#SOMOS2030

HIGH-TEMPERATURE HEAT PUMPS FOR DECARBONIZATION IN INDUSTRY 4.0

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UNED

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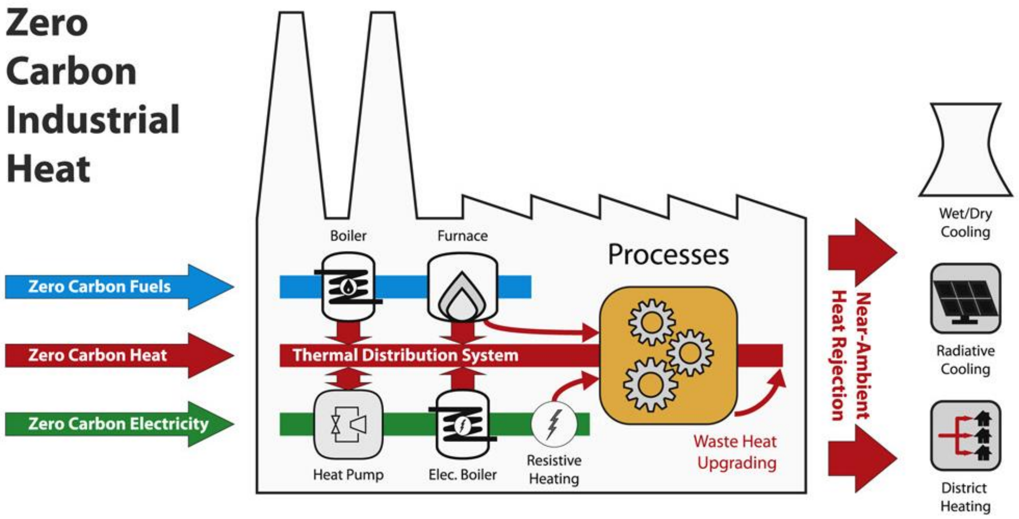
Introduction (I)

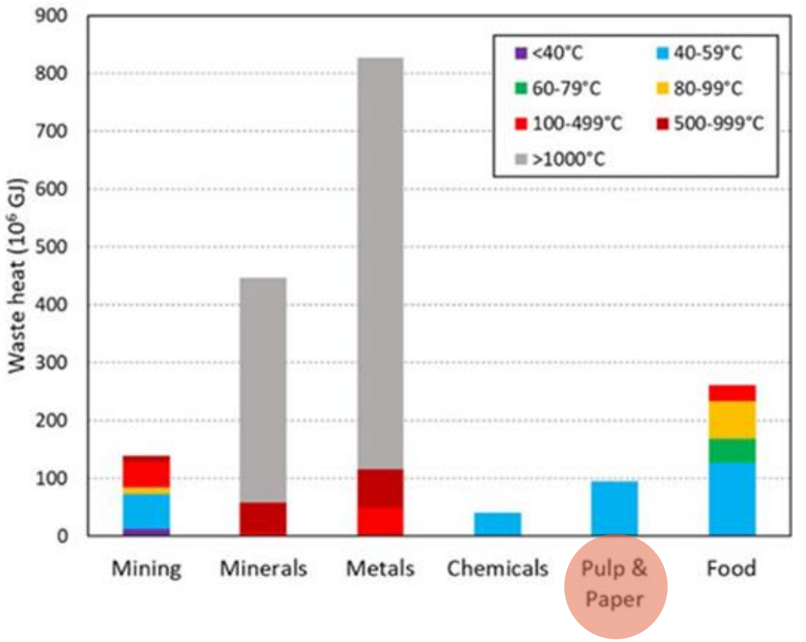
- **Objective:** Achieve a net-zero CO2 emissions balance by 2050.
- **Challenge:** Reduce net greenhouse gas emissions by at least 55% by 2030 (compared to 1990).
- **Strategies:**
  - Improving energy efficiency.
  - Integration of renewable energy sources.
  - Electrification of demand.
  - Hydrogen as an energy carrier.
  - Carbon capture, utilization, and storage (CCUS).
- **Proposal:** Heat pumps with thermal storage technologies and AI-based control systems.
- **Challenge:** Supplying heat to industrial processes above 160 °C.



Source: Gregory P. Thiel, et al, (2021)

Introduction (II)

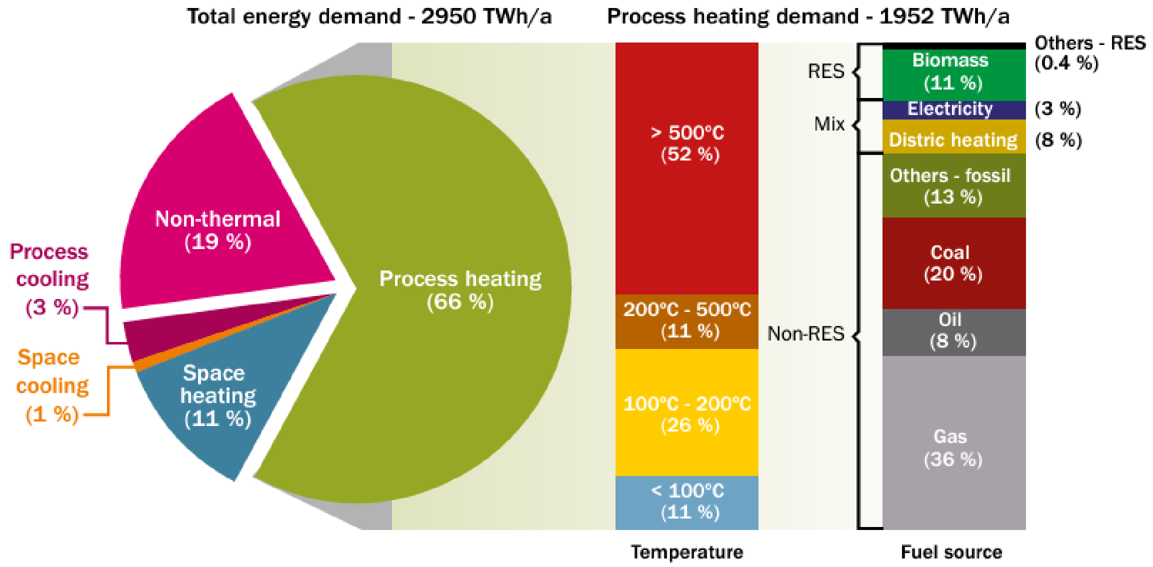
- **Benefits:**
  - Transition multiple industrial sectors to a sustainable heat supply. Significant **decrease in fossil fuel consumption**.
  - Provide large **reductions in primary and final energy consumption** as well as CO2 emissions of industrial heat demand.
  - Provide **demand-side flexibility**
  - Increased **integration of renewable energies**.
  - **Minimises the release of waste energy** into the environment.
- **Digital Transformation:**
  - **Reduction of carbon footprint**.
  - Enhance **flexibility**
  - **Economic benefits**
  - **Optimal and tailored solutions**.
  - Effective **integration across sectors**
  - Foster **new business models**.



Source: De Boer et al. (2020)

EU-Industry Thermal Energy Demand

- **Thermal energy demand constitutes 81%** of total energy consumption, with **process heating** accounting for **66% of the final energy demand**.
- **37% of the European industry's process** heat demand is for temperatures **below 200 °C**, 730TWh/a.
- **Current Energy Sources and Emissions: Fossil fuels cover 78% of industrial process heat demand**, leading to estimated CO2 emissions of 552 Mt/a.
- **Limited Sustainable Contribution:** Biomass and electricity only meet 14% of process heat demand, indicating a reliance on fossil fuels.

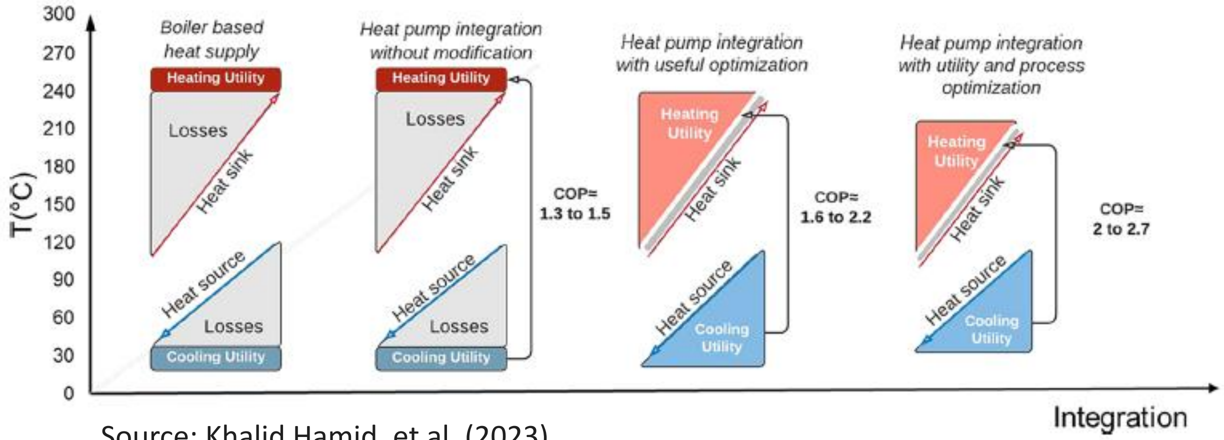


Source: De Boer et al. (2020)

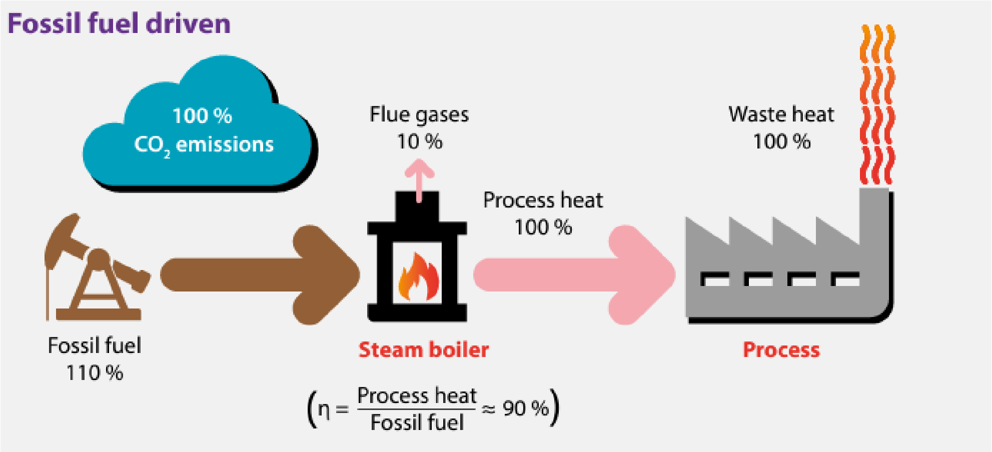
Industrial Heat Pumps

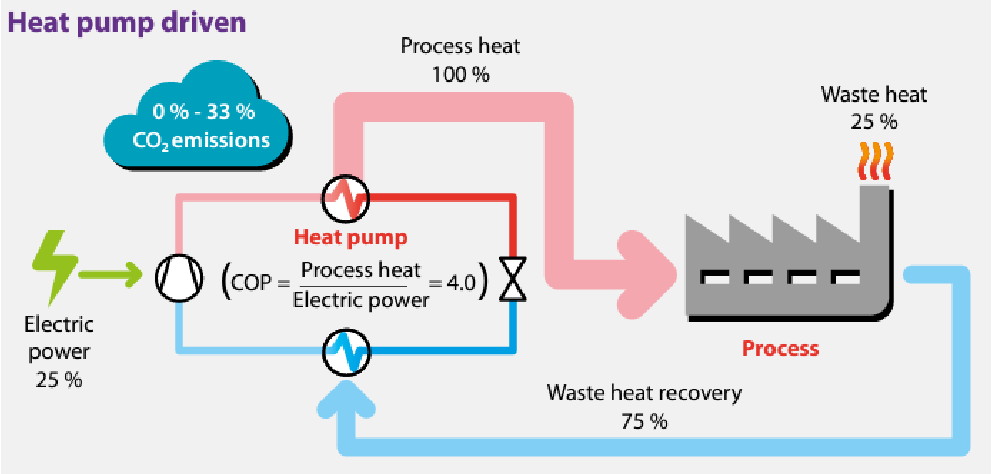
- **Zero CO2 footprint with a 100 % share of renewables** in the future electricity mix.
- **Regardless of the current electricity**, due to the high efficiencies (COPs) directly lead to a reduction in both final and primary energy consumption and CO2 emissions, **33% based on the current EU mix**.

- **Correct integration is a key factor** in the performance.



Source: Khalid Hamid, et al, (2023)



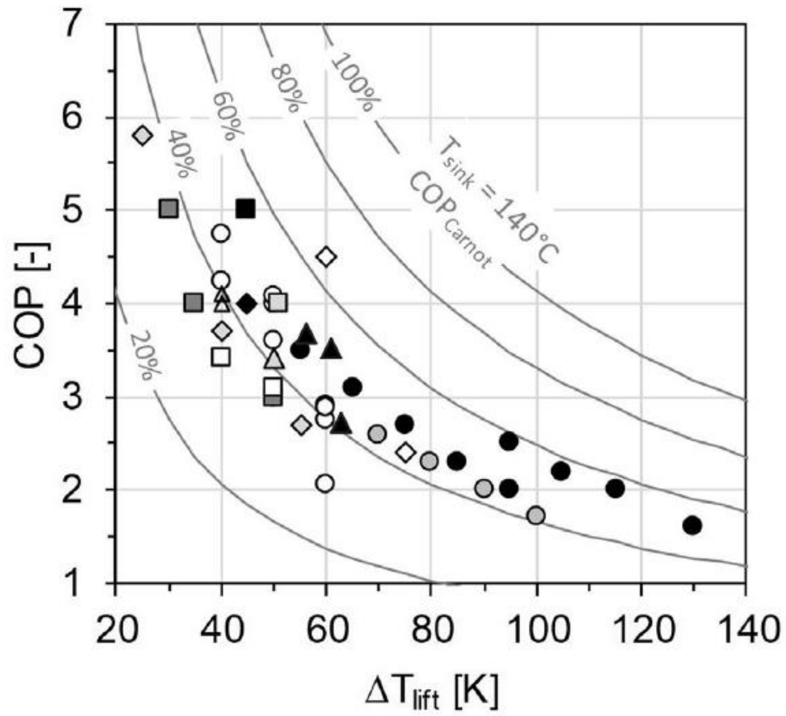


Source: De Boer et al. (2020)

High Temperature Heat pumps (HTHP)

Comparison of different HTHP technology. IEA HPT Annex 58 (https://heatpumpingtechnologies.org/annex58/task1)

- Performance data
- Capacity range
- Temperature range
- Working fluid (refrigerant)
- Compressor technology
- Specific investment costs
- Technology Readiness Level (TRL)
- Expected lifetime (years)
- Size
- Project examples



Source: Arpagaus C., et al (2018)

Adaptation of HTHP to industry demand

Sector	Process	Temperature (°C)
Paper	Drying	90 - 240
	Boiling	110 - 180
	Bleaching	40 - 150
	De-inking	50 - 70
Food & beverage	Drying	40 - 250
	Evaporation	40 - 170
	Pasteurization	60 - 150
	Sterilization	100 - 140
	Boiling	70 - 120
	Distillation	40 - 100
	Blanching	60 - 90
	Scalding	50 - 90
	Concentration	60 - 80
	Tempering	40 - 80
	Smoking	20 - 80
Chemicals	Destillation	100 - 300
	Compression	110 - 170
	Thermoforming	130 - 160
	Concentration	120 - 140
	Boiling	80 - 110
	Bioreactions	20 - 60
Automotive	Resin molding	70 - 130
Metal	Drying	60 - 200
	Pickling	20 - 100
	Degreasing	20 - 100
	Electroplating	30 - 90
	Phosphating	30 - 90
	Chromating	20 - 80
	Purging	40 - 70
Platic	Injection molding	90 - 300
	Pellets drying	40 - 150
	Preheating	50 - 70
Mechanical Engineering	Surface treatment	20 - 120
	Cleaning	40 - 90
Textiles	Coloring	40 - 160
	Drying	60 - 130
	Washing	40 - 110
	Bleaching	40 - 100
Wood	Glueing	120 - 180
	Pressing	120 - 170
	Drying	40 - 150
	Steaming	70 - 100
	Cocking	80 - 90
	Staining	50 - 80
	Pickling	40 - 70
Several sectors	Hot water	20 - 110
	Preheating	20 - 100
	Washing/Cleaning	30 - 90
	Space heating	20 - 80

Technology Readiness Level (TRL):

- Conventional HP <80°C, established in industry
- Commercial available HP <80°C, established in industry
- Prototype status, technology development, HTHP 100 - 140°C
- Laboratory research, functional models, proof of concept, VHTHP >140°C

Source: Arpagaus et al.

- **EHPA, "Industrial Heat Pumps Can Deliver", 2022:**
  - Temperature levels of **up to 160°C**.
  - Prototypes are **operating at around 180°C** and
  - Industry experts expect **temperatures of 200°C and beyond in this decade**.

Heat Pump Challenges and Barriers

Challenges of heat pump systems in industrial applications

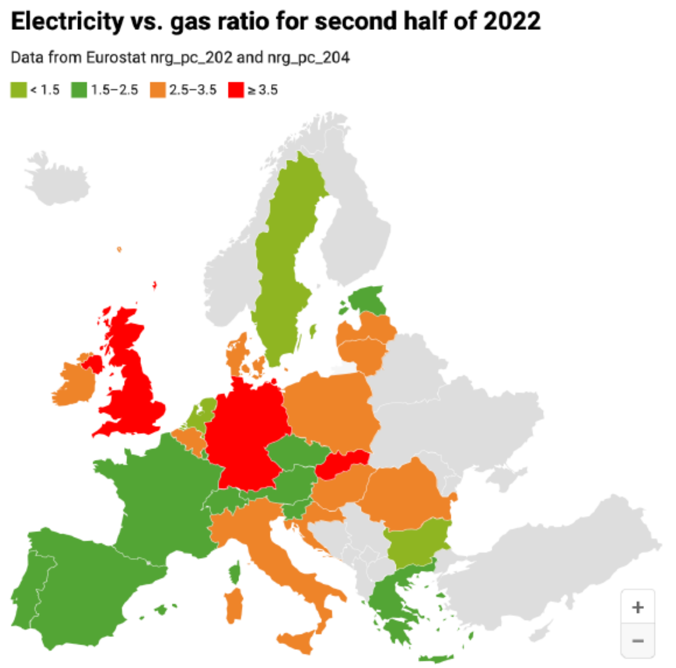
- **High upfront costs**
- **Limited operating temperature range**
- **Electrical power supply challenges**
- **Maintenance and servicing complexities**
- **Integration with existing systems**
- **Environmental considerations**

Barriers

- **Limited awareness** of viable technical solutions and economically feasible applications.
- **Extended payback periods** exceeding 3 years, longer than for gas or oil-fired boilers.
- Competition from **fossil fuel-based heating technologies with low energy prices**, dependent on electricity-to-gas price ratios.
- **Insufficient understanding of integrating HTHPs** into industrial processes, leading to costly custom designs.
- **Scarcity of refrigerants available for high-temperature application**s with low Global Warming Potential (GWP).
- **Lack of pilot and demonstration systems**.
- **Lack of training programs** and events to foster wider dissemination of HTHP knowledge.

Key Considerations for Heat Pump Adoption

- **Awareness of the benefits:** decarbonisation, waste heat utilization, ...
  - Dissemination, education and training
- **High upfront costs**
  - **Several countries have introduced policies** to lower upfront costs (IEA, 2022).
- **Electricity price** (Cost of electricity (ct/kWhel) / Cost of gas (ct/kWhel))
  - **A ratio of 2 is considered an activator**
  - **Flexibility and new business models** can be crucial.
- **Complex integration** with existing infrastructure/ **performance**/ **maintenance**
  - **Projects**
- **Grid infrastructure**
  - **Commitment to electrification and anticipatory investments**.



Source: EHPA

SUSHEAT Project

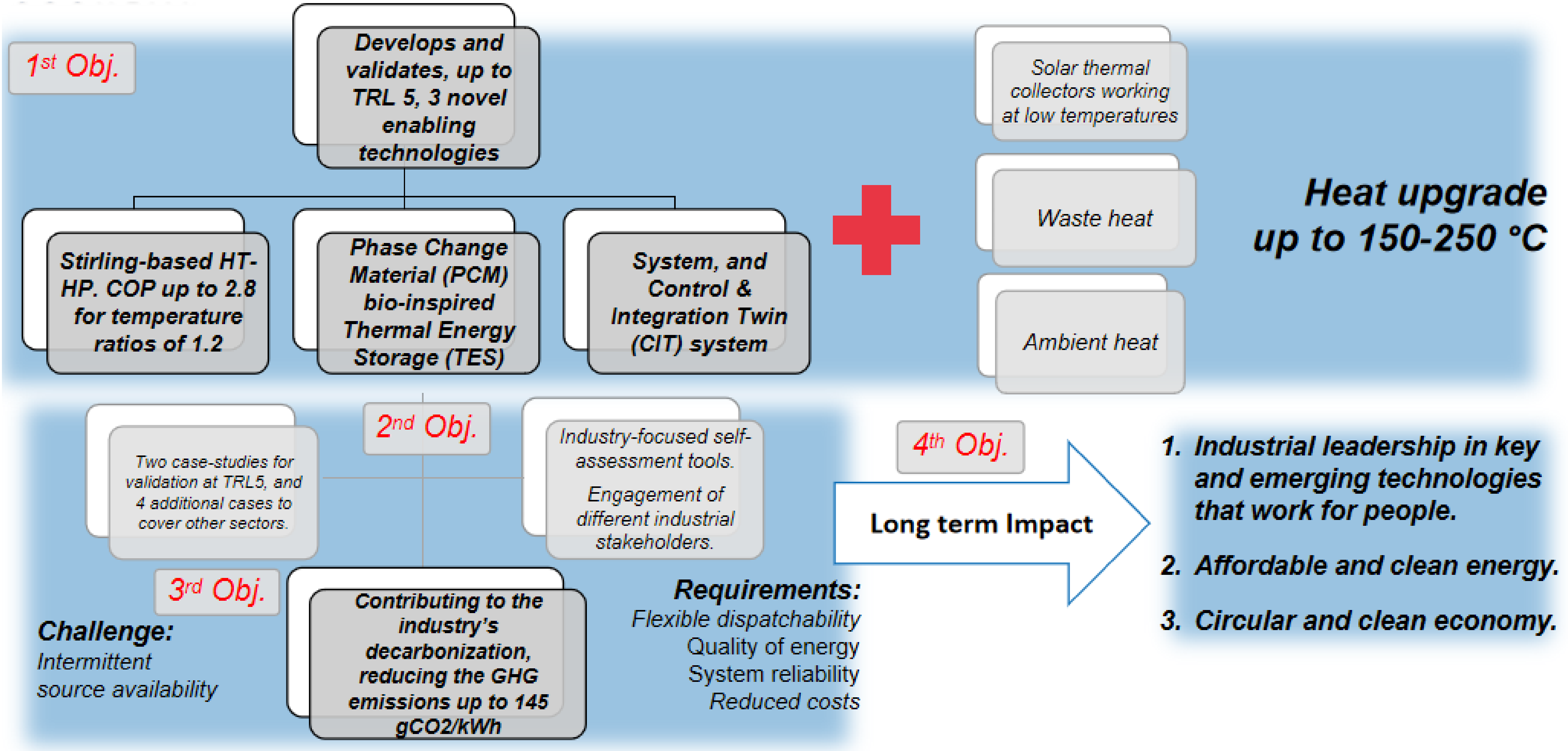
Smart Integration of Waste and Renewable Energy for Sustainable Heat Upgrade in the Industry

HORIZON-CL5-2022-D4-01

www.susheat.eu

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them. Grant Agreement No 101103552.

SUSHEAT Project Summary

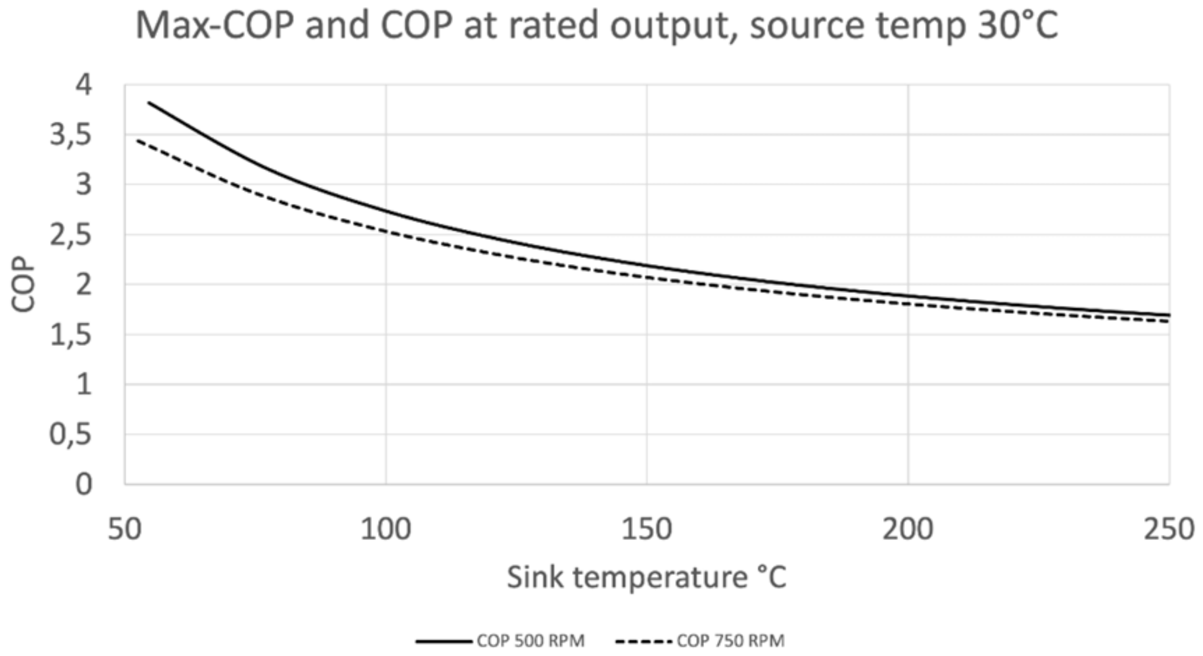


Stirling Based High Temperature Heat Pump (I)

- **HoegTemp heat pump (ENERIN):** Stirling cycle, whose ideal process involves two isochoric and two isothermal changes of state.
- **Fluid: R-704 helium** (alternative refrigerants: nitrogen and hydrogen)
  - **Inert, non-toxic,**
  - **0 Ozone Depletion Potential (ODP)**
  - **0 Global Warming Potential (GWP)**
- **Expected COP: higher than vapour compression cycles** for temperature ratios above 1.3 K/K (30°C to 120°C or 70°C to 170°C).

Stirling Based High Temperature Heat Pump (II)

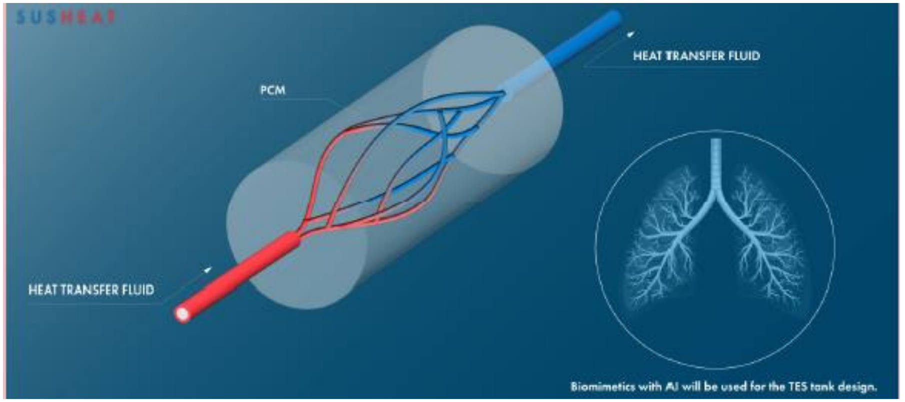
- **Challenges**
  - Designing the components: sealing, and piston rings.
  - Optimizing the COP for high temperatures
- **Objective:** COP of 1.9 at 250°C sourced from 70°C



Source: Høeg, A., Løver, K., Asphjell, T.A. (2023)

TES, Control System & Decision-Making Software

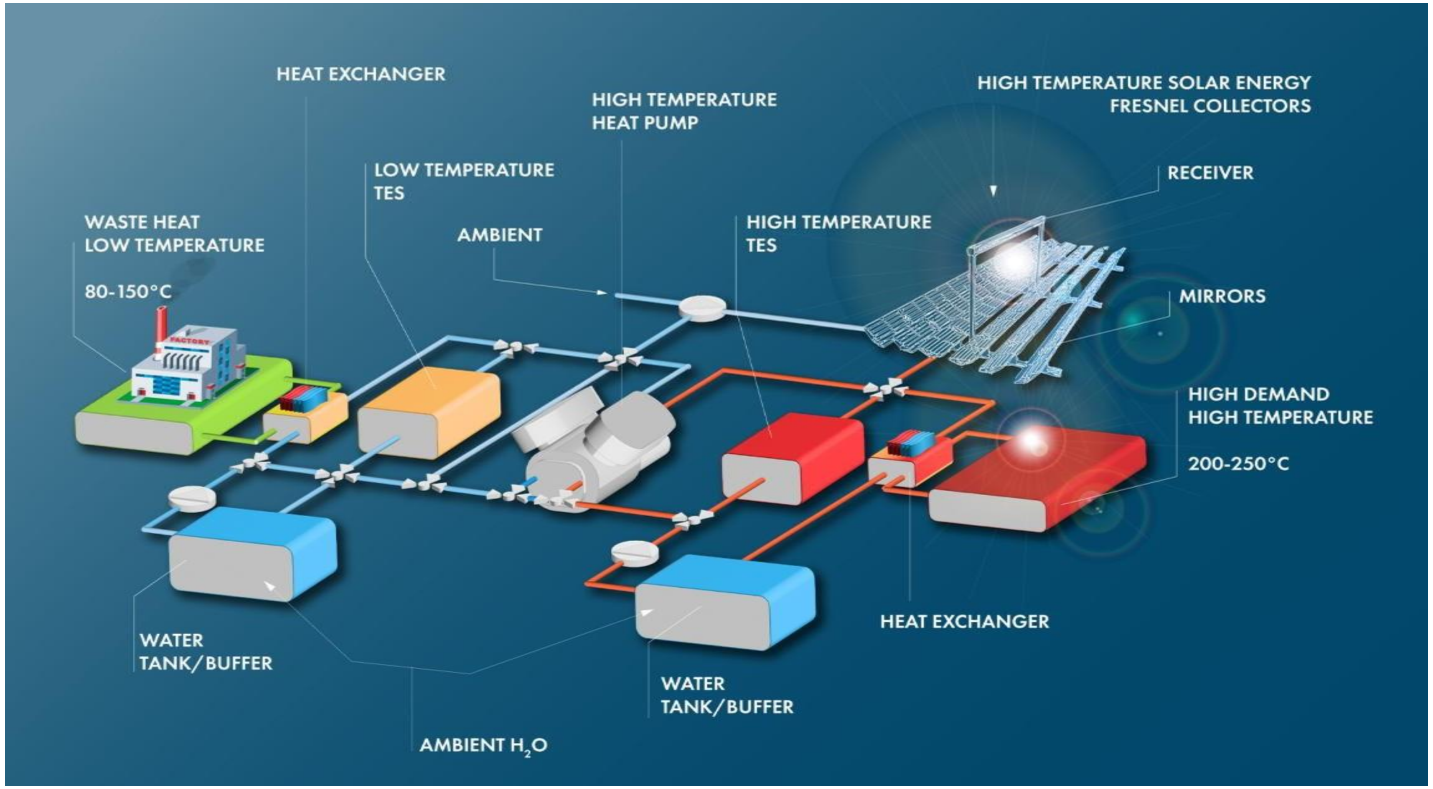
- **Thermal Energy Storage (TES):**
  - Development of two new storage tanks for the SUSHEAT system, based on **Phase Change Materials (PCM)**
  - Utilizes **inspiration from nature combined with AI**, representing a novel approach in TES design.
  - Utilization of **additive manufacturing (3-D printing)** for constructing the TES tank.



- **Control System and Decision-Making Software**
  - A **control system for the SUSHEAT test rig** by integrating the different components.
  - A **tool to get optimal configurations** of energy generation and storage based on use case profiles.

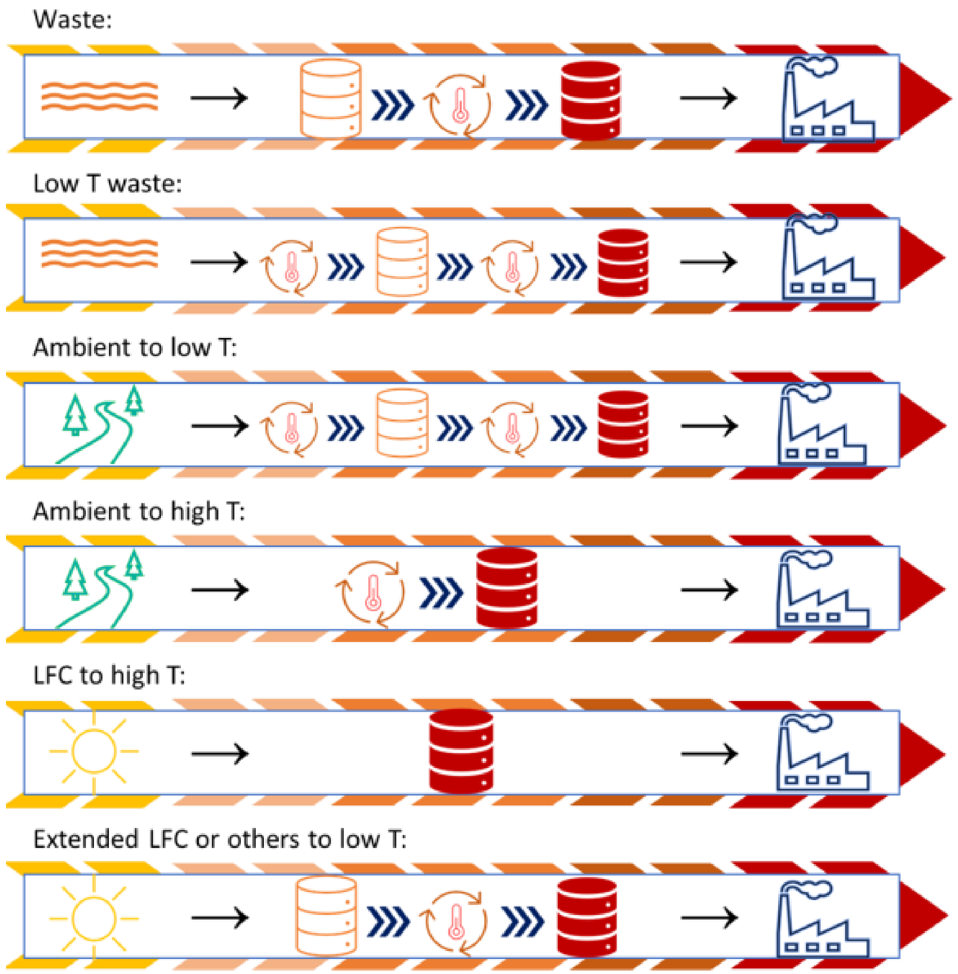
- **Benefits**
  - **Increase flexibility and performance.**
  - The **control and integration of the heat pump is crucial**

Validation at TRL 5



- **SUSHEAT concept validation at TRL 5**
- **Two use cases:**
  - **Pelagia:** Steam demand at 175°C. Waste heat 60–90 °C, 24 h of operation.
  - **Mandrekas:** Steam demand at 175°C. Waste heat recovery and solar-thermal input.
- **Linear Fresnel Collectors (LFC)** could provide high and low-temperature heat.
- **Four replication cases** to increase marketability.

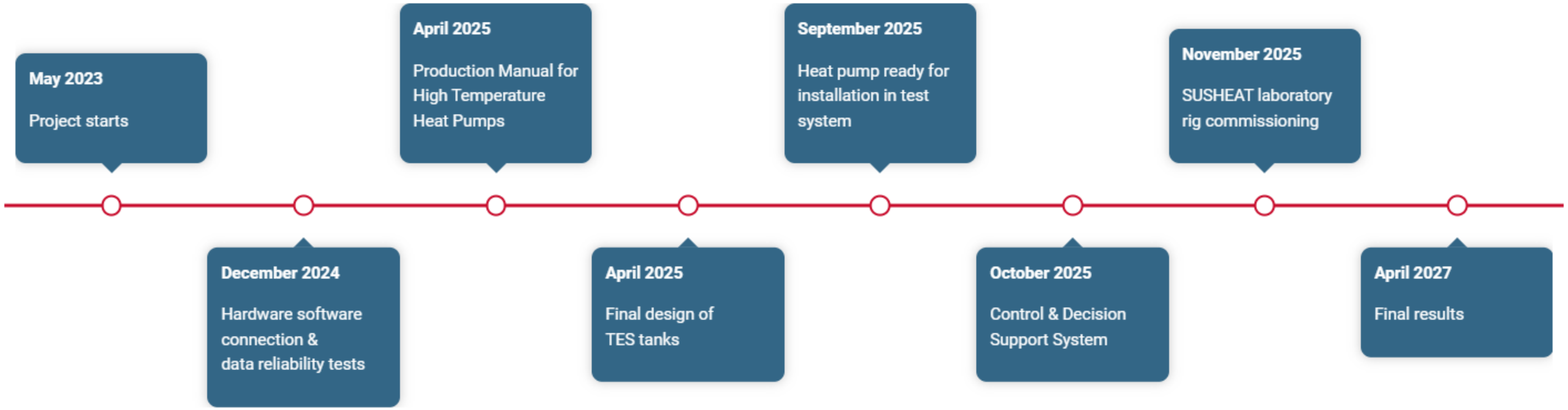
The Versatility of the SUSHEAT concept



- ❑ The HT-HP system can **upgrade heat from ambient**, **waste heat or solar collectors.**
- ❑ It can be **stored at low-T TES or upgraded and then stored**.
- ❑ Alternatively, heat can be **upgraded and introduced** directly into the **high-temperature TES**.
- ❑ Heat introduced to the **low-temperature TES is later upgraded** before being transferred to the high-temperature TES.
- ❑ **Solar collectors complement the system** by supplying heat directly to either the high-temperature or low-temperature TES.

SUSHEAT Project Impacts

- Aiming for an **annual energy saving of over 100 TWh in Europe**, **reducing approximately 15 million tons of CO2 emissions**.
- **Increase in energy efficiency** in factories and manufacturing processes.
- **Reduced need** for industries to purchase costly, unsustainable **carbon credits for pollution**.
- **Europe emerging as a leader** in industrial solutions **utilizing residual energy and renewable sources**.



Conclusions

- Studies suggest that **heat pumps** generating steam could have a **significant impact on the paper industry across Europe**.
- There are a series of **barriers and challenges**, in some cases, gradually being overcome.
- **Research projects like SUSHEAT and others such as Push2Heat or Spirit** are crucial for **overcoming these barriers and disseminating the potential** of high-temperature heat pumps.
- The **SUSHEAT project** proposes a concept that integrates high-temperature heat pumps with thermal energy storage and a control system based on AI, allowing for **performance optimization and increased cost competitiveness**.

Thank you for your attention!!

Any questions?