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# High-Temperature Heat Pumps Update

6 March 2024, Webinar

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  - Leon Brendel, PhD
  - Michael Uhlmann
  - Prof. Stefan Bertsch, PhD



## Content

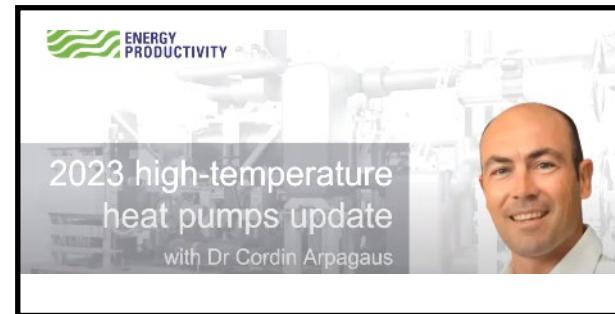
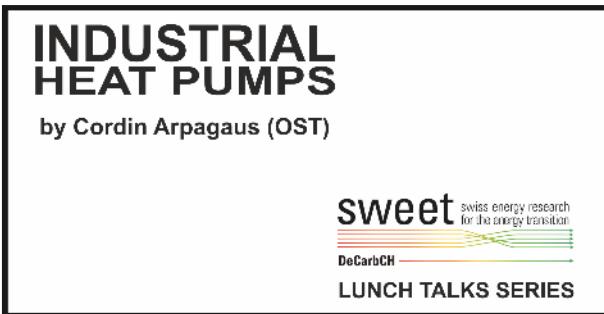
- Motivation
- State of the Art
- Realized Examples
- Sustainable Refrigerants
- Business Models
- Economic Conditions
- Summary and Conclusions

**“The engineers help me with my presentation!”**



To get started

# YouTube Videos on High-Temperature Heat Pumps



To get started

## Webinar on 18 March 2024



Registration [[link](#)]:  
[www.sweet-decarb.ch](http://www.sweet-decarb.ch) → Events

The programme for the webinar is as follows:

- 18 March 2024 → registration link ←
- PROGRAM**
- 13:30 Introduction  
Dennis Roskosch  
CO<sub>2</sub>-neutral process steam for industry: Model-based analysis of technologies and strategies
- 14:05 C. Latham & M. Vandevorde  
Transforming air compressor energy into process value for steam compression
- 14:25 Ch. Schlemminger & M. Bantle  
Integration of a 1.6 MW steam supplying heat pump into the feed production process
- 14:45 Martin Pihl Andersen  
Testing and modelling of a steam-generating heat pump at up to 175 °C (SuPrHeat project)  
*10 min break*
- 15:15 Wouter de Vries  
Demonstration of a full-scale industrial heat pump producing steam above 140 °C
- 15:35 Mogens Weel  
High temperature heat pump test result and further development of high speed centrifugal compressors for steam production
- 15:55 Hans Madsbøll  
Steam compressor technology and development: a general overview
- 16:15 Arne Høeg  
Decarbonizing industry with stirling-cycle steam generating heat pumps
- 16:35 Wrap-up & Conclusions

Logos of participating institutions are displayed around the programme:

- OST (Eastern Switzerland University of Applied Sciences)
- IESI (Institut für Energiesysteme)
- ETH Zürich
- Atlas Copco
- ANEO
- DTU
- TNO innovation for life
- Weel & Sandvig
- TEKNOLOGISK INSTITUT
- enerin

To get started

Webinar on 14 March 2024

# Sustaining success of industrial heat pumps – a call to action!

14 March 2024 | 10:00 - 12:00 CET | Teams webinar



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the European Union

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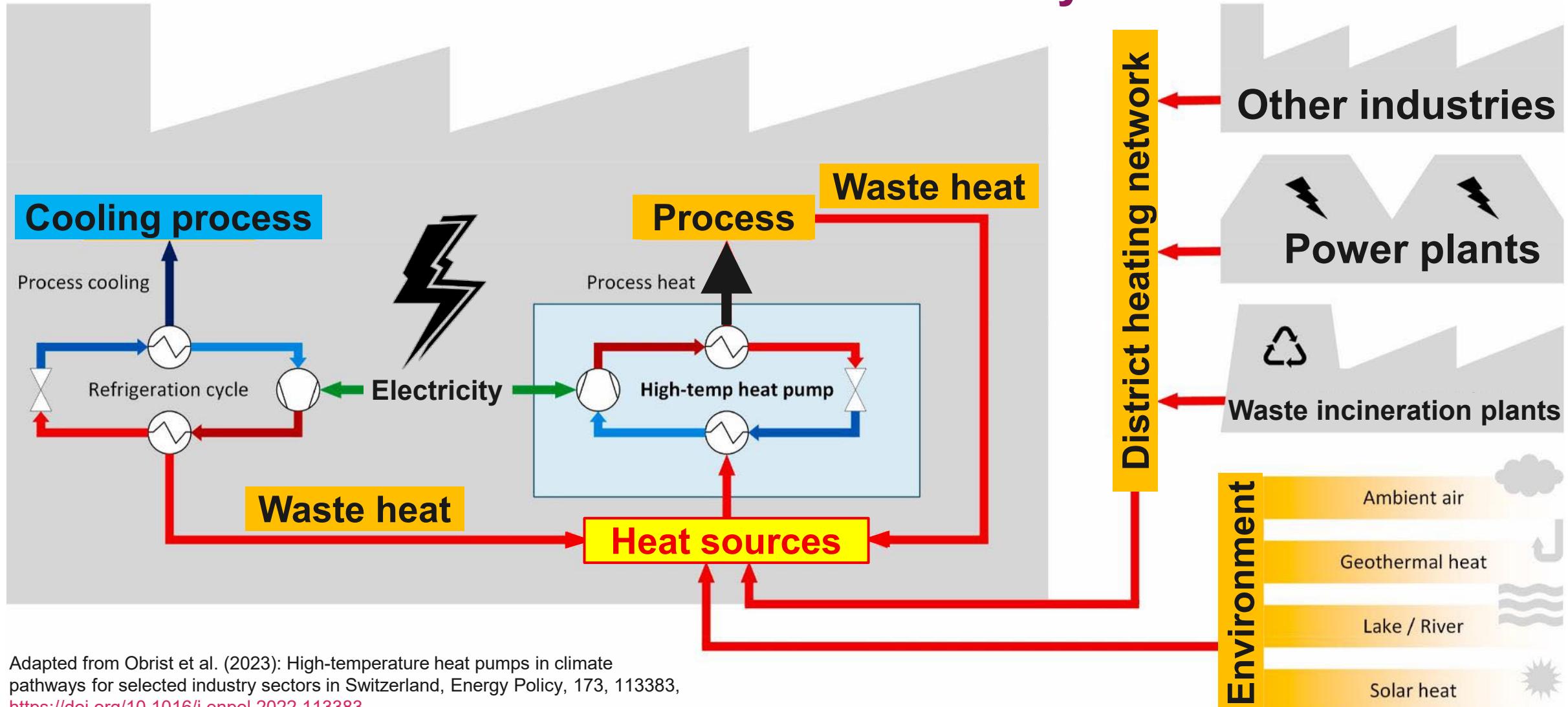


Registration [[link](#)]

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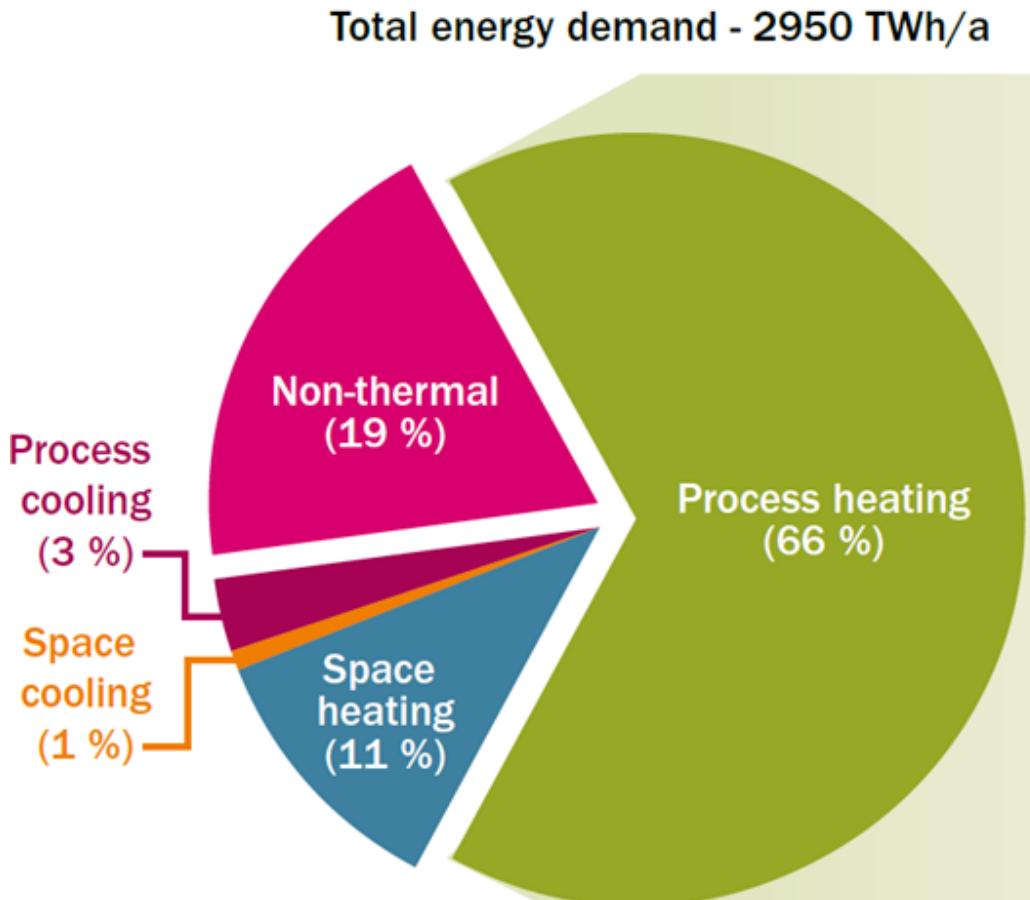
## Motivation

# Potential heat sources for HTHPs in industry

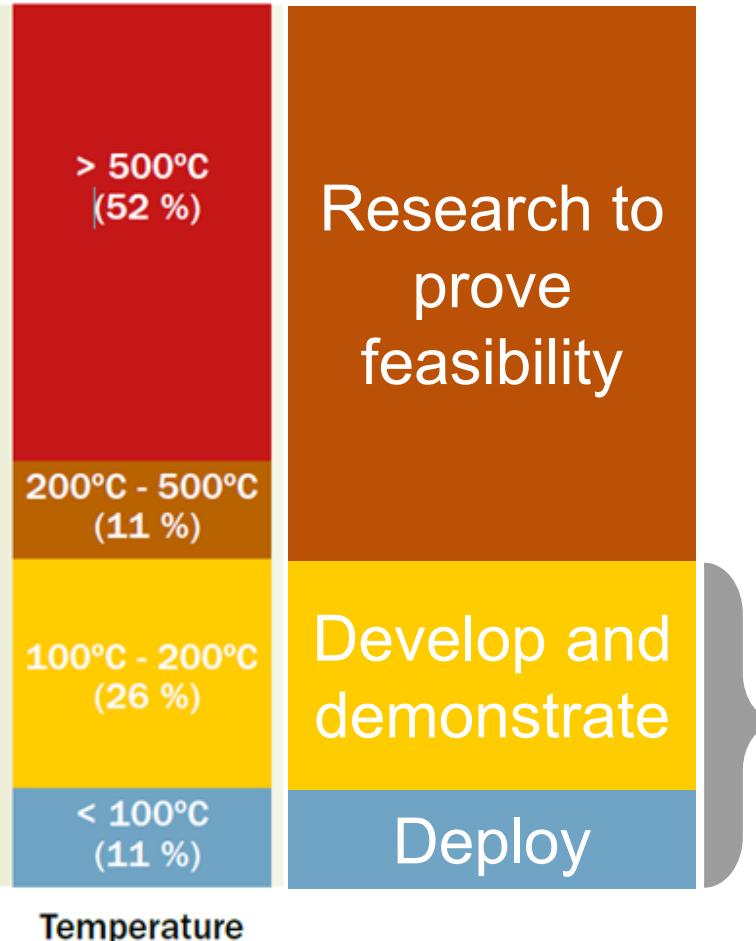


## Motivation

# Process Heat Demand in the European Industry



Process heating demand - 1952 TWh/a



Heat pumps are identified as a key technology for the decarbonization of this share of the industrial heat supply (< 200 °C)



37% of process heat of European industry is < 200 °C (730 TWh/a)

Source: De Boer et al. (2020): White Paper, [Strengthening Industrial Heat Pump Innovation, Decarbonizing Industrial Heat](#)

## Motivation: Process heat consumption & temperature levels

# Europe EU-28 – Industrial sectors

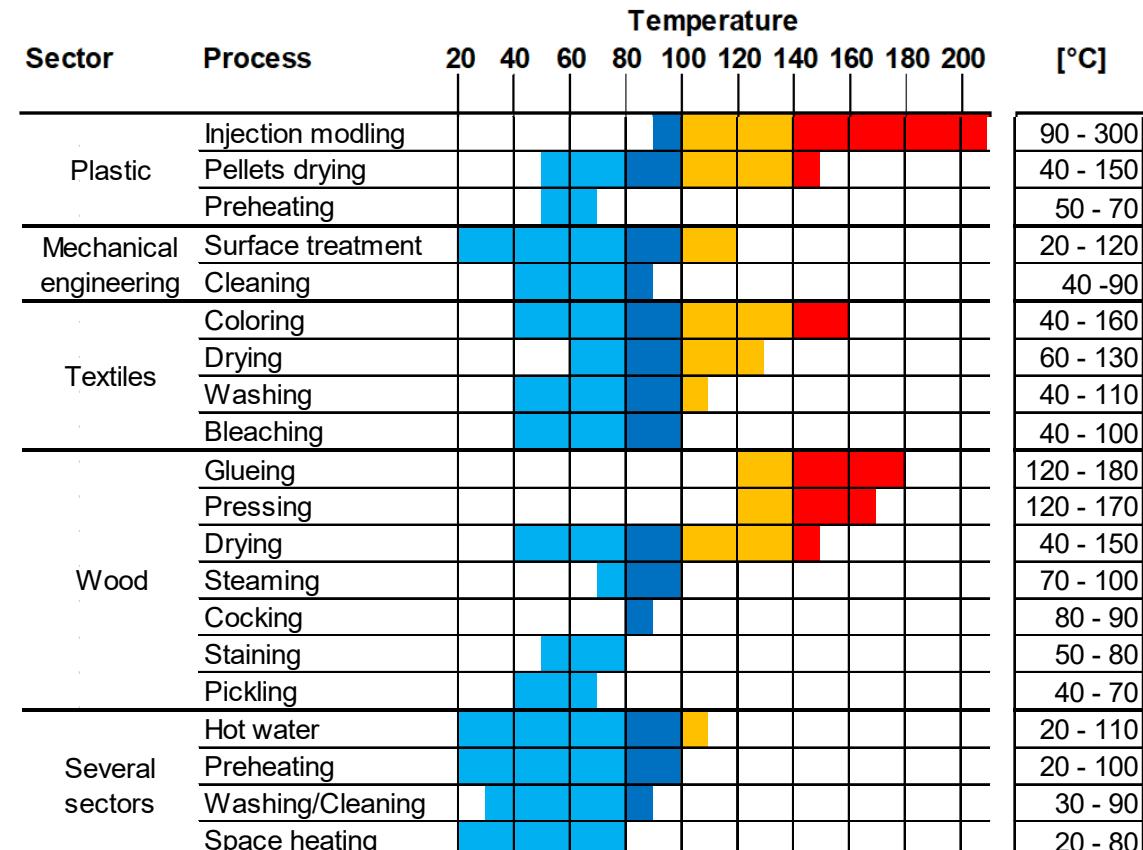
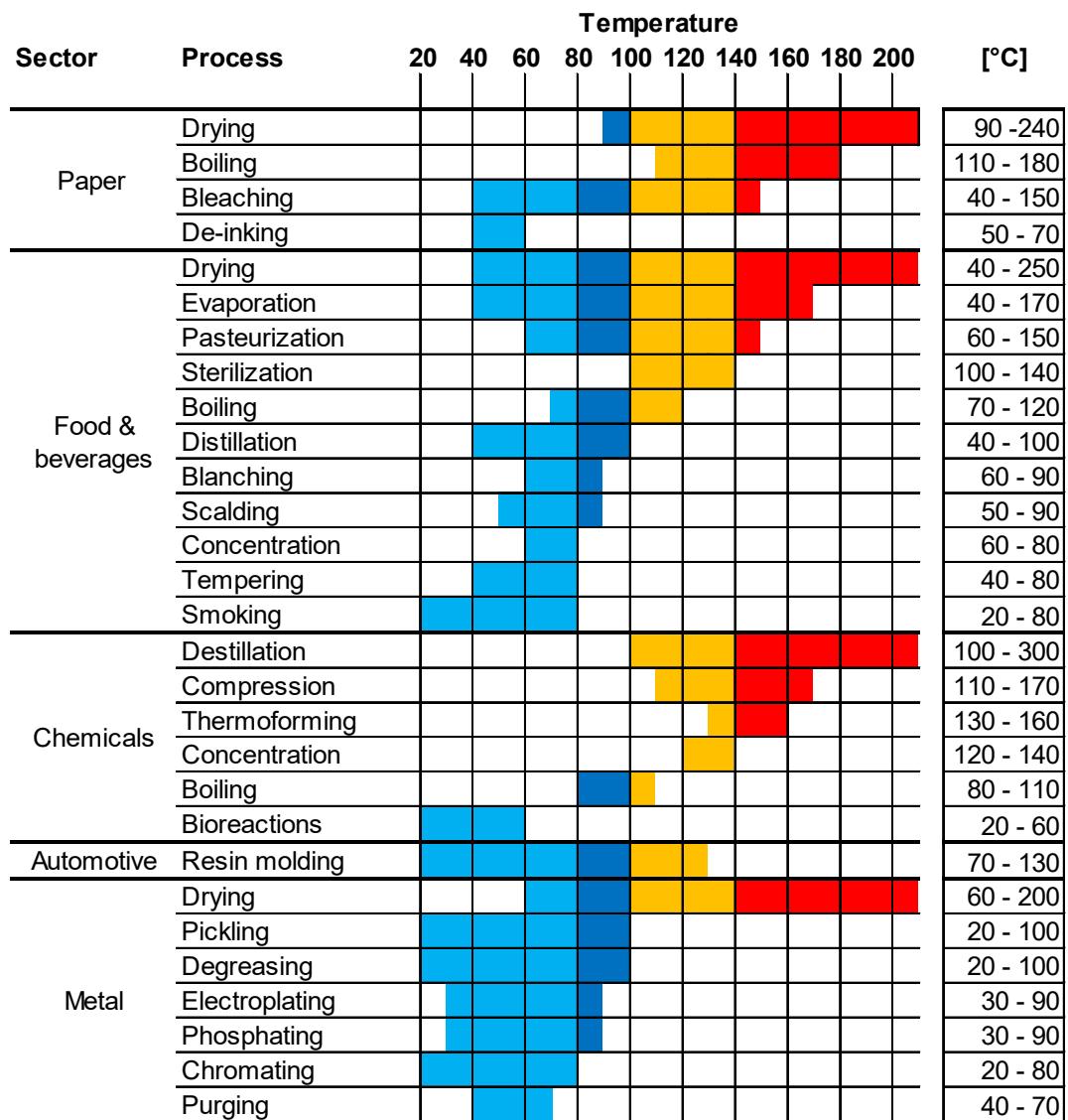
	Heat Consumption (TWh/a)	EU-28
Process heat	Space heating	297 16%
	Hot water	25 1%
	PH <60 °C	55 3%
	PH 60 to 80 °C	53 3%
	PH 80 to 100 °C	89 5%
	PH 100 to 150 °C	192 11%
	PH 150 to 200 °C	80 4%
	PH 200 to 500 °C	151 8%
	PH 500 to 1'000 °C	376 21%
	PH >1'000 °C	504 28%
	Total Heat Consumption (TWh/year)	1'821 100%
	Total Process Heat <60 °C to >1'000 °C (TWh/year)	1'499
	<b>Total Process Heat 90 °C to 160 °C (TWh/year)</b>	<b>237 16%</b>

Industrial sector	Process Heat Consumption (TWh/a)	
	PH 100 to 150 °C	PH 150 to 200 °C
Iron and steel	19.8	7.3
Chemical	19.3	15.4
Non-ferrous metal	2.7	1.0
Non-metallic minerals	36.5	0.0
Food and tobacco	68.0	8.8
Paper, pulp and print	10.0	39.4
Machinery	6.9	2.9
Wood and wood products	0.2	0.7
Transport equipment	1.2	0.2
Textile and leather	6.9	0.0
Other	19.1	4.2
<b>Total</b>	<b>191</b>	<b>80</b>

Data source: Kosmadakis (2019): Estimating the potential of industrial (high-temperature) heat pumps for exploiting waste heat in EU industries, Applied Thermal Engineering, 156, 287-298, <https://doi.org/10.1016/j.applthermaleng.2019.04.082>

## Motivation: Potential applications

# Temperature levels of industrial processes



### Technology Readiness Level (TRL):

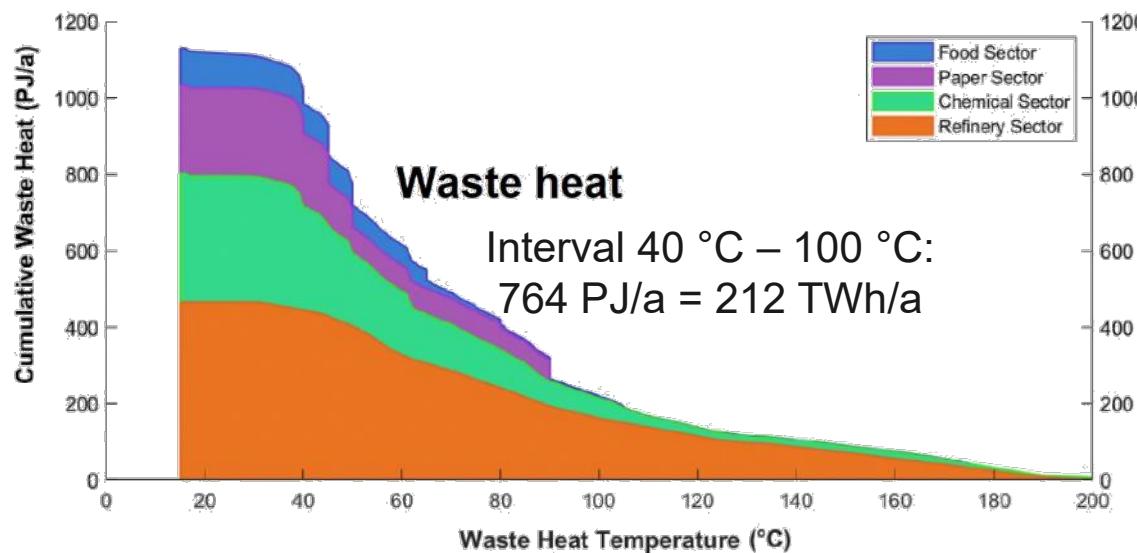
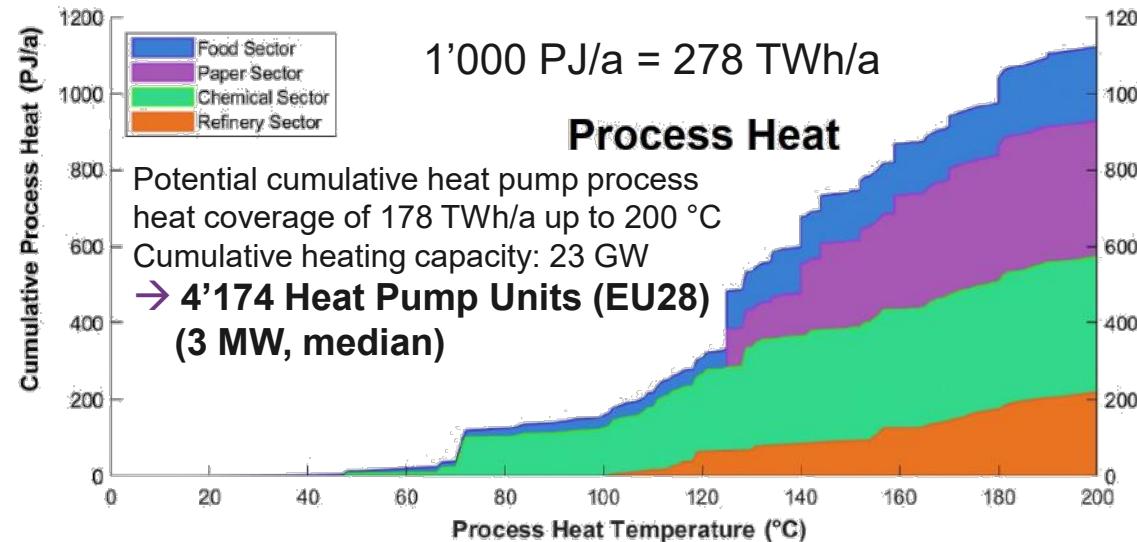


- conventional HP < 80°C, established in industry
- commercial available HP 80 - 100°C, key technology
- prototype status, technology development, HTHP 100 - 140°C
- laboratory research, functional models, proof of concept, VHTHP > 140°C

Source: Arpagaus et al. (2018): Review on High-Temperature Heat Pumps,  
<https://doi.org/10.1016/j.energy.2018.03.166>

## Motivation

# The Role of High-Temperature Heat Pumps (HTHP)



The heat pump market potential to 200 °C is large:

- Highest potential in the **food, paper, and chemical sectors**
- Available **waste heat** between 40 °C and 100 °C is estimated to be 212 TWh/a (764 PJ/a) (EU28)
- ... but still, **the actual market of industrial heat pumps is emerging**

Source: Marina et al. (2021): An estimation of the European industrial heat pump market potential, Renewable and Sustainable Energy Reviews, 139, 110545, <https://doi.org/10.1016/j.rser.2020.110545>

## Comparison of different HTHP supplier technology



Technology Collaboration Programme  
by IEA

Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Annex 58

High-Temperature Heat Pumps

Task 1 – Technologies

Final Report

Operating Agent:  
Benjamin Zühsdorf, PhD  
Danish Technological Institute

August 2023  
Report no. HPT-AN58-2

### Task 1 report

[https://heatpumpingtechnologies.org/  
annex58/task1](https://heatpumpingtechnologies.org/annex58/task1)

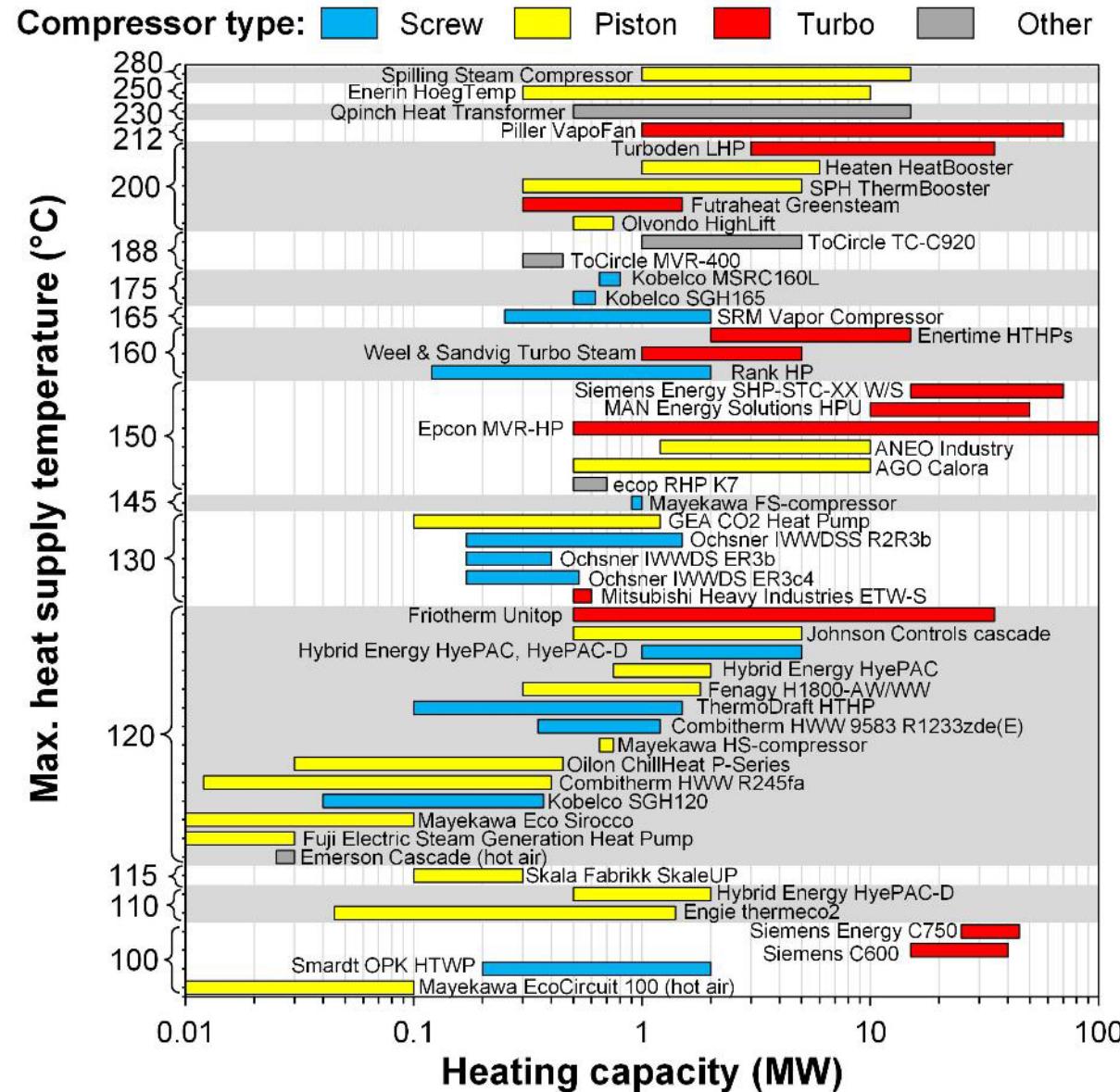
Report content:

- Background information on HTHPs
- Review of supplier technologies
- Review of demonstration cases
- National perspectives for 13 countries
- Technology development perspectives

### Fact sheets about the HTHP technology

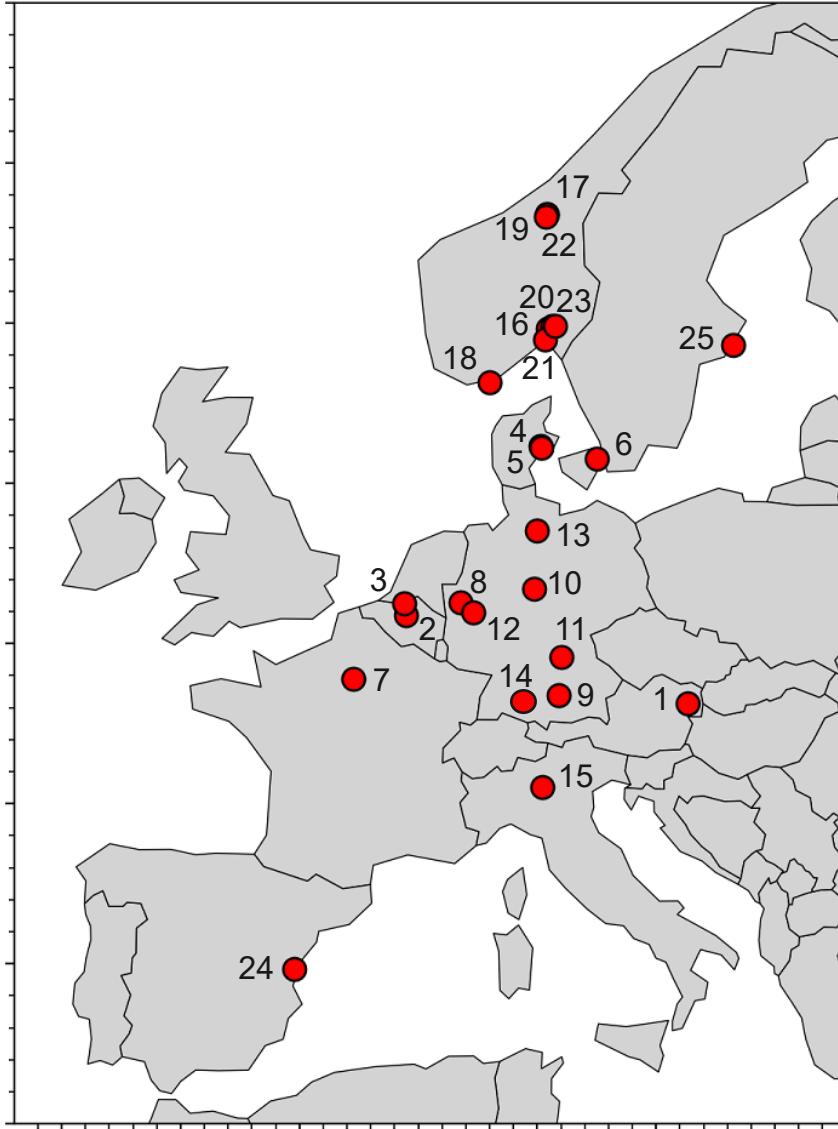
- Performance data
- Capacity range
- Temperature range
- Working fluid (refrigerant)
- Compressor technology
- Specific investment costs
- TRL level
- Expected lifetime (years)
- Size (weight, footprint)
- Project examples

# HTHP technology for supply temperatures above 100 °C



# Commercial High-Temperature Heat Pumps for Supply Temperatures > 100 °C

## Headquarters of HTHP suppliers in Europe



cordin.arpagaus@ost.ch

- |    |                       |
|----|-----------------------|
| 1  | Ecop (AT)             |
| 2  | Mayekawa MYCOM (BE)   |
| 3  | Qpinch (BE)           |
| 4  | Fenagy (DK)           |
| 5  | Johnson Controls (DK) |
| 6  | Weel and Sandvig (DK) |
| 7  | Enertime (FR)         |
| 8  | GEA (DE)              |
| 9  | MAN (DE)              |
| 10 | Piller (DE)           |
| 11 | Siemens (DE)          |
| 12 | SPH (DE)              |
| 13 | Spilling (DE)         |
| 14 | Combitherm (DE)       |
| 15 | Turboden (IT)         |
| 16 | Enerin (NO)           |
| 17 | Epcon (NO)            |
| 18 | Heaten (NO)           |
| 19 | Hybrid Energy (NO)    |
| 20 | ANEO (NO)             |
| 21 | Olvondo (NO)          |
| 22 | Skala Fabrikk (NO)    |
| 23 | ToCircle (NO)         |
| 24 | Rank (ES)             |
| 25 | SRM (SE)              |

## Japan

- |    |                 |
|----|-----------------|
| 26 | Fuji (JP)       |
| 27 | KOBELCO (JP)    |
| 28 | Mitsubishi (JP) |



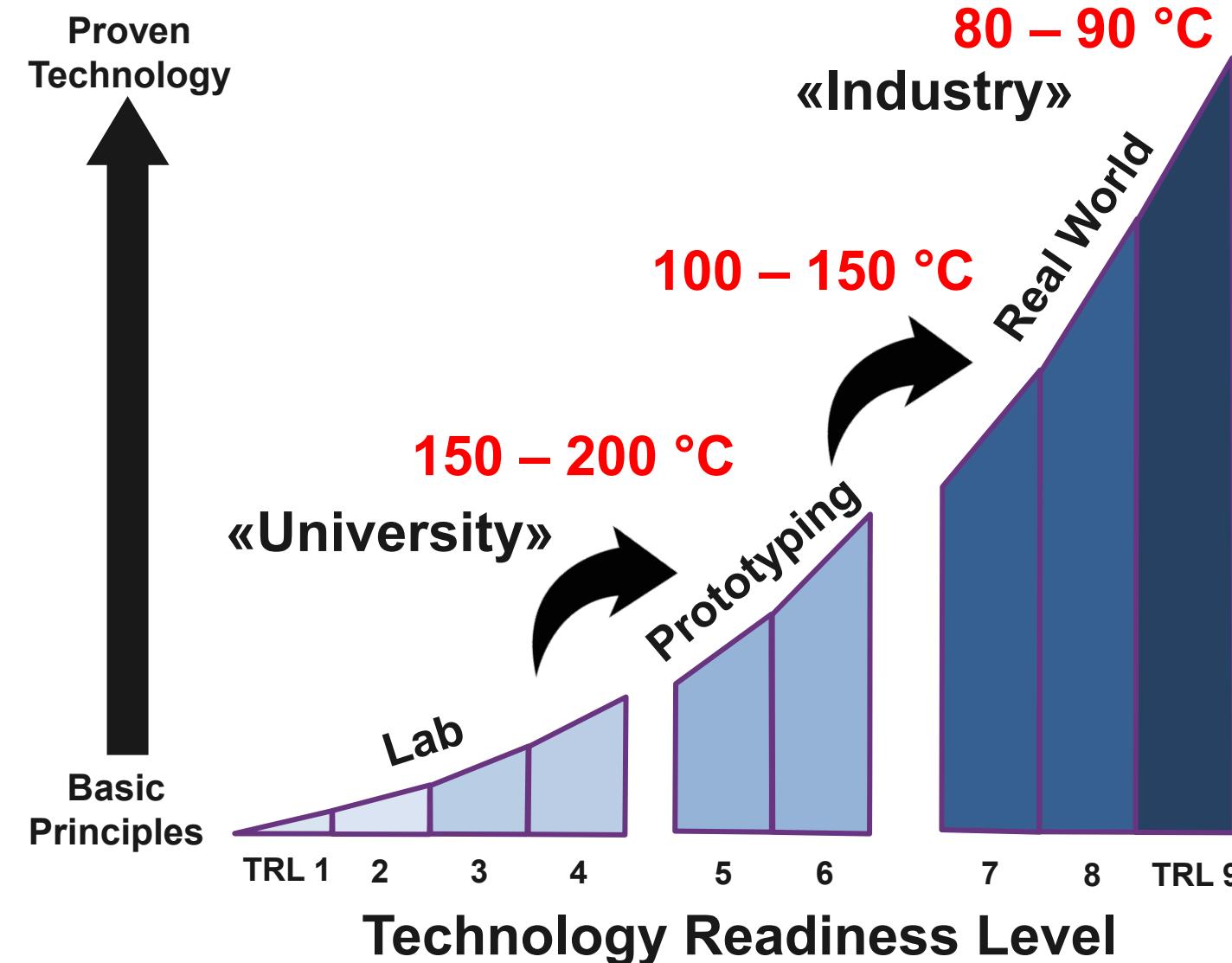
Based on database of  
IEA HPT Annex 58:

<https://heatpumpingtechnologies.org/annex58/task1>



## Technology Readiness: HTHP Technologies

# What is the Technology Readiness Level (TRL) of HTHP ?



## Technology Readiness Levels (TRL)

TRL 9	Actual system proven in operational environment
TRL 8	System complete and qualified
TRL 7	System prototype demonstration in operational environment
TRL 6	Technology demonstrated in relevant (industrial) environment
TRL 5	Technology validated in relevant (industrial) environment
TRL 4	Technology validated in lab
TRL 3	Experimental proof of concept
TRL 2	Technology concept formulated
TRL 1	Basic principles observed

Source: TRL scale definition in Horizon Europe projects,  
[https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014\\_2015/annexes/h2020-wp1415-annex-g-trl\\_en.pdf](https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf)

# HTHP Technologies Indicated TRL levels

- 23 market available (TRL 8-9)
- 7 prototype and demonstration systems (TRL 6-7)
- 3 lab/small-scale prototypes (TRL 4-5)

Data source: IEA HPT Annex 58

<https://heatpumpingtechnologies.org/annex58/task1>

## Note:

All information has been provided by the suppliers without third-party validation.

The information was provided as an indicative basis and may be different in final installations depending on application-specific parameters.

HTHP supplier (High-Temperature Heat Pump)	Product	Max. heating capacity (MW)	Max. supply temp. (°C)	TRL (Technology Readiness Level)								
				1	2	3	4	5	6	7	8	9
Spilling	Steam Compressor	15	280									9
Enerin	HoegTemp	10	250								6	
Qpinch	Heat Transformer	2	230									9
Piller	VapoFan	70	212								8	9
Olvondo	HighLift	5	200									9
Turboden	LHP	30	200							7	8	9
ToCircle	TC-C920	5	188						6	7		
Kobelco MSRC160	MSRC160	0.8	175									9
Kobelco SGH165	SGH165	0.62	175									9
Heaten	HeatBooster	6	165							7	8	9
SPH	Thermonbooster	5	165						6	7	8	
SRM	Compressor for water vapor	2	165						5			
Siemens Energy	Industrial Heat Pump	70	160									9
Enertime	HTHPs	10	160					4	5	6	7	8
Weel & Sandvig	WS Turbo Steam	5	160					4	5	6	7	8
Rank	Rank® HP	2	160								7	
MAN	ETES CO <sub>2</sub> Heat Pump	50	150							7	8	
Epcon	MVR-HP	30	150									9
Ohmia Industry	SPHP	10	150						7	8		
ecop	Rotation Heat Pump K7	0.7	150					6	7			
Mayekawa FC Comp	FC-compressor	1	145					5				
GEA Refrigeration	CO <sub>2</sub> Heat Pump	1.2	130							8		
Mitsubishi Heavy Ind.	ETW-S	0.6	130								9	
Hybrid Energy	HyPAC-S	5	120								9	
Johnson Controls	Cascade Heat Pump System	5	120					7	8			
Fenagy	H1800-AW/WW	1.8	120					5	6			
Mayekawa HS Comp	HS-compressor	0.75	120						7			
Kobelco SGH120	SGH120	0.37	120							9		
Mayekawa EcoSirocco	Eco Sirocco	0.1	120							9		
Fuji Electric	Steam Generation Heat Pump	0.03	120							9		
Emerson	Cascade Solution	0.03	120					6				
Skala Fabrikk	SkaleUP	0.3	115						7			
Mayekawa EcoCircuit	Eco Circuit 100	0.1	100							8	9	

**Other suppliers:**

- Ago Calora (150 °C)
- Ochsner (130 °C)
- Oilon (120 °C)
- PureThermal (120 °C)
- ThermoDraft (120 °C)
- Combitherm (120 °C)
- ...

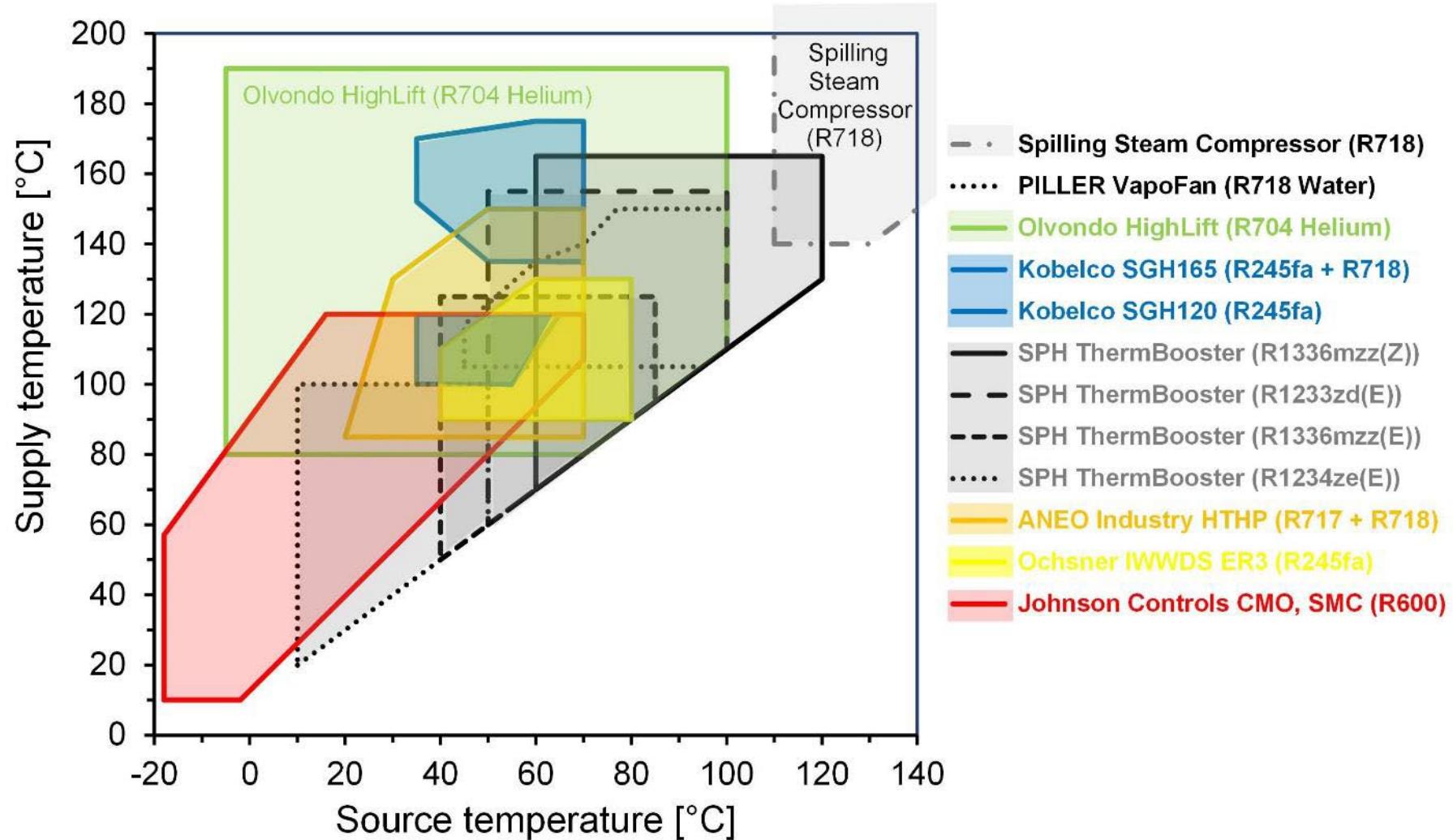
## Large-scale:

- Frioetherm
- MAN Energy Solutions
- Turboden
- Mitsubishi MHPS
- Siemens Energy
- ...



# Commercial High-Temperature Heat Pumps for Supply Temperatures > 100 °C

## Operating maps of some industrial HTHPs

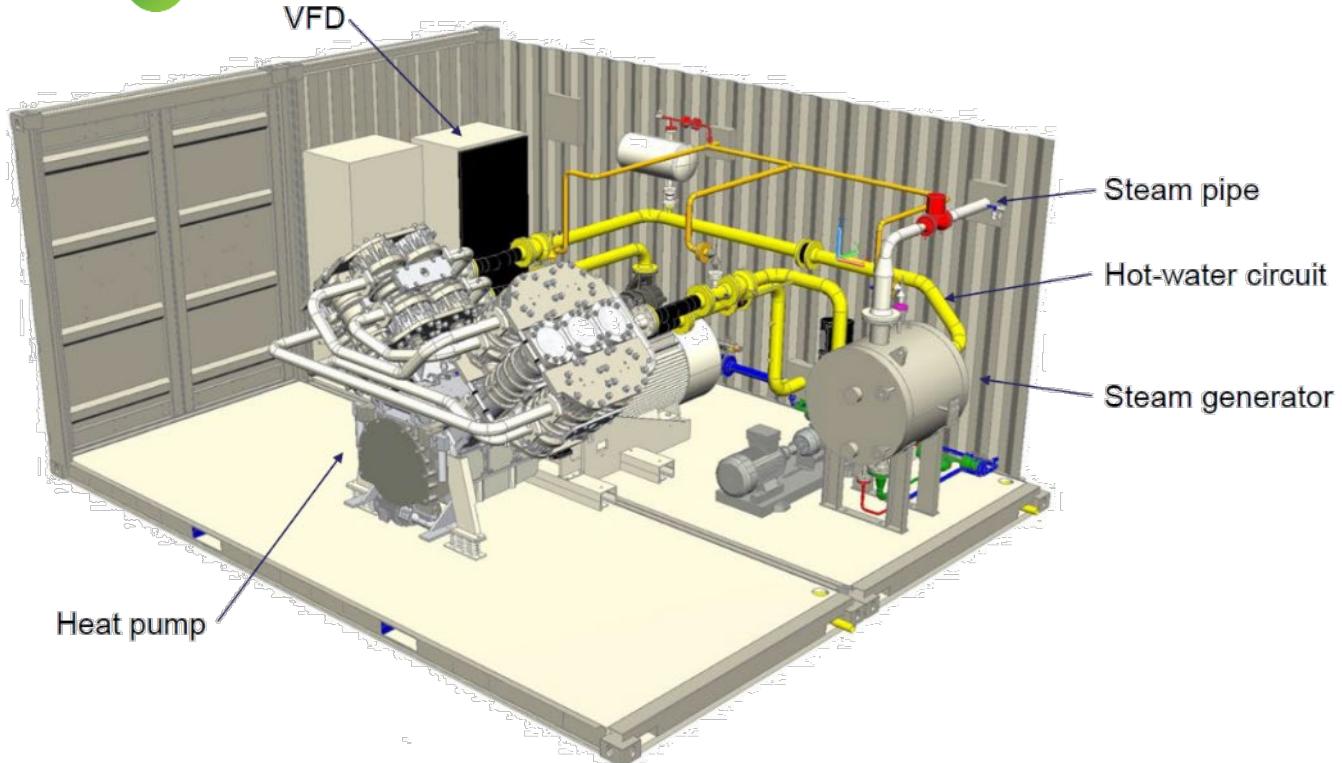


# Commercial High-Temperature Heat Pumps for Supply Temperatures > 100 °C



## HoegTemp heat pump

*HoegTemp means  
“high temperature” in Norwegian*



- 6-cylinder stirling-cycle heat pump
- R704 (helium) = inert, zero GWP, zero ODP
- Heating capacity: 400 kW

Sources: <https://www.enerin.no/hoegtemp>,  
<https://susheat.eu/half-of-2050-energy-mix-from-heat-pumps-heaters>,  
<https://susheat.eu/ht-hp-enerin>

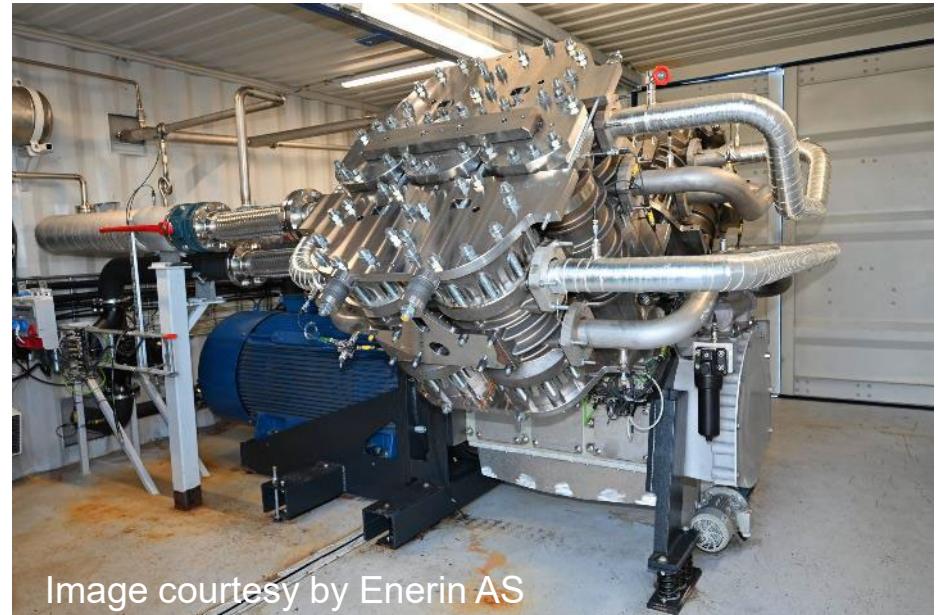


Image courtesy by Enerin AS

- Pilot at IVAR Grødaland to supply steam for CO<sub>2</sub> removal from biogas
- Steam 2 bar(g) 134°C
- Installed in June 2023, automatic operation since August 2023

# Commercial High-Temperature Heat Pumps for Supply Temperatures > 100 °C



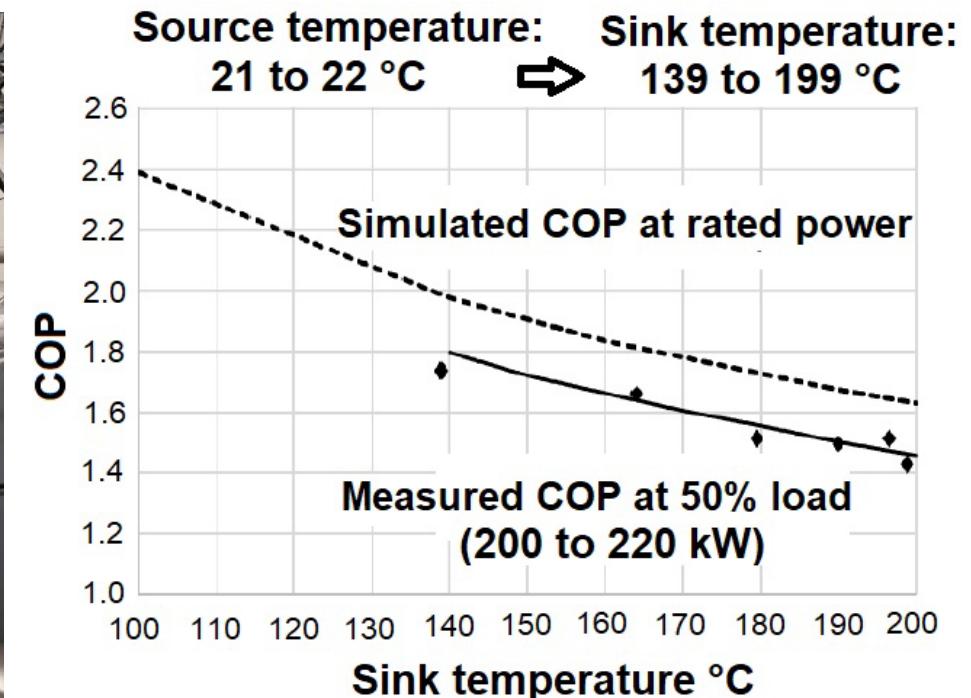
## HoegTemp heat pump



Image courtesy by Enerin AS

### Sources:

- Høeg, A., Løver, K., Vartdal, G., Enerin AS (2024), Performance of a High-Temperature Industrial Heat Pump using Helium as Refrigerant, High-Temperature Heat Pump Symposium 2024, Copenhagen
- Høeg, A., Løver, K., Asphjell, T.A. (2023): [Performance of a new ultra-high temperature industrial heat pump, 14<sup>th</sup> IEA Heat Pump Conference, Chicago, USA, 15 May 2023](#)



### Next steps:

- Commercial installations 2024
- Performance mapping to 250 °C (EU-funded [SUSHEAT project](#))

New Developments and Products for Supply Temperatures above 100 °C

## Steam generating version of the ThermBooster™



Image courtesy by SPH Sustainable Process Heat GmbH



- High-temperature 4-cylinder piston compressor (multiple possible)
- Heating capacity: 400 kW to 1 MW (dependinig on operating point)
- Synthetic refrigerants: R1233zd(E), R1336mzz(E), R1336mzz(Z)
- Max. steam pressure: 6 bar(a), 165 °C



New Developments and Products for Supply Temperatures above 100 °C

## Laboratory for testing the ThermBooster™

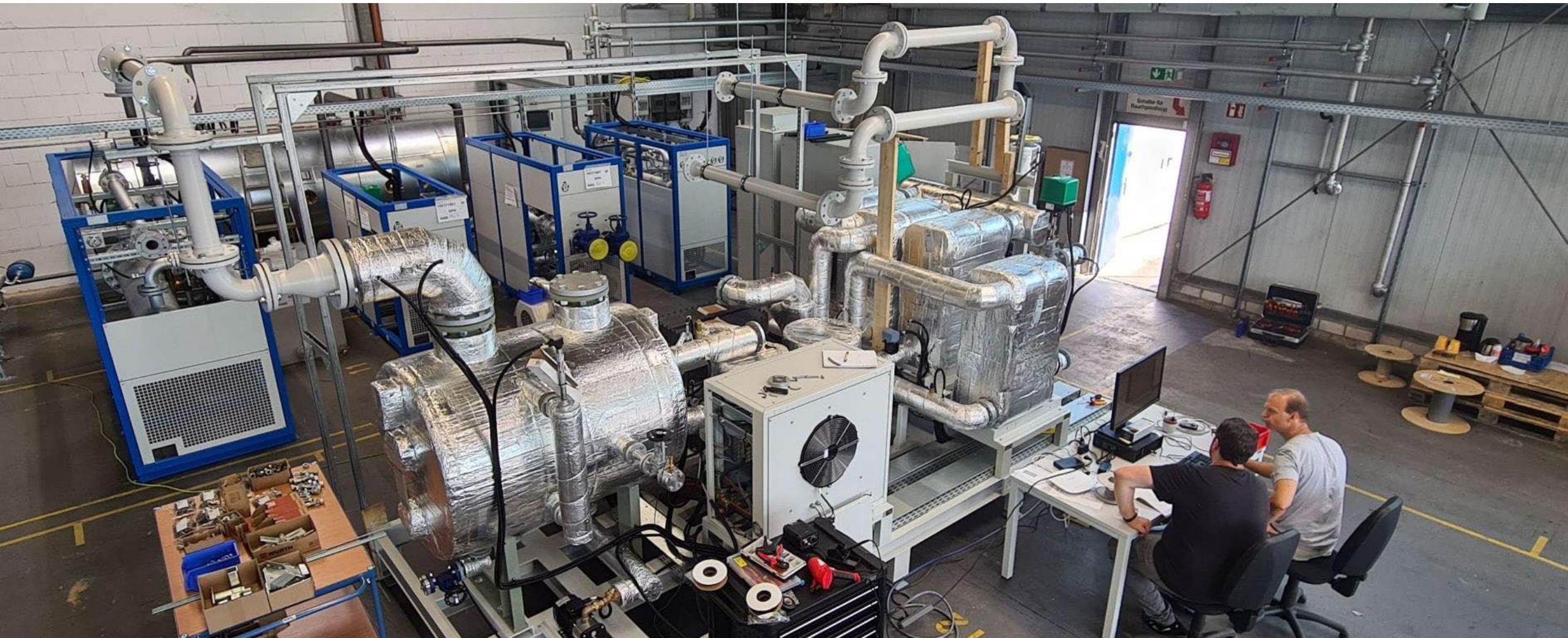
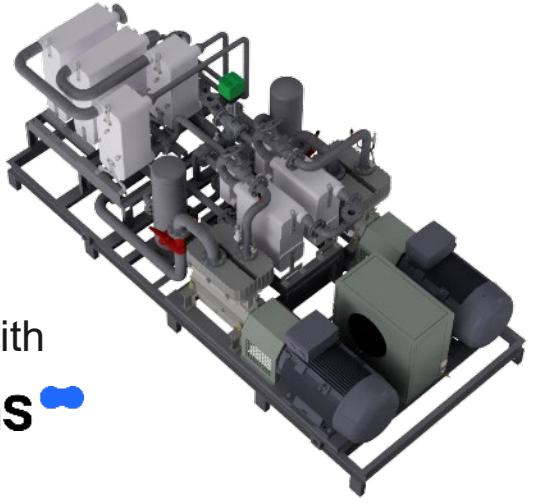


Image courtesy by SPH Sustainable Process Heat GmbH

## New Developments and Products for Supply Temperatures above 100 °C

# References of the ThermBooster™ (Q1/2024)

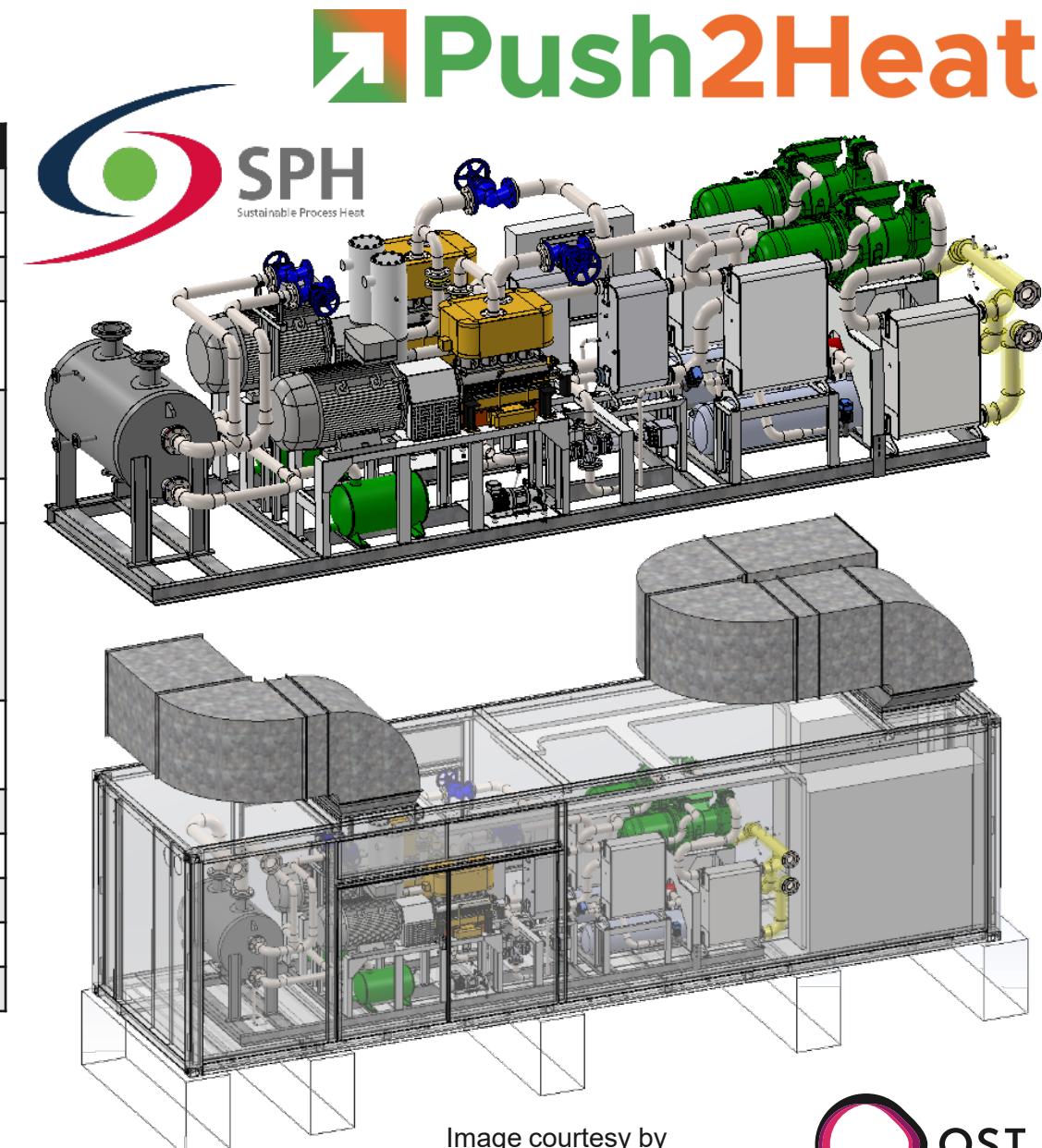
Application	Gelatine	Thermoplastic from waste
Heat source	85/70 °C	75/65 °C (water)
Heat sink	812 kg/h steam at 2 bar	90/130 °C (hot water) for drying process
Heating capacity	514 kW	1'017 kW (2 cycles)
Cooling capacity	407 kW	809 kW
Electrical power	118 kW	229 kW (2 compressors)
COP	4.4	4.4
Energy savings	4.1 GWh <sub>th</sub> /a	1.25 Mio. m <sup>3</sup> gas/a
CO <sub>2</sub> emission reduction	550 t CO <sub>2</sub> /a	~2'400 t CO <sub>2</sub> /a
	 In cooperation with  Energy AG	  In cooperation with <b>technotrans</b> 

## Steam-Generating Heat Pump

<b>Industry sector</b>	<b>Demo 1: Paper industry</b>
<b>Plant owner</b>	Felix Schoeller Group
<b>Location</b>	Weissenborn, Germany
<b>Heat pump supplier</b>	SPH
<b>Heat pump technology</b>	2-stage cascade with piston and screw compressors
<b>Refrigerants (1<sup>st</sup> stage, 2<sup>nd</sup> stage)</b>	2 x 180 kg R515B, 350 kg R1233zd(E)
<b>Size (L x W x H)</b>	11 x 3 x 3 m (in container)
<b>Heat source inlet / outlet (waste heat)</b>	46 °C / 41 °C (exhaust humid air from paper machine dryer using a water-glycol circuit)
<b>Heat sink inlet / outlet</b>	90 °C / 123.5 °C (low-pressure steam at 2.2 bara)
<b>Heating capacity</b>	1'180 kW
<b>Steam mass flow rate</b>	1'800 kg/h
<b>Cooling capacity</b>	690 kW
<b>Electrical power</b>	517 kW
<b>COP (Carnot efficiency)</b>	2.3 (43%)



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 the European Climate Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.



## Steam generator and condenser from

**VAHTERUS**

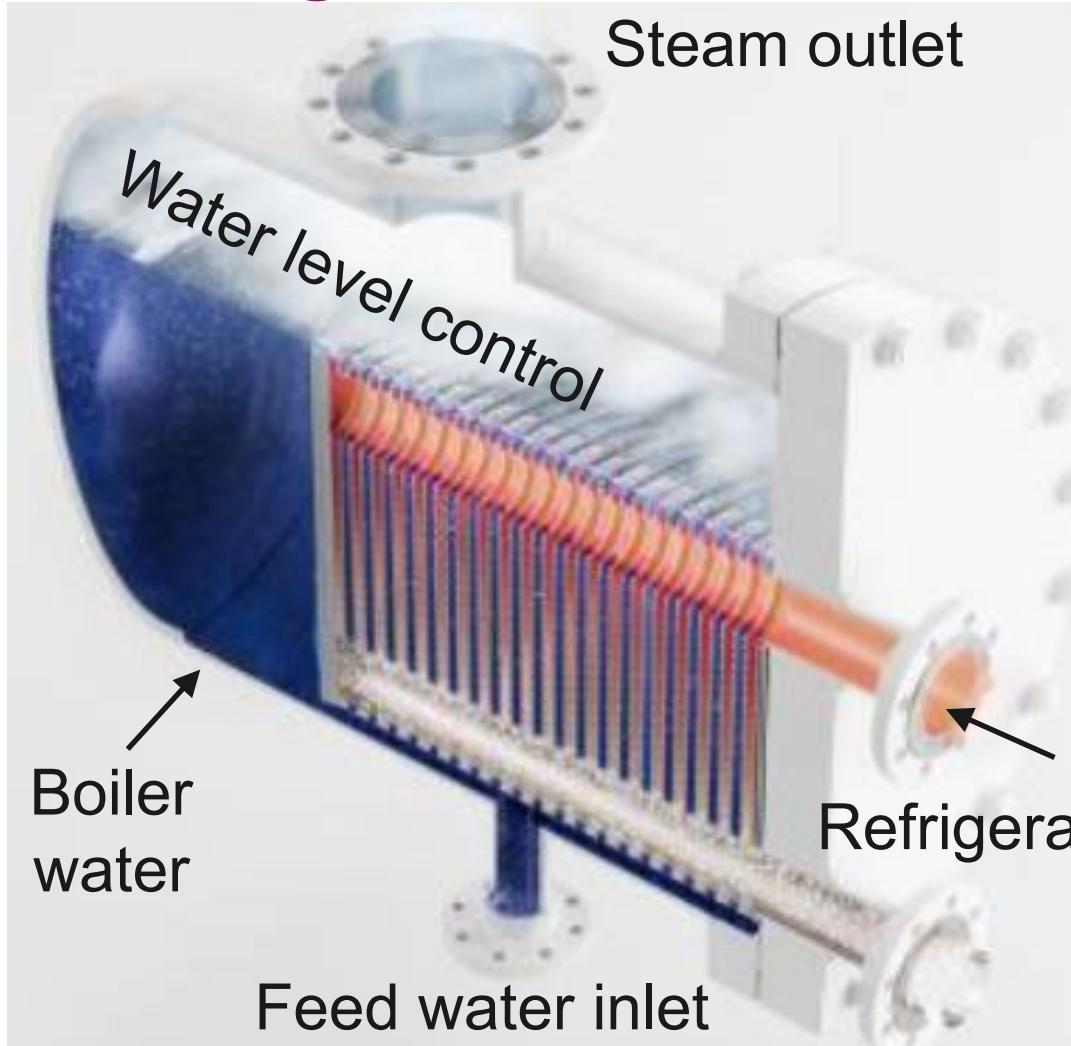
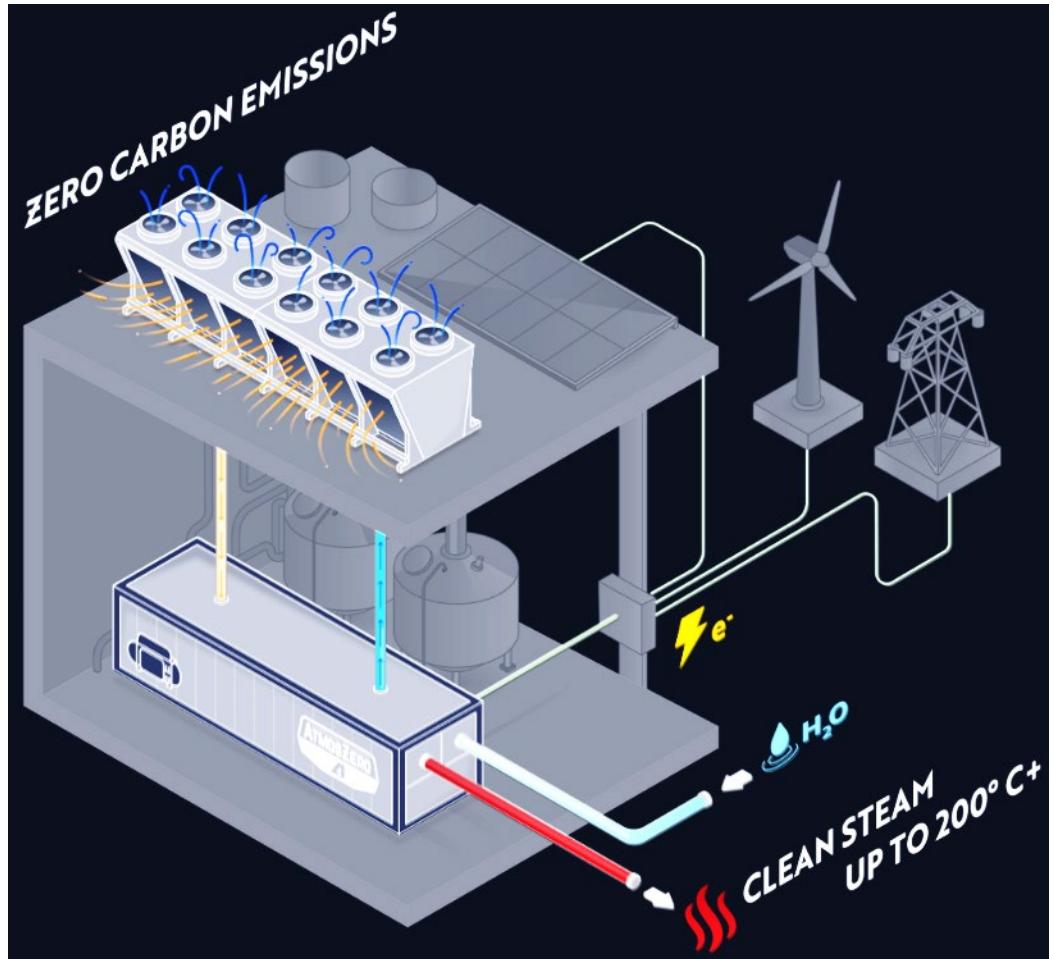


Image courtesy by Vahterus

# New Developments and Products for Supply Temperatures above 100 °C

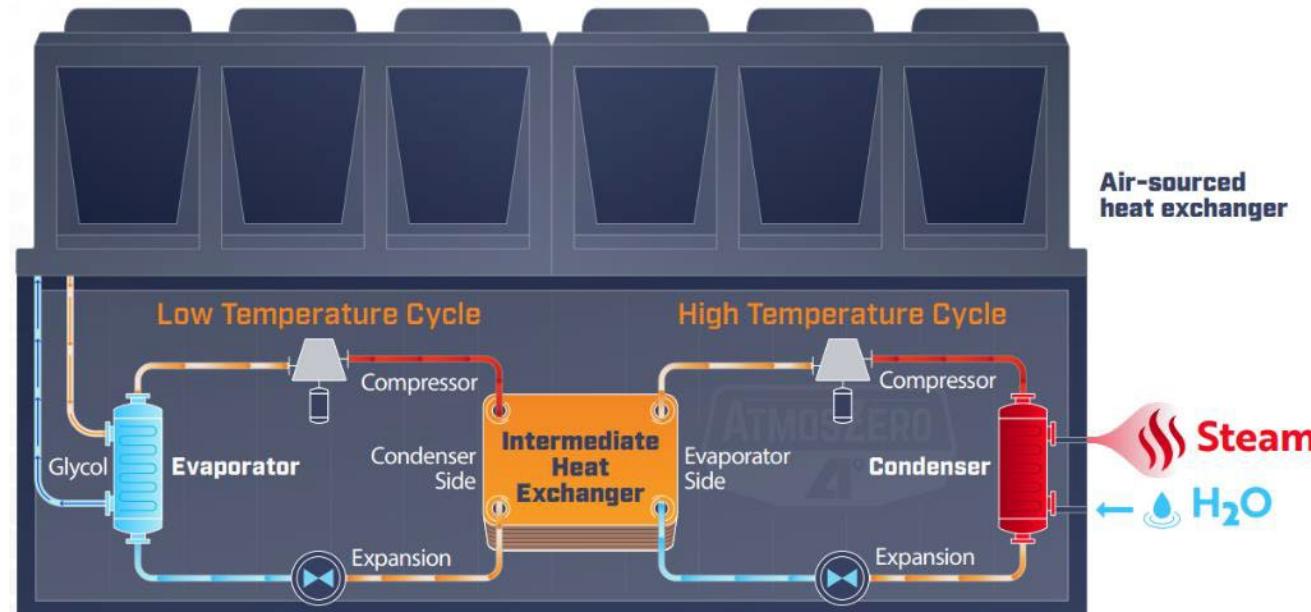


## AtmosZero Boiler 2.0



Source: <https://atmoszero.energy/technology>

Salvi, A., Bandhauer, T., Roberts, N., Malloy, E., Siegel, M., Huyett, J., Joekes, D., Stark, A. (2024): Technoeconomic analysis of electrified boiler technologies to decarbonize industrial steam, High-Temperature Heat Pump Symposium 2024, Copenhagen



# Commercial High-Temperature Heat Pumps for Supply Temperatures > 100 °C



AHASCRAUGH  
DISTILLERY

Ahascragh Distillery  
2.703 Follower:innen  
1 Jahr • Bearbeitet •

Some major equipment arrivals over the past few days.

The last of our heat pump equipment is in place. This technology is a first for the industry. Furthermore, these heat pumps are the first in Ireland to reach up to 120 degrees.

- Combined process cooling and process heating
- Design supply temperature: 115 °C
- Heating capacity: 1 MW
- Splitting heating demand into several temperature levels increases the system's efficiency

Source: [LinkedIn post](#)



2 x P450 series heat pumps (can generate 120 °C)  
1 x P150 series heat pump

# Commercial High-Temperature Heat Pumps for Supply Temperatures > 100 °C

## HTHPs for Pet Food Dryers

geelen  
counterflow



First electric counterflow dryer from Geelen Counterflow with 15 drying decks for drying aqua feed at the Cargill-Ewos plant in Bergneset, Norway

Source: [YouTube Video](#)

Images by courtesy of Geelen Counterflow

**Combi***therm*  
APPARATE- UND  
ANLAGENBAU

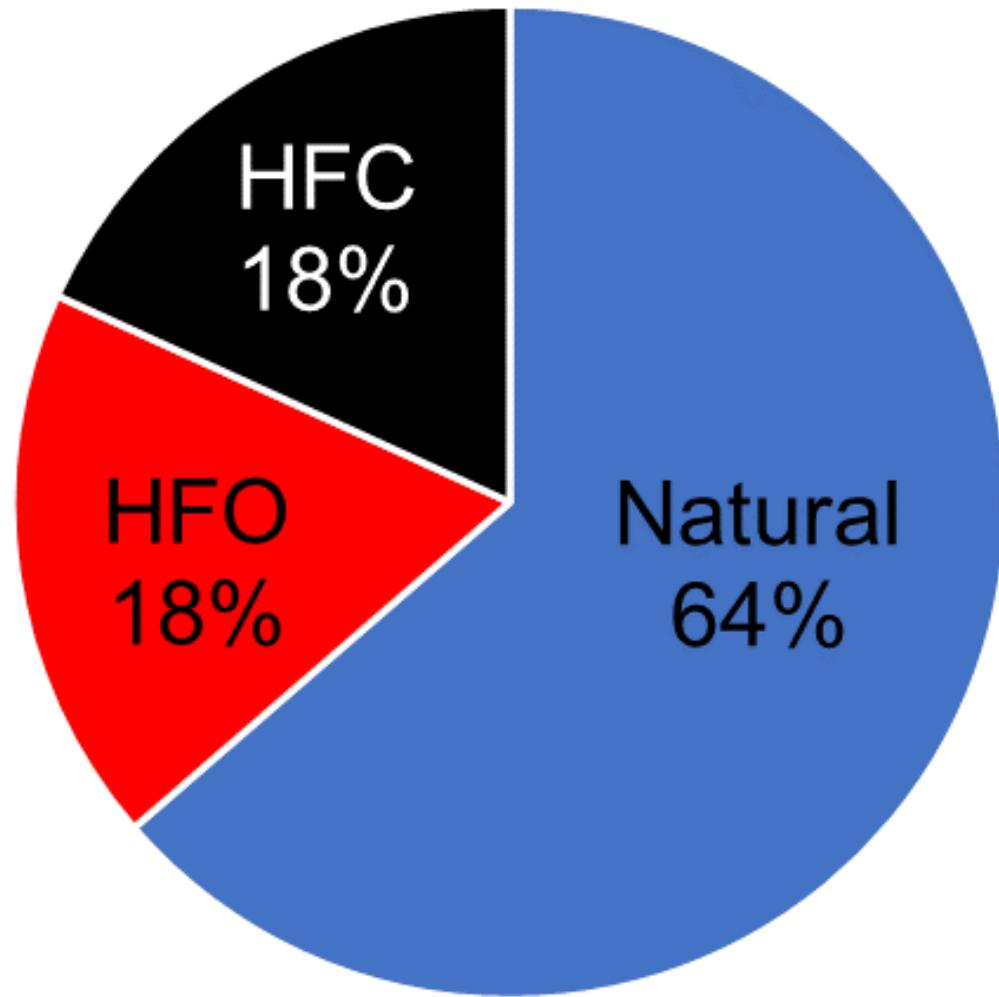


4 x HTHPs from Combitherm (3.5 MW heating capacity, R1233zd(E), screw compressor from Bitzer) use the dryer exhaust air as a heat source and generate 120 °C via an intermediate circuit to heat the drying air

Source: [YouTube Webinar](#)

# Commercial High-Temperature Heat Pumps for Supply Temperatures > 100 °C

## Refrigerants in HTHPs



R718 (Water)	12
R744 (CO2)	4
R717 (Ammonia)	4
R601 (n-Pentane)	1
R600 (n-Butane)	3
R290 (Propane)	1
R704 (Helium)	2
ecop (Nobel gas)	1
R1336mzz(Z)	2
R1233zd(E)	3
R1234ze(E)	1
HFOs	2
R245fa	5
R410a	1
R134a	2
<b>Natural</b>	<b>28</b>
<b>HFO</b>	<b>8</b>
<b>HFC</b>	<b>8</b>

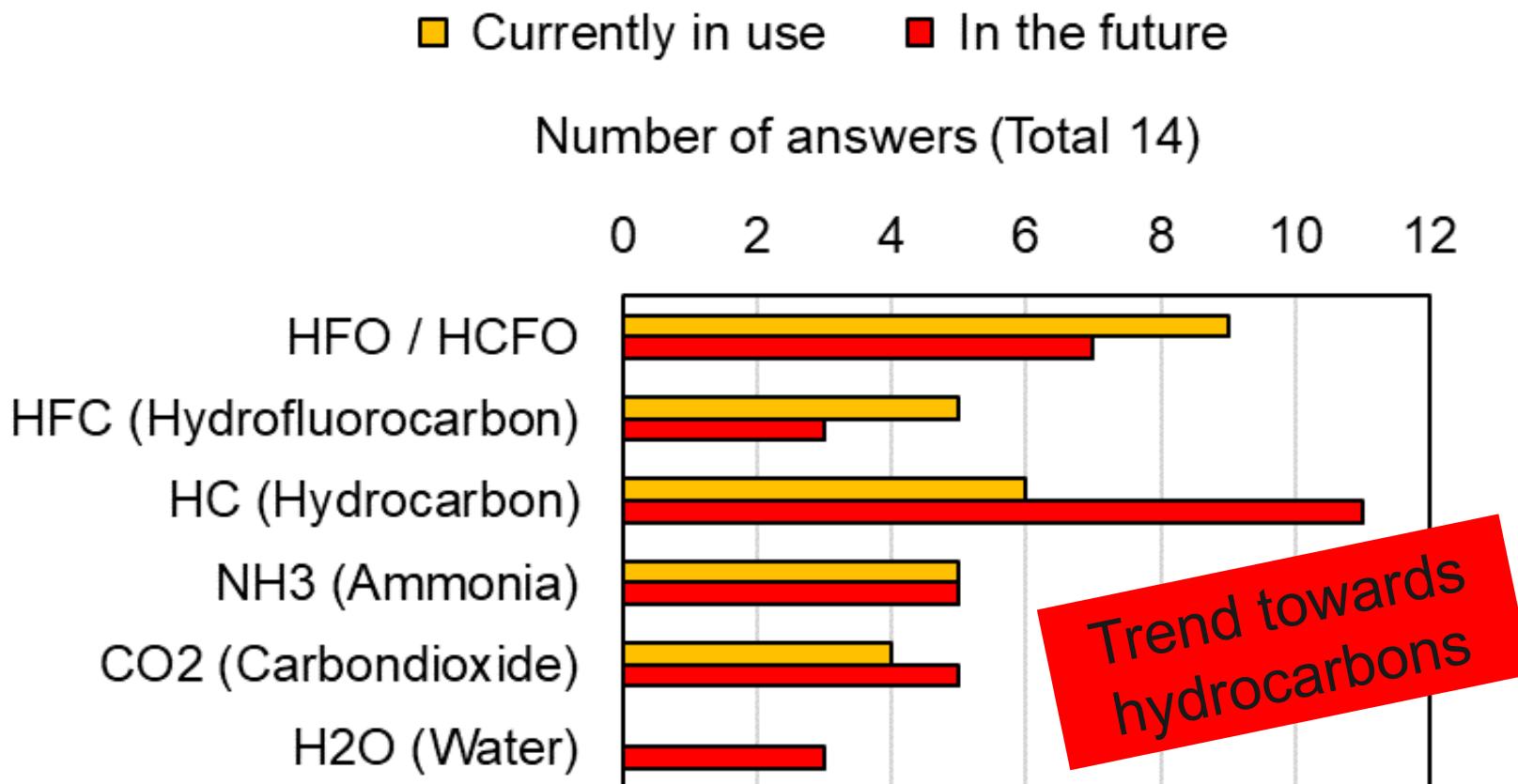
Based on data from IEA HPT Annex 58  
<https://heatpumpingtechnologies.org/annex58/task1>



## Refrigerants

# Survey results on refrigerants for large heat pumps

Which refrigerants are **currently in use** and which are **planned for the future**?



### ■ Main selection criteria:

- Thermodynamic suitability
- Environmental impact (GWP, ODP, TFA, etc.)
- Efficiency

### ■ Development time to switch from synthetic to natural refrigerant:

- 6 months to 5 years

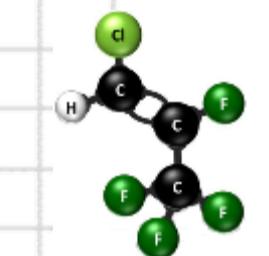
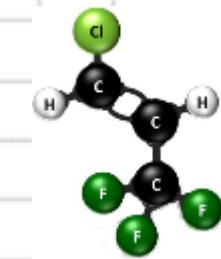
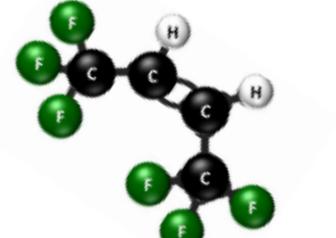
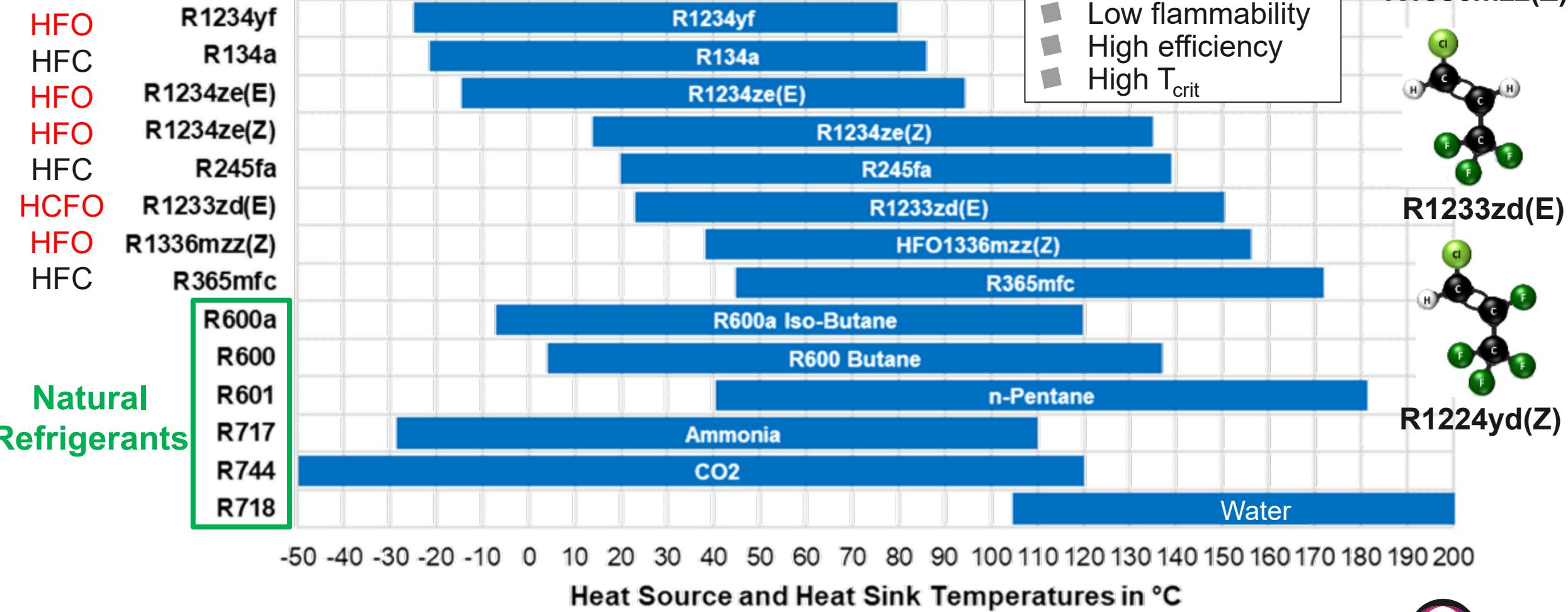
Source: Arpagaus, C., Bever, P.-M., Brendel, L., Bertsch, S. (2023): [Kältemittel heute und in der Zukunft: Neue Vorgaben, neue Kältemittel](#), 7. Internationaler Grosswärmepumpen Kongress, 24./25. Mai 2023, Zürich

# Commercial High-Temperature Heat Pumps for Supply Temperatures > 100 °C

## Suitable refrigerants for HTHPs

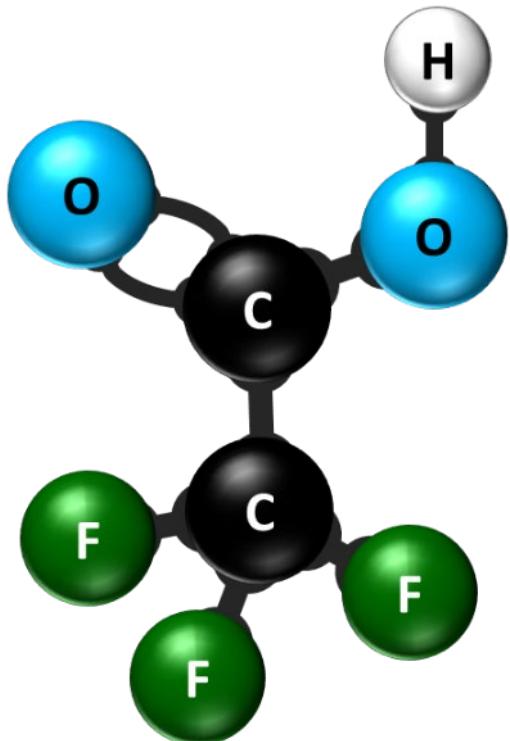
**Selection criteria :**

- Low GWP
- Short atm. lifetime
- Zero/low ODP
- Low flammability
- High efficiency
- High  $T_{crit}$



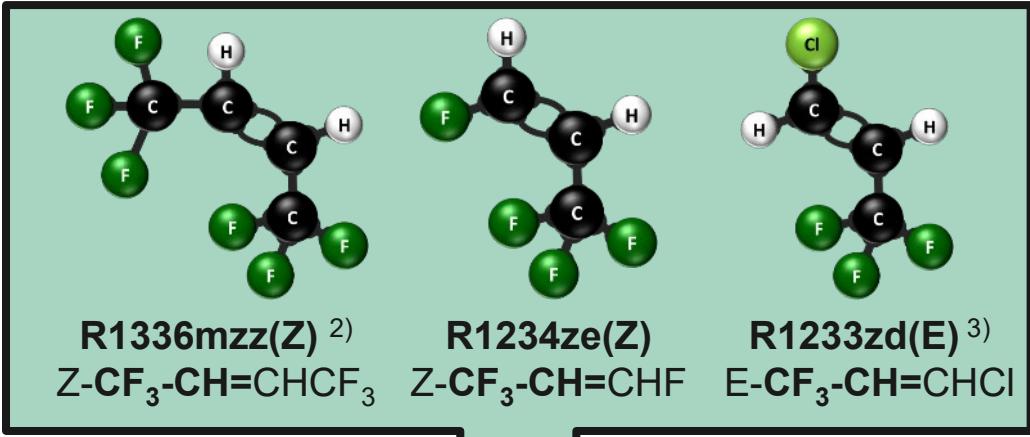
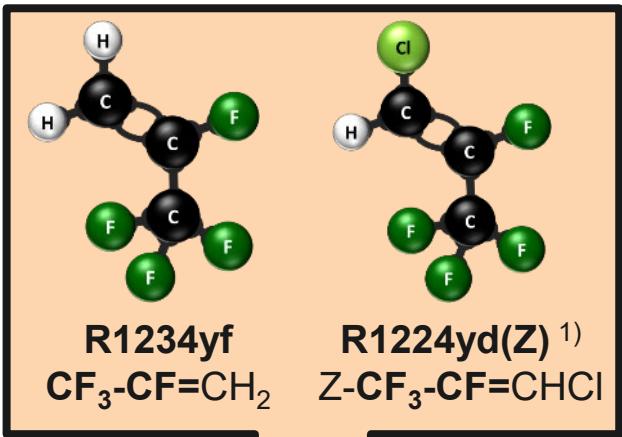
## Formation of trifluoroacetic acid (TFA, $\text{CF}_3\text{COOH}$ )

### Trifluoroacetic acid (TFA)



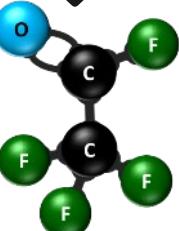
- TFA is an end product of atmospheric degradation of halogenated refrigerants
- Persistent in the environment and also mobile in the aquatic environment
- TFA can basically be formed from various substances, the presence of a  **$\text{CF}_3\text{-CF=}$  group** is considered a prerequisite for TFA formation

# Molar yield of TFA during atmospheric degradation of HFOs

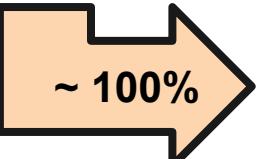


$\text{CF}_3\text{-CF=}$   
group

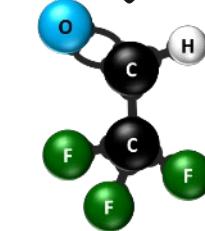
Trifluoracetyl fluoride (TFF)  
 $\text{CF}_3\text{-C(O)F}$



<sup>1)</sup> 97%  
(Guo et al., 2019)



Trifluoroacetic acid (TFA)  
 $\text{CF}_3\text{-C(O)OH}$

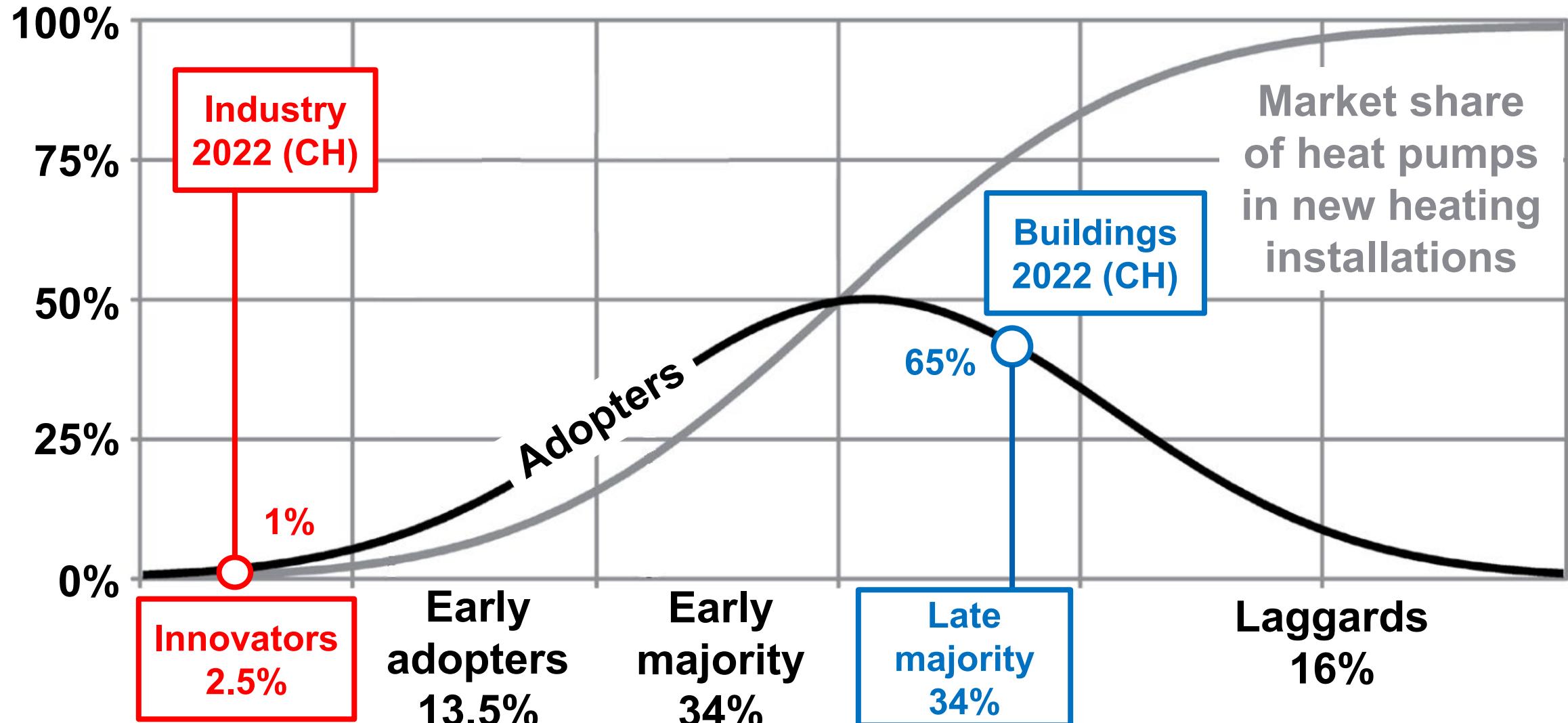


<sup>2)</sup> < 20%, because of 2 x  $\text{CF}_3\text{-CH=}$   
(Henne et al., 2012)

<sup>3)</sup> ~2% (Sulbaek Andersen et al., 2018)

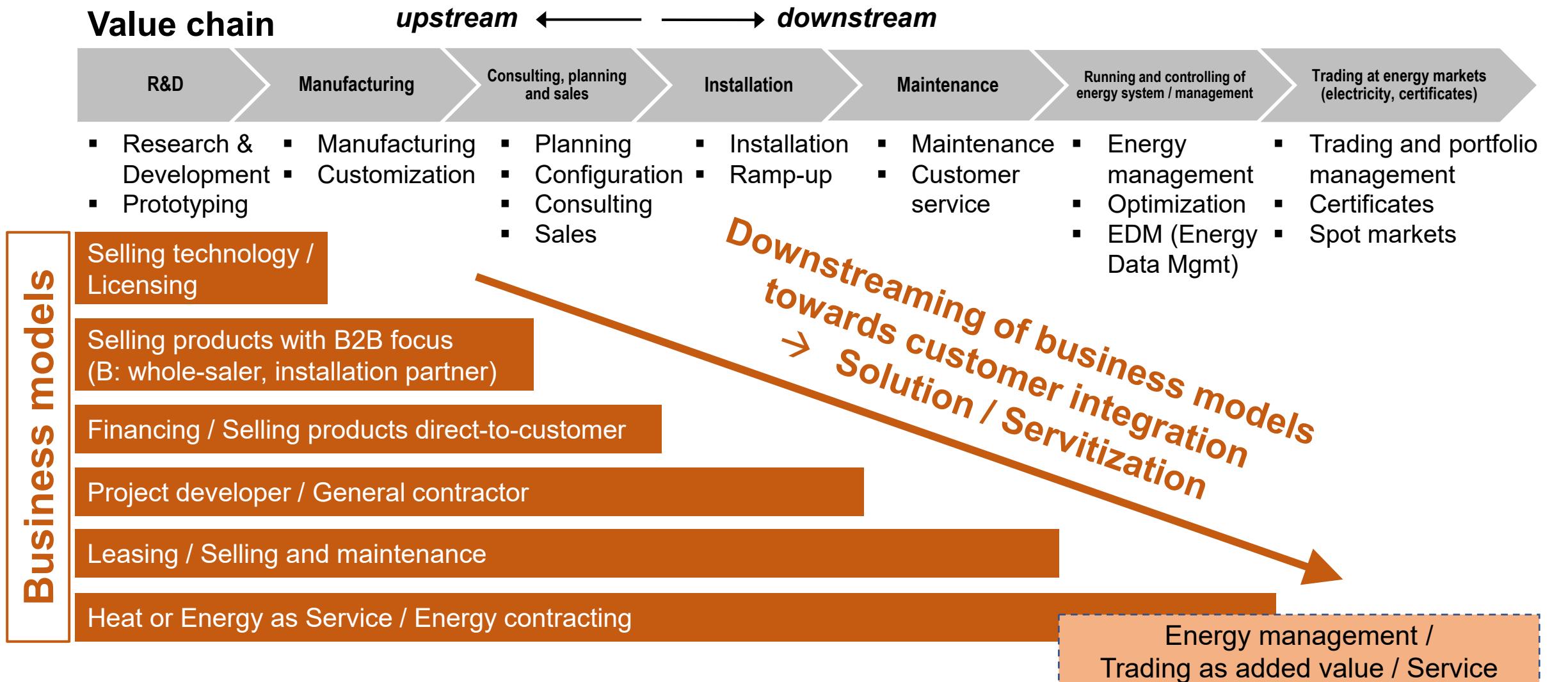
## Market Analysis – Diffusion of Innovation

# Technology Adoption of Heat Pumps in Switzerland – Status 2022



# Market Analysis – Industrial heat pumps

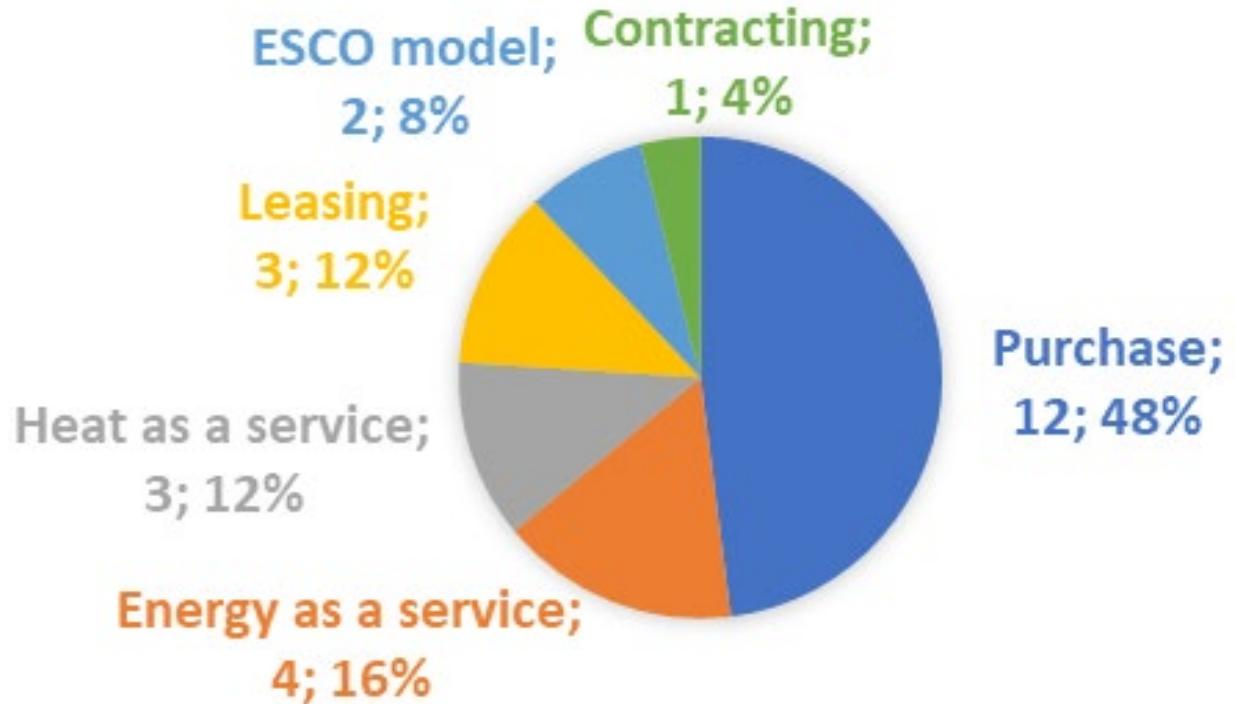
## Business models and value chain



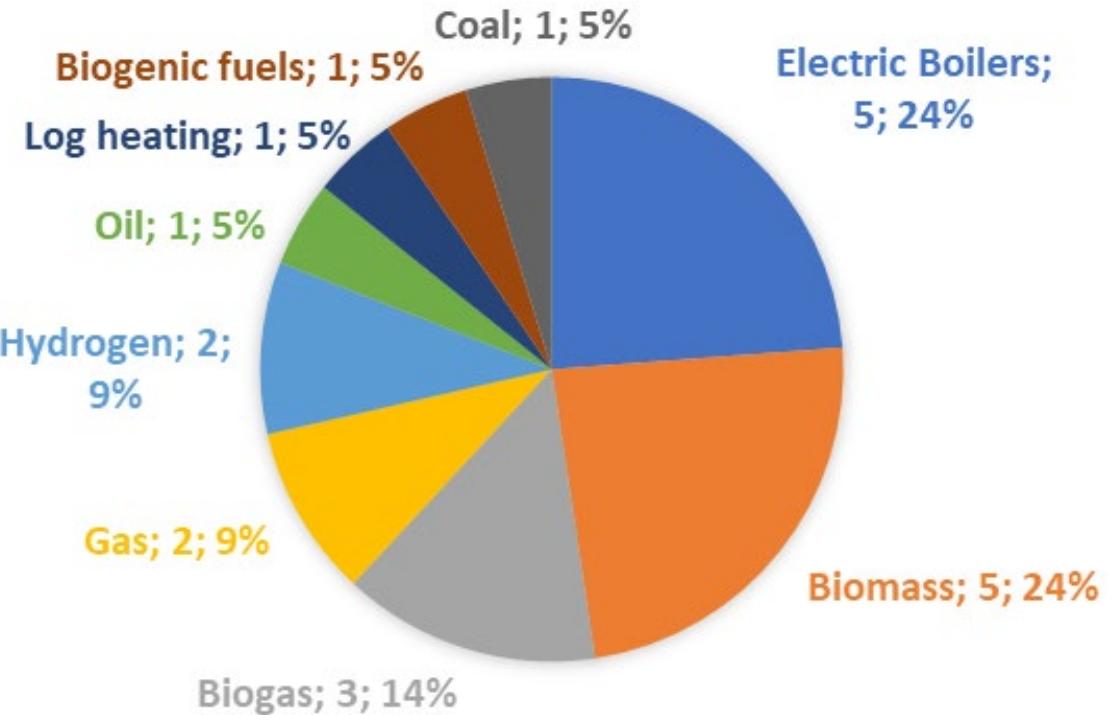
## Interview results with 16 HTHP manufacturers (in Q4/2023)



### Promising Business Models



### Possible Substituting Technologies

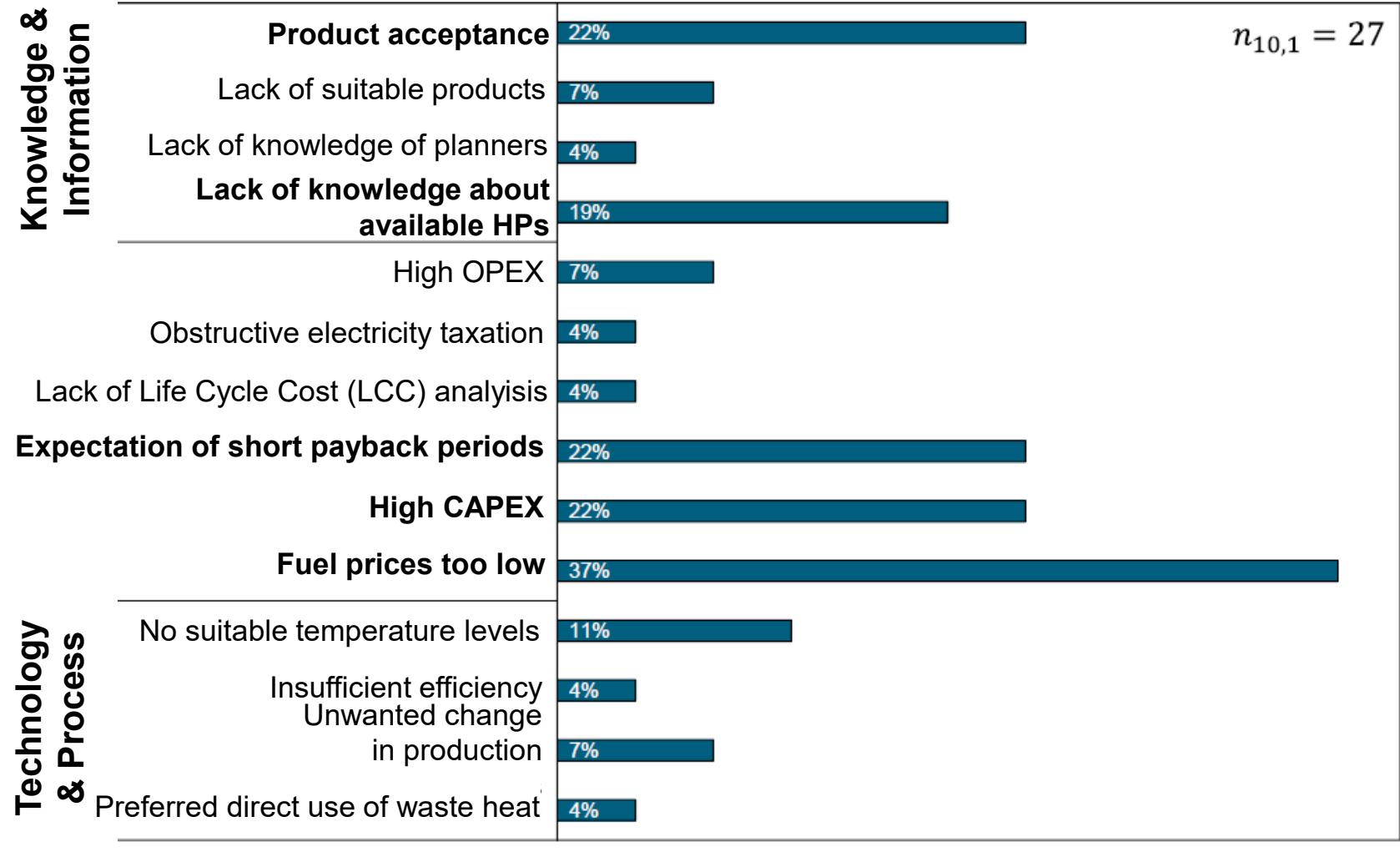
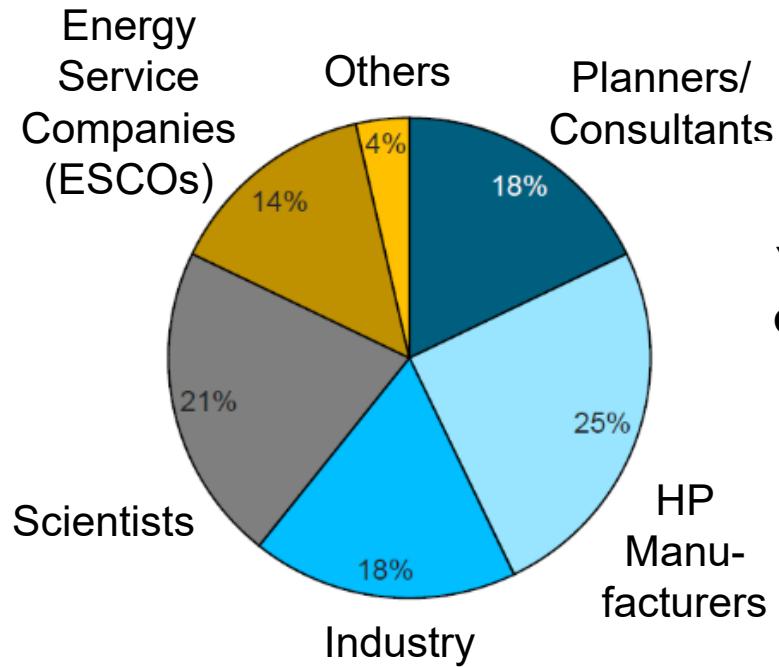


- Direct2Customer (purchase) appears to be the most widespread business model (i.e., direct sales, installation commissioning, maintenance, ownership)
- New market opportunities are especially Heat-as-a-Service (HaaS) (highly customer-integrated)
- Alternative heating solutions (i.e., electric boilers, biomass, biogas,

## Market analysis

# Market Barriers for Industrial Heat Pumps

**Survey among 27 experts  
on heat pumps and heat  
recovery**

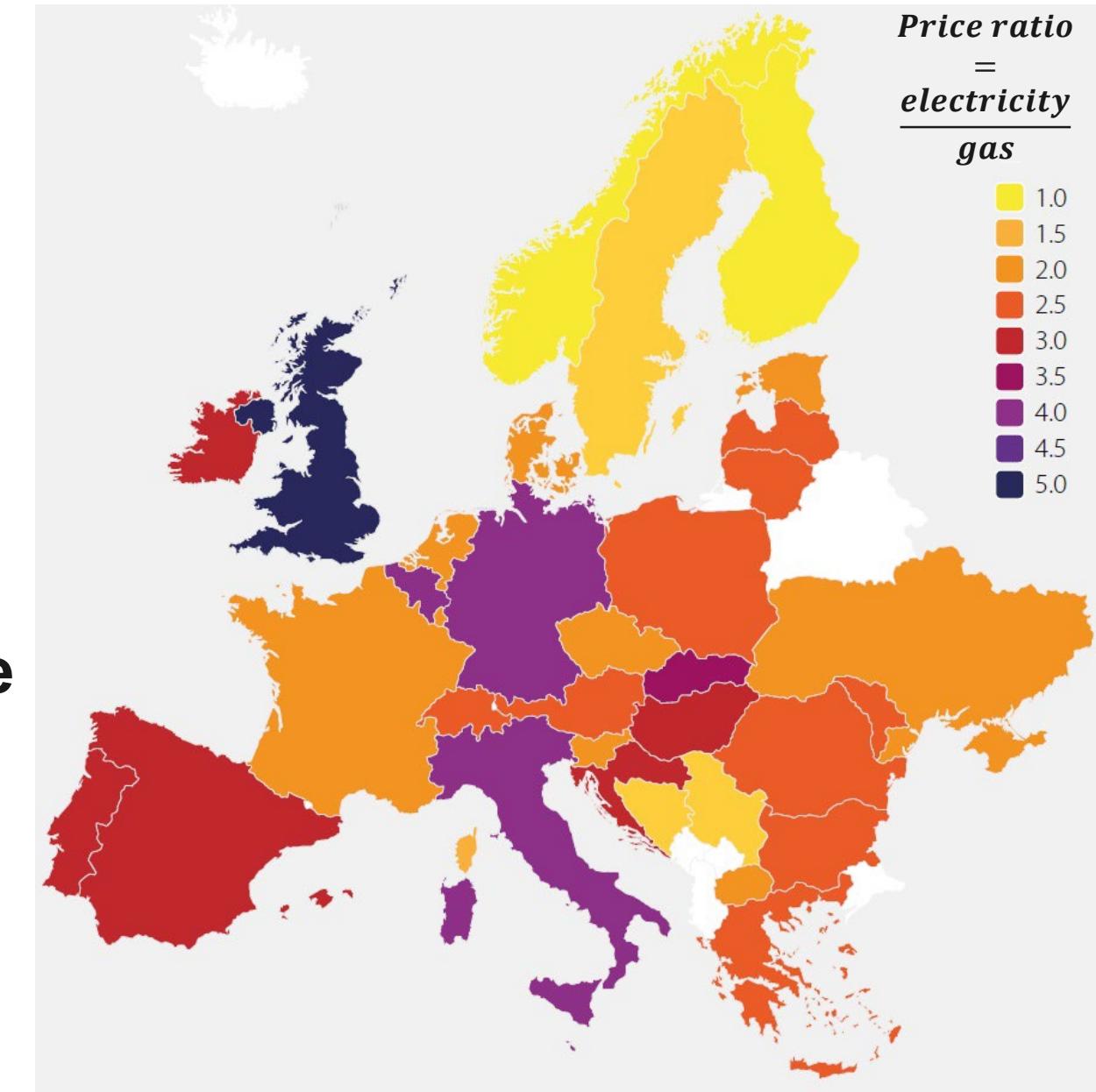


Adapted from [Wolf et al. \(2017\): Systematische Anwendung von Großwärmepumpen in der Schweizer Industrie, Endbericht, 10. Mai 2017](#) and [Wolf \(2020\): Rahmenbedingungen und Märkte für Industriewärmepumpen, ETV Online Tagung 2020, Industrielle Gross- und Hochtemperaturwärmepumpen im Energiesystem, 22. Juli 2020](#)

# Market Attractiveness depends on Price Ratio between Electricity and Gas

- Decarbonization requires increased use of **renewable electricity**
- **Electricity is more expensive** than fossil fuel in many European countries

For small scale industrial end-users with  
2 GWh/a to 20 GWh/a electricity  
3 GWh/a to 28 GWh/a gas



# Price Ratio Electricity to Gas (2023-S1)

For small-scale industrial end-users

**Electricity:**

2 GWh/a to 20 GWh/a (band ID),

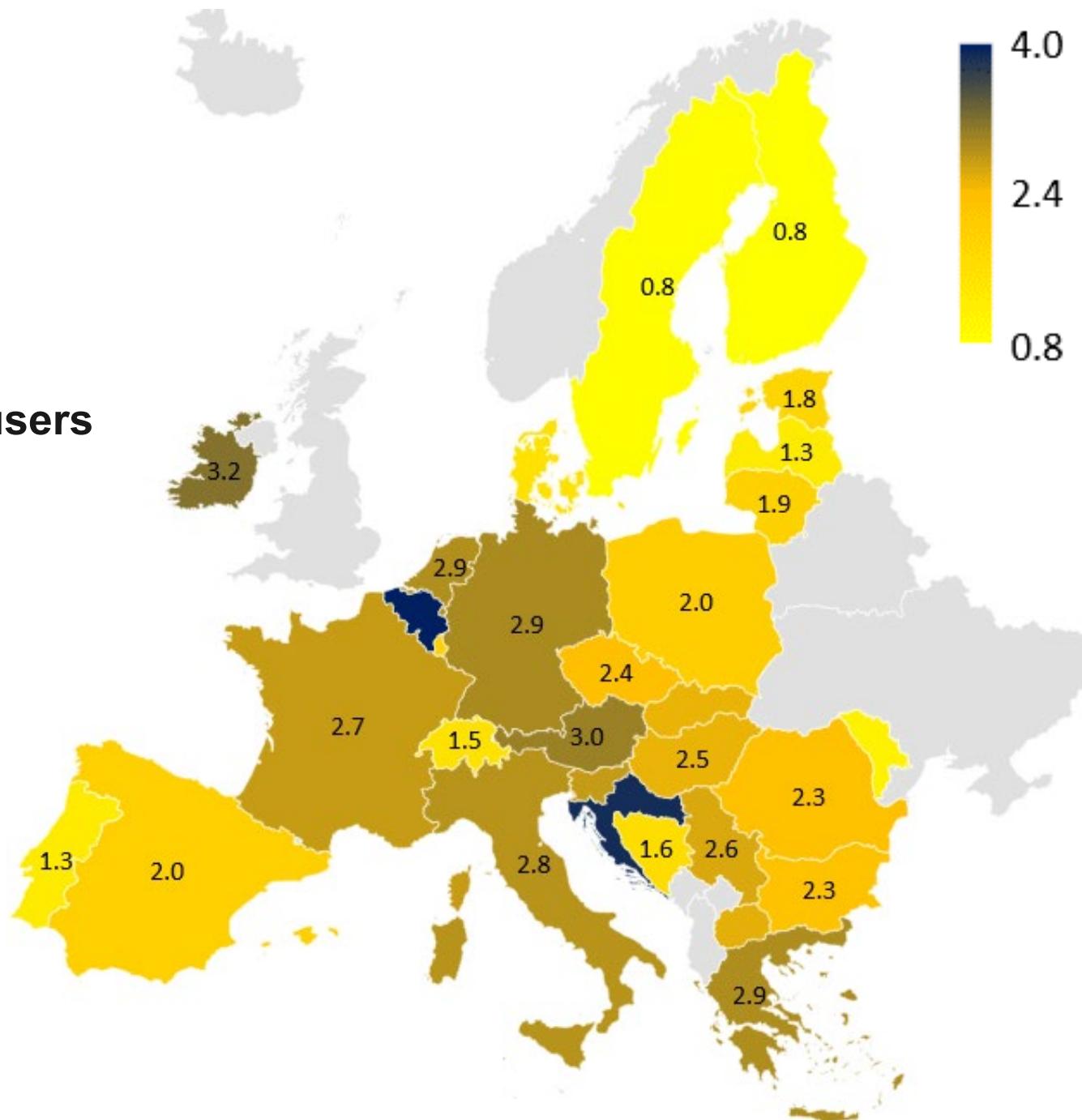
[nrg\\_pc\\_205](#)

**Gas:** 3 GWh/a to 28 GWh/a (I3),

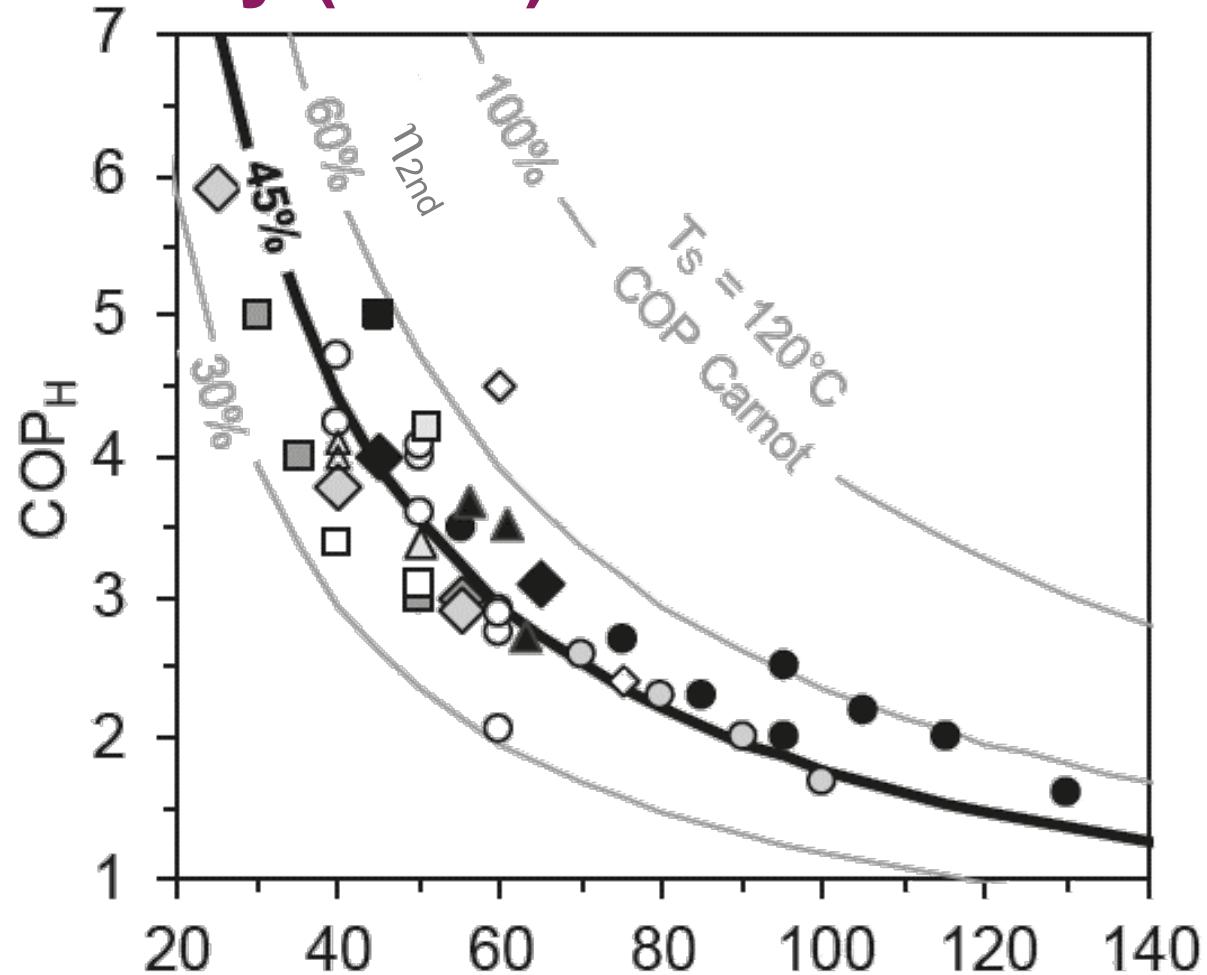
[nrg\\_pc\\_203](#)

(all taxes and levies included)

Source: Eurostat, 31/10/2023



## Efficiency (COP) of industrial heat pumps



$\Delta T_{Lift}$  in K  
 $(= T_{Sink,out} - T_{Source,in})$

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COP Fit-curve  
(45% 2<sup>nd</sup> Law efficiency)

$$COP_H = 68.455 \cdot \Delta T_{Lift}^{-0.76}$$

$\Delta T_{Lift}$	$COP_H$
30 K	5.2
40 K	4.1
50 K	3.5
60 K	3.0
70 K	2.7
80 K	2.4

Source: Arpagaus C., Bless F., Uhlmann M., Schiffmann J., Bertsch S.S. (2018): Review on High-Temperature Heat Pumps, <https://doi.org/10.1016/j.energy.2018.03.166>

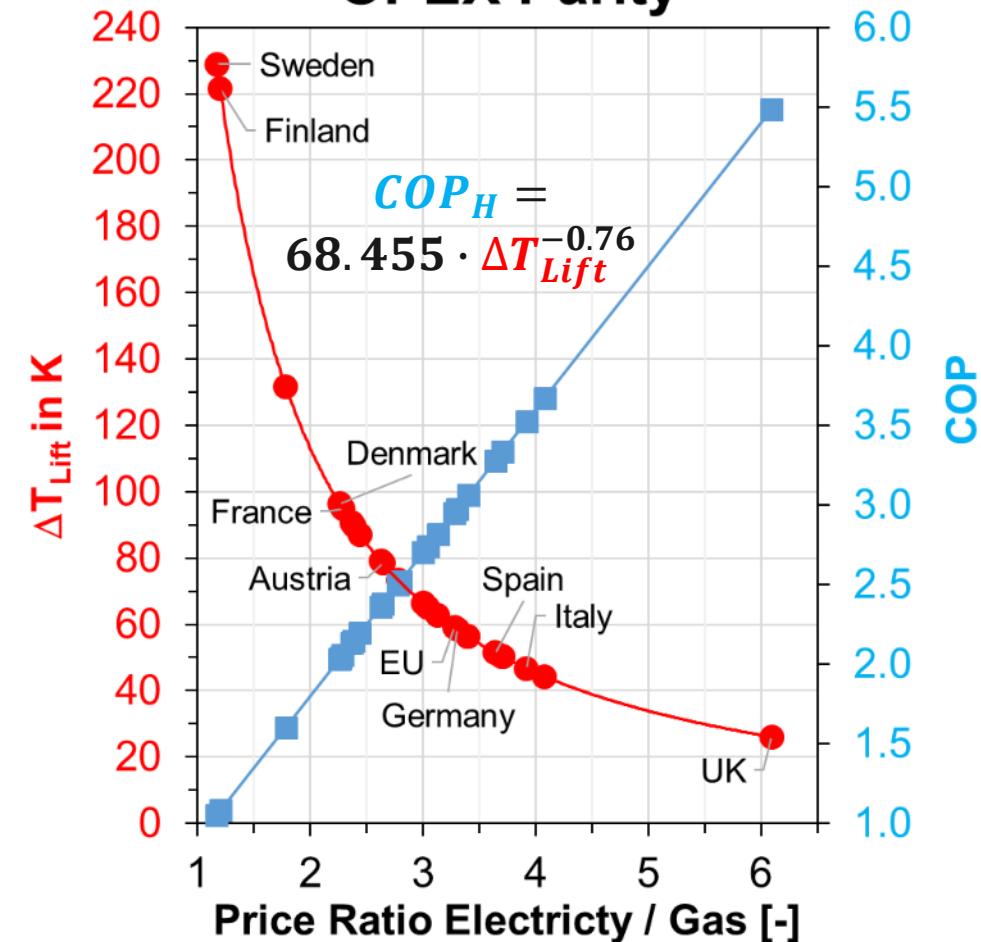
# OPEX Parity COP and Temperature Lift

$$COP = \frac{Price_{Electricity}}{Price_{Gas}} \cdot \eta_{Gas\ Boiler}$$

Country	Prices without refundable			OPEX Parity	
	Gas	Electricity	Price Ratio	COP	$\Delta T_{Lift}$
Sweden	4.1	4.8	1.17	1.1	229
Finland	4.5	5.4	1.20	1.1	222
Luxembourg	2.3	4.1	1.78	1.6	132
Lithuania	3.0	6.8	2.27	2.0	96
Denmark	3.1	7.0	2.26	2.0	96
France	2.8	6.4	2.29	2.1	95
Netherlands	2.6	6.2	2.38	2.1	90
Slovenia	2.5	6.1	2.44	2.2	87
Estonia	3.0	7.1	2.37	2.1	91
Czech Republic	2.4	6.3	2.63	2.4	79
Austria	2.8	7.4	2.64	2.4	78
Latvia	2.7	7.5	2.78	2.5	73
Hungary	2.5	7.0	2.80	2.5	73
Greece	2.5	7.5	3.00	2.7	66
Poland	2.4	7.2	3.00	2.7	66
Romania	2.3	7.0	3.04	2.7	65
Croatia	2.3	7.2	3.13	2.8	63
Belgium	2.0	6.8	3.40	3.1	56
Germany	2.6	8.6	3.31	3.0	58
Bulgaria	2.0	6.8	3.40	3.1	56
Spain	2.5	9.1	3.64	3.3	51
Portugal	2.4	8.9	3.71	3.3	50
Ireland	2.7	10.0	3.70	3.3	50
Italy	2.4	9.4	3.92	3.5	47
Slovakia	2.5	10.2	4.08	3.7	44
UK	2.1	12.8	6.10	5.5	26
EU	2.5	8.2	3.28	3.0	59

Market Attractiveness

## Heat Pump vs. Gas Boiler (90% efficiency) OPEX Parity



90%

# Cost model – Input and Output parameters



## Inputs

$\dot{Q}_h$	Heating capacity	kW
$\Delta T_{lift}$	Temperature lift	K
$c_{inv,HP}$	Specific investment costs of HP	EUR/kW
$f_{inv,HP}$	Cost factor for planning & HP integration	-
$t$	Annual operating time	h/a
$f_{maintain}$	Maintenance factor (on capital costs)	-
$\eta_{fuel}$	Efficiency of gas boiler	-
$i$	Interest rate (discount rate)	-
$c_{fuel}$	Fuel price (gas, oil)	EUR/kWh
$c_{el}$	Electricity price	EUR/kWh
$c_{CO2\ tax}$	CO <sub>2</sub> tax	EUR/tCO <sub>2</sub>
$f_{CO2,el}$	CO <sub>2</sub> emissions factor electricity	kgCO <sub>2</sub> /kWh
$f_{CO2,fuel}$	CO <sub>2</sub> emissions factor fuel	kgCO <sub>2</sub> /kWh

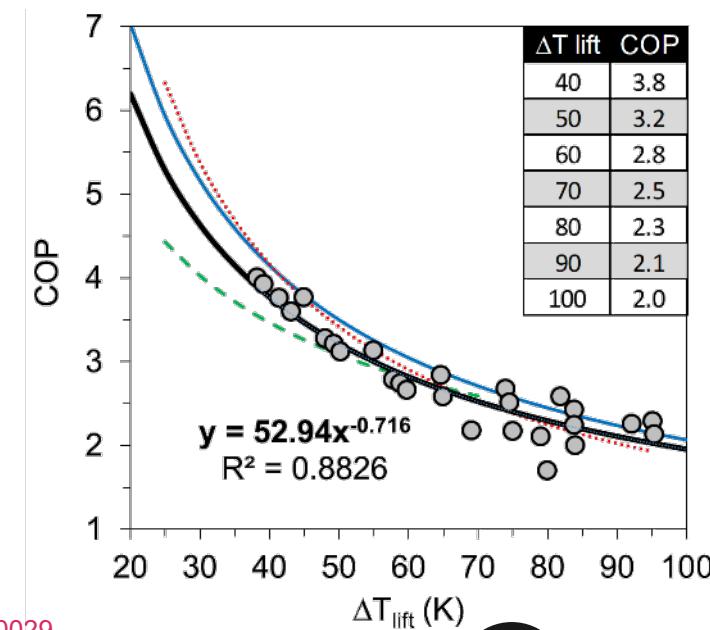
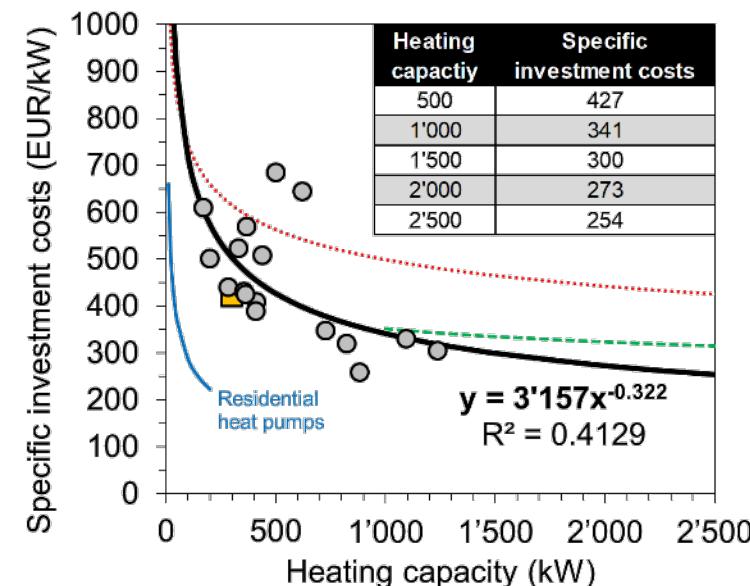
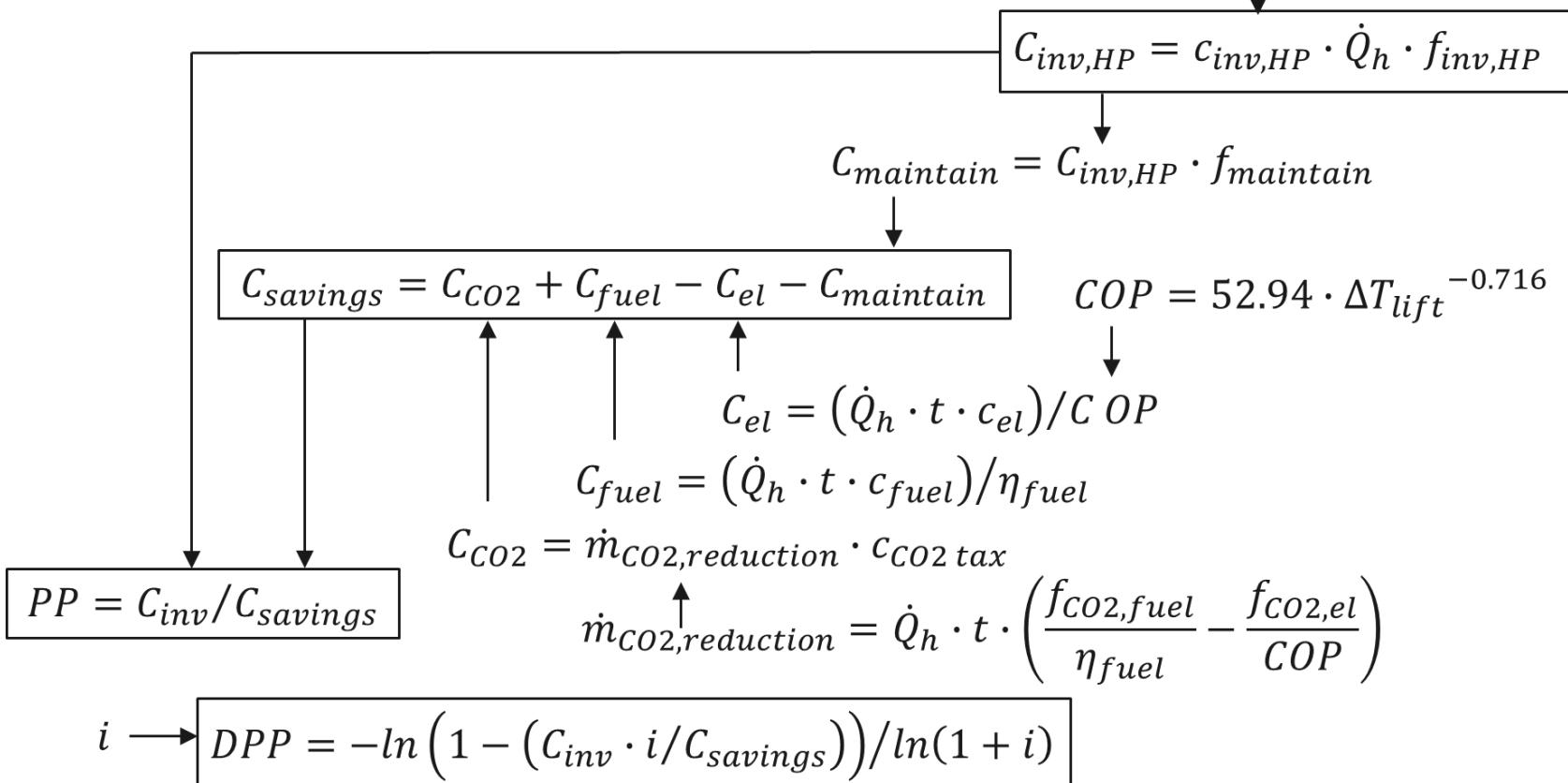
## Outputs

$C_{inv,HP}$	Investment costs of HP	EUR
$\dot{m}_{CO2,reduction}$	Annual CO <sub>2</sub> emissions reduction	tCO <sub>2</sub> /a
$E_{savings}$	Annual energy savings	kWh/a
$C_{fuel}$	Annual fuel cost savings	EUR/a
$C_{el}$	Annual electricity costs	EUR/a
$C_{maintain}$	Annual HP maintenance costs	EUR/a
$C_{CO2}$	Annual CO <sub>2</sub> tax compensation	EUR/a
$C_{savings}$	Annual cost savings	EUR/a
$PP$	Payback period	a
$DPP$	Discounted payback period	a

Source: Arpagaus et al. (2022): Techno-economic analysis of steam generating heat pumps for integration into distillation processes, 15th IIR-Gustav Lorentzen conference on Natural Refrigerants, June 13-15, 2022, Trondheim, Norway, <http://dx.doi.org/10.18462/iir.glo2022.0029>

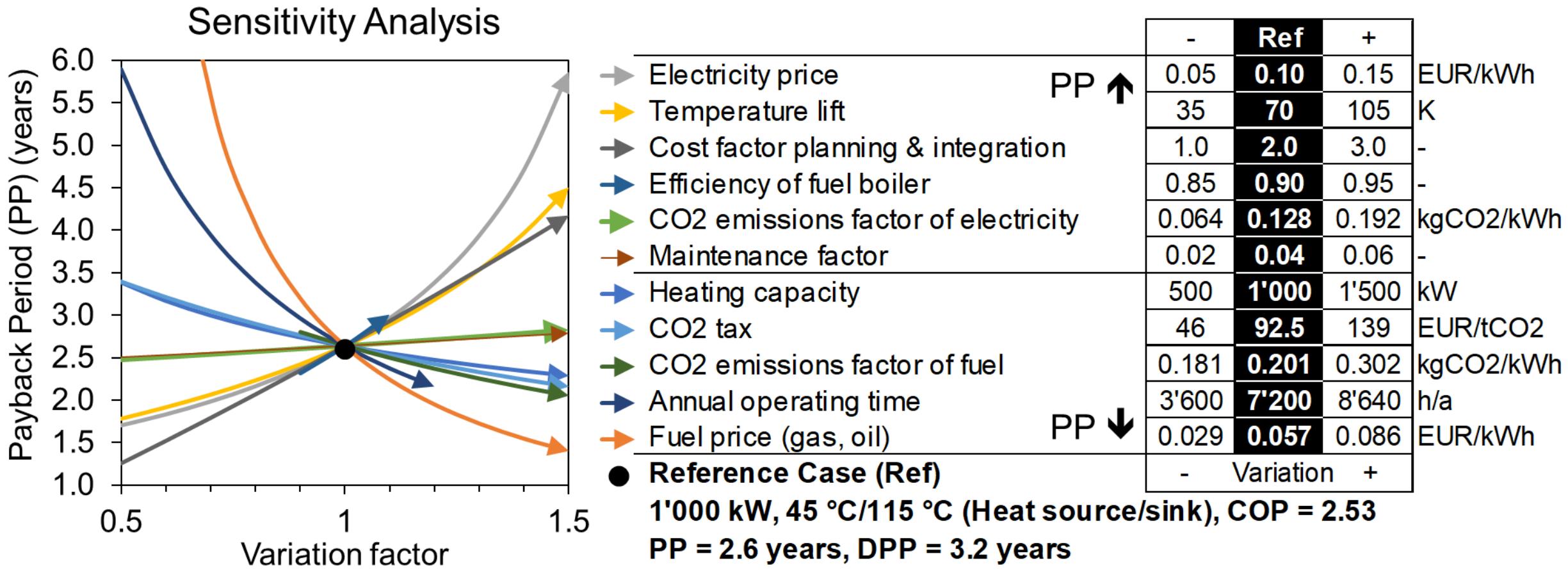
# Economic Evaluation

## Cost model



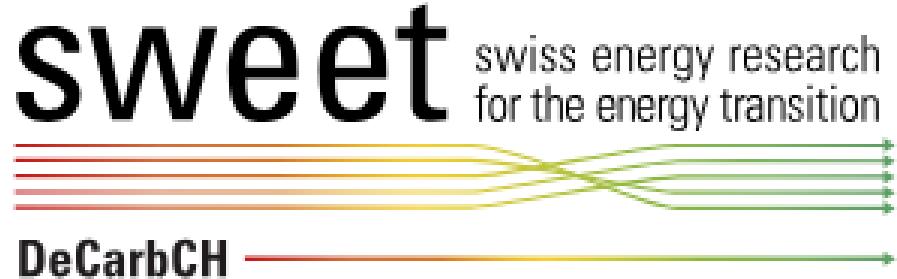
## Economic Evaluation – Sensitivity analysis

# Payback period for a reference case at 45 °C/115 °C (heat source/sink) and 1 MW heating capacity



Source: Arpagaus et al. (2022): Techno-economic analysis of steam generating heat pumps for integration into distillation processes,  
15th IIR-Gustav Lorentzen conference on Natural Refrigerants, June 13-15, 2022, Trondheim, Norway, <http://dx.doi.org/10.18462/iir.gl2022.0029>

## Free Tools



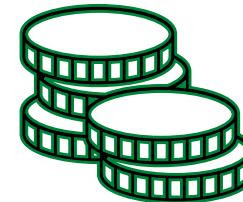
### Heat pump economical calculator



Download

[https://www.sweet-decarb.ch/fileadmin/downloads/Tools/Heat\\_Pump\\_IntegrationCalculation\\_Example.xlsx](https://www.sweet-decarb.ch/fileadmin/downloads/Tools/Heat_Pump_IntegrationCalculation_Example.xlsx)

### Payback calculator with country comparison

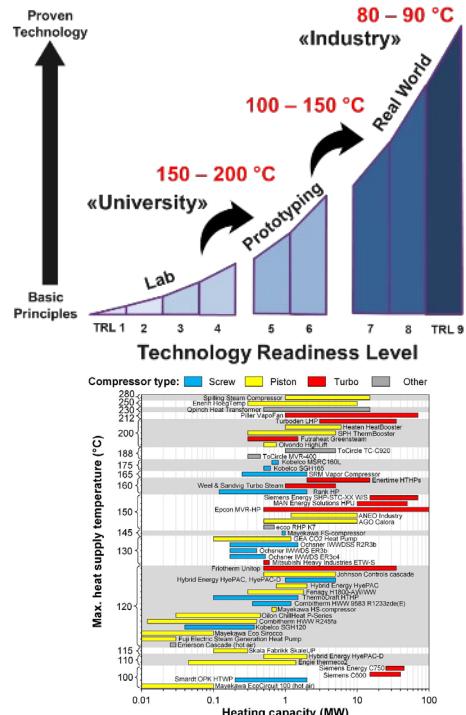


Online version

<https://www.sweet-decarb.ch/futher-info/heat-pump-tool>

## Summary and conclusions

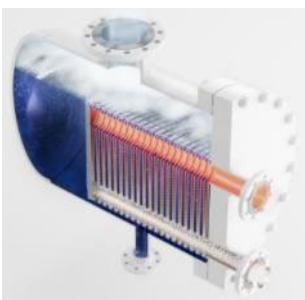
- **State of the Art:** HTHP products and technologies with >100 °C supply temperature are increasingly available in Europe (TRL 8 to 9), HTHP innovation is going on → see IEA HPT Annex 58 Overview
- **Application examples:** Various realized references, demonstration projects, case studies, and many potential applications (e.g., pressurized water, hot air for drying processes, low-pressure steam)
- **Economic conditions:** Market attractiveness depends on electricity to gas price ratio and COP (temperature lift), favorable countries
- **Direct2Customer** (purchase, ownership) is the most widespread **business model** (i.e., direct sales, installation, commissioning, maintenance)
- **Sustainable refrigerant:** European regulations (F-gas, PFAS, TFA) push towards natural refrigerants (e.g., H<sub>2</sub>O, CO<sub>2</sub>, NH<sub>3</sub>, hydrocarbons, noble gases) and synthetic HFO/HCFO with low GWP



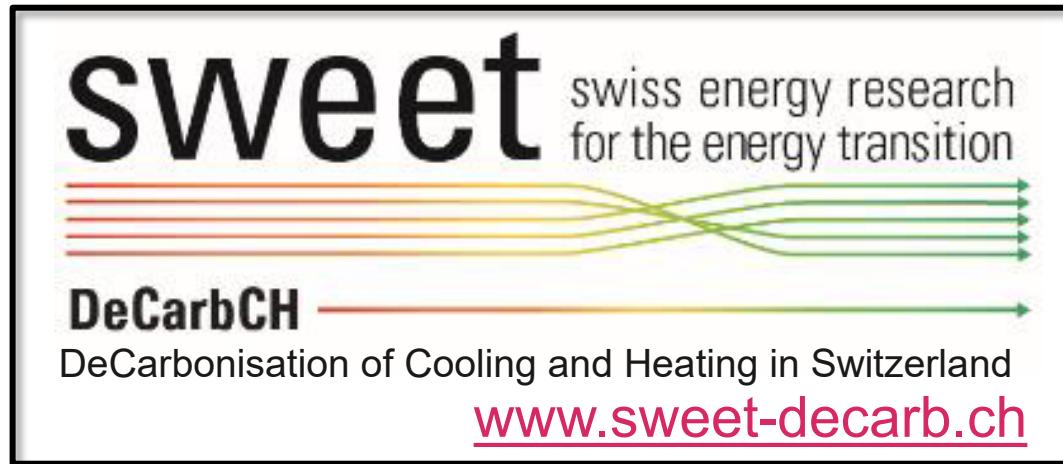
**HOT WATER**  
**HOT AIR**  
**STEAM**



**“Have confidence and give  
HTHP technology a try!”**



# Acknowledgments



**Project: Annex 58 HTHP-CH**  
Integration of High-Temperature  
Heat Pumps (HTHPs) in Swiss  
Industrial Processes  
(SI/502336-01)



# Thank you for your attention !



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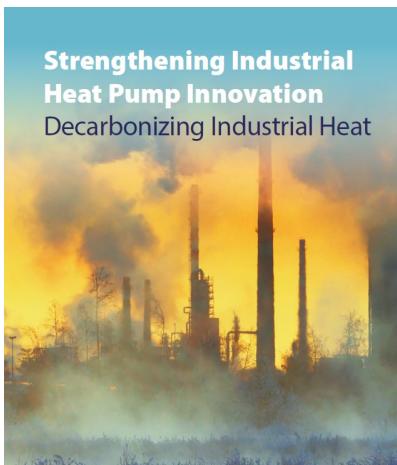
Tel. +41 58 257 34 94

[www.ost.ch/ies](http://www.ost.ch/ies)

**IES** | Institute for  
Energy Systems



# Literature References



- Arpagaus, C.; Bless, F.; Bertsch, S.: Techno-Economic Analysis of Steam-Generating Heat Pumps in Distillation Processes, [3rd High-Temperature Heat Pump Symposium 2022, 29-30 March 2022, Copenhagen, Denmark](#)
- Mateu-Royo, C.; Arpagaus, C.; Mota-Babiloni, A.; Navarro-Esbrí, J.; Bertsch, S.: Advanced High Temperature Heat Pump Configurations using low GWP Refrigerants for Industrial Waste Heat Recovery: A Comprehensive Study, *Energy Conversion and Management*, Vol. 229, 1 February 2021, 113752, <https://doi.org/10.1016/j.enconman.2020.113752>
- Kosmadakis, G.; Arpagaus, C.; Neofytou, P.; Bertsch, S.: Techno-Economic Analysis of High-Temperature Heat Pumps with low-GWP Refrigerants for upgrading Waste Heat up to 150 °C, *Energy Conversion and Management*, Vol. 226, 113488, pp. 1-19, <https://doi.org/10.1016/j.enconman.2020.113488>
- Schiffmann, J.; Kontomaris, K.; Arpagaus, C.; Bless, F.; Bertsch, S.: Scale Limitations of Gas Bearing Supported Turbocompressors for Vapor Compression Cycles, *International Journal of Refrigeration*, Vol. 109, pp. 92-104, 2020, <https://doi.org/10.1016/j.ijrefrig.2019.09.019>
- Schlosser, F.; Jesper, M.; Vogelsang, J.; Walmsley, T.G.; Arpagaus, C.; Hesselbach, J.: Large-Scale Heat Pumps: Applications, Performance, Economic Feasibility and Industrial integration, *Renewable and Sustainable Energy Reviews*, Vol. 133, 1102019, pp. 1-20, 2020, <https://doi.org/10.1016/j.rser.2020.110219>
- Arpagaus, C.; Bertsch, S.: [Industrial Heat Pumps in Switzerland – Application Potentials and Case Studies](#), Final Report, on behalf of the Swiss Federal Office of Energy, SFOE contract number: SI/501782-01, Bern, 23 July 2020.
- De Boer, R.; Marina, A.; Zühlendorf, B.; Arpagaus, C.; Bantle, M.; Wilk, V.; Elmegård, B.; Corberán, J.; Benson, J.: [Strengthening Industrial Heat Pump Innovation, Decarbonizing Industrial Heat](#), White Paper, 14 July 2020.
- Arpagaus, C.; Bertsch, S.: Experimental Comparison of R1224yd(Z) and R1233zd(E) in a High Temperature Heat Pump, 13th IEA Heat Pump Conference, Jeju, Korea, 26-29 April 2021.
- Arpagaus, C.; Bertsch, S.: Successful Application Examples of Industrial Heat Pumps in Switzerland, IIR International Rankine 2020 Conference, 27-31 July 2020, Glasgow, UK, <https://doi.org/10.18462/iir.rankine.2020.1183>
- Arpagaus, C.; Bertsch, S.: Experimental Comparison of HCFO R1233zd(E) and R1224yd(Z) in a High Temperature Heat Pump up to 150 °C, IIR International Rankine 2020 Conference, 27 to 31 July 2020, Glasgow, UK, <https://doi.org/10.18462/iir.rankine.2020.1129>
- Arpagaus, C.; Bertsch, S.: Experimental Comparison of HCFO and HFO R1224yd(Z), R1233zd(E), R1336mzz(Z), and HFC R245fa in a High Temperature Heat Pump up to 150 °C Supply Temperature, 18th International Refrigeration and Air Conditioning Conference at Purdue, 23-27 May 2021. <https://docs.lib.psu.edu/iracc/2200>
- Arpagaus, C.; Bless, F.; Bertsch, S.: Theoretical Analysis of Transcritical HTHP Cycles with low GWP HFO Refrigerants and Hydrocarbons for Process Heat Applications up to 200 °C, IIR International Rankine 2020 Conference, 27-31 July 2020, Glasgow, UK, <https://doi.org/10.18462/iir.rankine.2020.1168>
- Bless, F.; Arpagaus, C.; Bertsch, S.: Theoretical Investigation of High-Temperature Heat Pump Cycles for Steam Generation, 13th IEA Heat Pump Conference, Jeju, Korea, 26 -29 April 2021.
- Arpagaus, C.; Bless, F.; Bertsch, S.: Theoretical Analysis of Transcritical HTHP Cycles with low GWP HFO Refrigerants and Hydrocarbons for Process Heat Applications up to 200 °C, IIR International Rankine 2020 Conference, 27 to 31 July 2020, Glasgow, UK, <http://dx.doi.org/10.18462/iir.rankine.2020.1168>
- Diewald, K; Arpagaus, C.; Hebenstreit, B.: Thermodynamic Analysis of low GWP HFO and HCFO Refrigerants in HTHP with Large Temperature Glides on the Heat Sink, IIR International Rankine 2020 Conference, 27-31 July 2020, Glasgow, UK, <https://doi.org/10.18462/iir.rankine.2020.1166>