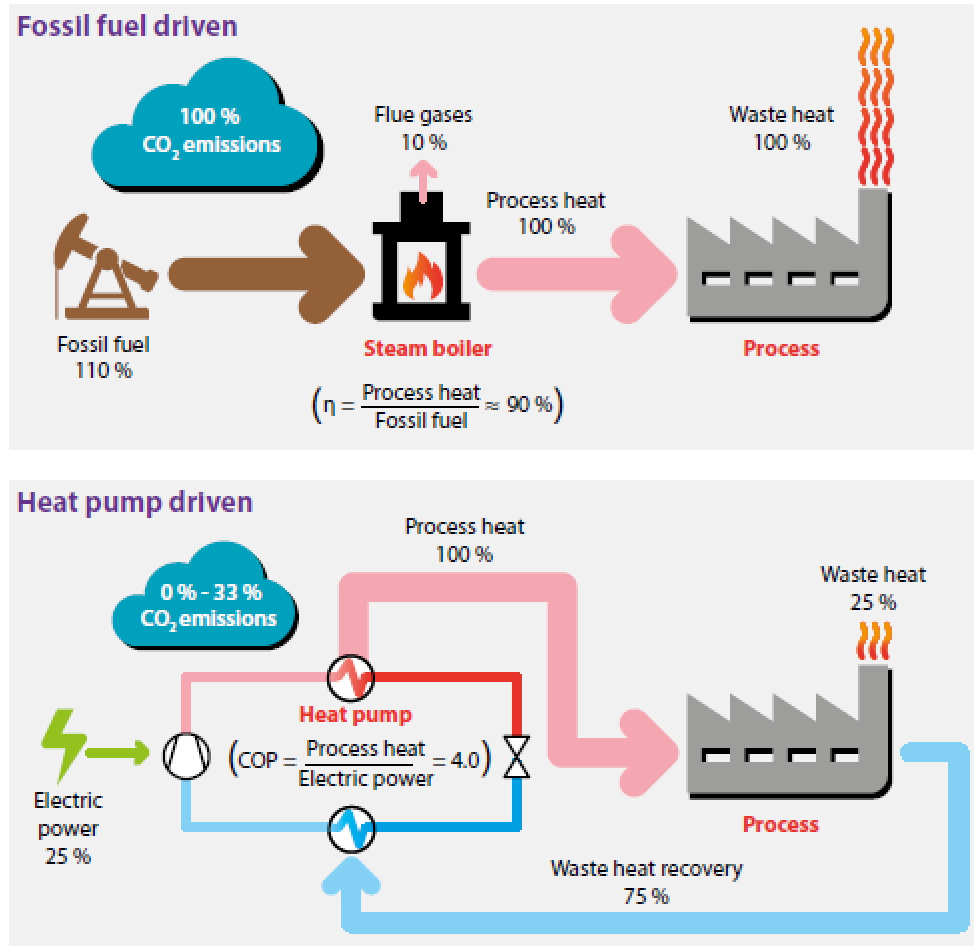
HEAT PUMPS FOR PROCESS HEATING

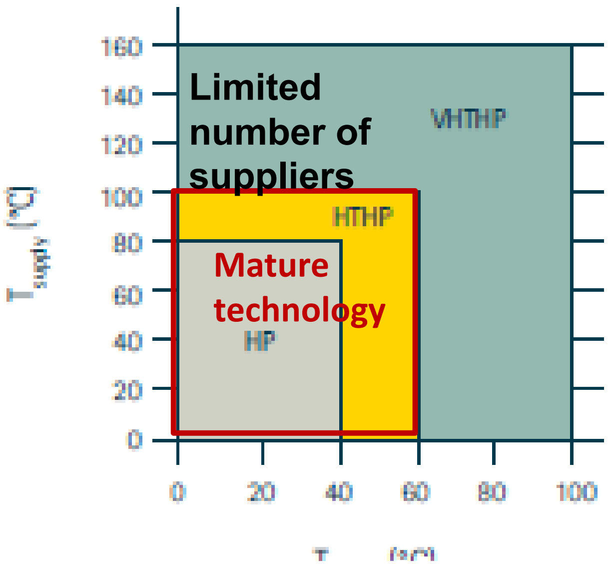
INCREASING THE OVERALL EFFICIENCY OF THE PROCESS WHILE ACHIEVING STRONG REDUCTION OF CO2 EMISSIONS

- Industrial heat pumps (IHP) are a technology which can upgrade the temperature of a waste heat source such that it can be re-used within a process
- Electrically-driven vapor compression cycle is the most commonly used IHP technology
- This is the most efficient power-to-heat technology (COP = 2.5 - 5)
- Can be implemented in both new and existing process operations

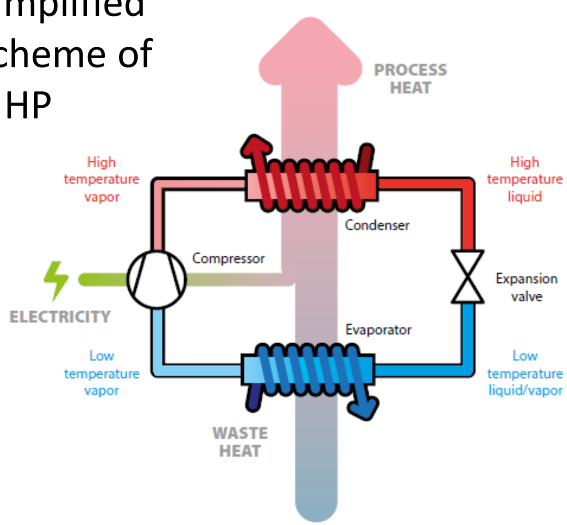


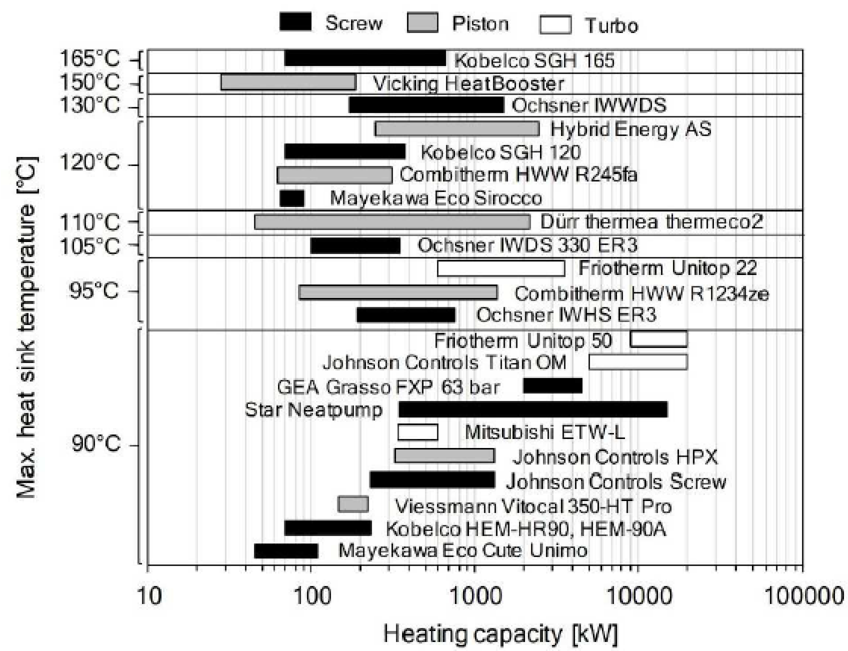
> HEAT PUMPS FOR PROCESS HEATING

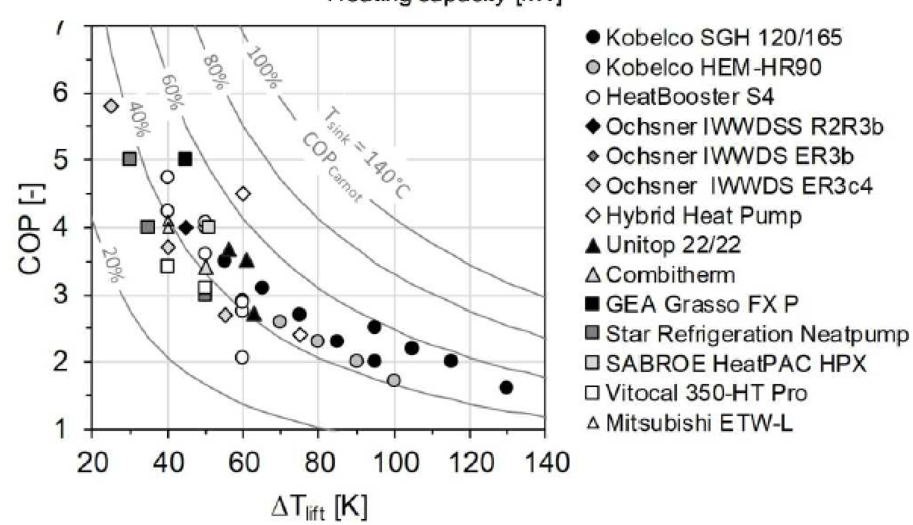
OVERVIEW OF INDUSTRIAL HEAT PUMPS



Simplified scheme of a HP





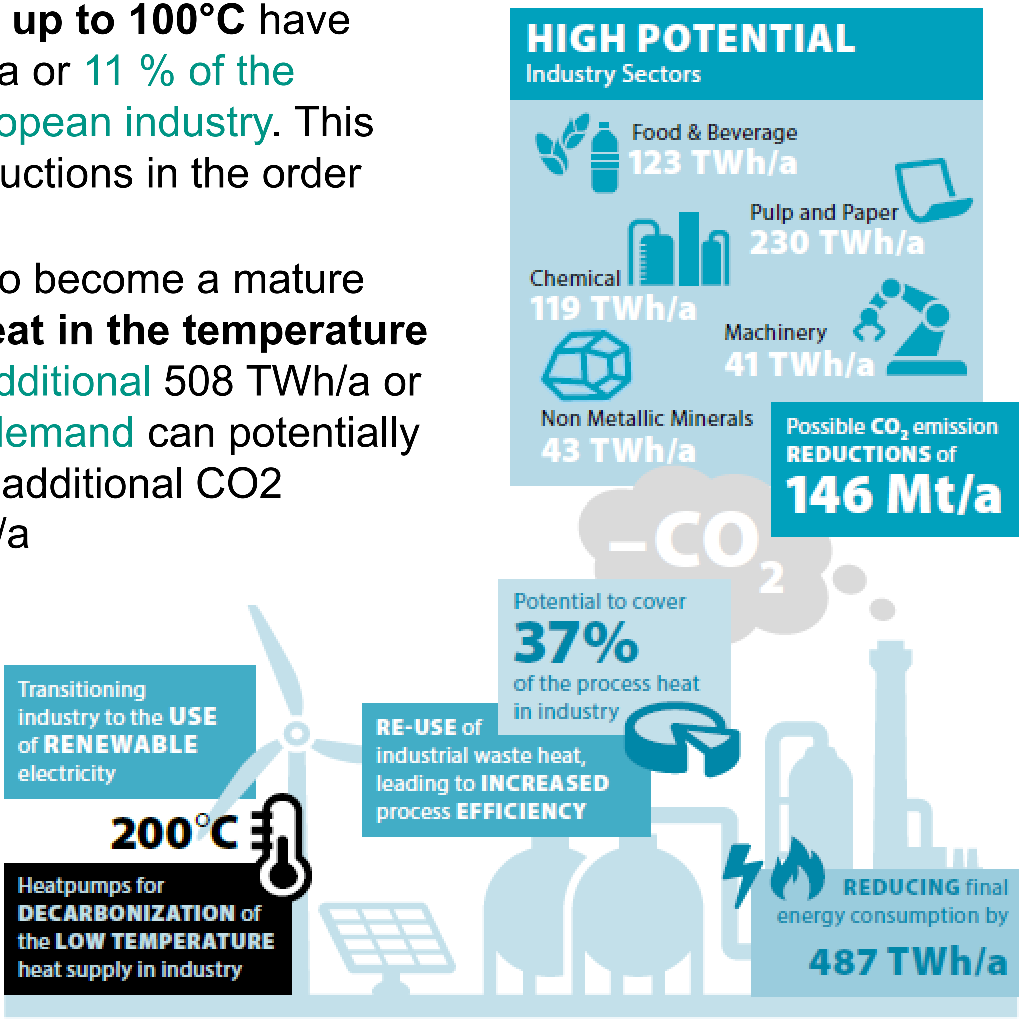


HEAT PUMPS FOR PROCESS HEATING

POTENTIAL APPLICATIONS

Heat pumps for temperatures up to 100°C have the potential to cover 222 TWh/a or 11 % of the process heating demand in European industry. This could lead to CO2 emission reductions in the order of 51 Mt/a.

In the case that heat pumps also become a mature technology for the **supply of heat in the temperature range of 100°C to 200°C**, an additional 508 TWh/a or 26 % of the total process heat demand can potentially be emission free, with potential additional CO2 reductions in the order of 95 Mt/a



https://doi.org/10.1007/s12053-017-9571-y
https://doi.org/10.2760/290197

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THERMAL ENERGY STORAGE

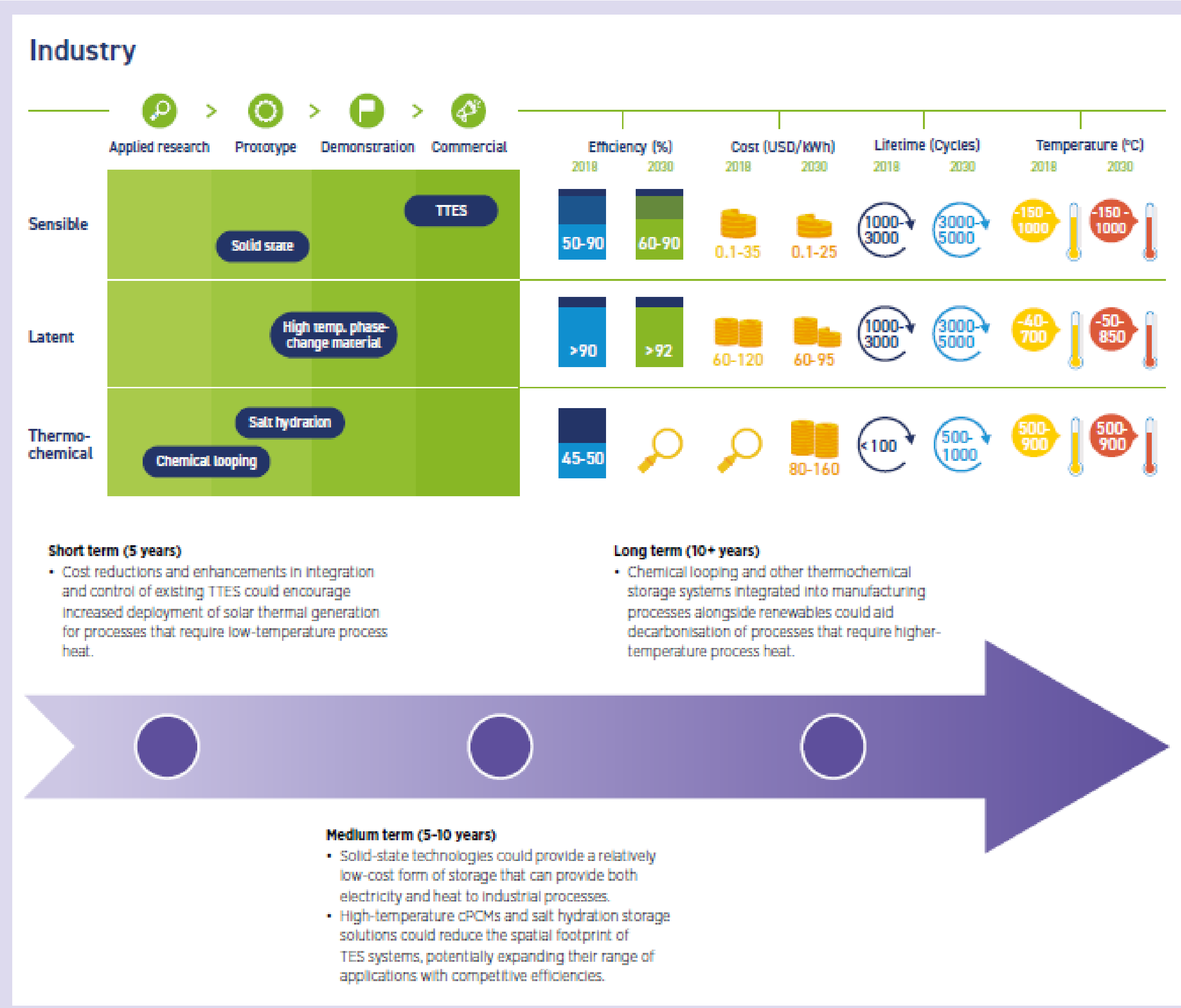
RESEARCH ACTIVITY AT CIC ENERGIGUNE

Applications	Temperature range (°C)	TES technology
Renewable heating and cooling in buildings and tertiary sector	40 – 120	**LHS** with organic solid-state PCMs
Renewable industrial process heat	80 – 200 up to 600	**LHS** with organic solid-state PCMs **LHS** with inorganic solid-state PCMs
Industrial waste heat valorization	up to 1000	**SHS** with low-cost solid materials
Applications in the power sector – CSP dispatchability, TPP and grid flexibility	up to 800	**SHS** in low-cost solids and molten salts **LHS** with inorganic solid-state PCMs or shape-stabilized PCMs **TCS** based on metal oxides supporting redox, carbonatation or hydration chemical reactions

SHS: Sensible heat storage
LHS: Latent heat storage
TCS: Thermochemical storage

THERMAL ENERGY STORAGE

TES TECNOLOGY STATUS AND INNOVATION OUTLOOK (IRENA 2020)



Competing technologies in the short-to-mid term

<u>Because of cost</u>

Water tanks

Solid-state

<u>Because of spatial footprint</u>

HT Latent heat

Salt hydration

Cost ($/kWh) targets by 2030

SEN < 25

LAT 60-95

TC 80-160

THERMAL ENERGY STORAGE

TES FOR INDUSTRIAL HEAT PUMPS (80 – 200 ℃)
Technology status and Research objective

Pressurized water tanks	Latent heat storage
Commercially available Proven technology Current cost: 35 $/kWh Target 2030: 25 S/kWh	Still under development Current cost: 60-120 $/kWh Target 2030: 60-95 $/kWh
Space footprint Low energy density (30 kWh/m3 approx.) COP degradation Increasing temperature lift	Space footprint 3-5 times higher energy density No COP degradation expected Isothermal storage

- Advantages
- Drawbacks

CIC´s CHALLENGING OBJECTIVE

Developing cost competitive (< 25 $/kWh) latent heat storage technology

THERMAL ENERGY STORAGE

STRATEGY OF DEVELOPMENT

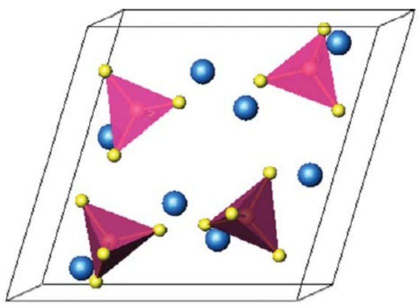
Currently used PCMs are solid-liquid PCM with low thermal conductivity
Large surface area for PCM/HTF heat exchange is, therefore, needed
HX (or PCM macroencapsulation) usually account for more than 60% of CAPEX

Avoid using either HX or macroencapsulation by a **new class of PCMS** leading to low-cost **packed-bed storage system**

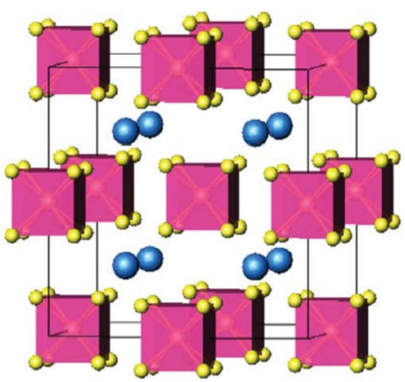
PCM-based fixed packed-beds

> THERMAL ENERGY STORAGE

SOLID-STATE PHASE CHANGE MATERIALS



Ordered crystallin low temperature phase



Plastic crystal like high temperature phase

Organic plastic crystals undergoing a solid-state phase transition from a compact, ordered crystalline phase (low-temperature phase) to a highly directionally disordered crystalline phase (high-temperature phase or plastic crystal)

ΔS - high

Surprisingly high enthalpy of transition

Many times comparable to that of melting/solidification processes

> THERMAL ENERGY STORAGE

MAIN FEATURES OF STUDIED PHASE CHANGE MATERIALS

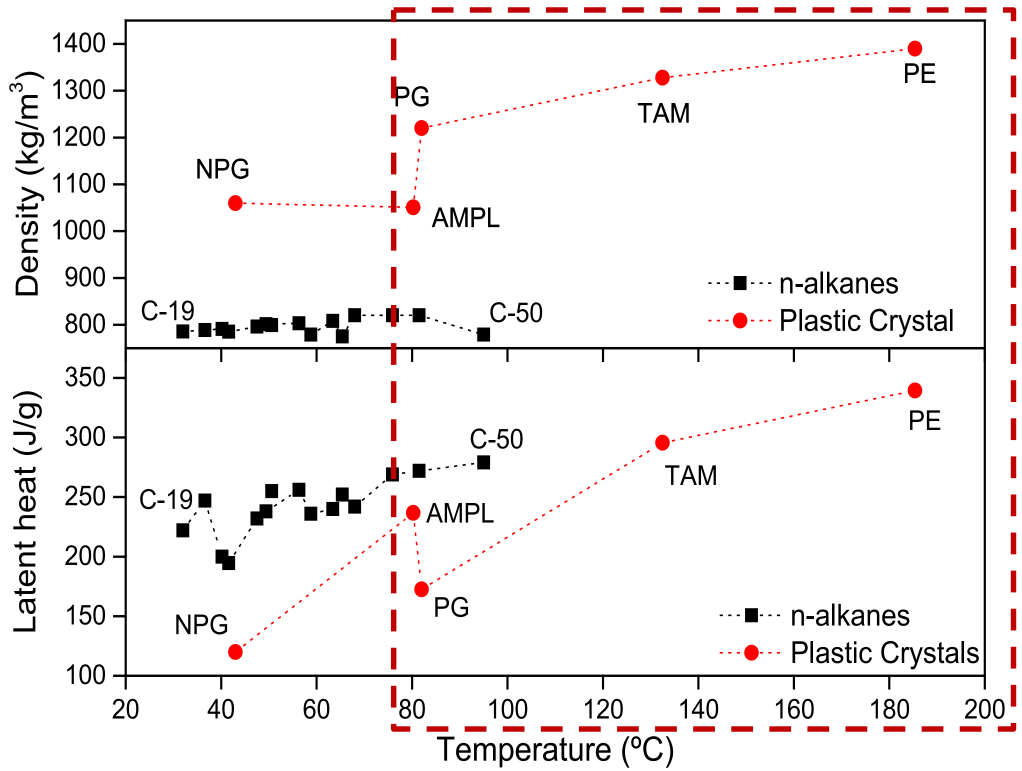
High volumetric energy density in a suitable T range

Easy working temperature tailoring

Easy improvement of initial performances

Compatibility with commonly used HTFs

Others



Together, high latent heat and high density lead to **volumetric energy density 3 times higher than that of water** under similar working conditions

> THERMAL ENERGY STORAGE

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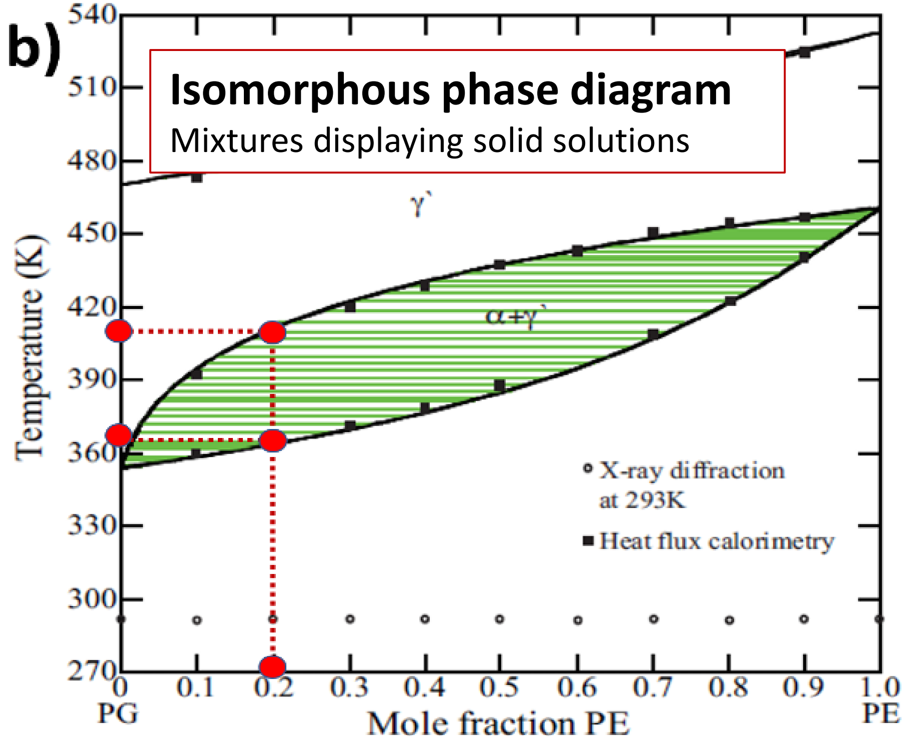

Changing phase transition properties in a continuous manner simply changing mixture composition – **Easy processing of the material** by powders mixing and pressing

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THERMAL ENERGY STORAGE

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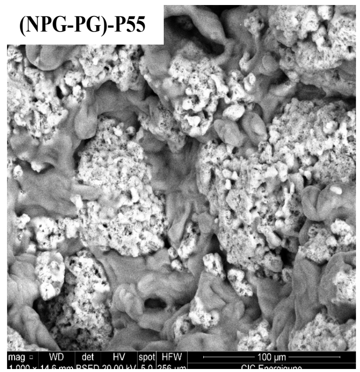
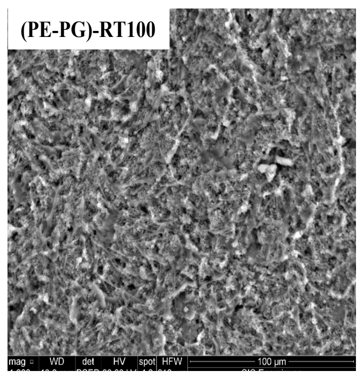


Shape-stabilized solid-liquid PCM with solid-state PCMC as active supporting media – Increasing up to 50% heat storage capacity while lowering specific material cost (up to 120 ℃ so far)



Increasing apparent thermal conductivity (x 5) by adding small amount of ENG (<10%) – Easy processing by powders mixing and pressing

T tr in charge
=
T tr in discharge

Overcoming hysteresis by controlling the size of crystals of initial powders

THERMAL ENERGY STORAGE

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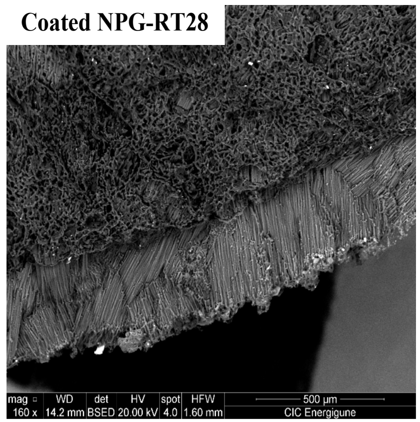
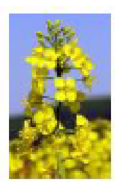
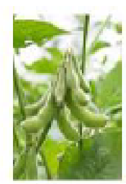


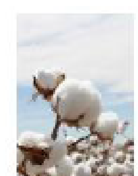
Soluble in water – Protective coating needed – Obtained by low-cost processing method (deep-coating or spraying)

Compatible with vegetal oils - Very low-cost attractive HTF

	Rapeseed	Sunflower	Soybean	Coconut	Cotton	Jatropha
Flashpoint	285°C	316°C	330°C	230°C	243°C	236°C
Density (20°C)	920 kg/m^3	925 kg/m^3	920 kg/m^3	915 kg/m^3	921 kg/m^3	920 kg/m^3
Cp (25°C) J/kg.K	2001.6	1989.7	2015.8	2205.5	2002.1	2039.6
Cp (200°C) J/kg.K	2682.8	2623.3	2690.1	2534.3	2509	2515
k (25°C) W/m.K						
k (200°C) W/m.K						








THERMAL ENERGY STORAGE

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- Easy working temperature tailoring
- Easy improvement of initial performances
- Compatibility with commonly used HTFs
- **Others**

- Easy and versatile integration into the storage system – Wide variety of shaping and sizing range
- Basic chemical components available in the market
- Affordable production cost (1.2 €/kg)
- Safe material, non-toxic, non corrosive
- Easy recycling (e.g. green H_2 production and valuable elemental carbon)

THERMAL ENERGY STORAGE

COST ESTIMATION (CAPEX)

Pressurized water tanks	Latent heat storage (SL- PCMs)	CIC energiGUNE technology
Commercially available Proven technology Current cost: 35 $/kWh Target 2030: 25 $/kWh	Still under development Current cost: 60-120 $/kWh Target 2030: 60-95 $/kWh	Still under development **Current cost: 35-45 $/kWh** **Target 2030: < 25 $/kWh**
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CONCLUSION

- The electrification of low-temperature process heat is seen as key solution toward the decarbonization of manufacturing industry
- Industrial heat pumps are the most efficient technology for converting renewable electricity into heat
- Heat pumps combined with thermal energy storage are flexibility heating systems allowing increased global energy efficiency and reduced process heat cost while providing demand-side flexibility to the grid
- Latent heat storage technology developed at CIC energigune has strong potential for improving the state of the art (water tanks), increasing compactness and reducing costs

GRACIAS · THANK YOU · ESKERRIK ASKO

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Making sustainability real

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