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Eastern Switzerland
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2024

Introduction

Steam Generating Heat Pumps Webinar

Presented by OST
Dr. Cordin Arpagaus

Explanations of today's webinar

- Recording
- Introduction
- OST IES Projects
- Research status
- Agenda
- Q & A

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Steam Generating Heat Pump Webinar

18 March 2024

13:30 Introduction C. Arpagaus

13:45 **Dennis Roskosch**
CO2-neutral process steam for industry: Model-based analysis of technologies and strategies

14:05 **C. Latham & M. Vandevoorde**
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

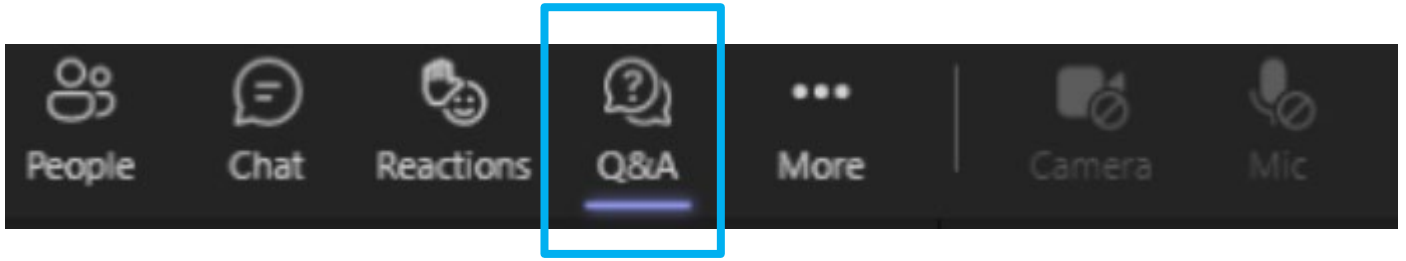
15:55 **Hans Madsbøll**
Steam compressor technology and development: a general overview

16:15 **Arne Høeg**
Decarbonizing industry with stirling-cycle steam generating heat pumps

16:35 Wrap-up & Conclusions

Webinar Housekeeping

- The webinar will be recorded
- The video and the presentation slides will be available after the event and published in the coming week on the SWEET DeCarbCH Events Website



Microsoft Teams

- Participant microphones and cameras are switched off
- Use the **Q&A tab** to ask questions (first type speaker name & insert question)
- If time permits, we will answer questions live after each presentation, otherwise via the Q&A tab

Introduction

Webinar Recordings will be available on YouTube CH

- https://www.sweet-decarb.ch/events/event/webinar-on-steam-generating-heat-pumps-2024
- https://www.youtube.com/@sweetdecarbch

sweet swiss energy research for the energy transition

DeCarbCH

Decarbonisation of **C**ooling and **H**eating in **Switzerland**

(SFOE funded project SI/502260)

Mission Statement:

Facilitate, speed up and de-risk decarbonization of heating and cooling

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Introduction – Where we are

Heat pump test center (WPZ) at OST in Buchs, Switzerland

OST

Introduction – Our competences

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OST Eastern Switzerland University of Applied Sciences

«Engineering a Net Zero Future that Works»

Heat Pump & Refrigeration Technology

Accredited Heat Pump Test Center

Heat Pump Field Tests

Heat Pump & HVAC Control

Residential

IES | Institute for Energy Systems

Photovoltaics

Decentralized Energy Supply

Grids (Electrical and Thermal)

Energy Supply

Power Electronics

Thermal Management

Test Bench Development

Mobility

Industrial Heat Pumps

Energy Analysis

Efficiency Optimization

Industry

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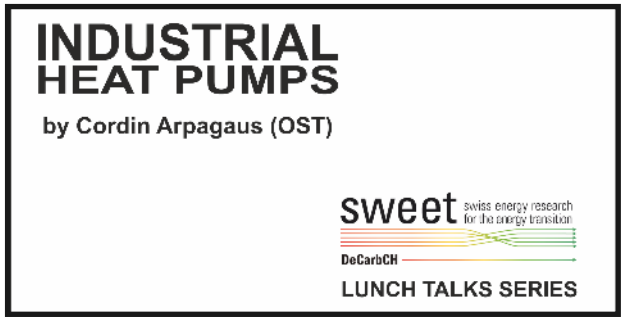
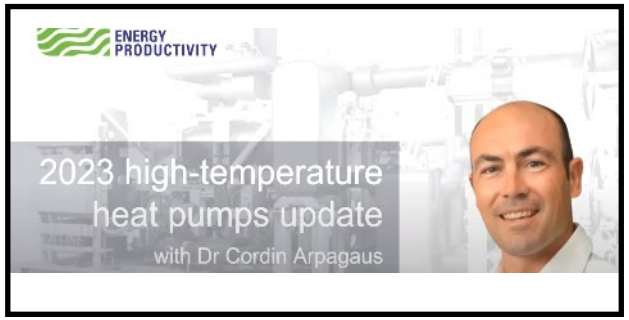
Introduction – Available webinar recordings

YouTube Videos on High-Temperature Heat Pumps

~ 70 participants





23 March 2023
(991 views)

19 November 2021
(1’446 views)

27 February 2023
(6’464 views)

28 October 2022
(481 views)

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Introduction – High international interest in the topic of Steam Generating Heat Pumps

We have more than 540 webinar registrations from 42 countries with different backgrounds and functions

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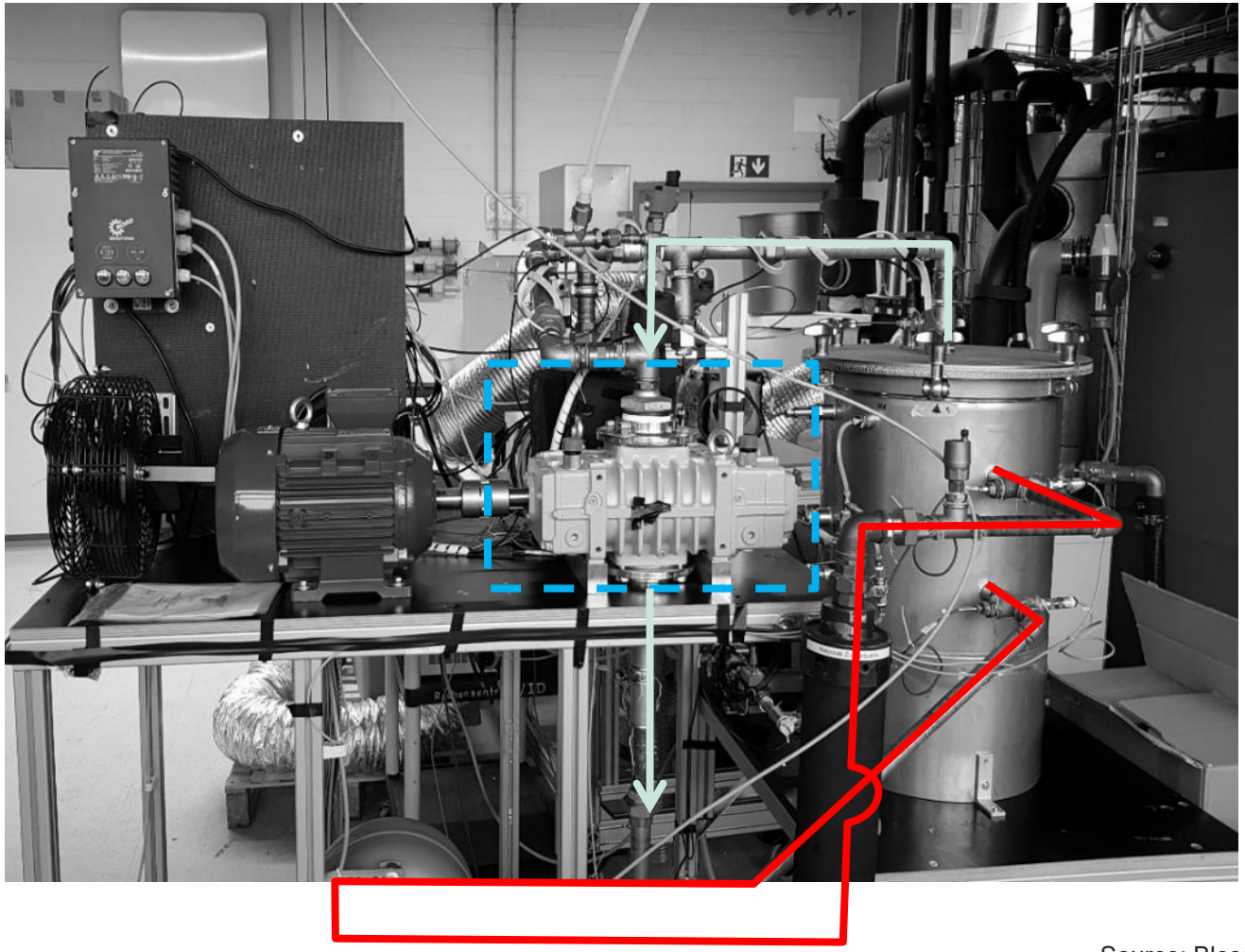
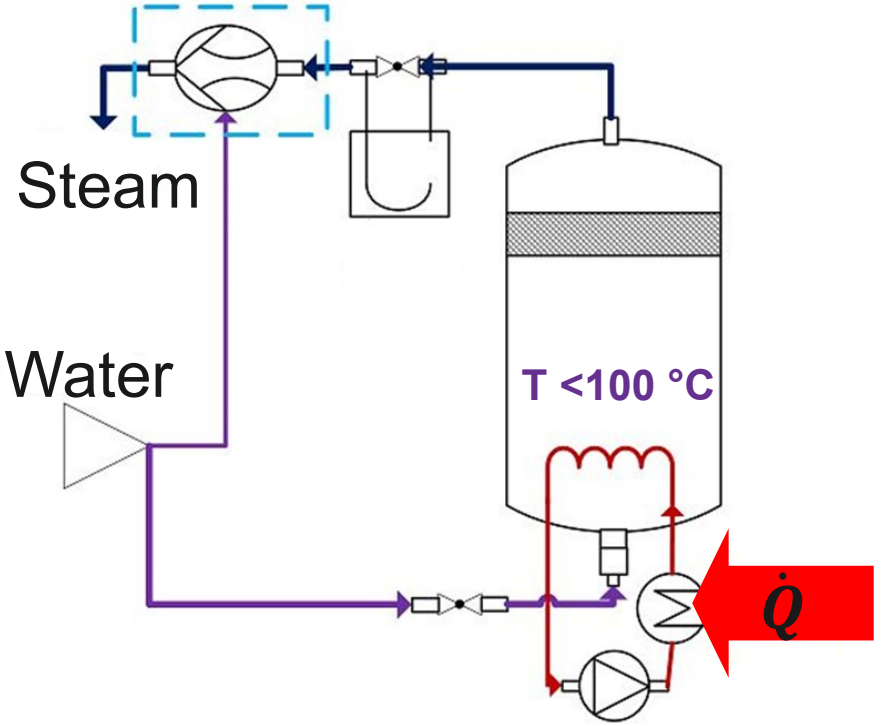
Prototype for steam generation from waste heat



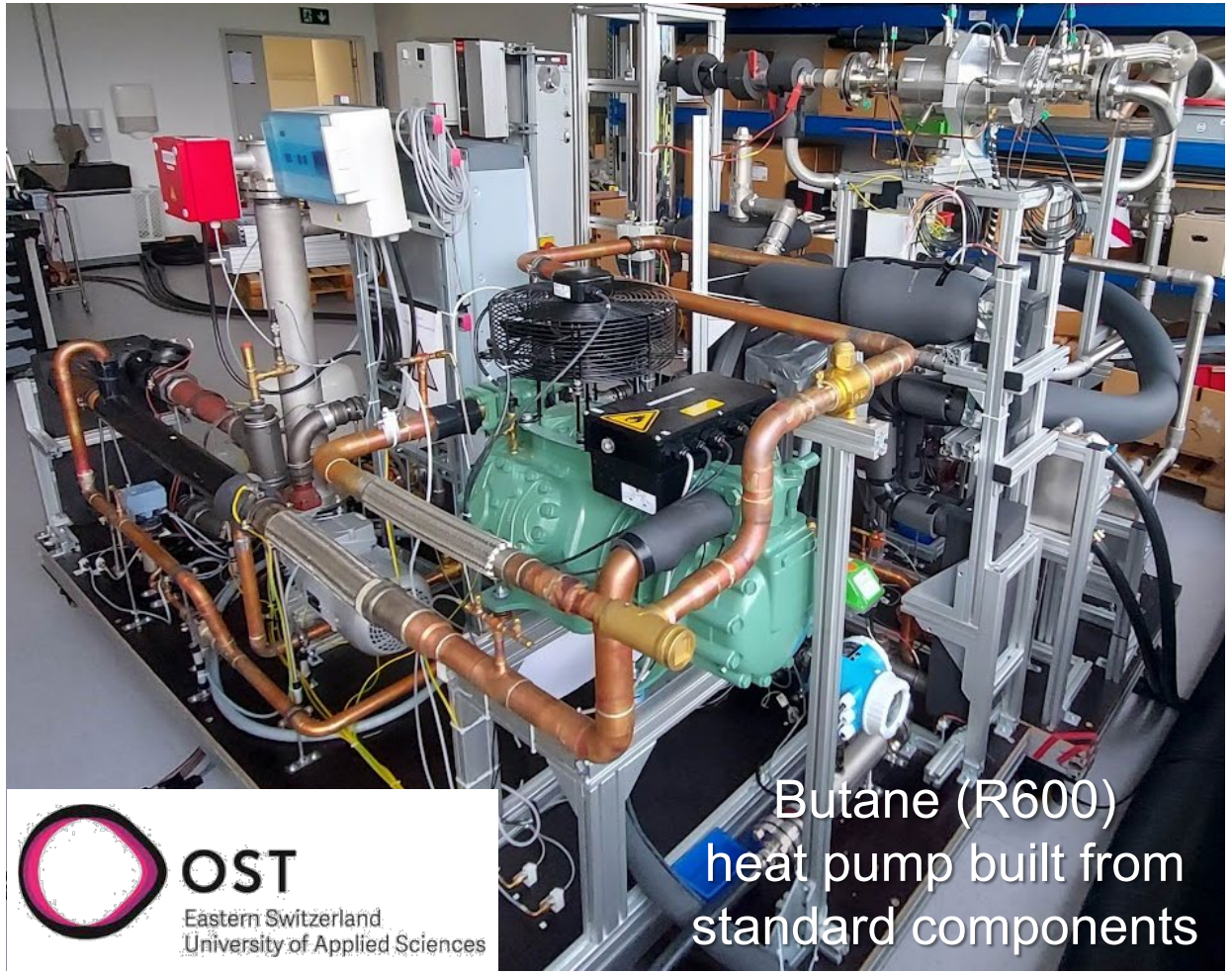
- Steam generating heat pump with an open water circuit
- 34.2 kg/h steam at 115 °C
- **Proof of concept**



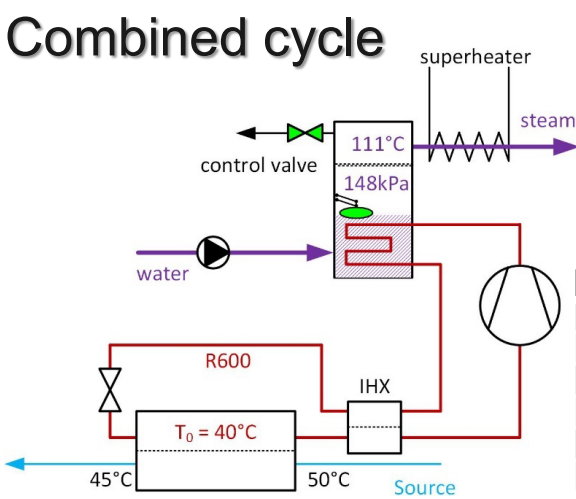
Source: Bless, F., Arpagaus, C., Bertsch, S.S., Schiffmann, J.: Theoretical analysis of steam generation methods - Energy, CO_2 emission, and cost analysis, Energy, 2017, 129, 114-121, https://doi.org/10.1016/j.energy.2017.04.088

Innovation project Efficient steam generation in industry, Innosuisse (42533.1 IP-EE) **ongoing**

R600/R718 (Butane/Water) Steam generating heat pump



Combined cycle



Parameters	Target value
Steam temperature turbo	148 °C (4.5 bar)
Steam temperature HP	111 °C (1.5 bar)
Heat sink water inlet	100 °C
Heat source water	50 °C
Heating capacity	115 kW
Mass flow	180 kg/h steam

Source: Uhlmann, M., Olmedo, L.E., Arpagaus, C., Bless, F., Schiffmann, J., Bertsch, S.: Efficient steam generation in industry – Combined heat pump cycle with mechanical vapor recompression, 15th IIR-Gustav Lorentzen conference on Natural Refrigerants, June 13-15, 2022, Trondheim, Norway, http://dx.doi.org/10.18462/iir.gl2022.0049

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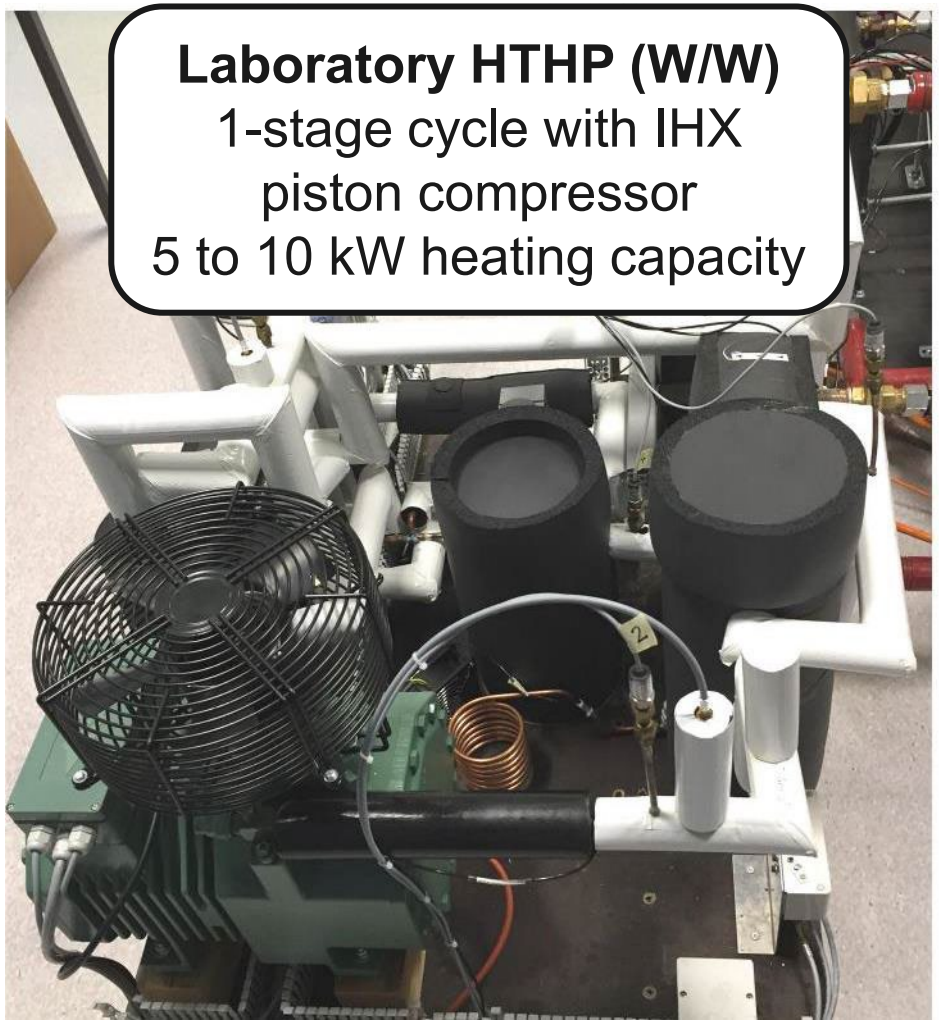
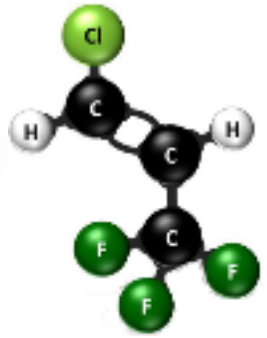
Testing synthetic HFO/HCFO refrigerants up to 150 °C



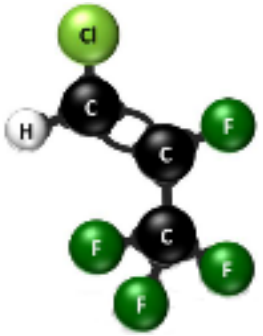
Laboratory HTHP (W/W)
1-stage cycle with IHX
piston compressor
5 to 10 kW heating capacity

HFO: Hydrofluorolefine, HCFO: Hydrochlorfluorolefine

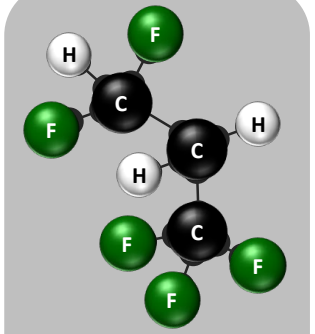
R1336mzz(Z)



R1233zd(E)



R1224yd(Z)



R245fa

Properties:
- Low GWP
- Zero/near zero ODP
- Short atmospheric life
- Not flammable
- Not toxic

Refrigerant	ODP	GWP_{100}	SG
R1336mzz(Z)	0	2	A1
R1233zd(E)	0.00034	1	A1
R1224yd(Z)	0.00023	0.88	A1
R245fa	0	858	B1

Source: 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, May 24-28, 2021, https://docs.lib.purdue.edu/iracc/2200

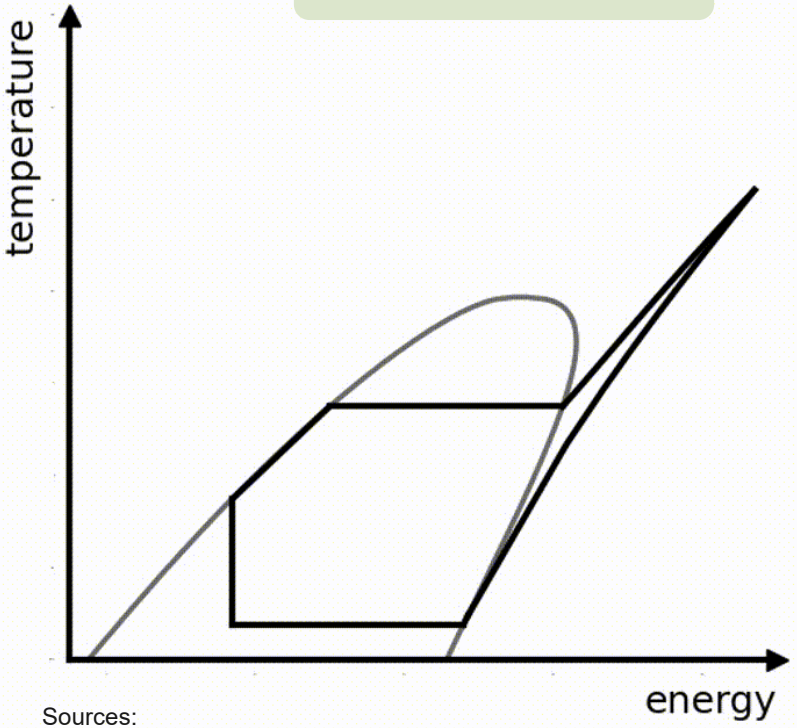
Bridge project (Grant No. 203645)

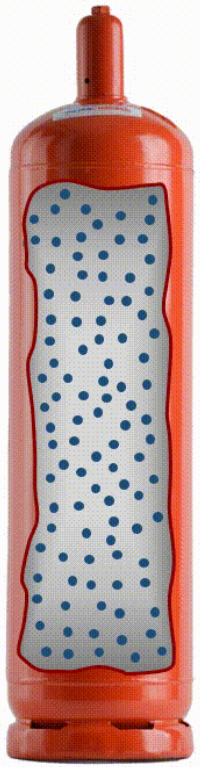
ongoing

High-Efficiency HTHPs with Temperature Glide

One refrigerant mixture offers **many** options

Mixture **A** + **B**





Adapted cycle for **maximum efficiency**

→ **Decrease of OPEX**

Flexibility through mixture adjustment

- One heat pump for various applications
- Increase of standardization

→ **Decrease of CAPEX**

Project goals

- **Experimental demonstration**
- Clustering of promising applications

  → Suitable refrigerant mixtures
- Guideline for handling mixtures in practice

Partners:

ETH zürich

OST Eastern Switzerland University of Applied Sciences

Funding:

Swiss National Science Foundation

Innosuisse BRIDGE

Sources:

- Brendel, L.P.M., Bernal, S.N., Arpagaus, C., Paranjape, S., Bertsch, S.S.: Mass fraction checks of an R1233zd(E) and R1234yf mixture in a high-temperature heat pump, 3rd IIR Conference on HFO Refrigerants and Low GWP Blends, 5-7 April 2023, Shanghai, China, http://dx.doi.org/10.18462/iir.HFO2023.0024
- Brendel, L.P.M., Bernal, S.N., Arpagaus, C., Widmaier, P., Roskosch, D., Bardow, A., Bertsch, S.S.: Experimental investigation of high-glide refrigerant mixture R1233zd(E)/R1234yf in a high-temperature heat pump, ICR 2023, The 26th IIR International Congress of Refrigeration, 21-25 August 2023, Paris, France, http://dx.doi.org/10.18462/iir.icr.2023.0376
- Brendel, L.P.M., Bernal, S.N., Roskosch, D., Arpagaus, C., Bardow, A., Bertsch, S.S.: Compressor performance for varying compositions of high-glide mixtures R1233zd(E)/R1234yf and R1336mzz(Z)/R1234yf, 13th International Conference on Compressors and their Systems, 11-13 September 2023, London, United Kingdom, https://doi.org/10.1007/978-3-031-42663-6_60

IntSGHP (Project Nr. SI/502292)

Integration of Steam Generating Heat Pumps

2021-2023

Guidelines for integrating industrial heat pump

Short summary

This short guideline is intended to help planners and end-customers to prepare when starting a project involving the integration of steam-generating heat pumps in their industrial processes.

Before implementing a steam-generating heat pump

Installing a steam-generating heat pump in a running industrial plant is not trivial. It requires a lot of preparation and information about the whole plant, not only where the heat pump will be installed.

There are two possible locations to install an industrial heat pump:

1. **Centralized heating** and cooling of the whole plant
2. Installation for one or a few **specific processes**

For the centralized heating and cooling, it is usually a bit easier to determine the requirement for the heat pump, since fuel data is available in most cases. However, since central supply temperatures are usually higher than the temperature range of the processes, this solution can lead to poor efficiency. In most cases simply replacing a fossil-fuel based steam generator with a heat pump is not successful.

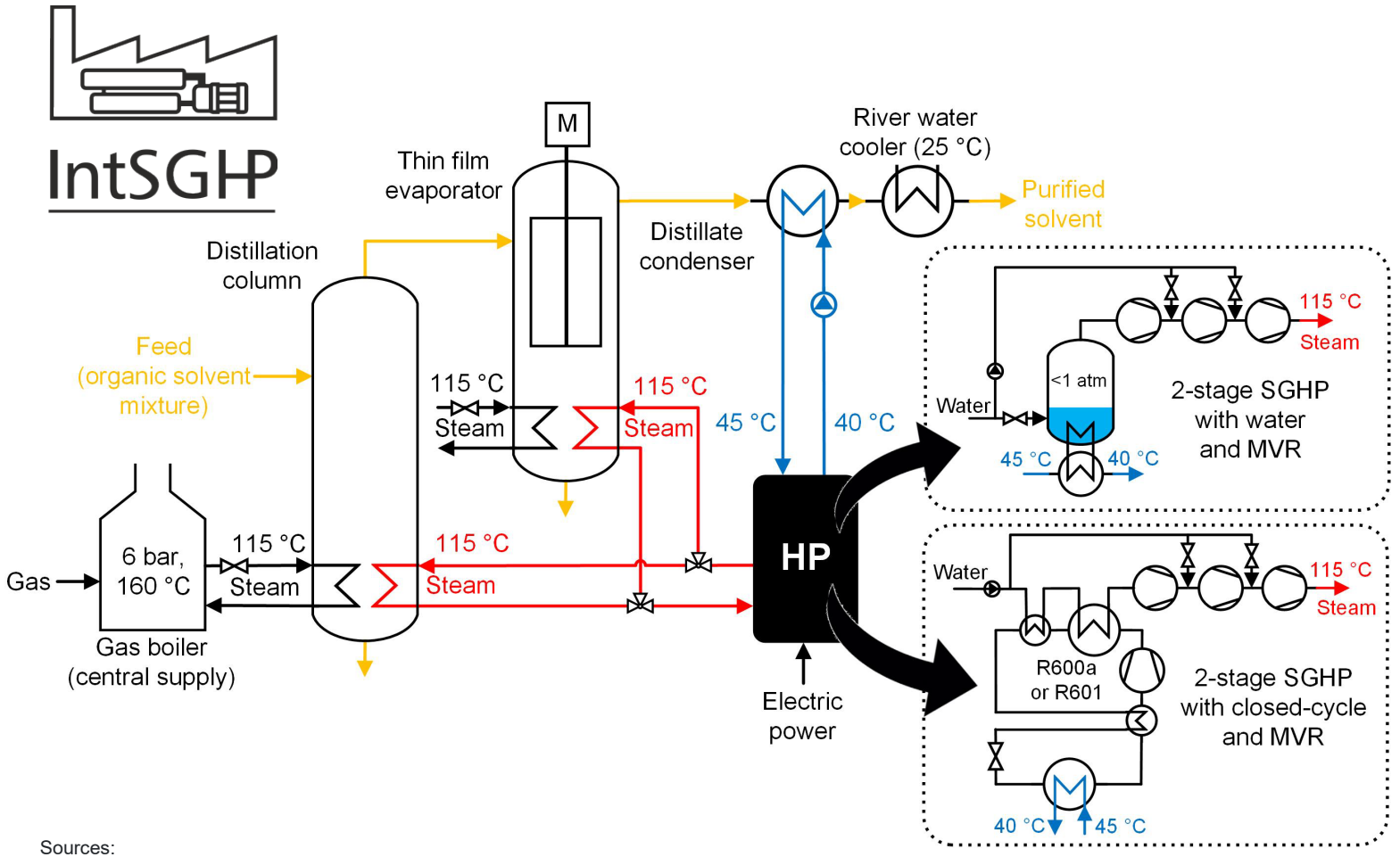
For a heat pump installation on a specific process, a **Pinch Analysis** of the process and the knowledge of **any potential modification planned on the process** are necessary before going forward with the project.

To have a good overview of the heating and cooling demand and to be ready to ascertain if a heat pump is the best technology for a centralized heating and cooling solution, it is highly encouraged to perform a **Pinch Analysis** of the whole plant. This analysis generates a grand composite curve of the plant for different periods of the year. Using this graphical summary of all the flows, it is convenient to determine the temperatures and capacities where a simple heat recovery via a heat exchanger is possible and where heat could be upgraded via a heat pump. The temperature lift between the cold and hot demand and the capacity are visible, clearly showing if and where a heat pump is the right solution. Results of a Pinch Analysis also help planners choose the right type of heat pump for the application. However, for simple processes, a full Pinch analysis may not be necessary. The list of process streams (with mass flow and temperatures) may be enough to design the best heat pump system.

It is also very important to have a **plan of future modifications to the plant** that are foreseeable. Heat pumps are designed to work at particular temperatures and capacity. Modifying the temperatures or the capacity can greatly reduce a heat pump's efficiency or even make it impossible to deliver new heating and cooling demands. While they can be very efficient, they are not as flexible as current steam boilers.

If the process does not match its cooling and heating demand well, looking for nearby process demands with similar running profiles is recommended.

Furthermore, a heat pump can only run if adequate cooling and heating demands are available at the same time. It is important not to neglect the **temporality of the processes**. If discrepancies exist or processes are not steady in power and temperature, adding heat storage is necessary.



Sources:

- Arpagaus, C., Bless, F., Bertsch, S.: Techno-economic analysis of steam generating heat pumps for integration into distillation processes, GL2022, 15th IIR-Gustav Lorentzen conference on Natural Refrigerants, June 13-15, 2022, Trondheim, Norway, http://dx.doi.org/10.18462/iir.gl2022.0029
- Bless, F., Arpagaus, C., Prinzing, M., Bertsch, S.: IntSGHP: INTegration of Steam Generating Heat Pumps (SGHP) in industrial sites (retrofit), WP Tagung 2022, https://www.sweet-decarb.ch/news/article/intsghp-integration-of-steam-generating-heat-pumps-in-industrial-sites-retrofit

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IEA HPT Annex 58 HTHP-CH (Project Nr. SI/502336)

Integration of HTHPs in Swiss Industrial Processes

2021-2025

www.heatpumpingtechnologies.org/annex58

Swiss Project Partners

OST Eastern Switzerland University of Applied Sciences

EPFL

HEIG-VD

National Coordinator

CSD INGENIEURS

INGÉNIEUX PAR NATURE

Industrial Partners

supporting with Case Studies

ELSA

Cremo DEPUIS 1927

Spiess Wurst für Feinschmecker.

Push2Heat

Pushing forward the market potential of heat upgrading technologies in the industrial sector

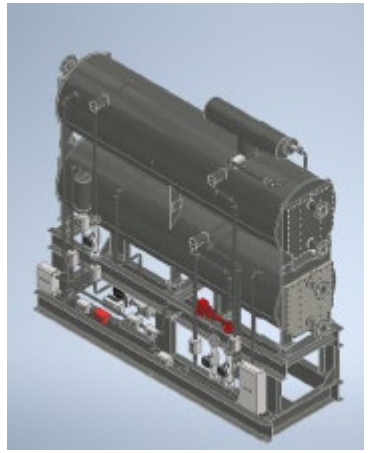
Grant Agreement No. 101069689

https://push2heat.eu

ongoing

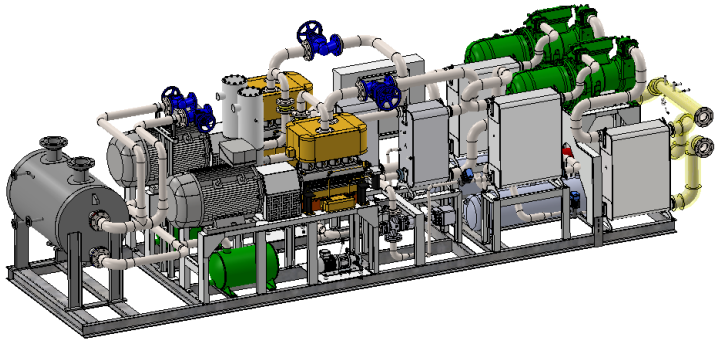
BS Nova

Absorption Heat Transformer (H_2O/LiBr)



SPH Sustainable Process Heat

2-stage cascade with piston and screw compressors



enertime

2-stage centrifugal compressor

QPINCH

Thermochemical Heat Transformer

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.

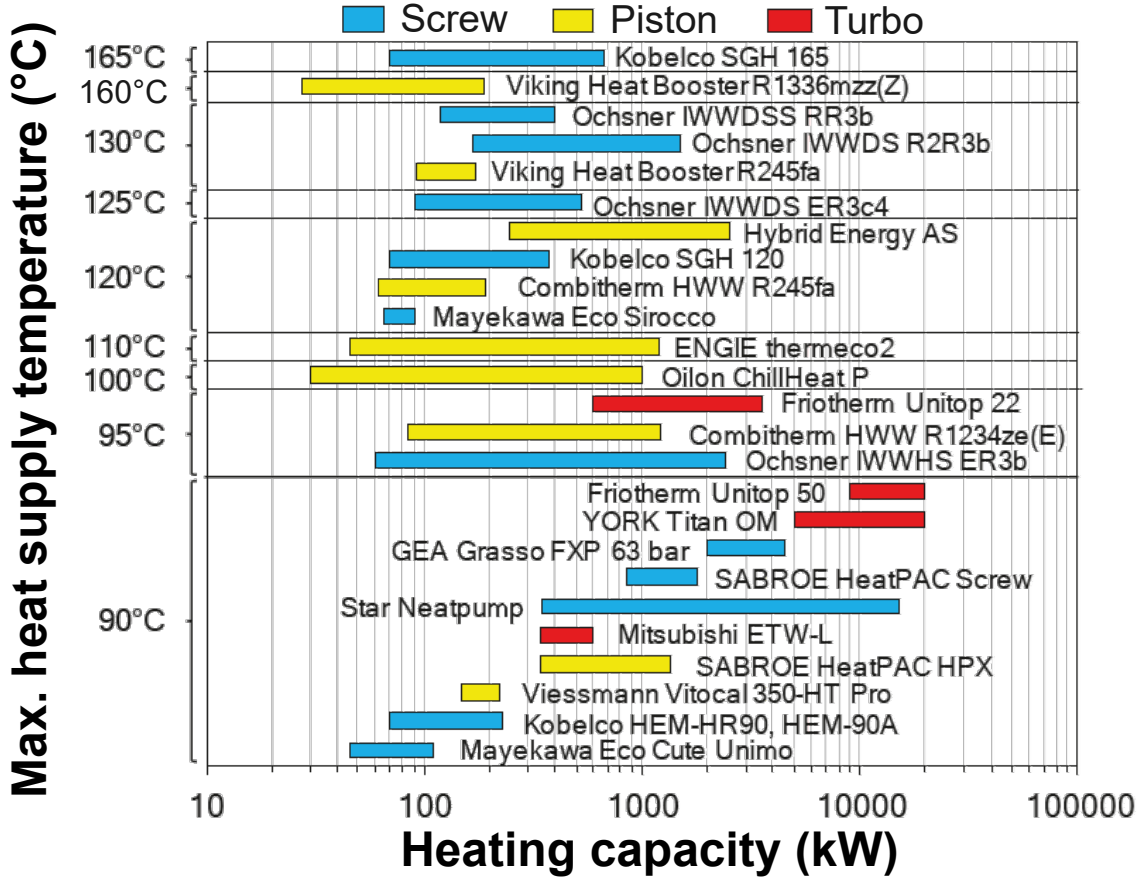
Evolution of the HTHP market

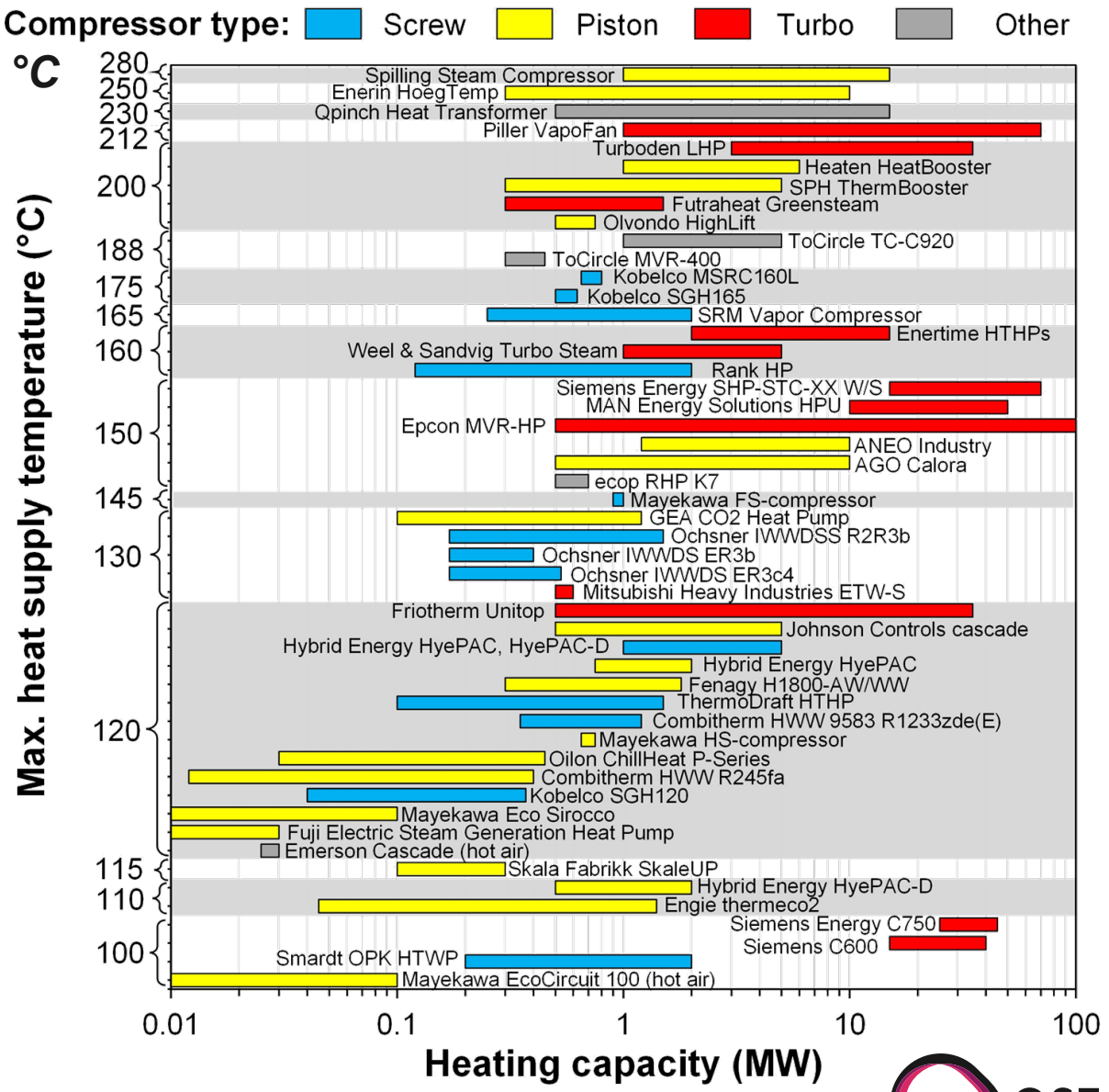
2018

25 HTHPs > 90 °C

50 HTHPs > 100 °C

2024





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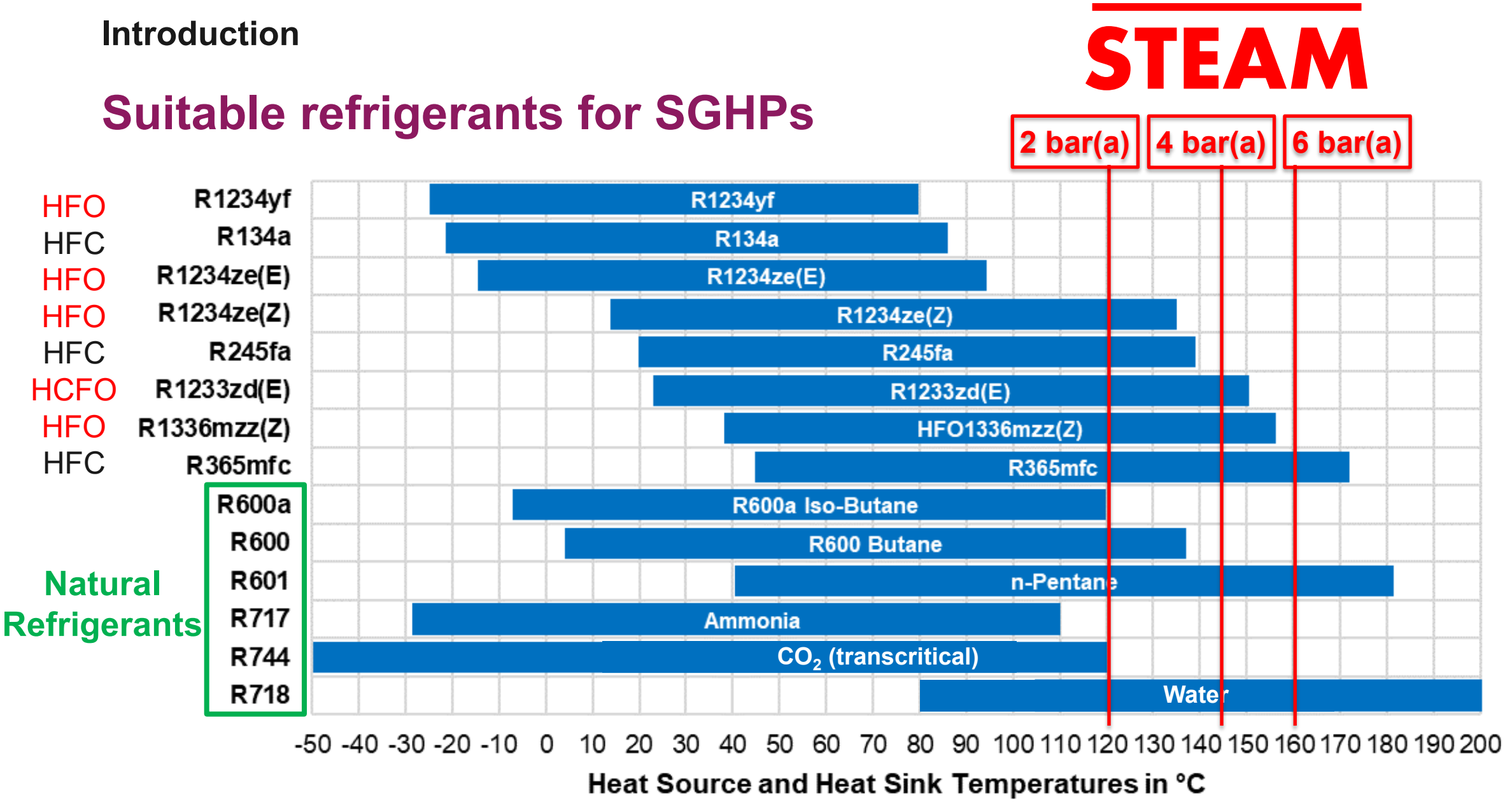
Suitable refrigerants for SGHPs



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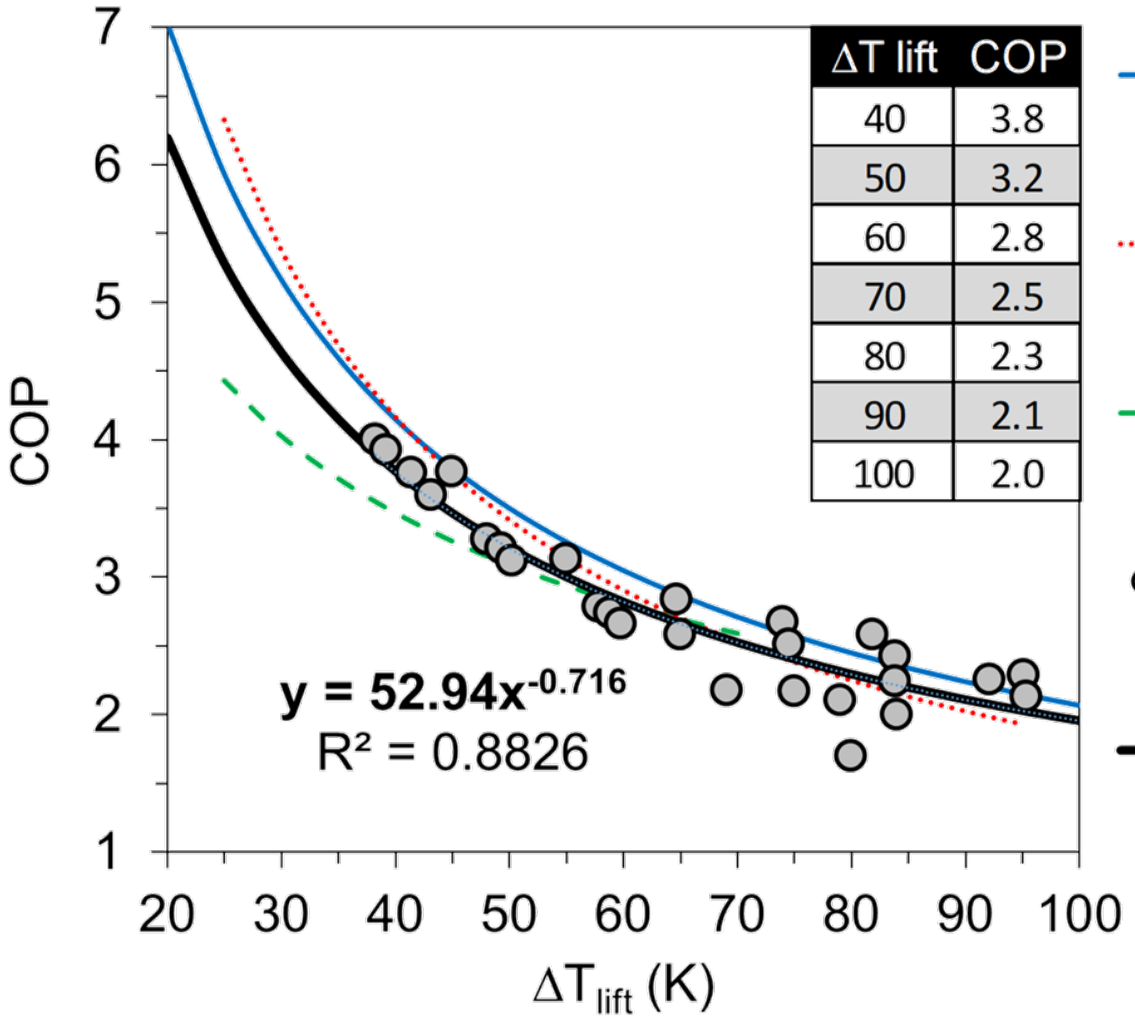
COP of Steam Generating Heat Pumps

STEAM



ΔT lift	COP
40	3.8
50	3.2
60	2.8
70	2.5
80	2.3
90	2.1
100	2.0

— Arpagaus et al. (2018), Several manufacturers of industrial HTHPs, y = 68.455x^-076

····· Schlosser et al. (2020) & Jesper et al. (2021), Water/Water-VHTHPs with HCFO, HFC or HFO, y = 110.38x^-0.888

– – Schlosser et al. (2020), Water/steam-VHTHPs, y = 23.642x-0.52

○ 32 data points of industrial SGHPs based on offers from heat pump suppliers

— Fit function based on 32 data points, y = 52.94x-0.716

$$COP = 52.94 \cdot \Delta T_{lift}^{-0.716}$$

Source: Arpagaus, C., Bless, F., Bertsch, S.: Techno-economic analysis of steam generating heat pumps for integration into distillation processes, GL2022, 15th IIR-Gustav Lorentzen conference on Natural Refrigerants, 13-15 June 2022, Trondheim, Norway, http://dx.doi.org/10.18462/iir.gl2022.0029

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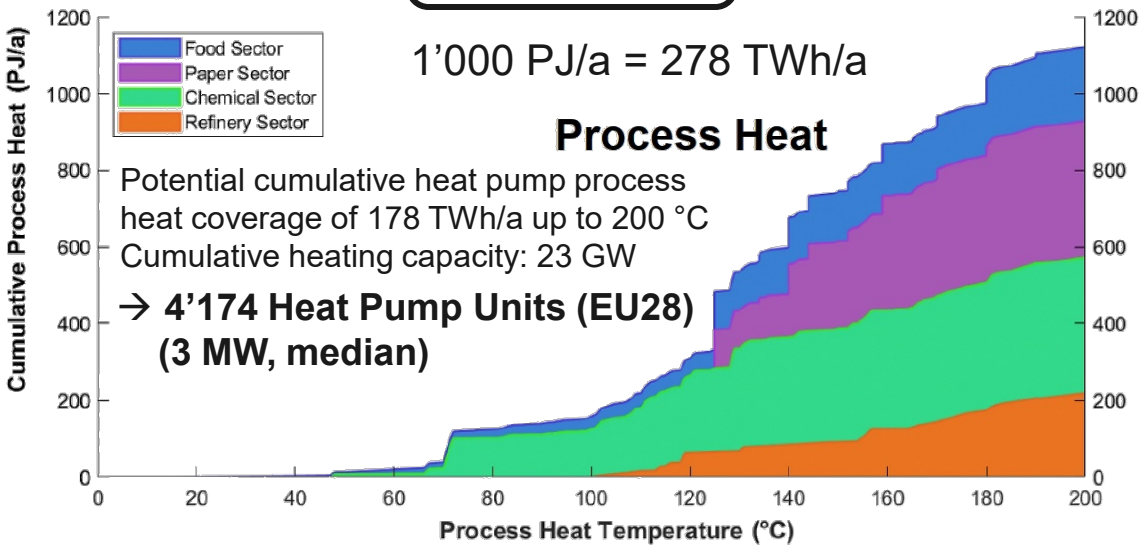
The heat pump market potential to 200 °C is large … but still emerging

Industrial process heat demand

EU28

1’000 PJ/a = 278 TWh/a



Process Heat

Potential cumulative heat pump process heat coverage of 178 TWh/a up to 200 °C
Cumulative heating capacity: 23 GW

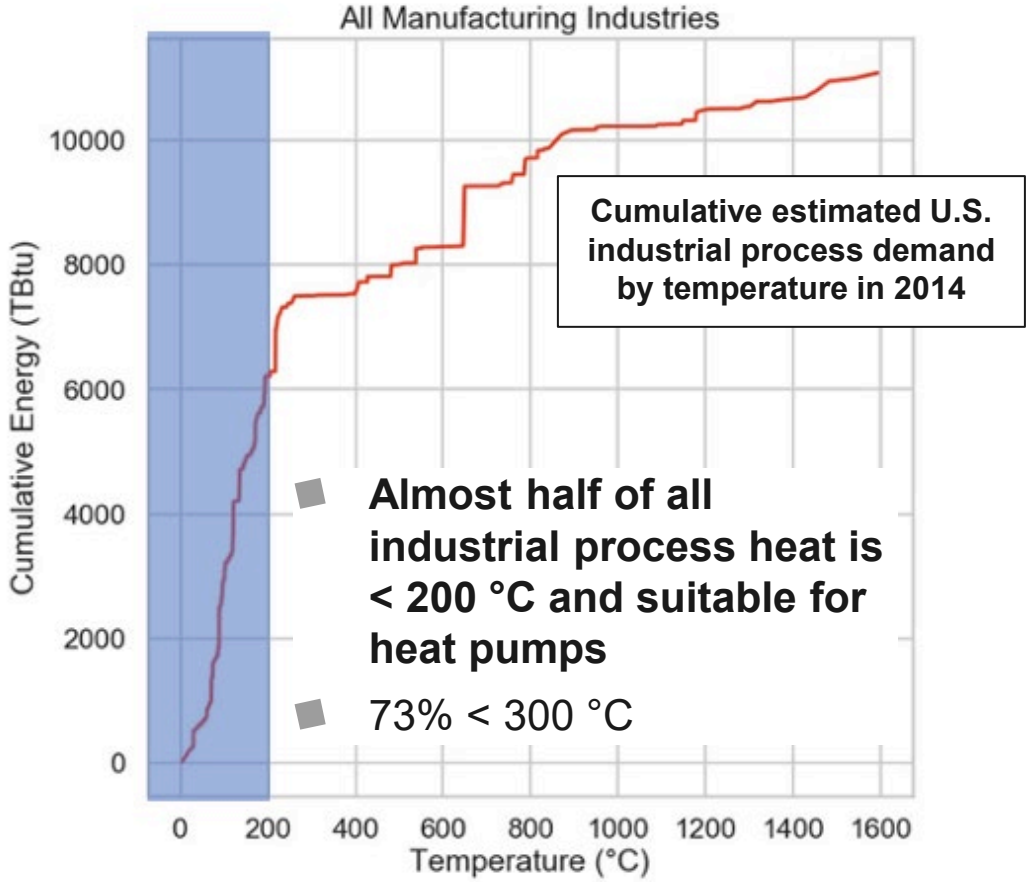
→ **4’174 Heat Pump Units (EU28) (3 MW, median)**

- Highest potential in the **food, paper, and chemical sectors**
- Available **waste heat** between 40 °C and 100 ºC is estimated to be 212 TWh/a (764 PJ/a) (EU28)

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

1’000 TBtu = 1’055 PJ

U.S.



Cumulative estimated U.S. industrial process demand by temperature in 2014

- **Almost half of all industrial process heat is < 200 °C and suitable for heat pumps**
- 73% < 300 °C

Source: McMillan et al. (2021): Opportunities for Solar Industrial Process Heat in the United States, Technical Report, NREL/TP-6A20-77760, https://www.nrel.gov/docs/fy21osti/77760.pdf

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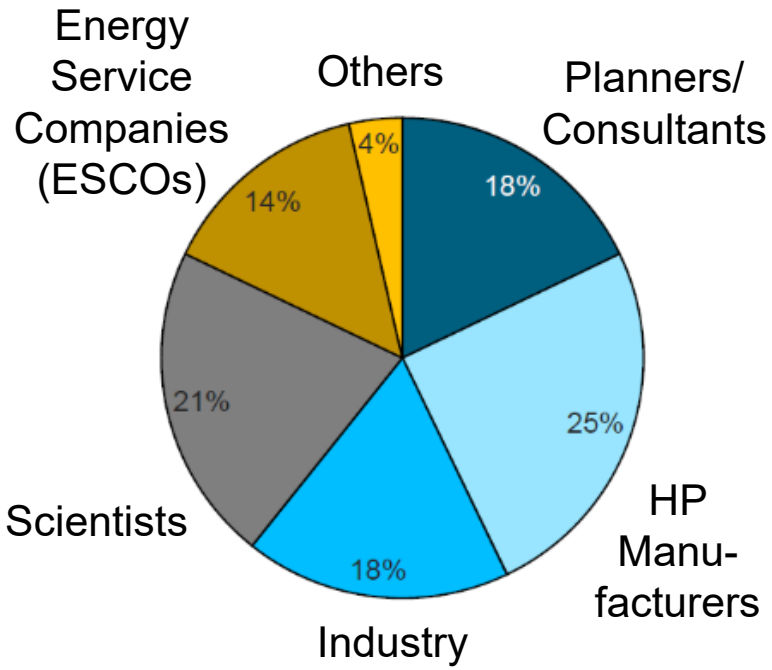
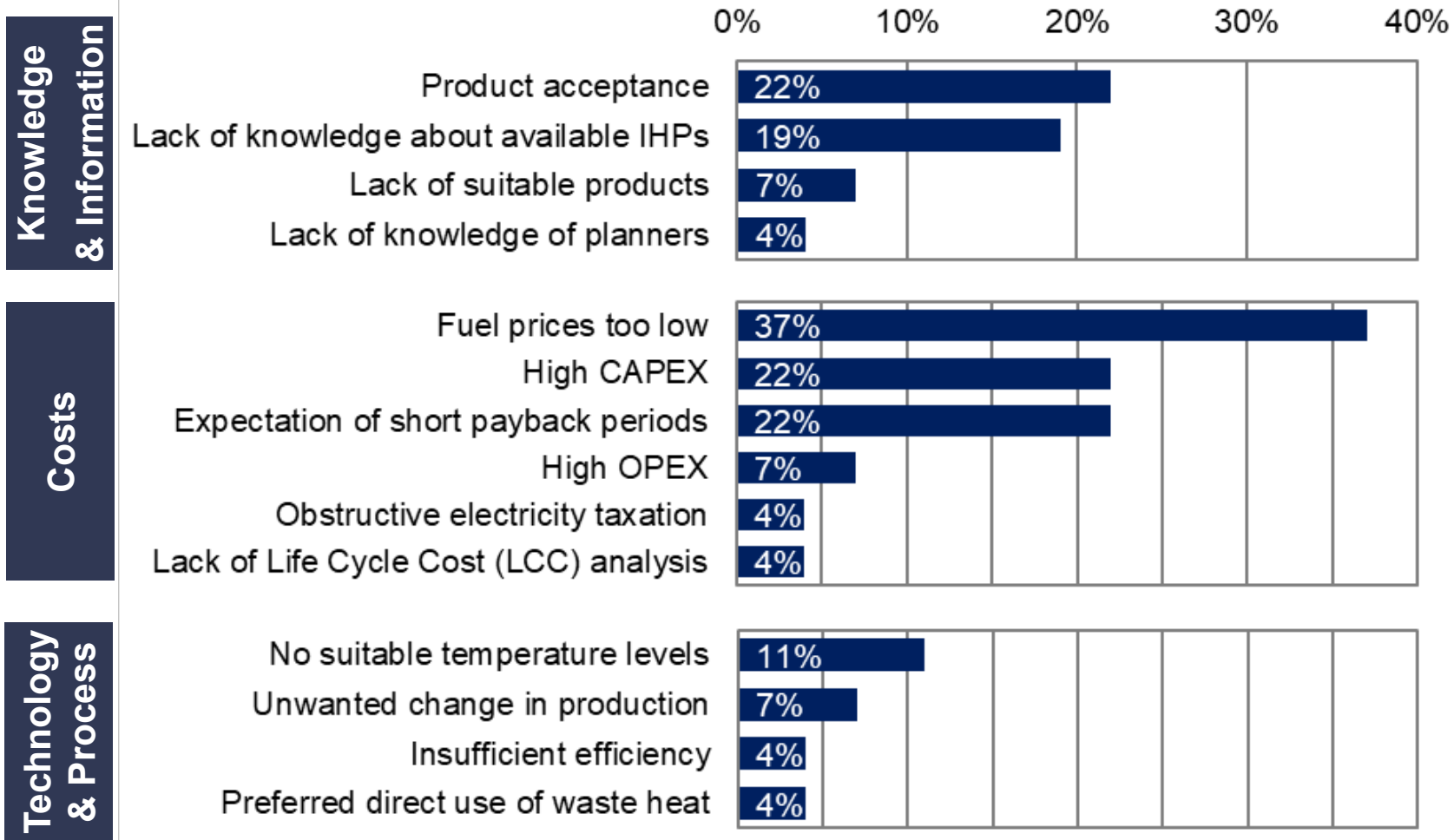
Challenging economics identified as key market barrier

Survey among 27 experts on heat pumps and heat recovery





Source: Data 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

Introduction – OST IES publications

Literature on Steam Generating Heat Pumps

STEAM

- **Arpagaus, C., Paranjape, S., Bless, F., Bertsch, S.S.,** Jansen, Ch.: Integration of a **steam-generating HTHP** in a Swiss meat factory, 4th HTHP Symposium, 23-24 January 2024, Copenhagen, Denmark https://www.hthp-symposium.org/hthp-symposium-2024
- **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, https://hthp-symposium.org
- **Arpagaus, C., Bless, F., Bertsch, S.**: Techno-economic analysis of **steam generating heat pumps** for integration into distillation processes, GL2022, 15th IIR-Gustav Lorentzen conference on Natural Refrigerants, June 13-15, **2022**, Trondheim, Norway, http://dx.doi.org/10.18462/iir.gl2022.0029
- **Arpagaus, C.**: High Temperature Heat Pumps – Market Overview, Refrigerants, Application Examples in Food Industry, and **Steam Generation Heat Pumps**, A2EP Briefing: Advances in industrial heat pumps, Australian Alliance for Energy Productivity, 3 September **2020** (Video Recording of Webinar)
- **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**
- **Bless, F., Arpagaus, C., Bertsch, S.S.**, Schiffmann, J., Theoretical analysis of **steam generation methods** – the case of high temperature heat pump, The Seventh International Symposium on Energy (Energy7), Manchester, UK, 13-17 August **2017**
- **Bless, F., Bertsch, S., Arpagaus, C.**, Schiffmann, J., 2016, Theoretical analysis of **steam generation methods** – Energy, CO_2 emission and cost analysis, Industrial Efficiency ECEE Conference, Berlin, 12-15 September **2016**
- **Bless, F., Arpagaus, C., Bertsch, S.S.**, Schiffmann, J.: Theoretical analysis of **steam generation methods** - Energy, CO_2 emission, and cost analysis, Energy, **2017**, 129, 114-121, https://doi.org/10.1016/j.energy.2017.04.088
- **Paranjape, S., Arpagaus, C., Bless, F., Bertsch, S.**: **Steam Generating Heat Pumps** for Process Heating in Agro Food Sector, Session IV, Application of Heat Pumps in Food Processing Industries, REFCOLD India, Chennai Trade Centre, 13 October **2023**
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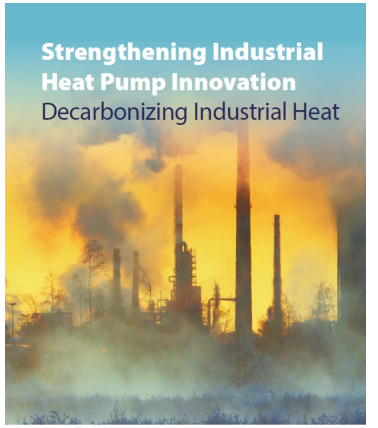

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Webinar wrap-up

Wrap-up & Conclusions

- **Dennis Roskosch (ETHZ):** Model-based analysis shows that highly efficient heat pumps cover the base load, various types of SGHP concepts are available (direct evaporation, flash evaporation, MVR)
- **Christian Schlemminger & Michael Bantle (Aneo Industry):** Demonstrated the integration of a 1.6 MW SGHP into a feed production process with ammonia/water as refrigerant. The combined heat pump system generates 2 t/h of 2 bar(a)/140 °C steam
- **Conrad Latham & Manuel Vandervoorde (Atlas Copco):** Atlas Copco is transforming air compressor technology to steam compression using existing technology, providing oil-free and air-free dry superheated steam using speed-controlled oil-free screw compression
- **Martin Pihl Andersen (DTU):** Tests with the Japanese Kobelco SGH165 with flash tank and steam compressor showed that the new synthetic and hydrocarbon refrigerants can be used as by drop-in replacements. The tests at 135 °C to 175°C made it possible to create an accurate model of the compressor efficiencies. The temperature of the expansion vessel is an optimizing variable.
- **Wouter de Vries (TNO):** Demonstration of a full-scale industrial heat pump producing steam above 140 °C, Carnot lab, pentane HP from Mayekawa, economizer cycle, test results
- **Mogens Weel (Weel & Sandvig):** Presented the challenges in the development of a compact, gearless turbo steam compressors with an isentropic efficiency of 73%, so far experience of 200 operating hours and 50 starts, in the future development of a new compressor family with 1-, 2- and 3-stage compression up to 83 K temperature
- **Hans Madsbøll (DTI):** Gave a nice overview of steam compressor types at a TRL 9 (centrifugal, piston, screw, roots, turbo fans), and new developemts TRL < 9 from direct drive turbo compressors, screw, rotary vane, to screw compressors
- **Arne Høeg (Enerin):** Presented the HoegTemp Stirling steam generating heat pump for decarbonizing industry, it uses helium as refrigerant, provides high temperature lifts, and is adaptable to high source and sink temperature

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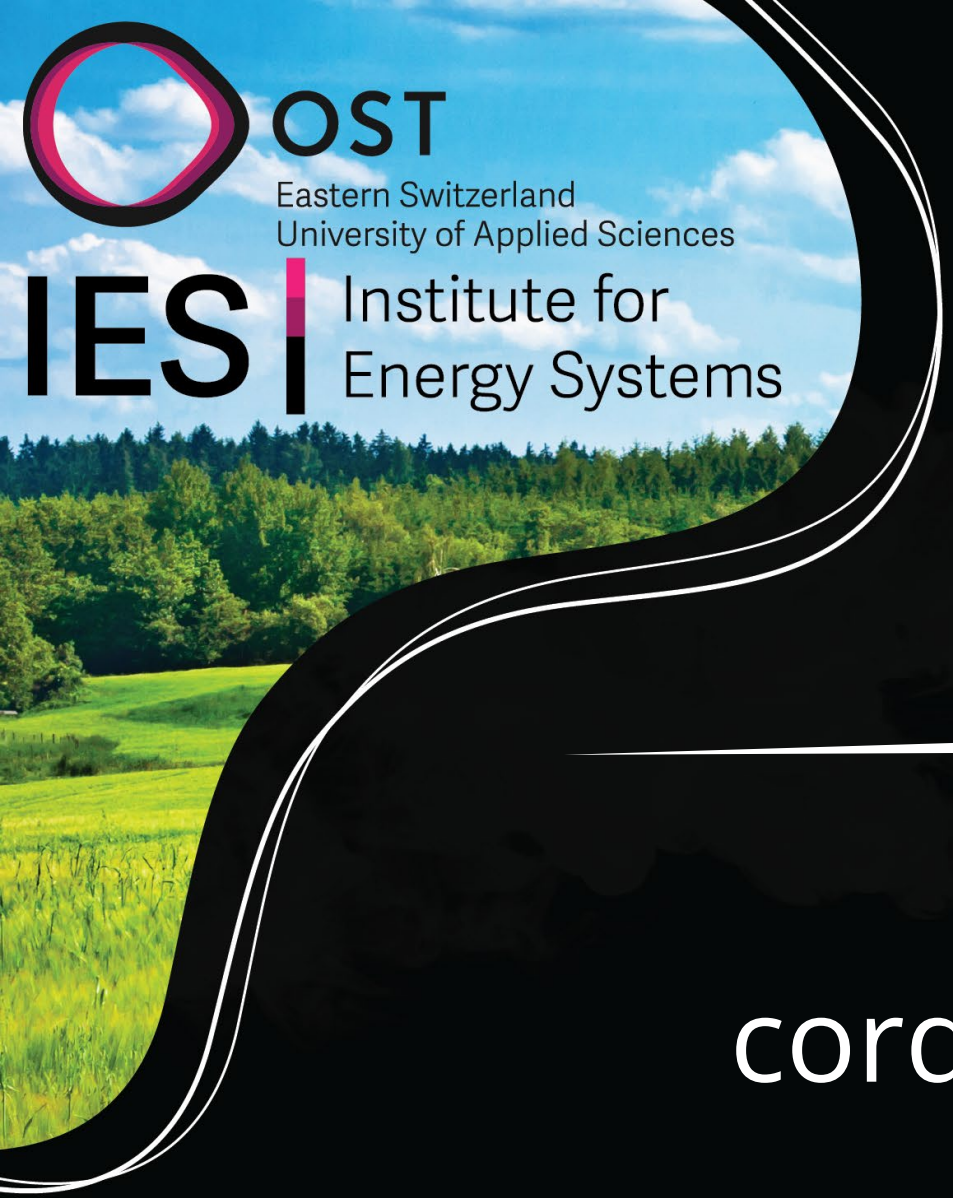

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Thank you

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