Industrial waste heat applications with High-Temperature Heat Pumps

Working Group 6.3: Waste heat utilisation in DHC
Session 2: Industrial waste heat applications

Reuven Paitazoglou
Berlin, 27.03.2025

Fraunhofer IEG

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Agenda

- Fraunhofer IEG
- Industrial Dercabonization
- Classification Heat Pump Technologies
- HTHP market availability and online database
- Research projects
- Summary

Fraunhofer-Gesellschaft at a glance

Application-oriented research for the direct benefit of the economy and society

Targets

- Affordable health care
- Digitalised value chain
- Security and resilient society
- Completed energy transition
- Holistic circular economy

Strategic research fields

- Bioeconomy
- Next Generation Computing
- Digital health care
- Artifcial intelligence
- Quantum technologies
- Ressource efficiency & climate technologies
- Hydrogen technologies

Lead markets

- Digital industry
- Mobility
- Mechanical engineering
- Health care industry
- Chemical industry
- Food industry
- Energy industry
- Construction industry
- Aerospace industry

30.000 employees in 76 Fraunhofer institutes

Research Institution for Energy Infrastructures and Geotechnologies IEG

Key Facts and Figures

~250 employees
2 directors

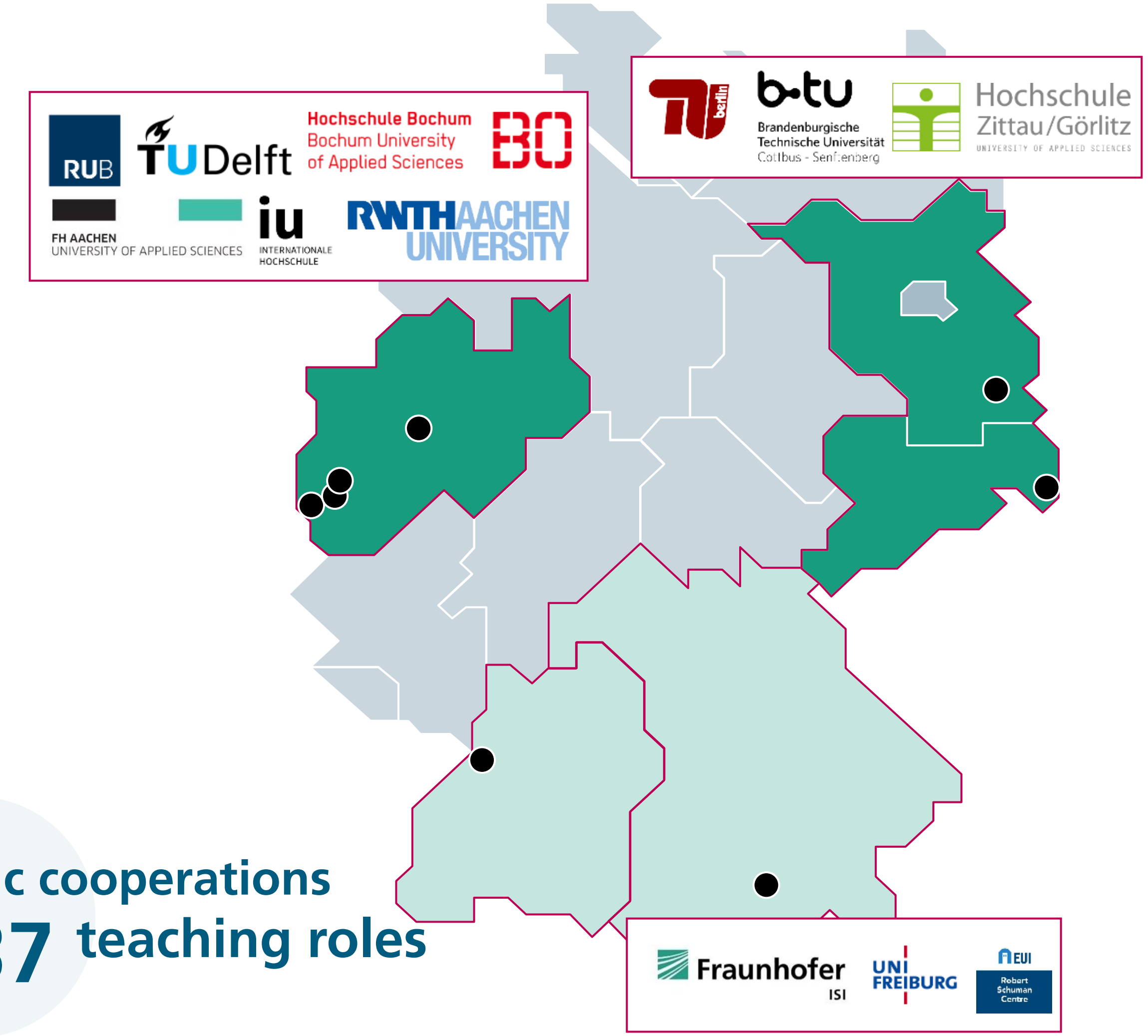
Founded on
01.12.2019

8 sites

22 scientific competence centers

8 business- & service units

15 academic cooperations
37 teaching roles



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Fraunhofer IEG

Fraunhofer IEG – research areas at a glance

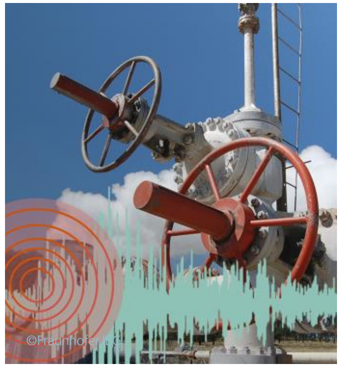
“We design the climate-neutral energy systems of the future“

- Integrated **energy infrastructures**
- Transmission and **distribution networks**
- Integrated **district supply** (Open District Hub)
- **Hydrogen** infrastructures (grids and storage)
- System transformation and technology transfer

- Exploration and exploitation of **georesources**
- **Geothermal energy**, shallow to deep geothermal systems
- **Geotechnologies**, drilling techniques and methods
- **Storage** for materials and heat, post-mining utilisation
- Carbon Capture & Storage/Utilization (**CCS/CCU**)

- Development of **thermal energy systems** that work **grid-balancing**
- 4th and 5th generation **heating/cooling networks**
- **Surface storage** for energy and **integration** of sector-coupled energy systems
- Efficient redesign of **chemical production processes** and **carbon capture**

- **Control, automation & operational management** of energy systems
- Decentralised, **smart and digital grids** and systems
- **Large-scale demonstrators / field scale laboratories**





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Industrial Decarbonization

Upgrading of waste heat

Industrial energy landscape

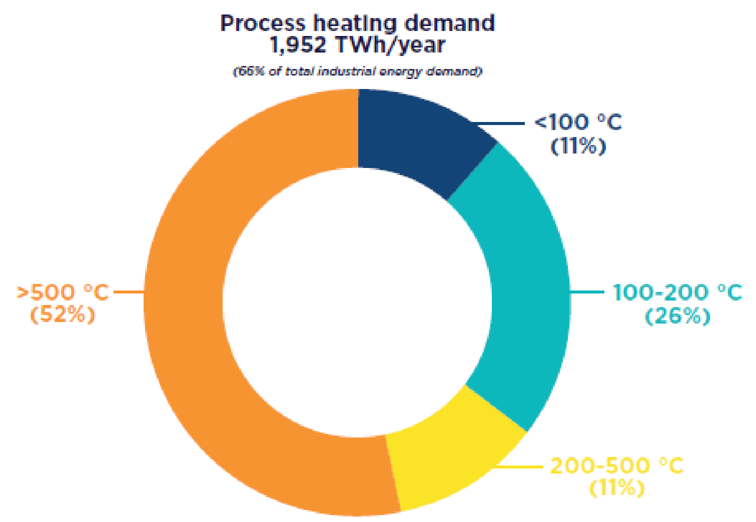
- ~ 75% Heat - Today mainly from fossils
- ~25% Electricity – today 50% from fossils

37% of the process heat required is **below 200°C** (730 TWh/year)

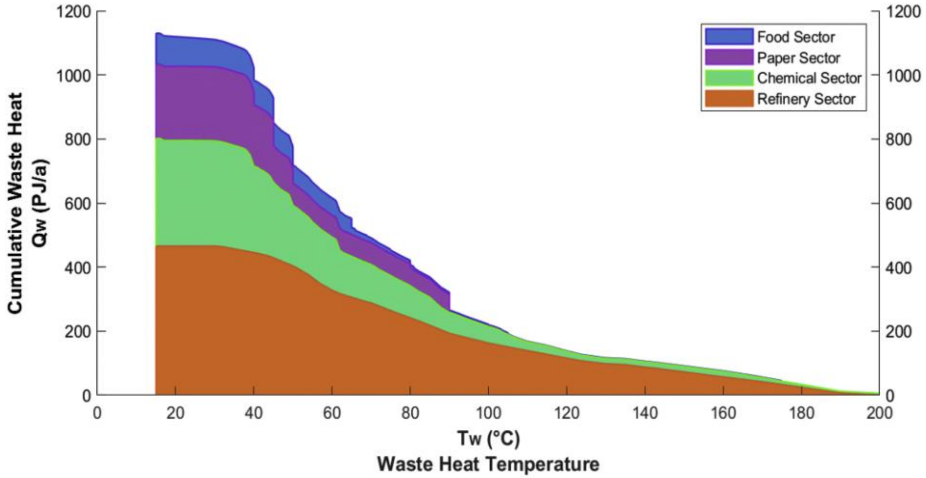
Available **waste heat** between 40-100°C is estimated in 220 TWh

Upgrading waste heat offers challenging but big potential for decarbonization of process heat demand

Process heating demand[1] in Europe by temperature range



Industrial process heat demand and waste heat analysis[2]



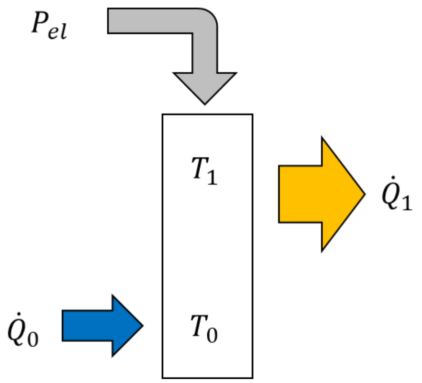
[1] de Boer, R., Marina, A., Zühlsdorf, B., Arpagaus, C., Bantle, M., Wilk, V., Imegaard, B., Corberán, J., & Benson, J. Strengthening Industrial Heat Pump nnovation: Decarbonizing Industrial Heat, 2020.

[2] A. Marina, S. Spoelstra, H.A. Zondag, A.K. Wemmers, An estimation of the European industrial heat pump market potential, Renewable and Sustainable Energy Reviews, Volume 139, 2021.

Industrial Decarbonization

Upgrading of waste heat

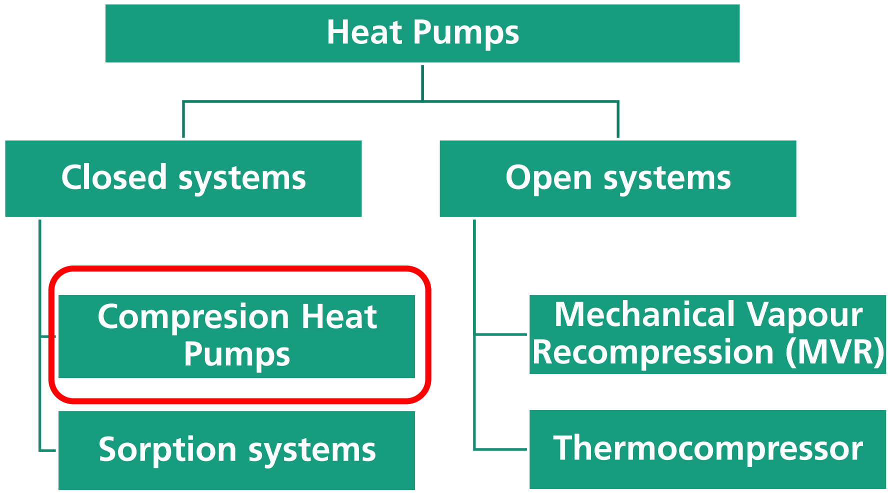
Compression Heat Pumps



- Main energy demand: Electricity
- Efficiency values COP: 1…10 (~COP=3)
- Established technology with high TRL
- Various compressor types (screw, scroll, piston, turbo)
- Synthetic vs. Natural refrigerants
- Many technology providers

P_{el} Electricity
$\dot{Q}_N$ Heat flow
T_N Temperature
N Temperature level

Classification of Heat Pump Technologies[3]



Source: HeatPAC Model (3MW) by Johnson Controls

[3] Cordin Arpagaus, Hochtemperatur-Wärmepumpen, Marktübersicht, Stand der Technik und Anwendungspotentiale, 2019.

Industrial Decarbonization

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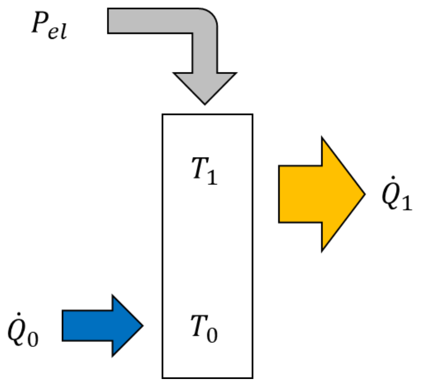

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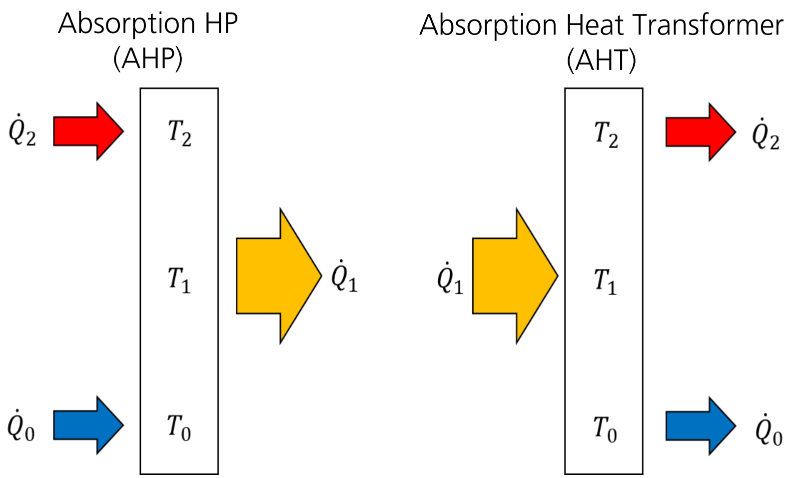
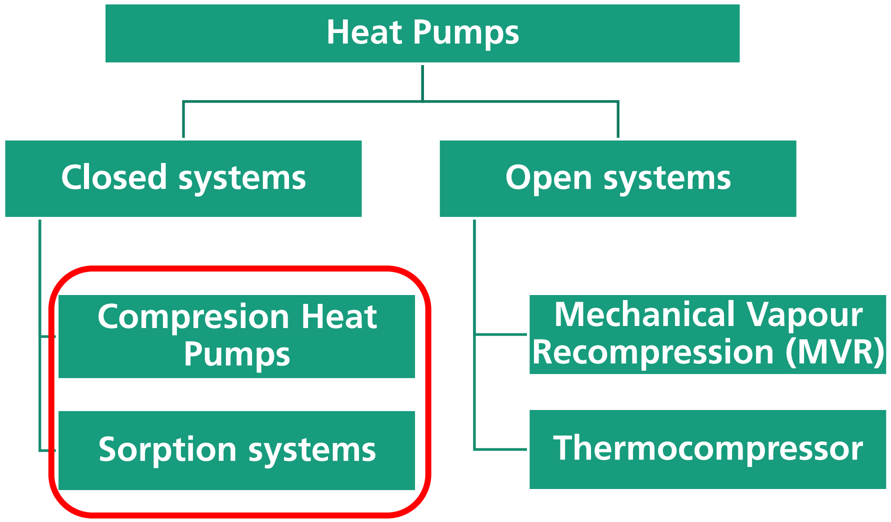
Sorption Systems



- Main energy demand: High-Temperature Heat
- Efficiency values AHP~1.75 AHT ~0,5
- Established technology with high TRL
- Working pairs: $H_20/LiBr$ and NH_3/H_20
- ‚Niche' applications

Classification of Heat Pump Technologies[3]



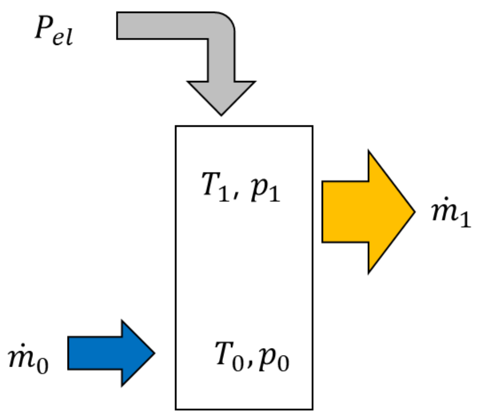
Source: AHT (500kW) by W. Baelz & Sohn GmbH & Co

[3] Cordin Arpagaus, Hochtemperatur-Wärmepumpen, Marktübersicht, Stand der Technik und Anwendungspotentiale, 2019.

Industrial Decarbonization

Upgrading of waste heat

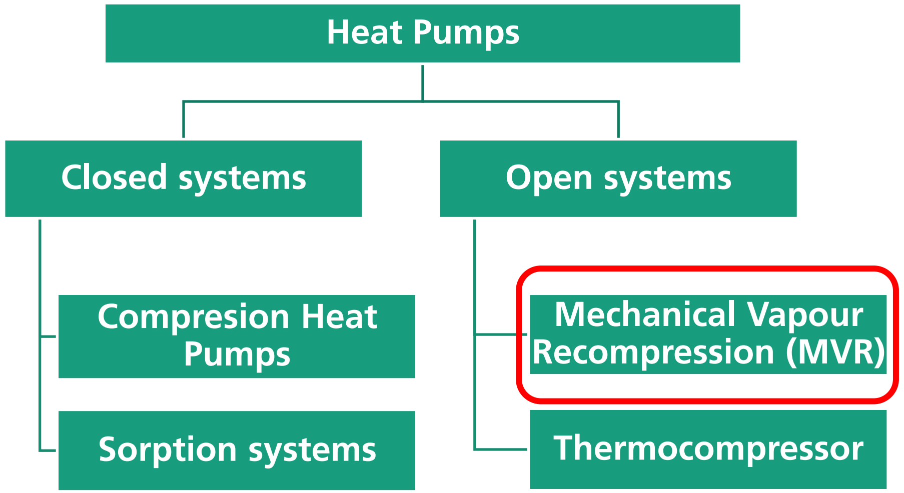
Mechanical Vapour Recompression (MVR)



- Main energy demand: Electricity
- Efficiency values COP: 2…14
- Closed loops possible
- Established technology with medium/high TRL
- Mainly water/steam based
- Few technology providers

P_{el} Electricity
$\dot{Q}_N$ Heat flow
$\dot{m}_N$ Mass flow
T_N Temperature
p_N pressure
N Temperature level

Classification of Heat Pump Technologies[3]



Source: Spilling Project Partner GmbH & Co.KG

[3] Cordin Arpagaus, Hochtemperatur-Wärmepumpen, Marktübersicht, Stand der Technik und Anwendungspotentiale, 2019.

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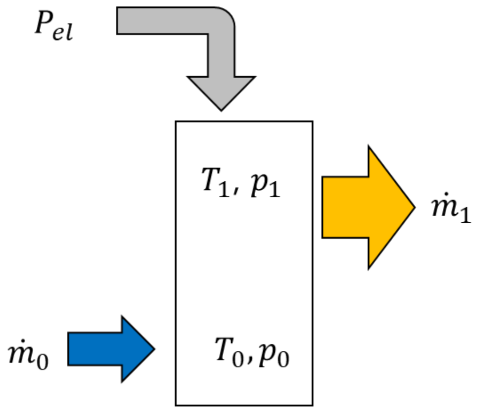

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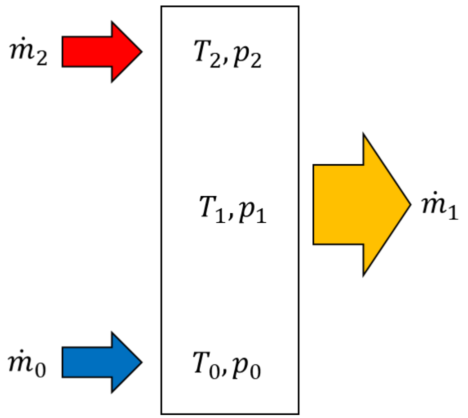
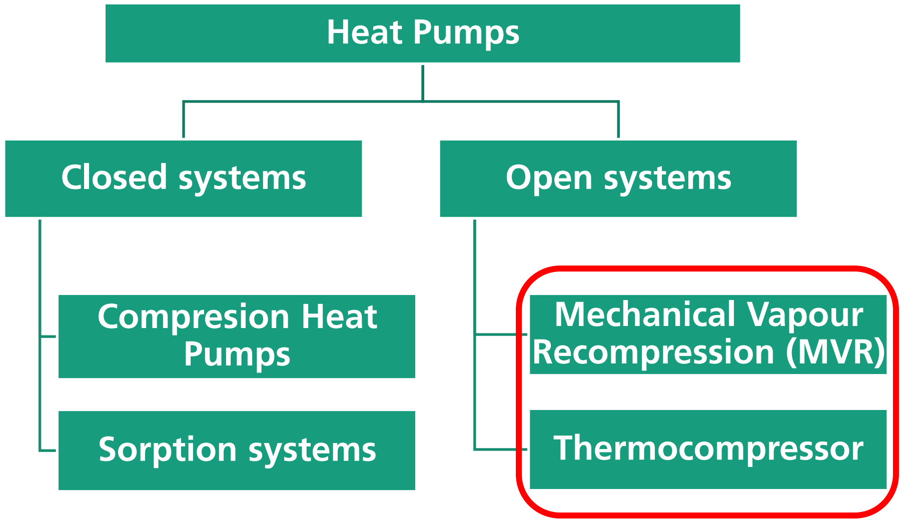
Thermocompressor



- Main energy demand: High-Temperature/Pressure Steam
- Pressure ratio[4] 1.5-10
- Low maintenance / high operational safety
- Working media: water, pressurized gases/air
- Low specific investments
- Nozzle adjustments allow part load

Classification of Heat Pump Technologies[3]



Source: Körting Hannover GmbH

[3] Cordin Arpagaus, Hochtemperatur-Wärmepumpen, Marktübersicht, Stand der Technik und Anwendungspotentiale, 2019.
[4] Pressure ratio: discharge pressure to suction pressure

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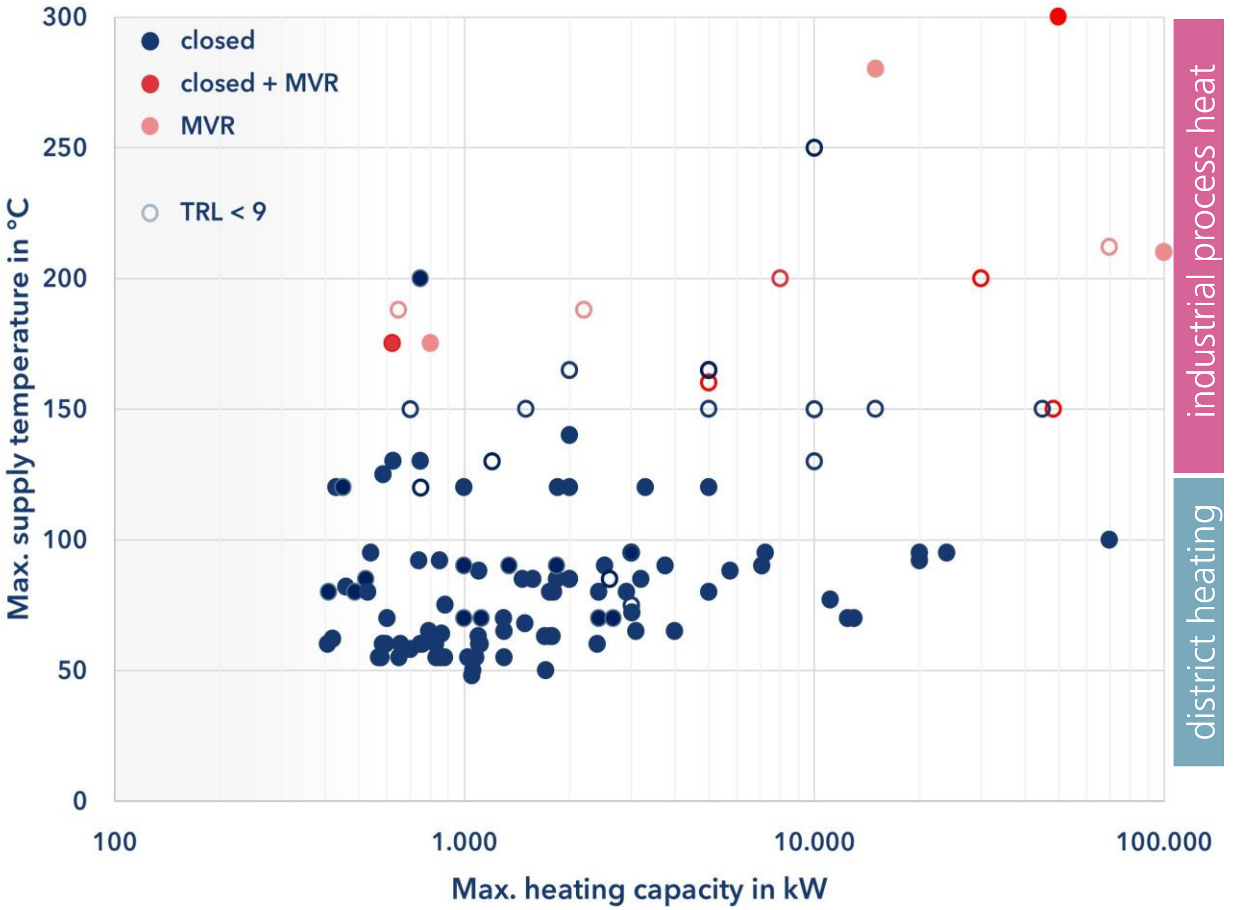
Market overview[5] HTHP

Availability of large-scale heat pumps

- Large-scale Heat Pumps up to 70MW available
- Few manufacturers with supply temperatures >120°C
- HTHP >150°C regarded mainly as prototypes

Identification of development needs:

- Increase in the supply temperature
- More industrial implementation / projects
- Standardization and “rules of thumb” for use cases



[5] Agora Energiewende, Fraunhofer IEG (2023): The roll-out of large-scale heat pumps in Germany. Strategies for the market ramp-up in district heating and industry.

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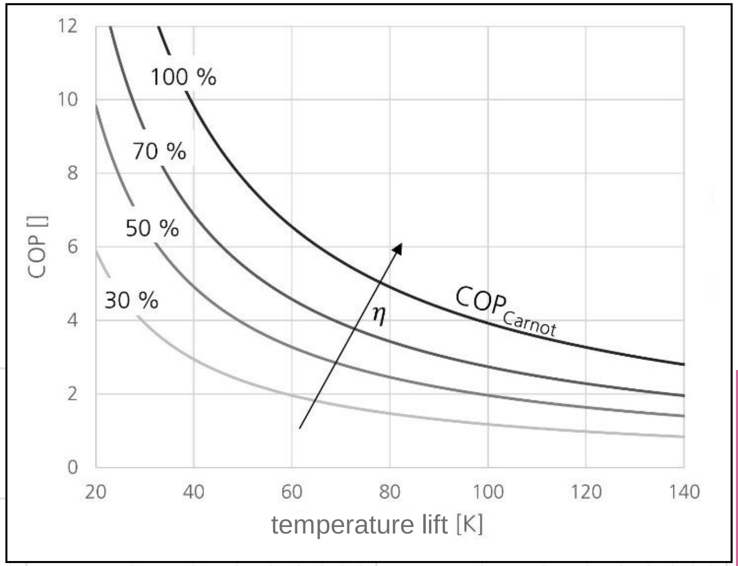
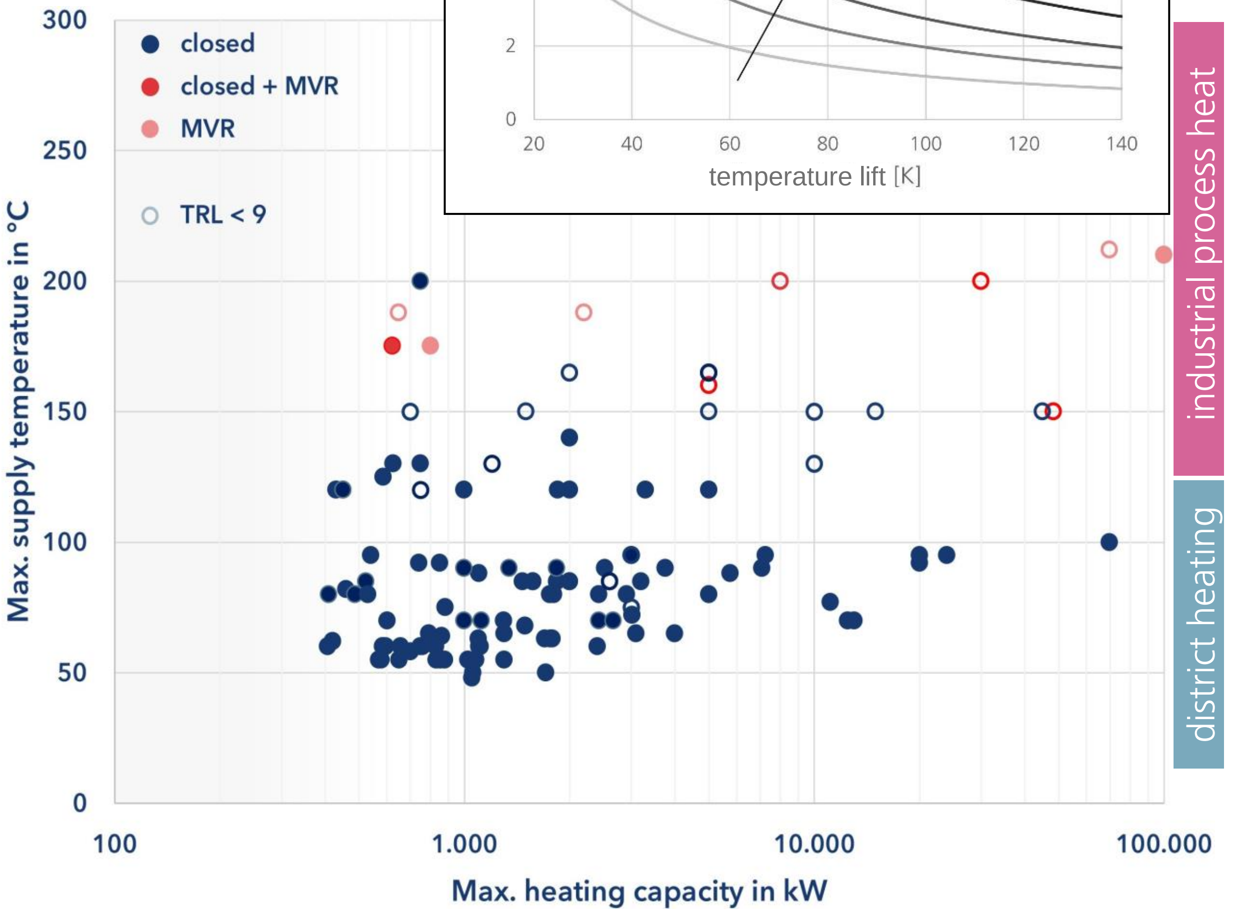
Coefficient **O**f **P**erformance

$$COP = \frac{\dot{Q}_{Heating}}{P_{Compressor}}$$





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Information portal for Large-scale Heat Pumps

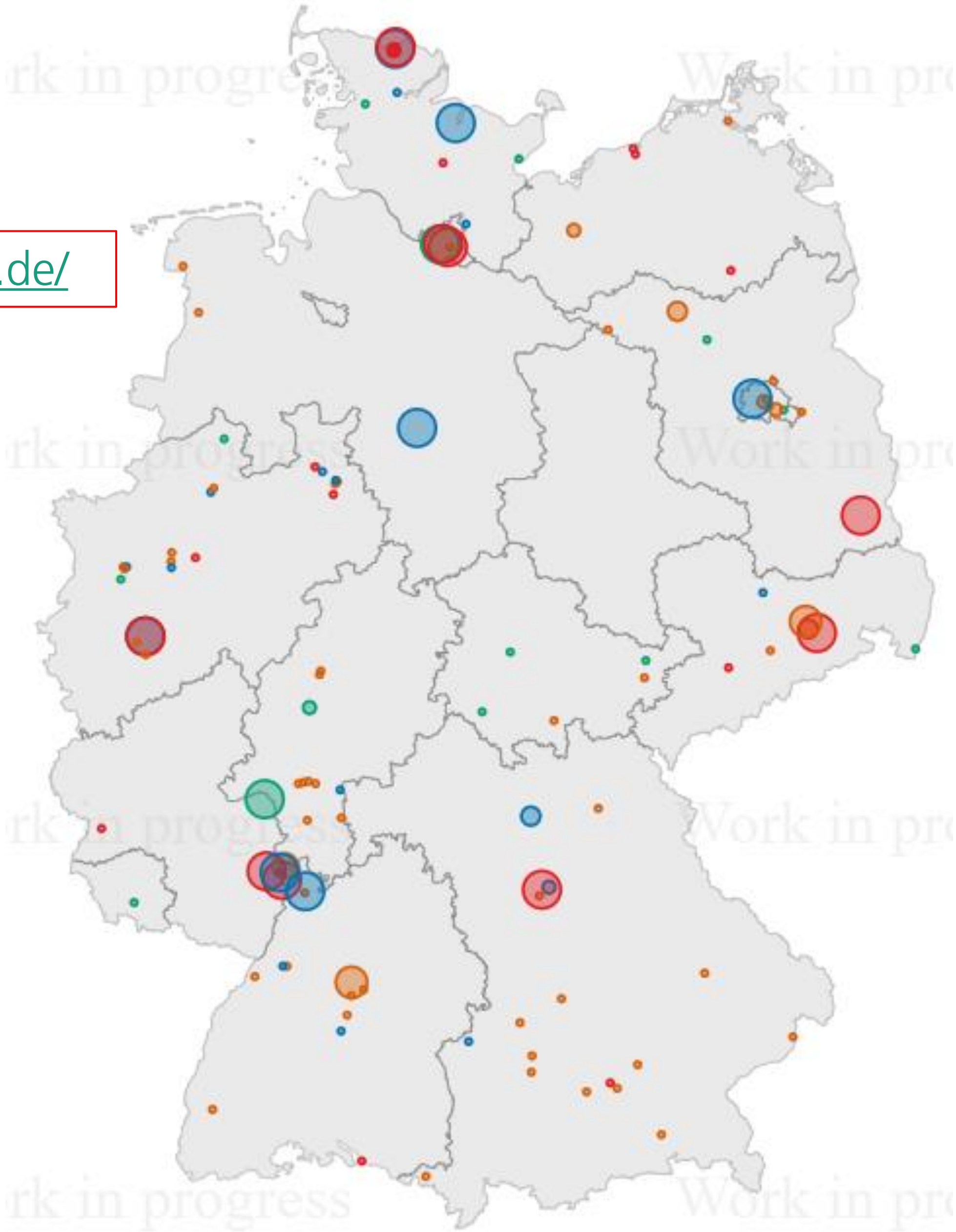
Database for planned/operating projects in Germany

NEW RELEASE: https://grosswaermepumpen-info.de/

Large-scale heat pumps with a thermal **output ≥ 500 kW_{th}**

Currently

- More than 100 planned and operating projects recorded in Germany
- Online research and inquiries with operators, municipal utilities



Recorded data

Project assignment
- Project name
- Location

General information
- Project participants
- Commissioning (status, year)

Heat source
- Type
- Temperature

Heat sink
- Type (district heating, industrial application)
- Temperature heat pump side
- Temperature district heating

Technical data
- manufacturer
- make
- refrigerant
- Compressor technology
- Thermal output, electrical power
- COP, SEPR
- Operating hours, heat quantity

Complementary systems
- Heat Storage
- Other heat generators

Economic data
- Investment volume
- Subsidy

FernWP project

District and process heat supply by heat pumps as a replacement for coal combustion

Main tasks

- Analysis of economic barriers and further development of economic framework conditions
- Identification and assessment of LT-sources and DH network specifics
- Further development of thermodynamic cycles for Heat Pumps
- COP-Optimization in laboratory environment
- Scale-up laboratory Heat Pump prototype to a pilot plant
- Operation of pilot plant in a hybrid concept (HP+CHP)
- Assessment of process heat supply using large-scale heat pumps

FernWP
Addressing the technical and economic barriers that currently still impede the widespread use of large-scale heat pumps in DH systems and for covering the process heat demand

Duration: 10.2021 – 09.2025 (48M)

Project budget: 4,5M€

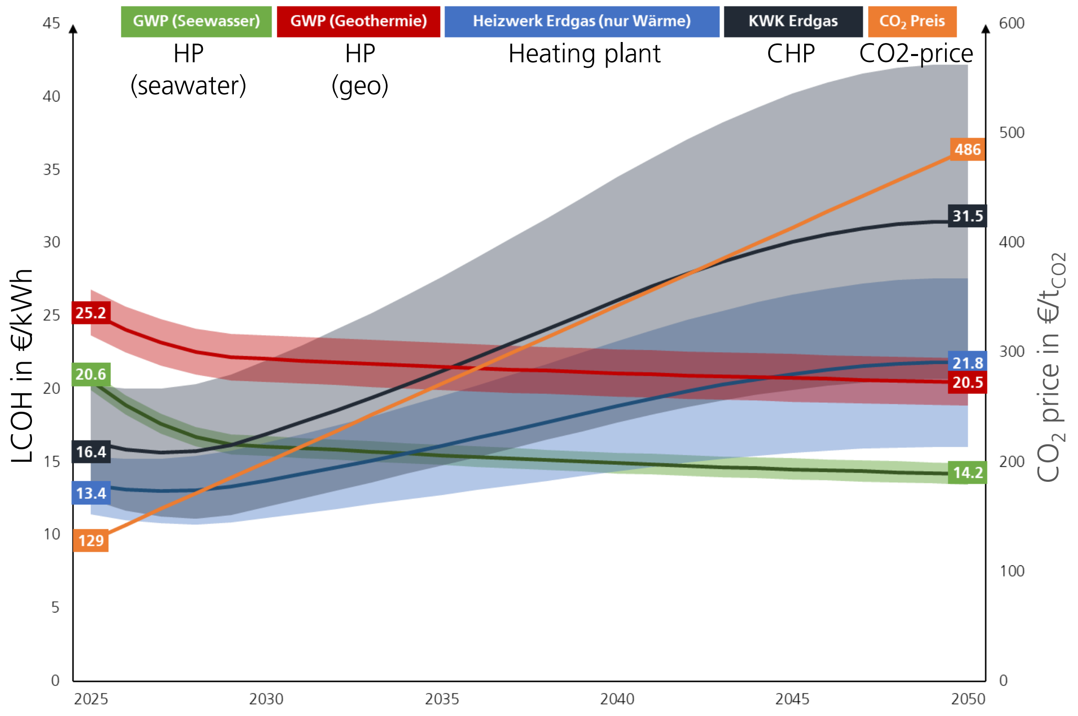
Fraunhofer (100%): 3,5€

7 partners

FernWP project

District and process heat supply by heat pumps as a replacement for coal combustion

Scenario based analysis[6] for assessment of economical framework for the introduction of large scale heat pumps



0) Baseline (no funding/CO_2-price)

1) CO_2-Scenario

2) Funding-Scenario

FernWP

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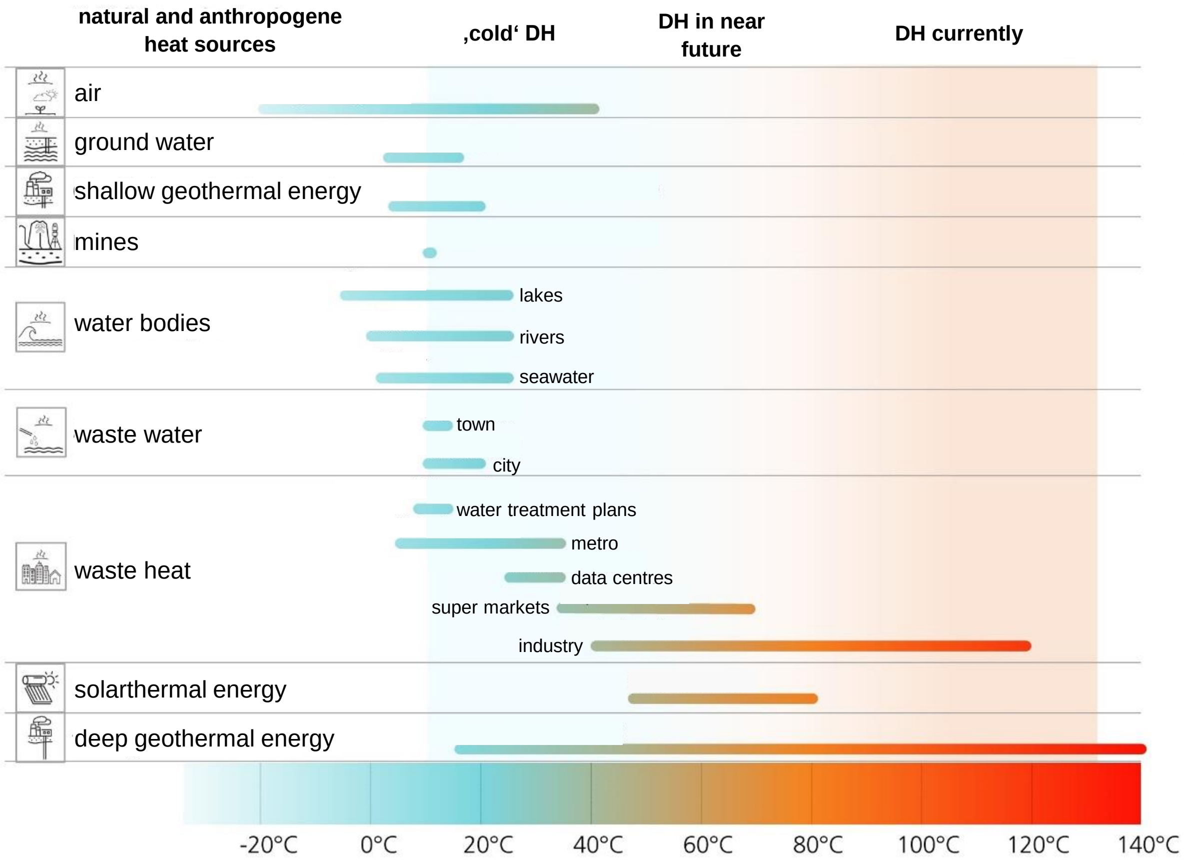
[6] Billerbeck et al, ‚Analysis of current economic bariers and further development of the economic framework for large-scale heat pumps', https://doi.org/10.24406/publica-1063 (2023)

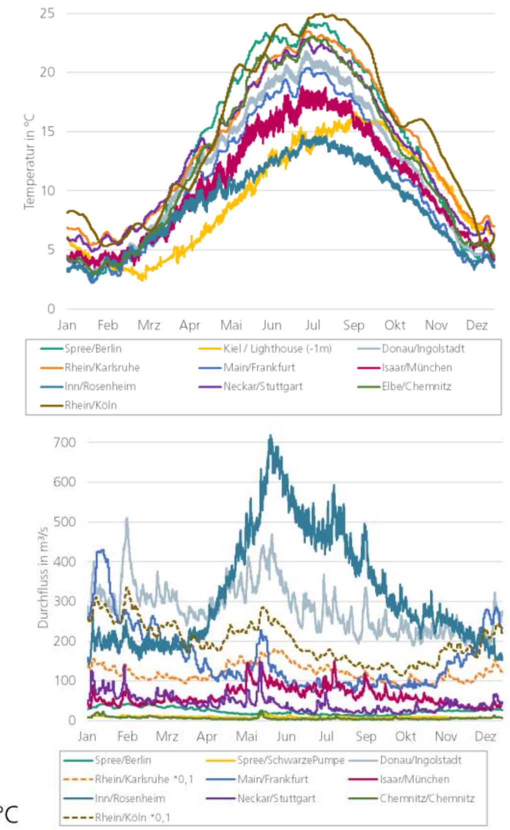
FernWP project

District and process heat supply by heat pumps as a replacement for coal combustion

Fraunhofer IEG · Fraunhofer ISE · Fraunhofer ISI · AGFW · GESMEX · Stadtwerke Cottbus · Johnson Controls

Classification of the heat sources[7]





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[7] Paitazoglou et al, ‚Analysis of the heat sources for the use of large heat pumps in heating networks ‘, https://publica.fraunhofer.de/handle/publica/470511 (2024)

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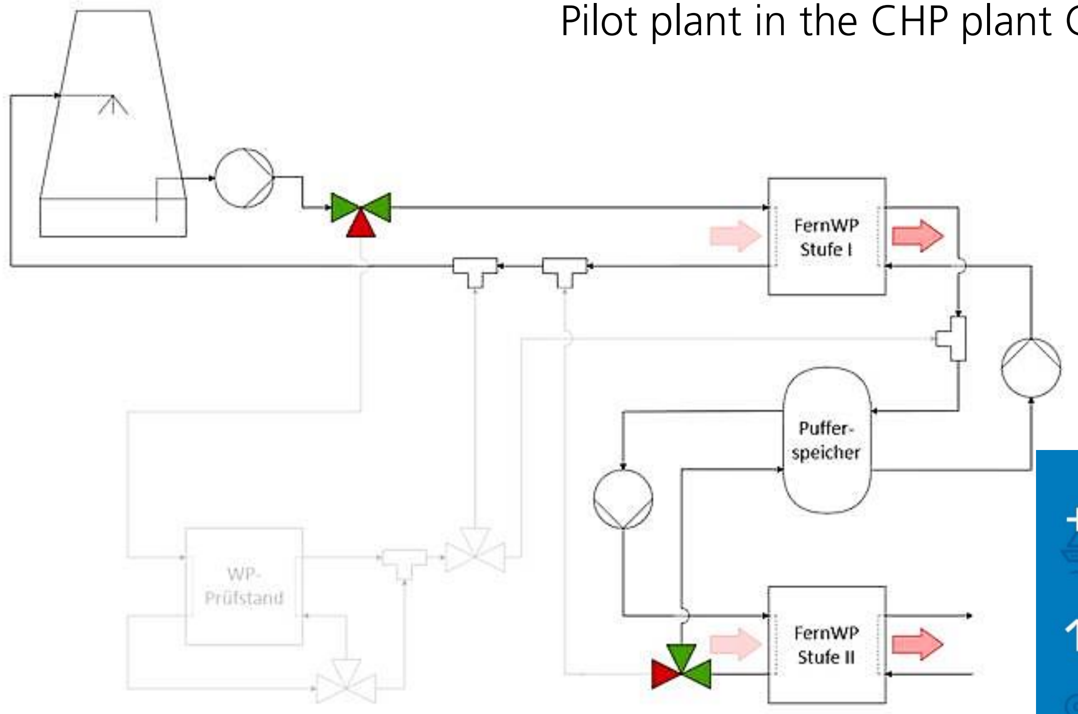
Fraunhofer IEG · Fraunhofer ISE · Fraunhofer ISI · AGFW · GESMEX · Stadtwerke Cottbus · Johnson Controls

Pilot plant in the CHP plant Cottbus



HP Test Rig
Fraunhofer IEG

2-stage HTHP
1st: R717 (NH_3)
2nd: R600 (Butane)

Utilization of the „Cottbuser Ostsee“ for heat supply (DH)
- Seawater transport using old coal transport corridor
- Analysis of heat sources

→ Near future: Large-scale HP
→ Currently: 500kW 2-stage HTHP

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Steam Screw project

Heat pumps for process heat applications

subsidy amount

2.6 Mio. €

Project duration

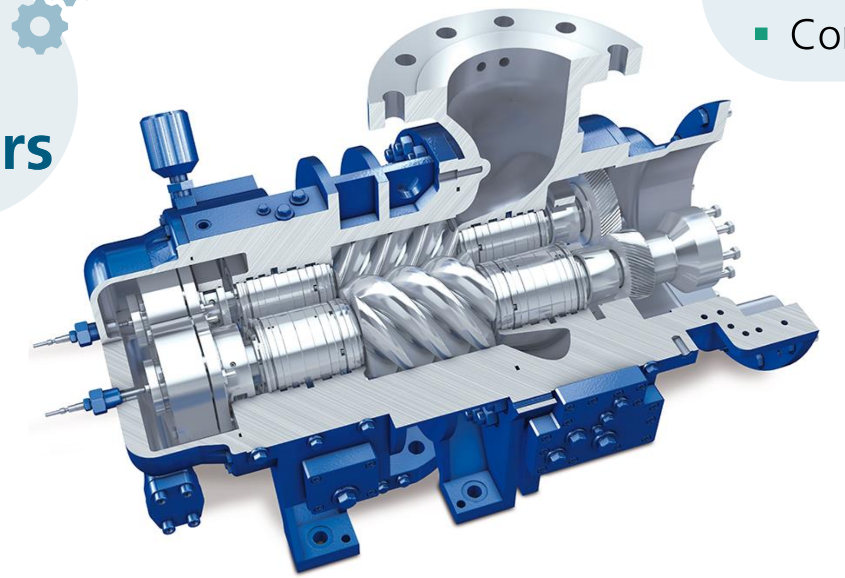
3.5 years

3 Partners

Project start on

01.01.2023

- Water-based High temperature heat pump
- Development of water-injected, oil-free screw compressor
- Peak heating power of approx. 500kW
- Sink temperatures 140-200°C
- Source temperatures 80-120°C
- Construction of an appropriate test bench



AERZEN

Fraunhofer IEG

fachgebiet fluidtechnik

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

Source: https://www.ieg.fraunhofer.de/de/referenzprojekte/SteamScrew.html

Steam Screw project

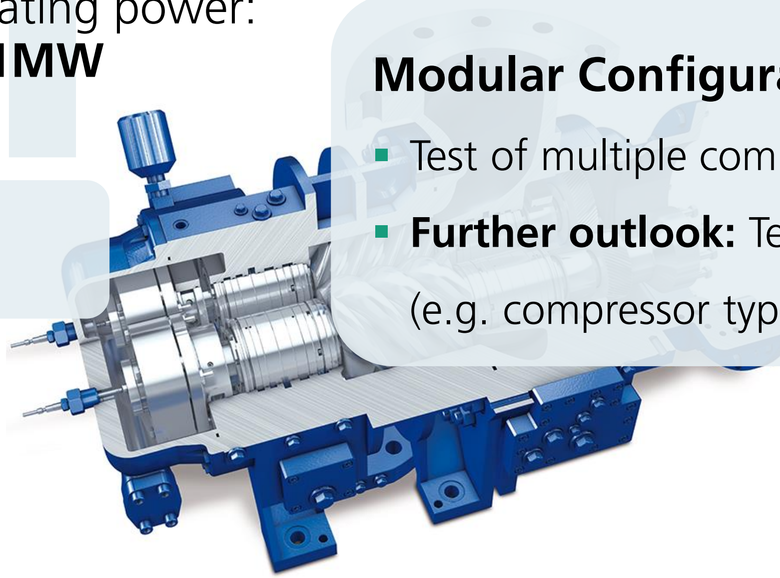
Heat pumps for process heat applications

HT-Heat Pump
Test bench

Temperature:
80-120°C
Max. heating power:
800kW

Temperature:
140-200 (250)°C
Max. heating power:
1MW

SteamScrew
HT-Heat Pump



Flexible Design (Test bench / heat pump)

- Operation in combination planned **within project scope**
- **Further outlook**: Operation of test bench and / or heat pump as independent unit

Modular Configuration of SteamScrew heat pump

- Test of multiple compressor generations **within project scope**
- **Further outlook:** Test of different technologies (e.g. compressor type, evaporator type)

Funded by the European Union

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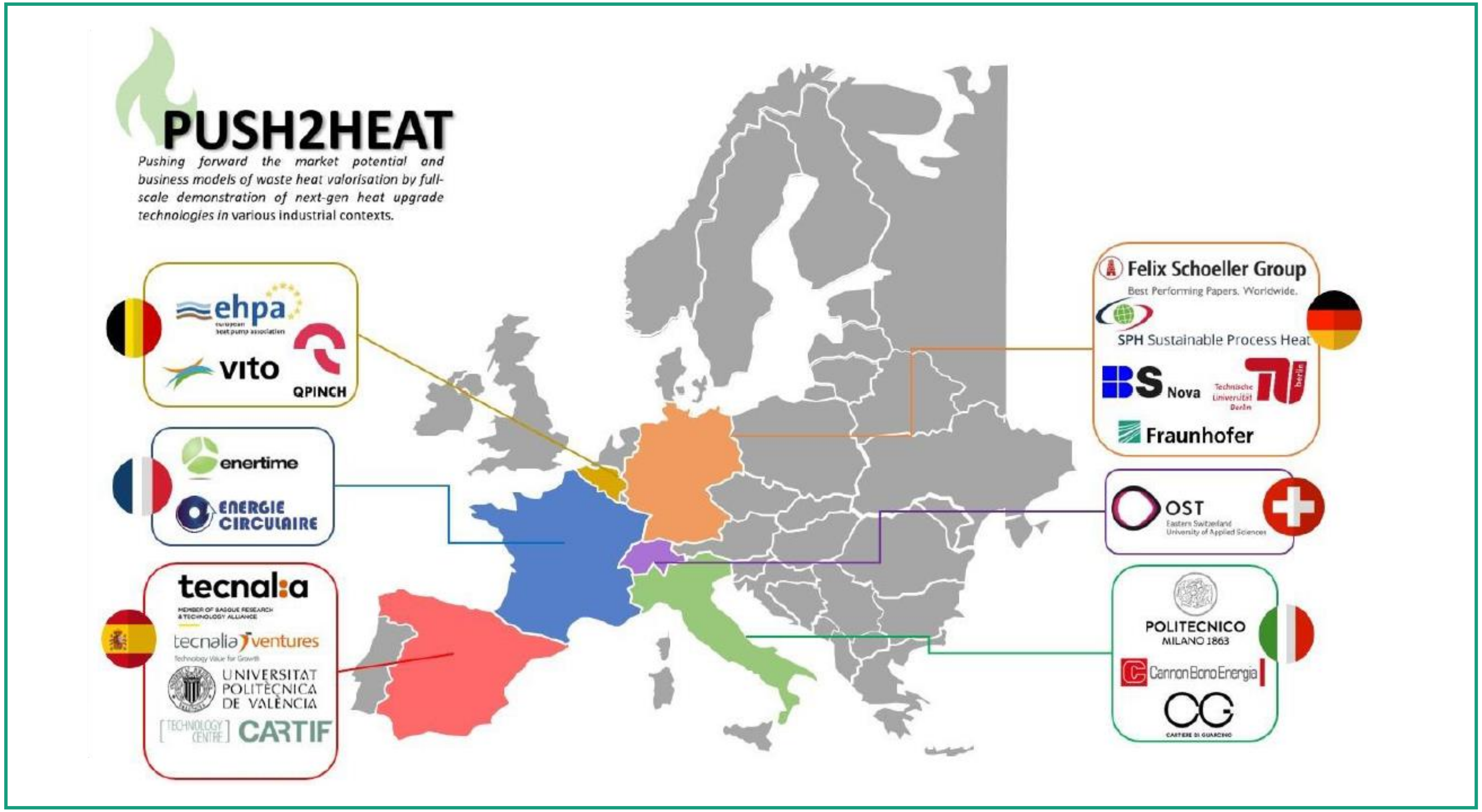
PUSH2HEA project

Decarbonization of industrial heat supply

Push2Heat



PUSH2HEAT

Pushing forward the market potential and business models of waste heat valorisation by full-scale demonstration of next-gen heat upgrade technologies in various industrial contexts

Duration: 10.2022 – 09.2026 (48M)

Project budget: 9.739.703€

Fraunhofer (100%): 598.750€

18 partners from 6 different countries

4 demo sites for heat upgrade
- Compression HP
- HP + MVR
- Absorption Heat Transformer
- Thermochemical HP (Test site)

Fraunhofer IEG

PUSH2HEAT project

Decarbonization of industrial heat supply

Main objectives

- **Optimization** of four heat upgrade technologies
- Pushing forward the **market potential**
- New business models and actions towards technologies **market deployment**
- **Demonstration** of 4 full-scale pilots plants in different industrial applications
- Waste heat 40-90°C
- Heat supply 100-160°C
- System size 0,5 – 3MW

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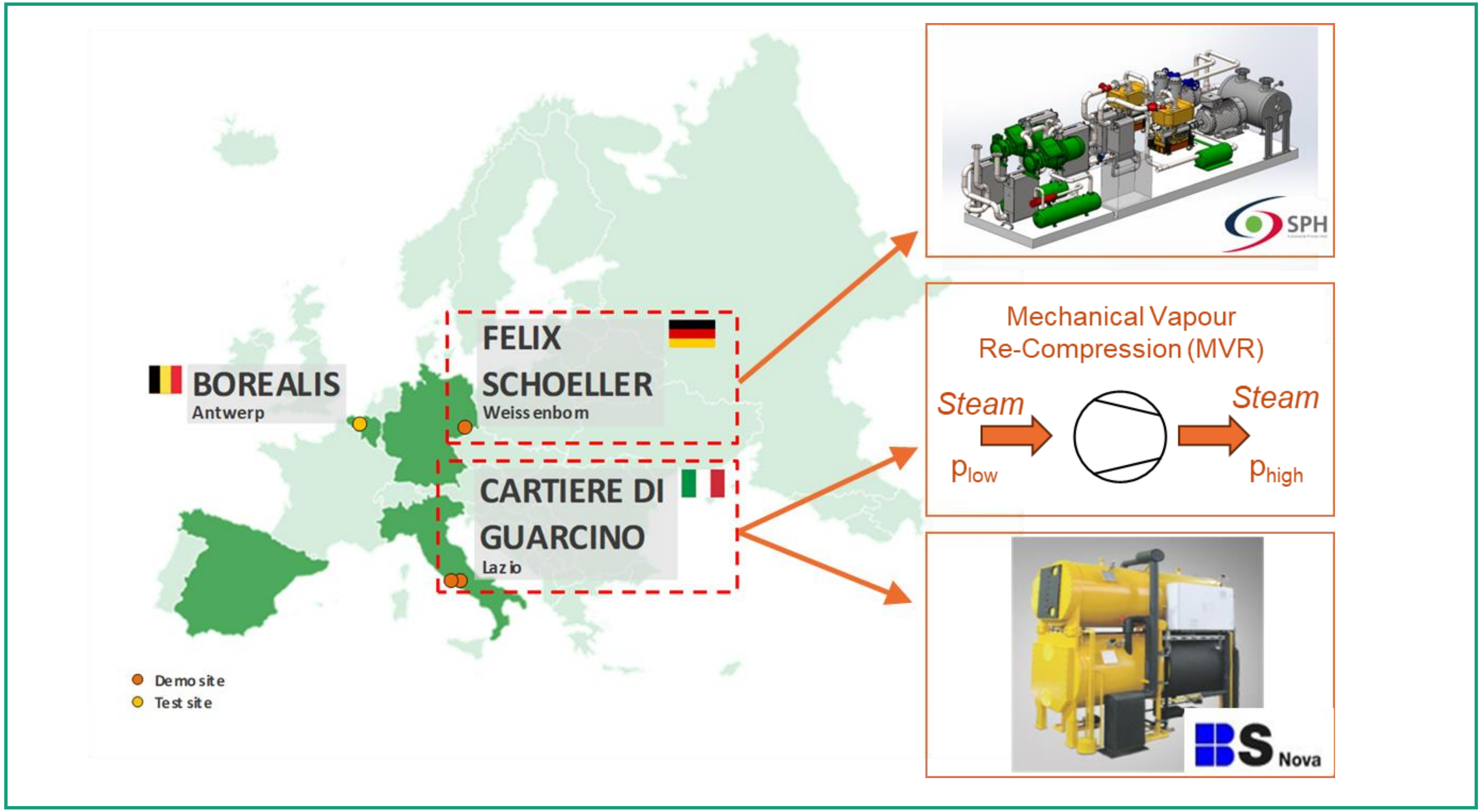

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PUSH2HEAT project

Decarbonization industrial heat supply

Push2Heat

Demo 1: Felix Schoeller

Sector: Paper Industry
Production: 100.000 t/a

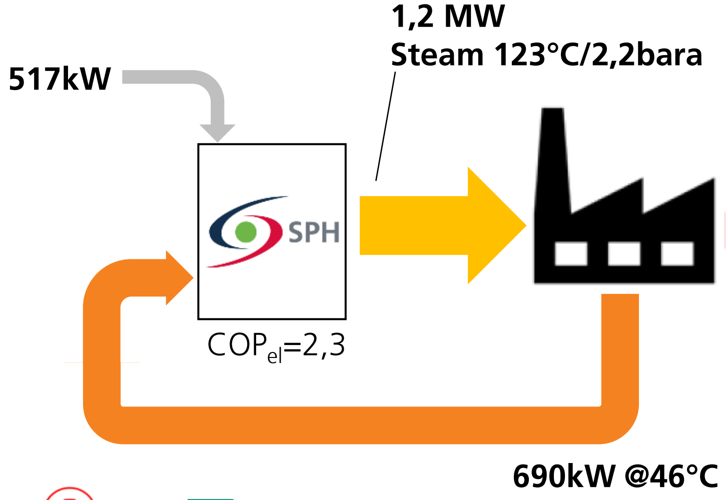
Technology: 2-stage HTHP

Demo 2 at Cartiere di Guarcino

Sector: Paper Industry
Production: 50.000 t/a

Technology: Absorption Heat Transformer

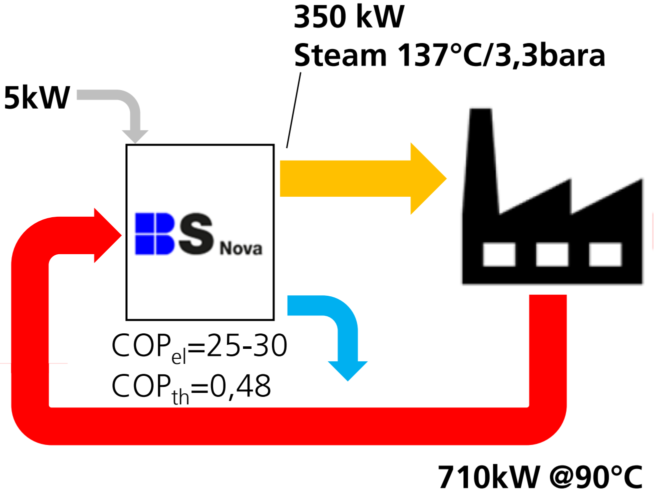
Heat Upgrade System based on 2stage HTHP



Expected output[8]

4 000 h/a	**Operation hours**	7 000 h/a
4 720 MWh/a	**Heat supply**	4 760 MWh/a
453 000 m³/a	**Gas savings**	457 000 m³/a
231 t/a	**CO2 savings**	1 083 t/a
2 414 MWh/a	**PE savings**	5 617 MWh/a
May 2025	**Commissioning**	June 2025

Heat Upgrade System based on AHT



FELIX SCHOELLER · Fraunhofer IEG · TECHNISCHE UNIVERSITÄT BERLIN · tecnalia · Cannon Bono

[8] Values are based on preliminary assumptions and design parameters

  Public

Fraunhofer IEG

Heat pumps for process heat applications

Economical aspect of heat pumps

- Barriers for the usage of industrial heat pumps
  - Needed Temperatures are too high
  - High manufacturing costs -> Higher capital expenditures (short CAPEX)

→ Long payback times, gas often the cheaper option

→ operational expenditures (short OPEX) dependent on the energy prices

	Cost of kWh_electricity [€]	Cost of kWh_gas [€]	Ratio [-]
Sweden	0.13	0.13	1.04
Austria	0.17	0.07	2.42
EU	0.20	0.07	2.94
Germany	0.18	0.05	3.74

[Source: eurostat2022, non-households]

1. **Main barriers for market deployment**
2. High electricity price and/or uncertainity in the energy market
3. High CAPEX
4. Amortisation too long for decision makers
5. Fex implemented project in an industrial context
6. Lack of knowledge over HP availability and integration potential
7. Temperature levels not matching / heat sources not available

  Public

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Heat pumps for process heat applications

Economical aspect of heat pumps

- Barriers for the usage of industrial heat pumps
  - Needed Temperatures are too high
  - High manufacturing costs -> Higher capital expenditures (short CAPEX)

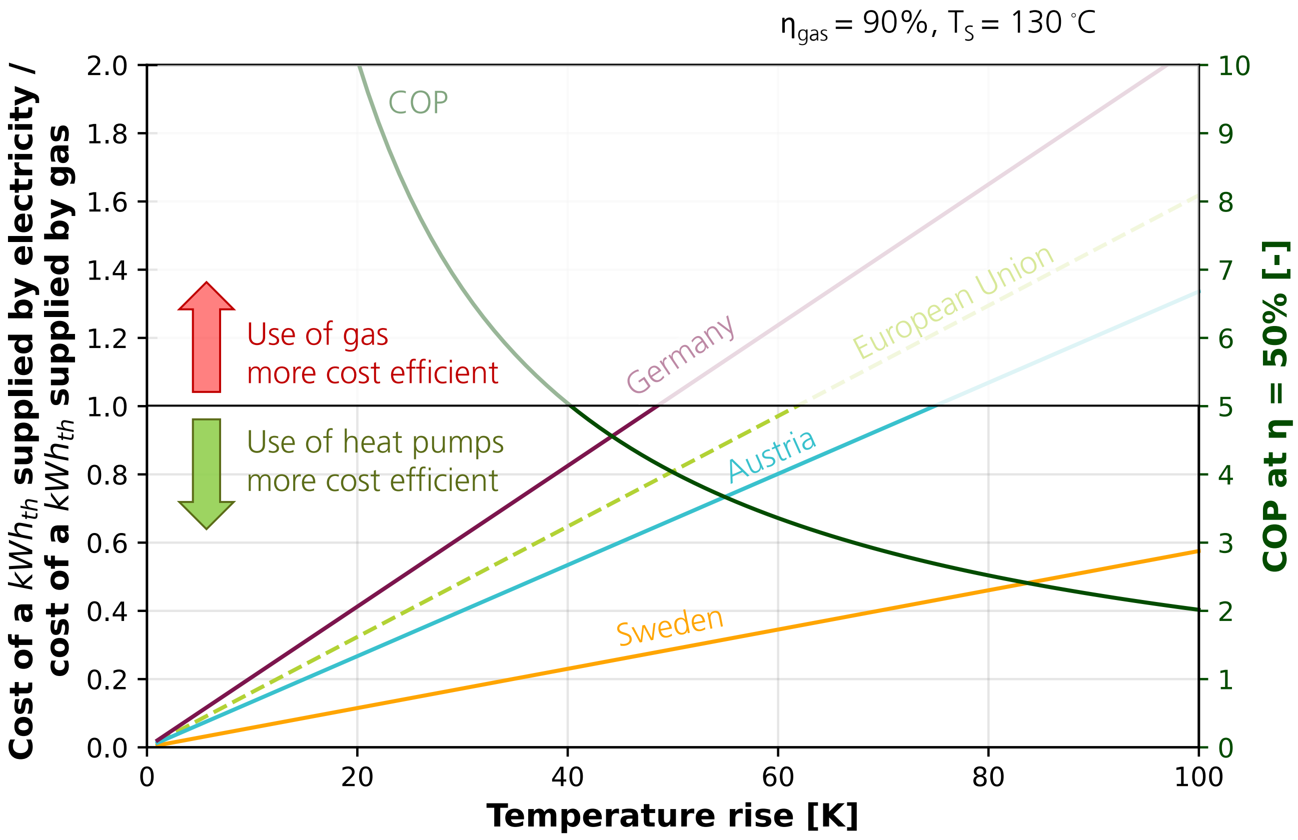
Long payback times, gas often the cheaper option

operational expenditures (short OPEX) dependent on the energy prices

	Cost of kWh_electricity [€]	Cost of kWh_gas [€]	Ratio [-]
Sweden	0.13	0.13	1.04
Austria	0.17	0.07	2.42
EU	0.20	0.07	2.94
Germany	0.18	0.05	3.74

[Source: eurostat2022, non-households]

OPEX:



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Summary

High potential for waste heat upgrade with High-Temperature Heat Pumps (HTHP)

Decarbonization of process heat up (<200°C)

R&D needed for reaching high supply temperatures (>150°C), MVR Systems, operational flexibility

Fraunhofer IEG on the front field regarding

- **Development of HTHPs (process simulation, compressors, refrigerant selection)**
- **Deployment, implementation, integration and monitoring**
- **Technoeconomic analysis**

Thank you for the attention

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