AUSTRALIAN ALLIANCE FOR ENERGY PRODUCTIVITY

OST
Eastern Switzerland
University of Applied Sciences

High-Temperature Heat Pumps for Industrial Applications –

New Developments and Products for Supply Temperatures above 100 °C

Webinar: 2023 High-Temperature Heat Pumps Update
22 February 2023

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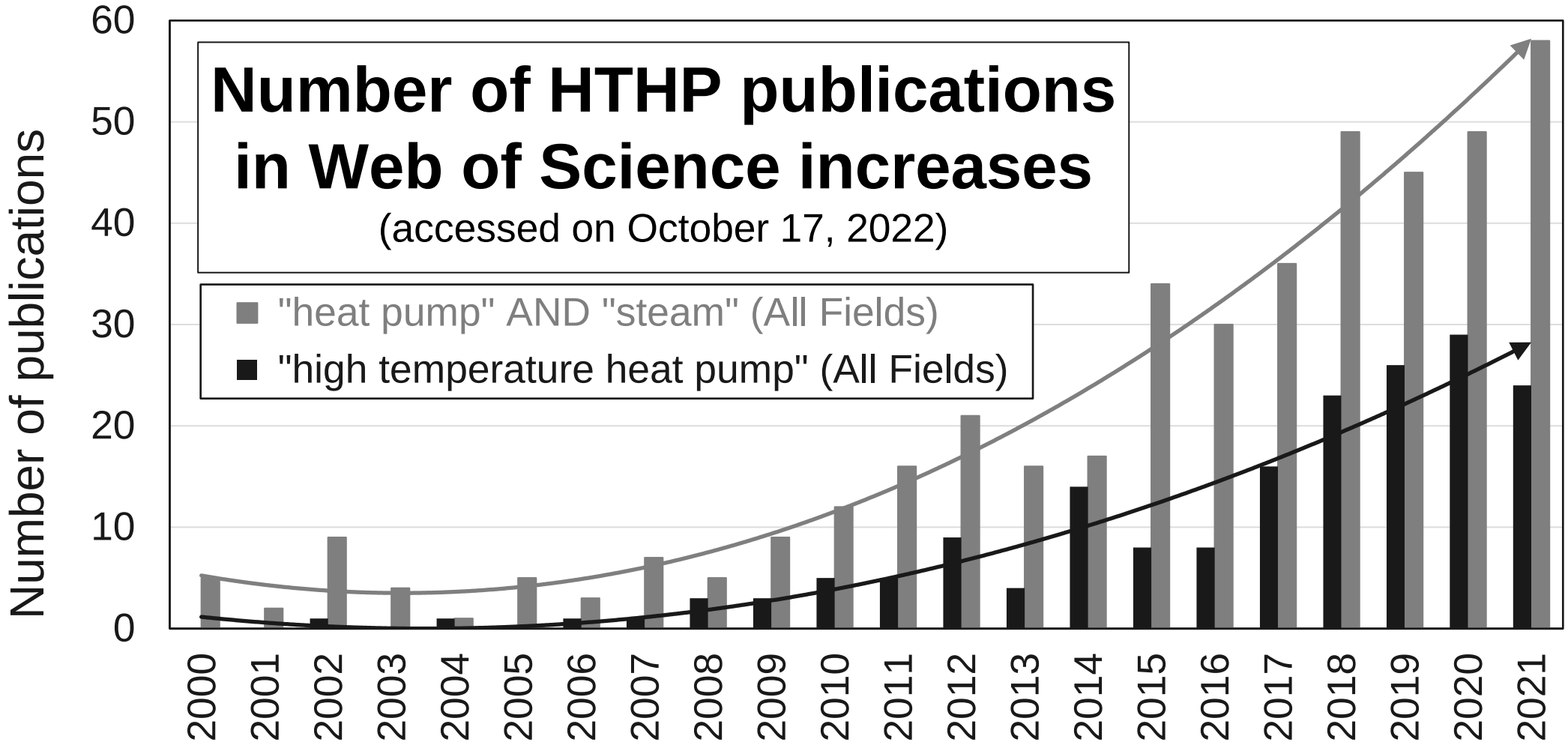
- Michael Uhlmann
- Prof. Stefan Bertsch

Research on HTHPs and Steam Generating Heat Pumps



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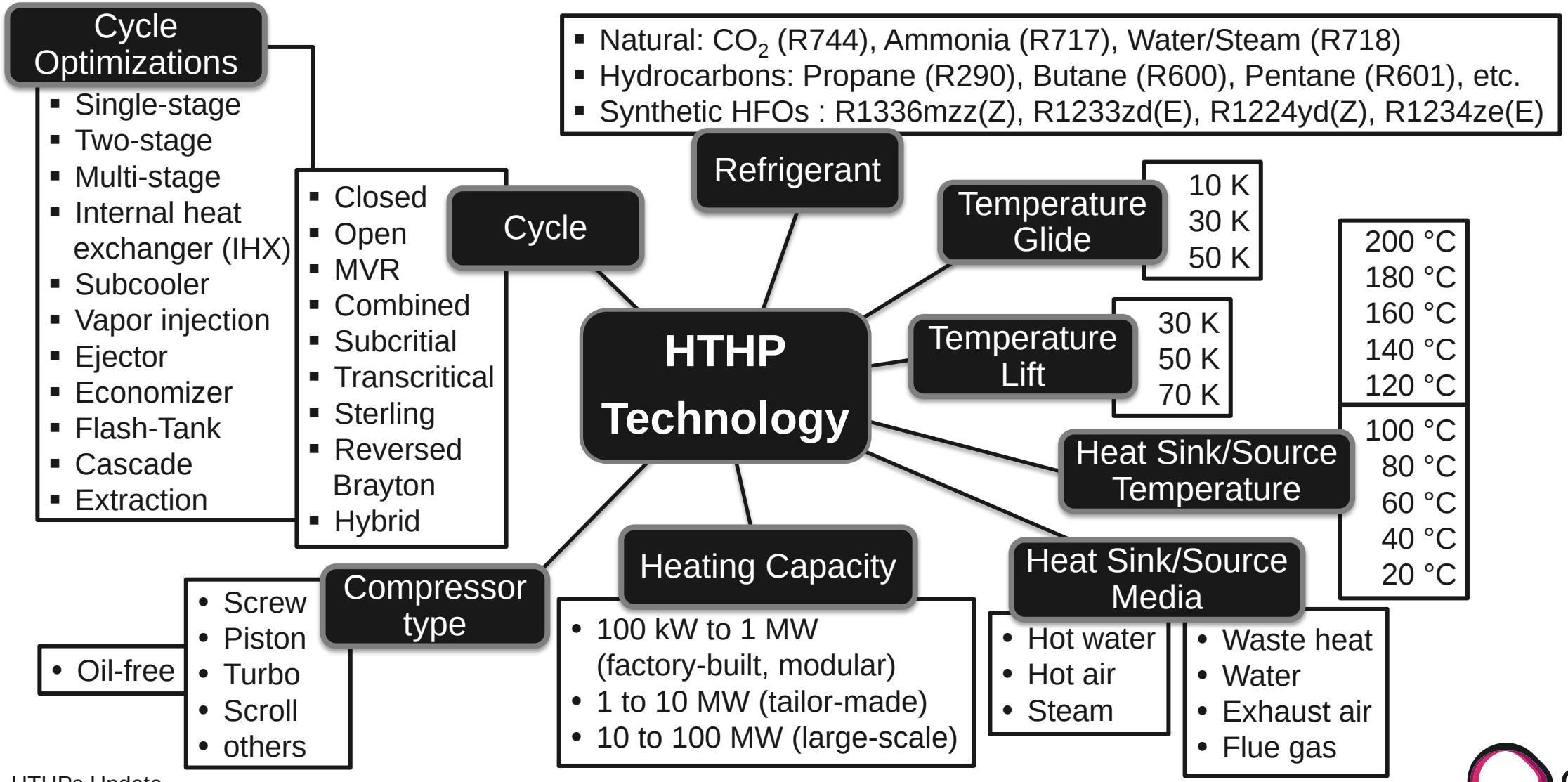
Selection Guide for High-Temperature Heat Pumps (HTHP)



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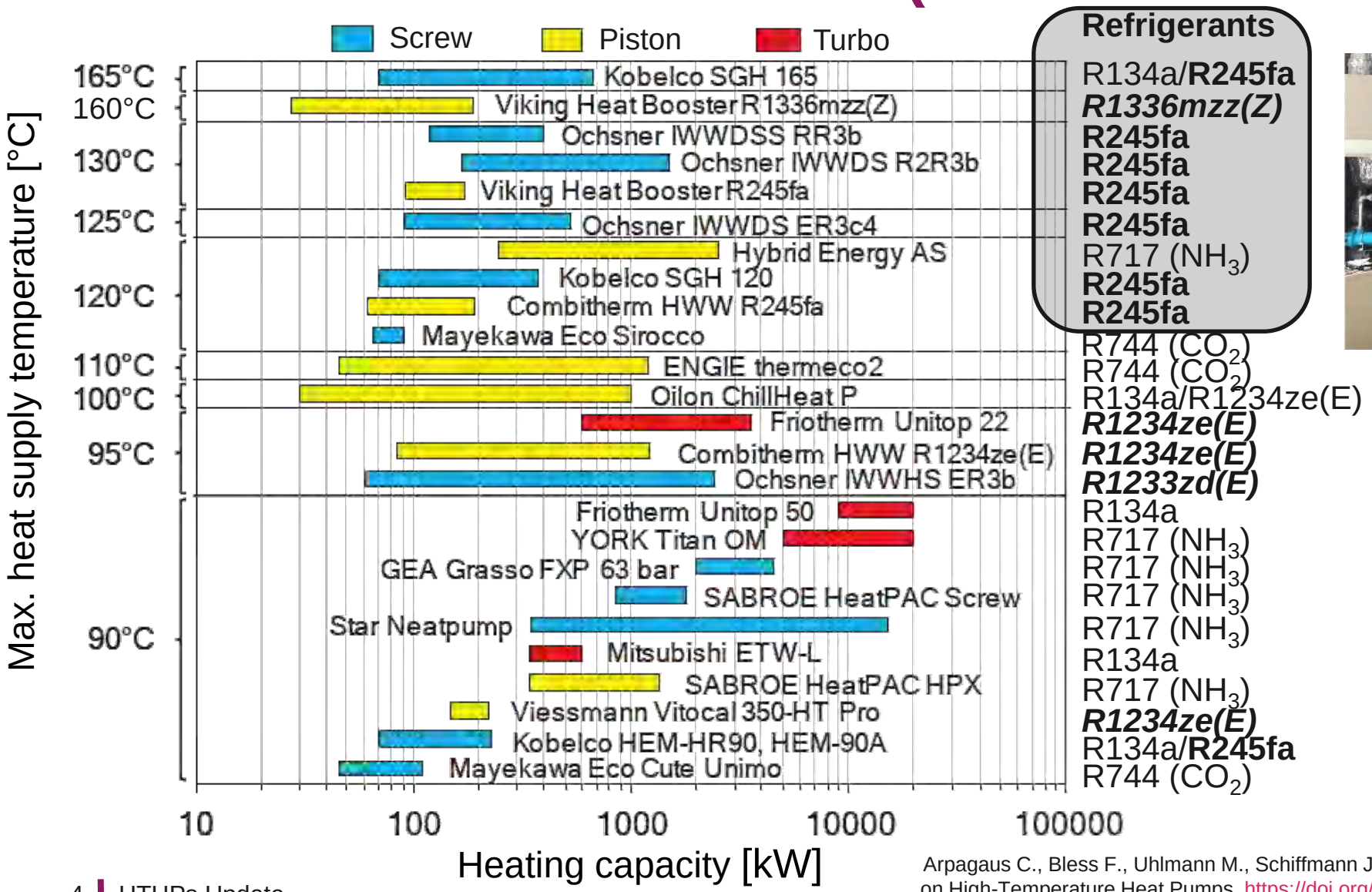
New Developments and Products for Supply Temperatures above 100 °C

Commercial Industrial HTHPs (Status end of 2018)



Refrigerants
R134a/**R245fa**
R1336mzz(Z)
R245fa
R245fa
R245fa
R245fa
R717 (NH_3)
R245fa
R245fa
R744 (CO_2)
R744 (CO_2)
R134a/R1234ze(E)
R1234ze(E)
R1234ze(E)
R1233zd(E)
R134a
R717 (NH_3)
R717 (NH_3)
R717 (NH_3)
R717 (NH_3)
R134a
R717 (NH_3)
R1234ze(E)
R134a/**R245fa**
R744 (CO_2)

KOBELCO

Kobelco SGH 120/165 (Steam Grow Heat Pump)

HeatBooster S4 (ex-Viking Heat Engines AS)

HEATEN

OCHSNER ENERGIE TECHNIK

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

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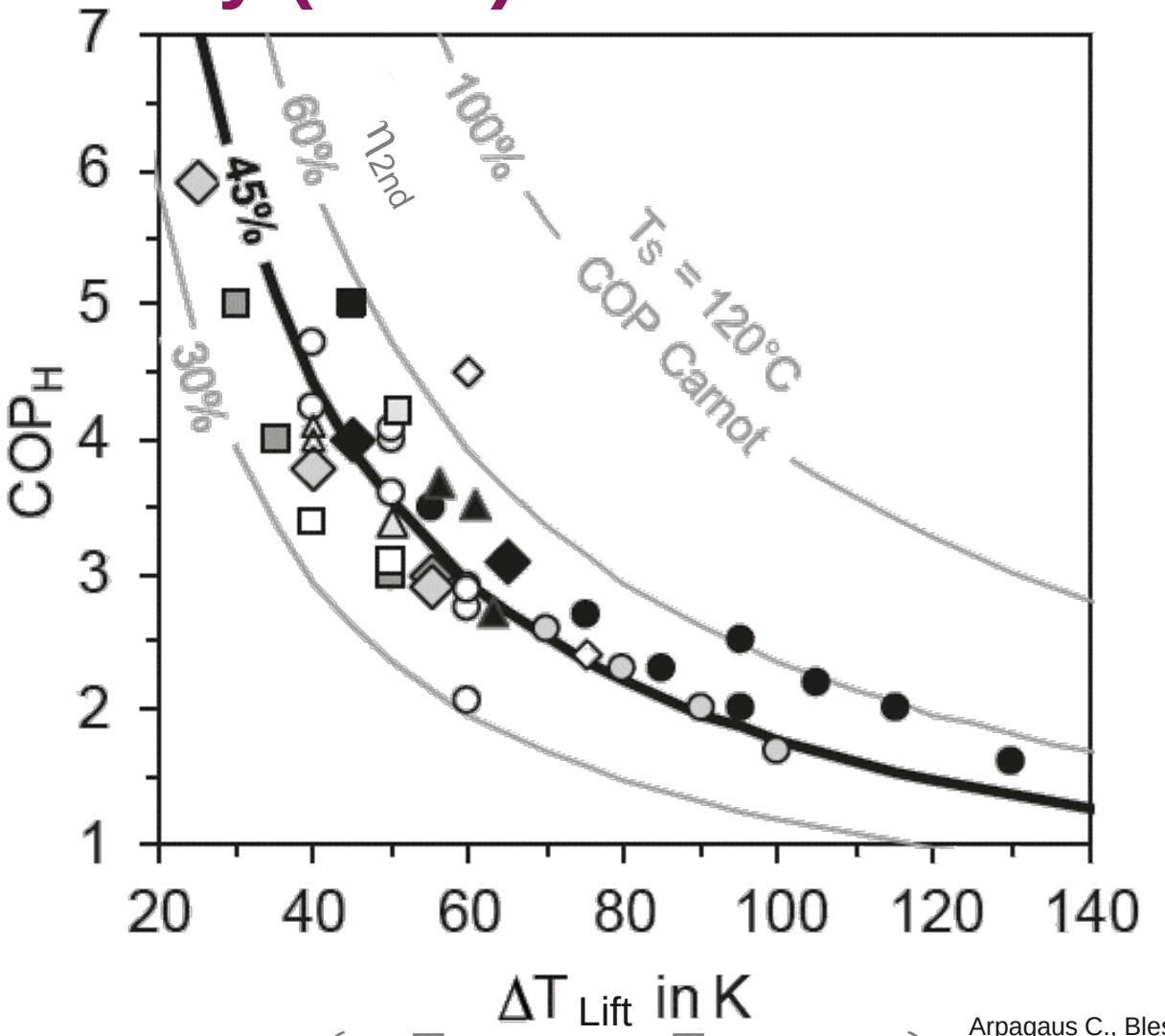
Efficiency (COP) of Industrial HTHPs



COP Fit-curve
(45% 2nd Law efficiency)

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

ΔT_{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

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

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IEA HPT TCP Annex 58 – HTHP Technology review

- **Task 1 report** will be published on homepage: https://heatpumpingtechnologies.org/annex58/task1
- **13 participating countries:** Austria, Belgium, China, Canada, Denmark, France, Germany, Netherlands, Japan, Norway, South Korea, Switzerland, US
- **Operating agent:** Danish Technological Institute

TRL level	4 to 9 (Technology Readiness)
Average specific cost	200 to 1’500 EUR/kW
Heating capacity	0.03 to 70 MW
Max. supply temperature	100 to 280 °C
Availability	Geographical dependent, e.g. Europe and Japan
Reviewed HTHP suppliers and technologies	28 suppliers, 33 technologies, 83 performance use cases

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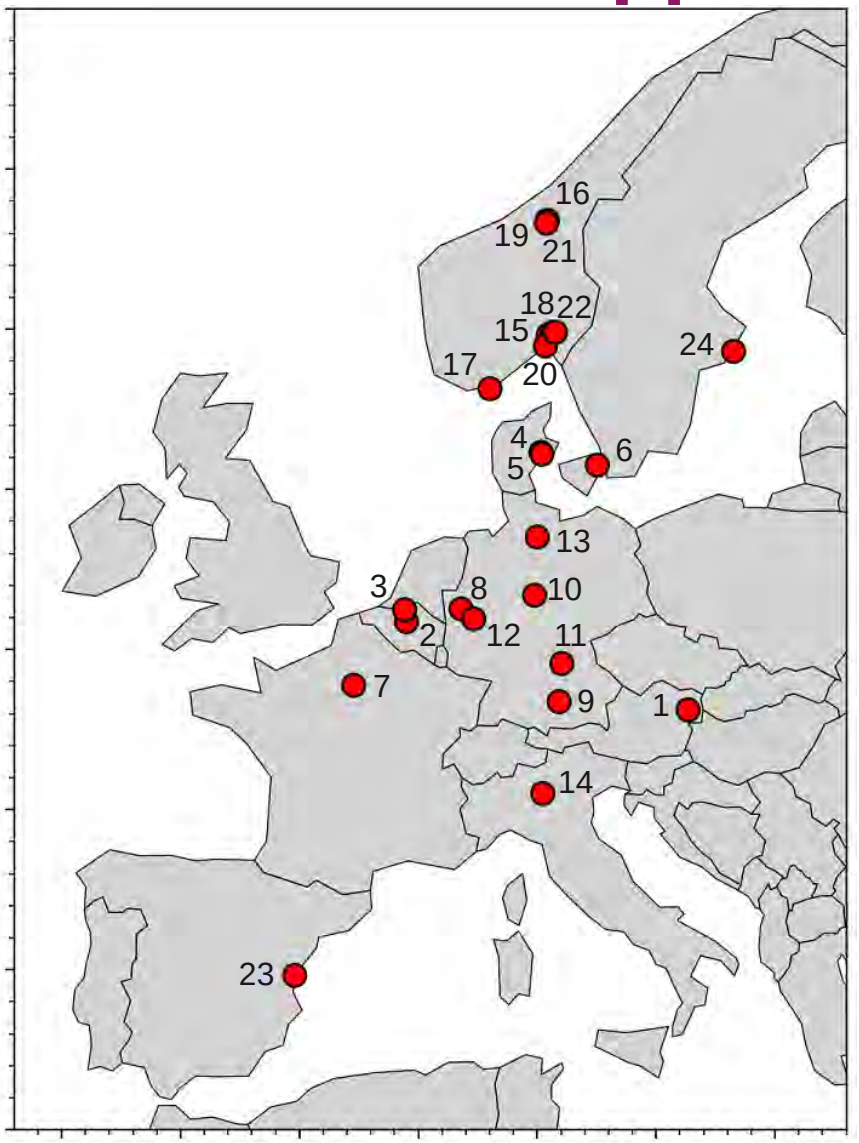
Headquarters of HTHP suppliers in Europe



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	Turboden (IT)
15	Enerin (NO)
16	Epcon (NO)
17	Heaten (NO)
18	Hybrid Energy (NO)
19	Ohmia (NO)
20	Olvondo (NO)
21	Skala Fabrikk (NO)
22	ToCircle (NO)
23	Rank (ES)
24	SRM (SE)

Japan

25	Fuji (JP)
26	KOBELCO (JP)
27	Mitsubishi (JP)

Based on database of IEA HPT Annex 58:

https://heatpumpingtechnologies.org/annex58/task1

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New Developments and Products for Supply Temperatures above 100 °C

HTHP supplier (High-Temperature Heat Pump)	Country	Compressor type	Working fluid (Refrigerant)	Max. heating capacity (MW)	Max. supply temp (°C)	TRL (Technology Readiness Level)	Spec. invest. cost (EUR/kW)
Spilling	DE	Piston (MVR)	R718 (water)	15	280	9	100 to 400
Enerin	NO	Piston	R704 (helium)	10	250	6	600 to 800
Qpinch	BE	Chemical heat transformer	R718, H_3PO_4 and derivatives	2	230	9	1000 to 2000
Piller	DE	Turbo (MVR)	R718	70	212	8 to 9	850
Olvondo	NO	Piston (double acting)	R704	5	200	9	1200
Turboden	IT	Turbo	Application specific	30	200	7 to 9	300 to 700
ToCircle	NO	Rotary vane	R717 (ammonia), R718	5	188	6 to 7	250 to 430
Kobelco MSRC160	JP	Twin -screw (MVR)	R718	0.8	175	9	n.a.
Kobelco SGH165	JP	Twin-screw (MVR)	R245fa/R134a (mixture), R718	0.62	175	9	n.a.
Heaten	NO	Reciprocating, custom design	HFOs (hydrofluorolefins)	6	165	7 to 9	250 to 350
SPH	DE	Piston	HFOs (hydrofluorolefins)	5	165	6 to 8	150 to 1000
SRM	SE	Screw (MVR)	R718	2	165	5	n.a.
Siemens Energy	DE	Turbo (geared or single-shaft)	R1233zd(E), R1234ze(E)	70	160	9 (to 90 °C)	250 to 800
Enertime	FR	1- or 2-stage centrifugal	R1336mzz(Z), R1224yd(Z), R1233zd(E)	10	160	4 to 8	300 to 400
Weel & Sandvig	DK	Turbo (MVR)	R718	5	160	4 to 9	150 to 250
Rank	ES	Screw	R245fa, R1336mzz(Z), R1233zd(E)	2	160	7	200 to 400
MAN	DE	Centrifugal turbo with expander	R744 (CO_2)	50	150	7 to 8	300 to 500
Epcon	NO	Centrifugal fan / Blower	R718	30	150	9	200 to 400
Ohmia Industry	NO	Piston, Centrifugal fan (MVR)	R717, R718	10	150	7 to 8	n.a.
ecop	AT	Rotational heat pump	ecop fluid 1 (He, Kr, Ar)	0.7	150	6 to 7	700
Mayekawa FC Comp	BE	Screw	R601 (n-pentane)	1	145	5	720
GEA Refrigeration	NL	Semi-hermetic piston	R744	1.2	130	8	200 to 300
Mitsubishi Heavy Ind.	JP	Two-stage centrifugal	R134a	0.6	130	9	n.a.
Hybrid Energy	NO	Piston/screw	R717/R718 mixture	5	120	9	200 to 600
Johnson Controls	DK	Reciprocating	R717, R600 (n-butane) (cascade)	5	120	7 to 8	n.a.
Fenagy	DK	Reciprocating	R744	1.8	120	5 to 6	250 to 425
Mayekawa HS Comp	BE	Piston	R600 (n-butane)	0.75	120	7	450
Kobelco SGH120	JP	2-stage twin-screw	R245fa	0.37	120	9	n.a.
Mayekawa EcoCircuit	JP	Reciprocating	R1234ze(Z)	0.1	120	9	n.a.
Fuji Electric	JP	Reciprocating	R245fa	0.03	120	9	n.a.
Emerson	US	Scroll and EVI scroll	R245fa, R410a, R718	0.03	120	6	n.a.
Skala Fabrikk	NO	Piston (semihermetic)	R290 (propane), R600 (cascade)	0.3	115	7	500 to 700
Mayekawa EcoSirocco	JP	Reciprocating	R744 (CO2)	0.1	100	8 to 9	n.a.

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.

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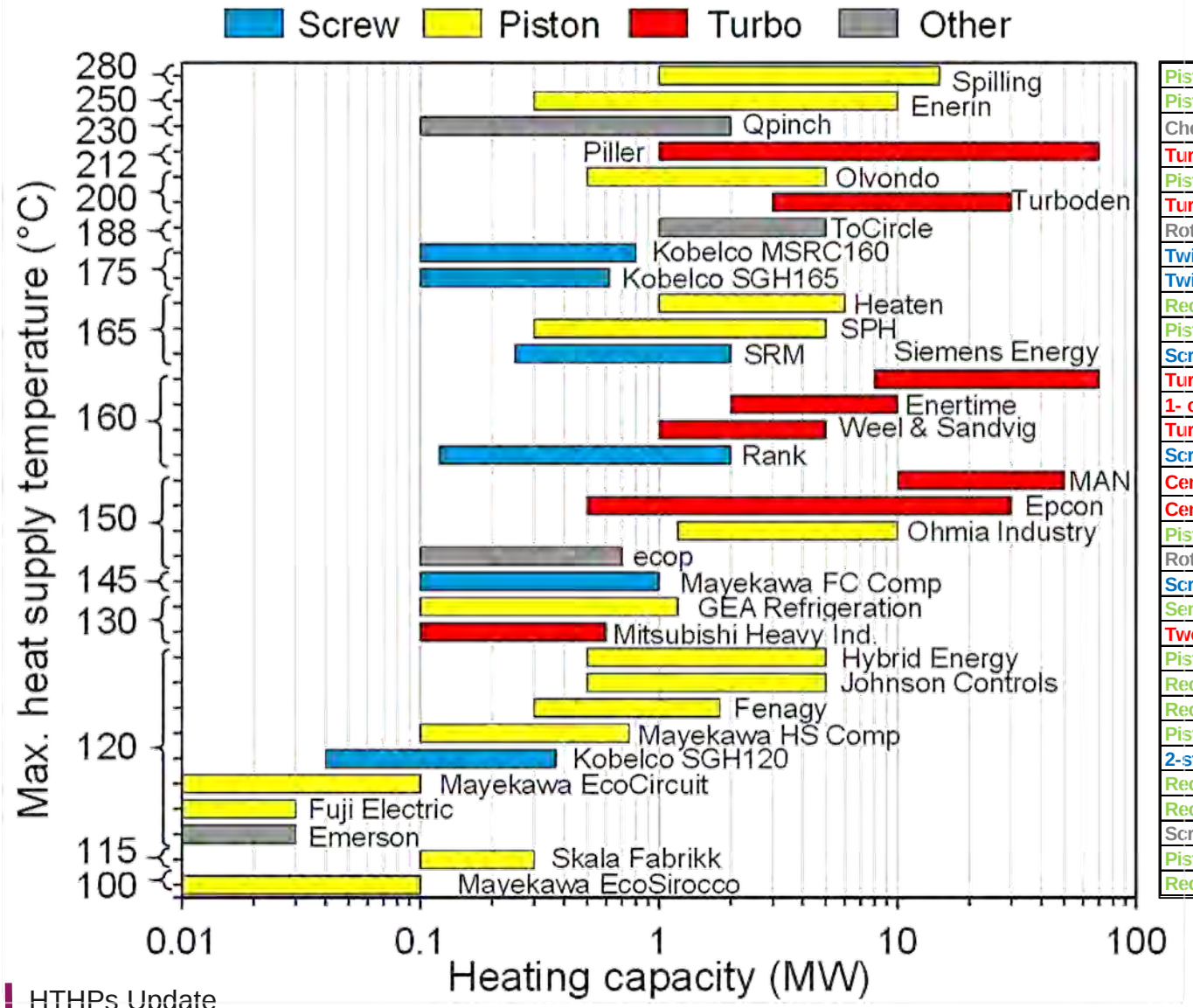
New Developments and Products for Supply Temperatures above 100 °C

Max. supply temperature vs. heating capacity of various HTHPs



Piston (MVR)	R718 (water)
Piston	R704 (helium)
Chemical heat transformer	R718, H_3PO_4 and derivatives
Turbo (MVR)	R718
Piston (double acting)	R704
Turbo	Application specific
Rotary vane	R717 (ammonia), R718
Twin -screw (MVR)	R718
Twin-screw (MVR)	R245fa/R134a (mixture), R718
Reciprocating, custom design	HFOs (hydrofluorolefins)
Piston	HFOs (hydrofluorolefins)
Screw (MVR)	R718
Turbo (geared or single-shaft)	R1233zd(E), R1234ze(E)
1- or 2-stage centrifugal	R1336mzz(Z), R1224yd(Z), R1233zd(E)
Turbo (MVR)	R718
Screw	R245fa, R1336mzz(Z), R1233zd(E)
Centrifugal turbo with expander	R744 (CO_2)
Centrifugal fan / Blower	R718
Piston, Centrifugal fan (MVR)	R717, R718
Rotational heat pump	ecop fluid 1 (He, Kr, Ar)
Screw	R601 (n-pentane)
Semi-hermetic piston	R744
Two-stage centrifugal	R134a
Piston/screw	R717/R718 mixture
Reciprocating	R717, R600 (n-butane) (cascade)
Reciprocating	R744
Piston	R600 (n-butane)
2-stage twin-screw	R245fa
Reciprocating	R1234ze(Z)
Reciprocating	R245fa
Scroll and EVI scroll	R245fa, R410a, R718
Piston (semihermetic)	R290 (propane), R600 (cascade)
Reciprocating	R744 (CO2)

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

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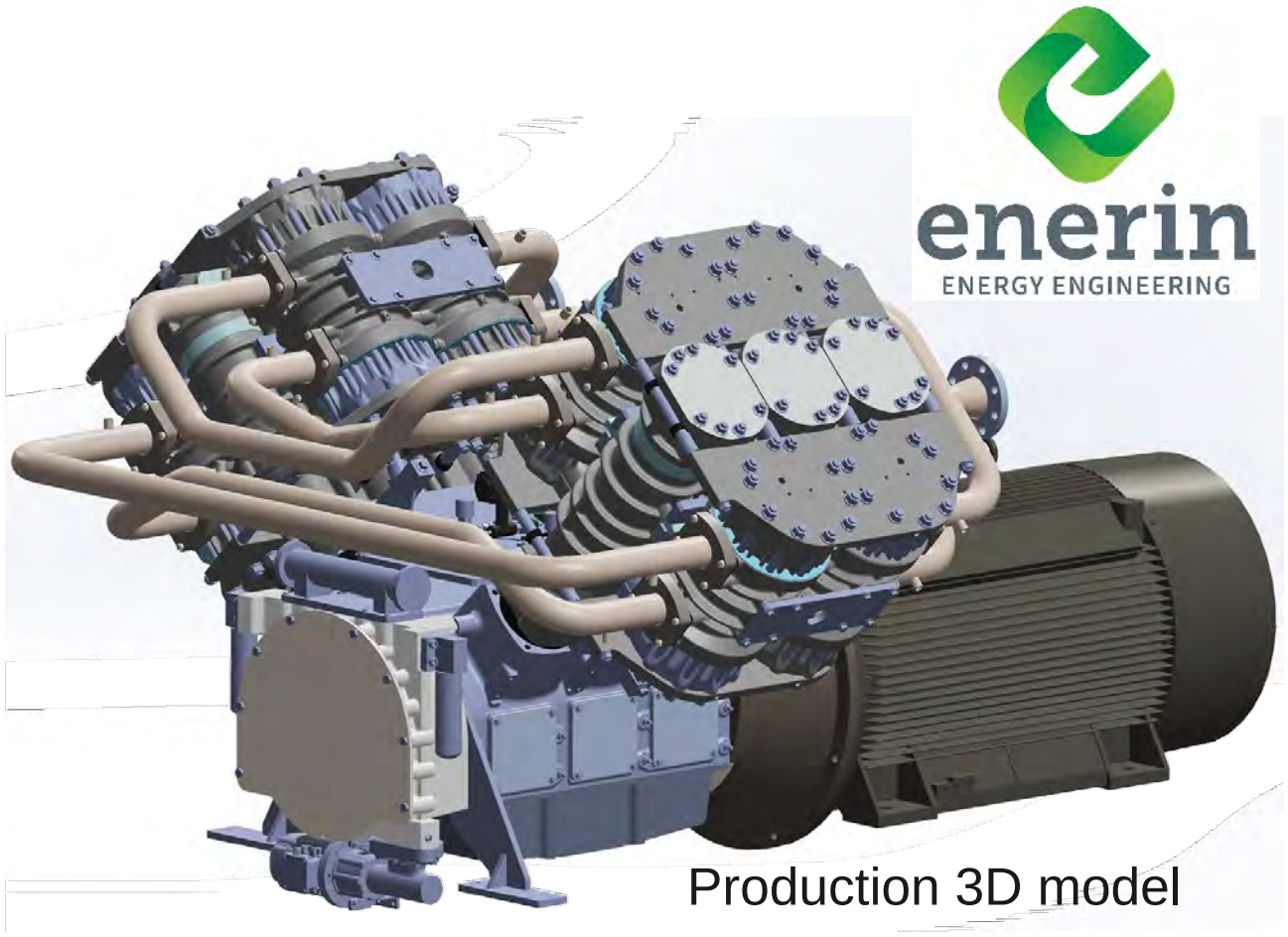
HoegTemp Ultra High-Temperature heat pump from Enerin AS



Production 3D model

Image courtesy by Enerin AS

- **6-cylinder stirling-cycle heat pump**
- **Double-acting piston compressor**
- **Helium (R704)** refrigerant: zero ODP and GWP
- Heating capacity: 400 kW
- Heat exchangers for heat source and heat sink integrated in compressor assembly
- Patented technology
- 45% Carnot efficiency for high temperature lifts
- More than 30’000 hours of operating experience with prototypes
- 2023: start of commercial deliveries and prototype in biogas facility
  (10 to 40 °C → 140 to 190 °C)
- 2025: 12-cylinder version (800 kW)

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Illustration of 3.2 MW system with 4 x V12 HoegTemp heat pumps

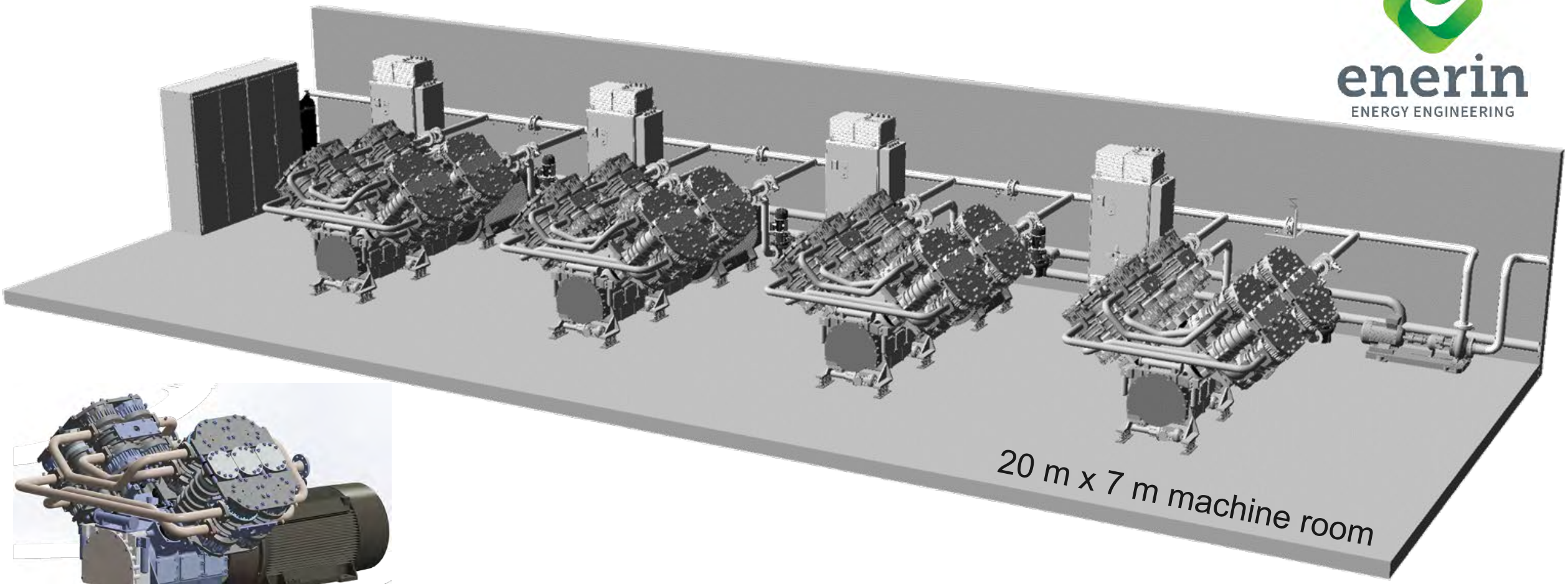

Image courtesy by Enerin AS

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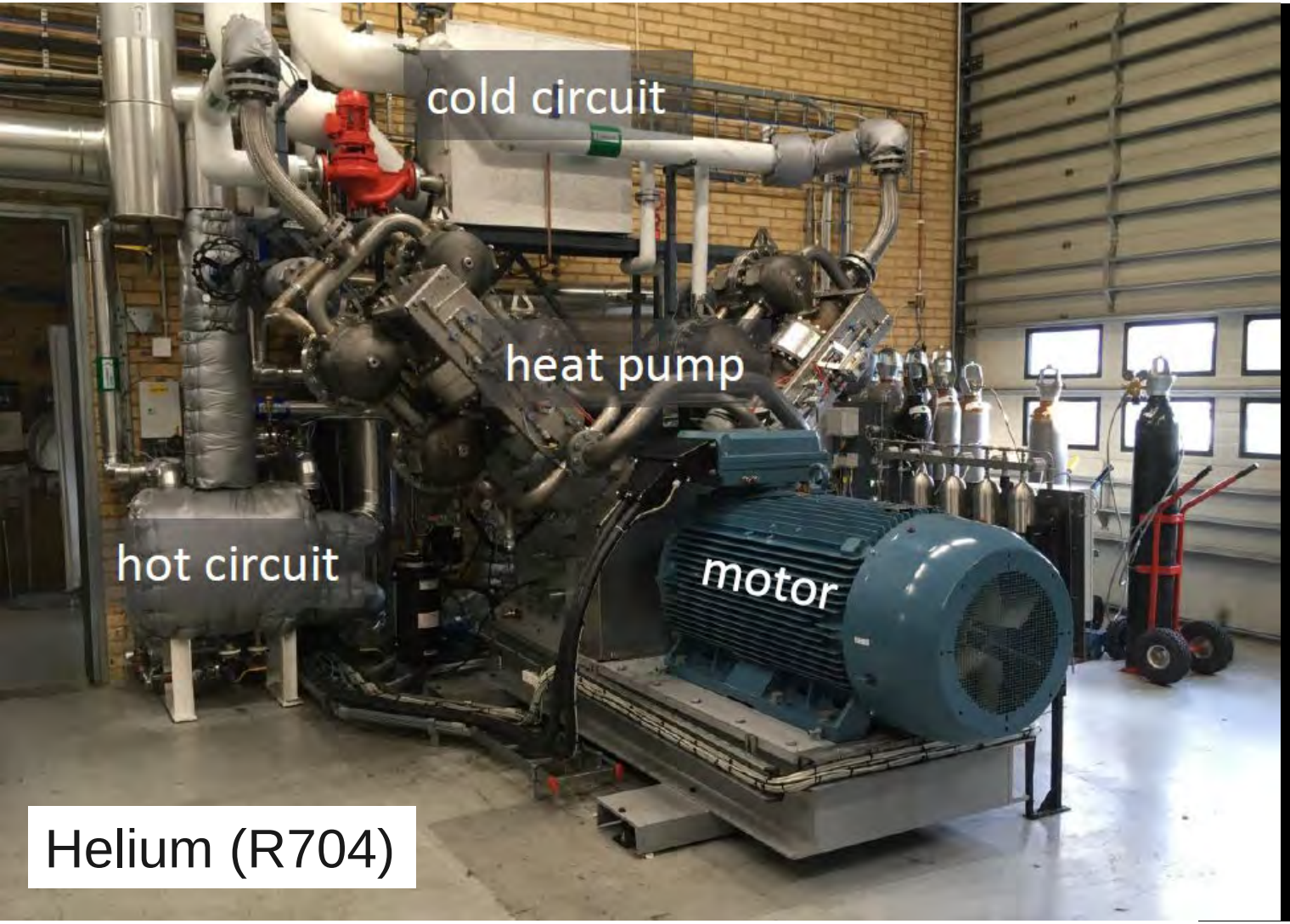
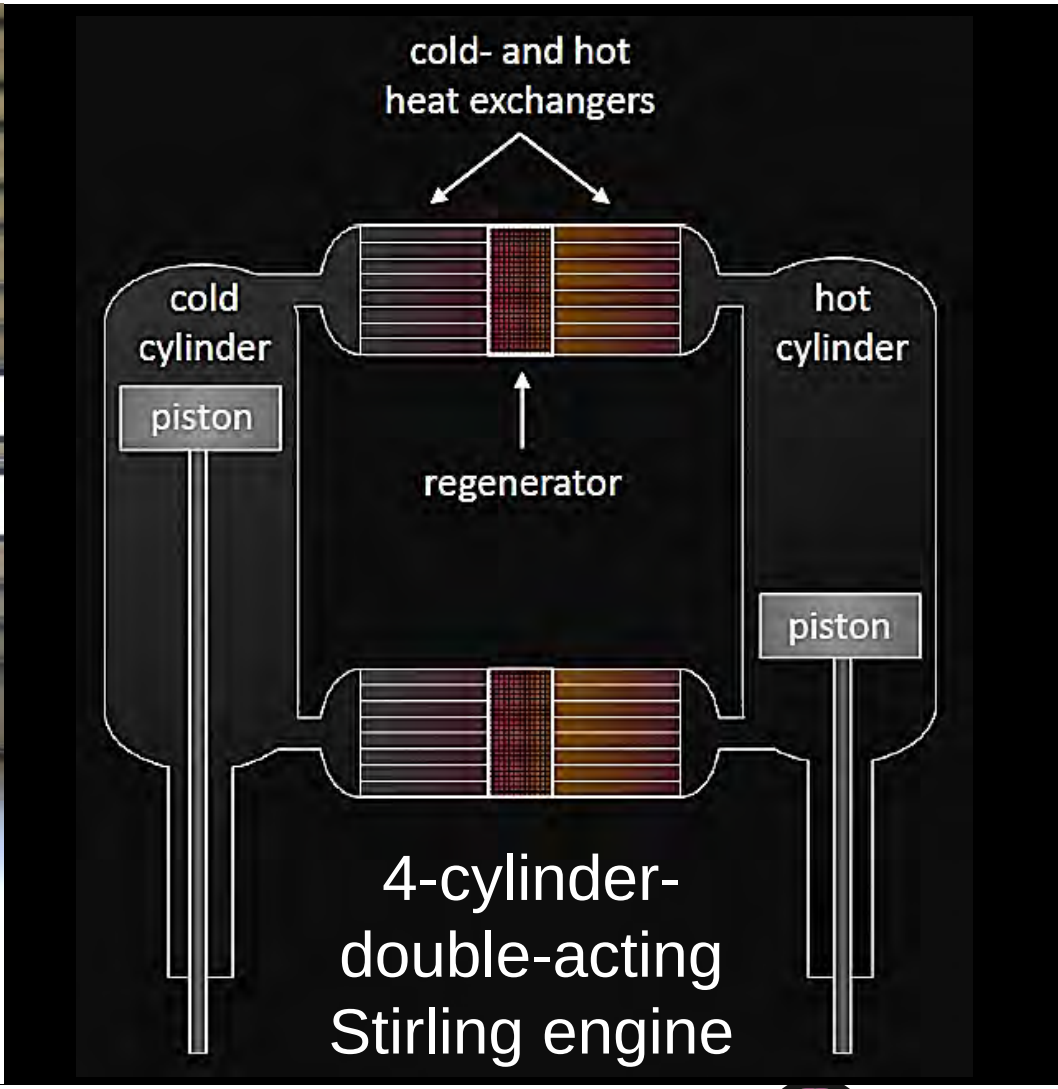
Olvondo HighLift





Images courtesy by Olvondo

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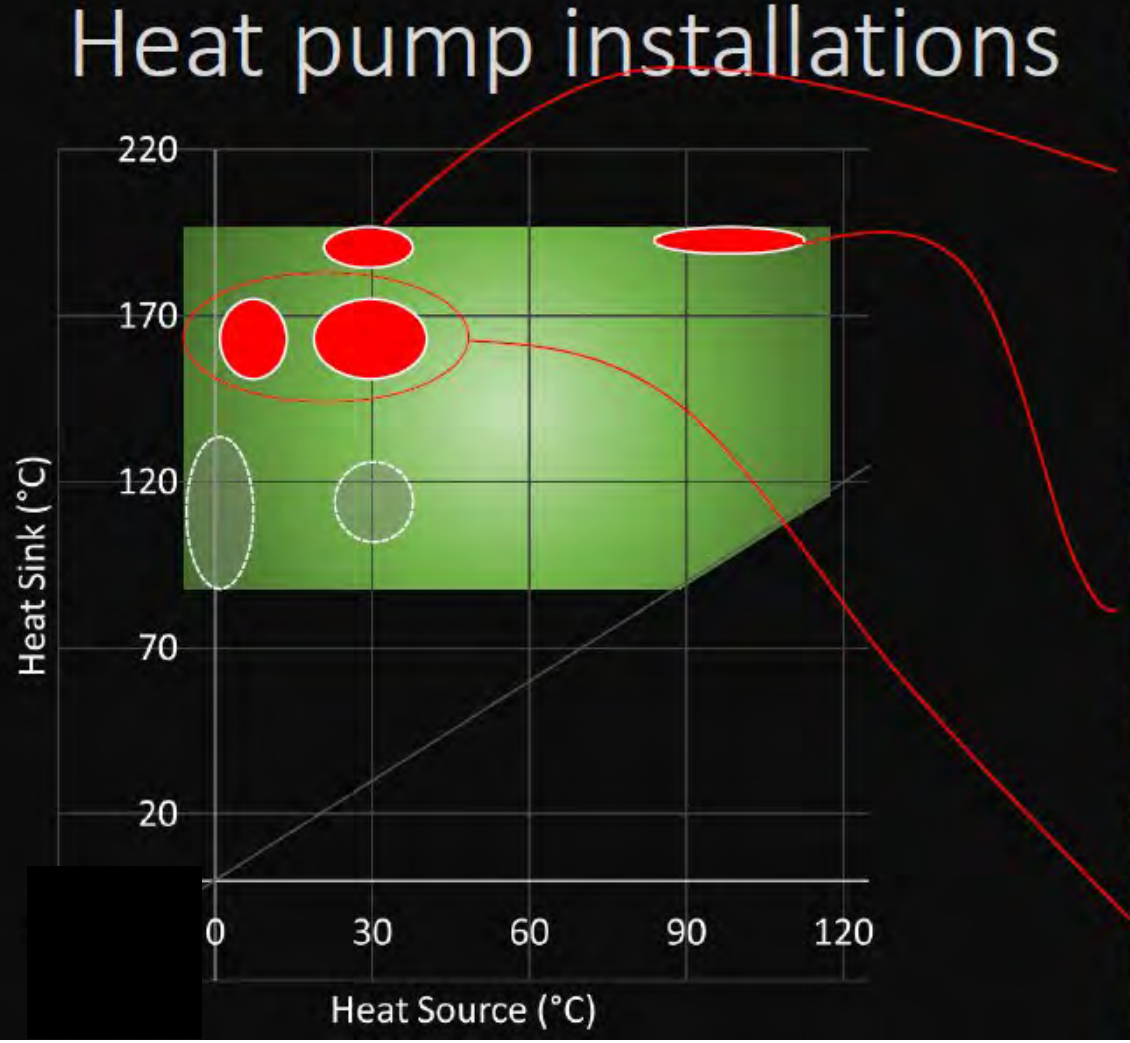
Olvondo HighLift – Examples of installations



Hot side: 180°C (10 bar)
Cold side:40°C

Heating: ~450-500 kW_{th}

Hot side: 180°C (10 bar)
Cold side:100°C (DH)

Heating: ~450-500 kW_{th}

Hot side: 170°C (6-7 bar)
Cold side: 10°C, 40°C

Heating: ~450-500 kW_{th}

Image courtesy by Olvondo

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HighLift – Operation metrics from an installation

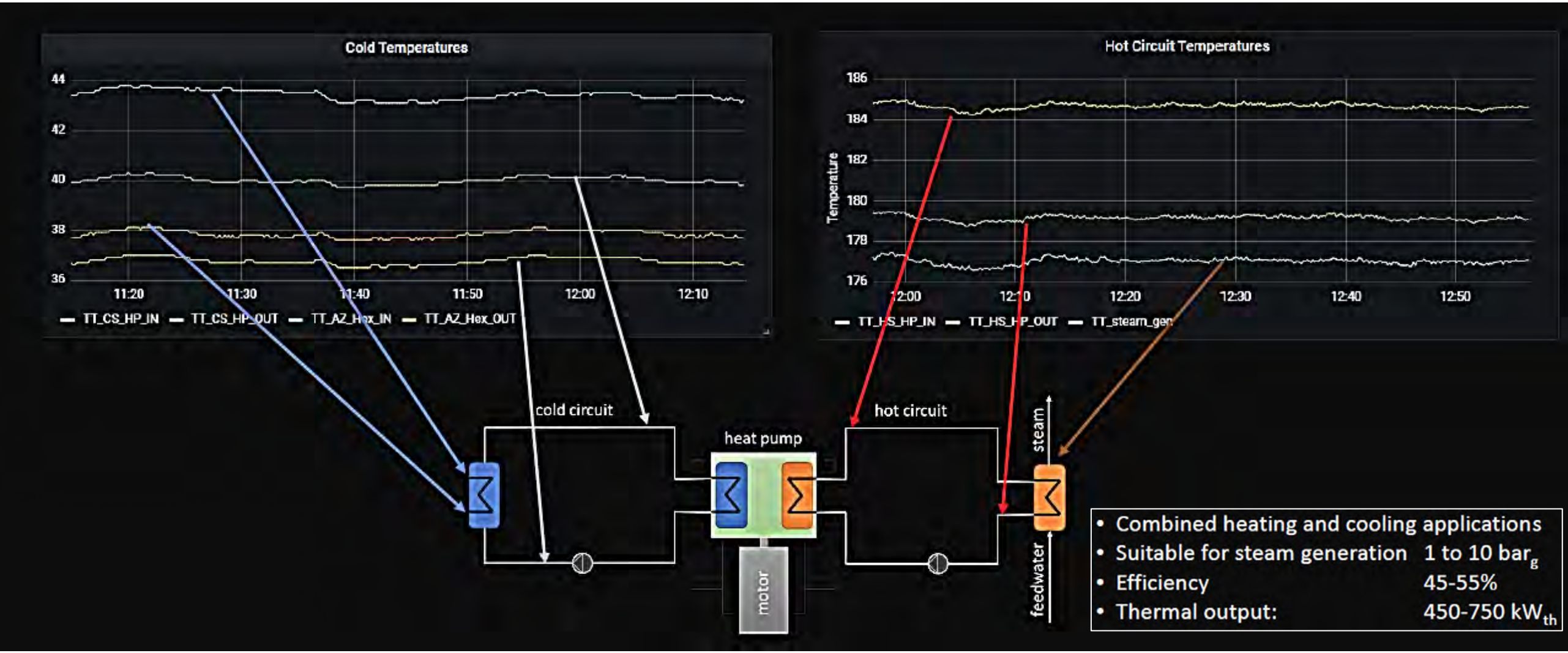

Image courtesy by Olvondo

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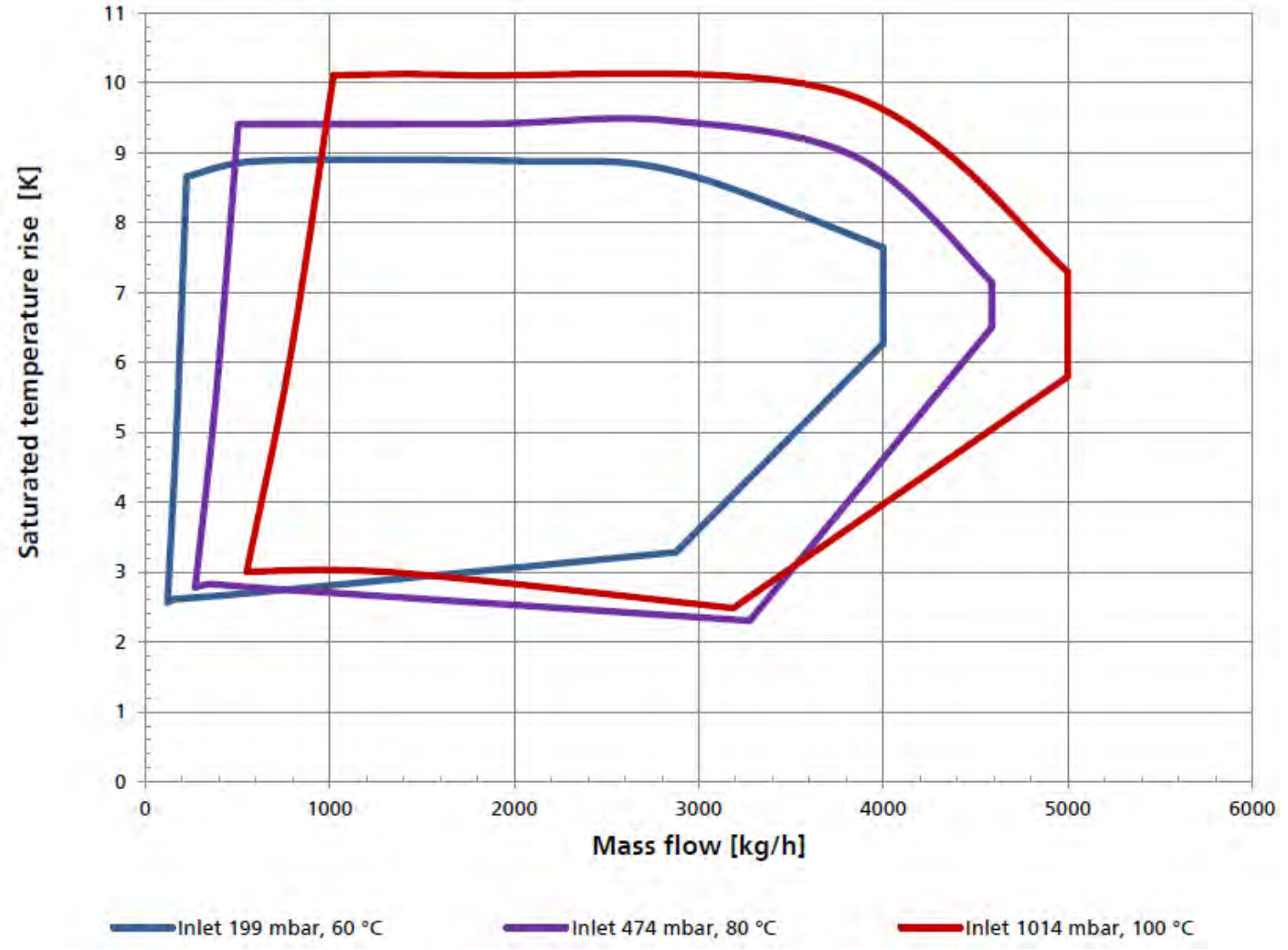
PILLER Steam Compressors – VapoFan



- Up to 10 K temperature rise
- Pressure up to 2.5 bar(g)
- Temperature up to 150 °C
- Mass flows from 200 to 5,000 kg/h

Images courtesy by PILLER

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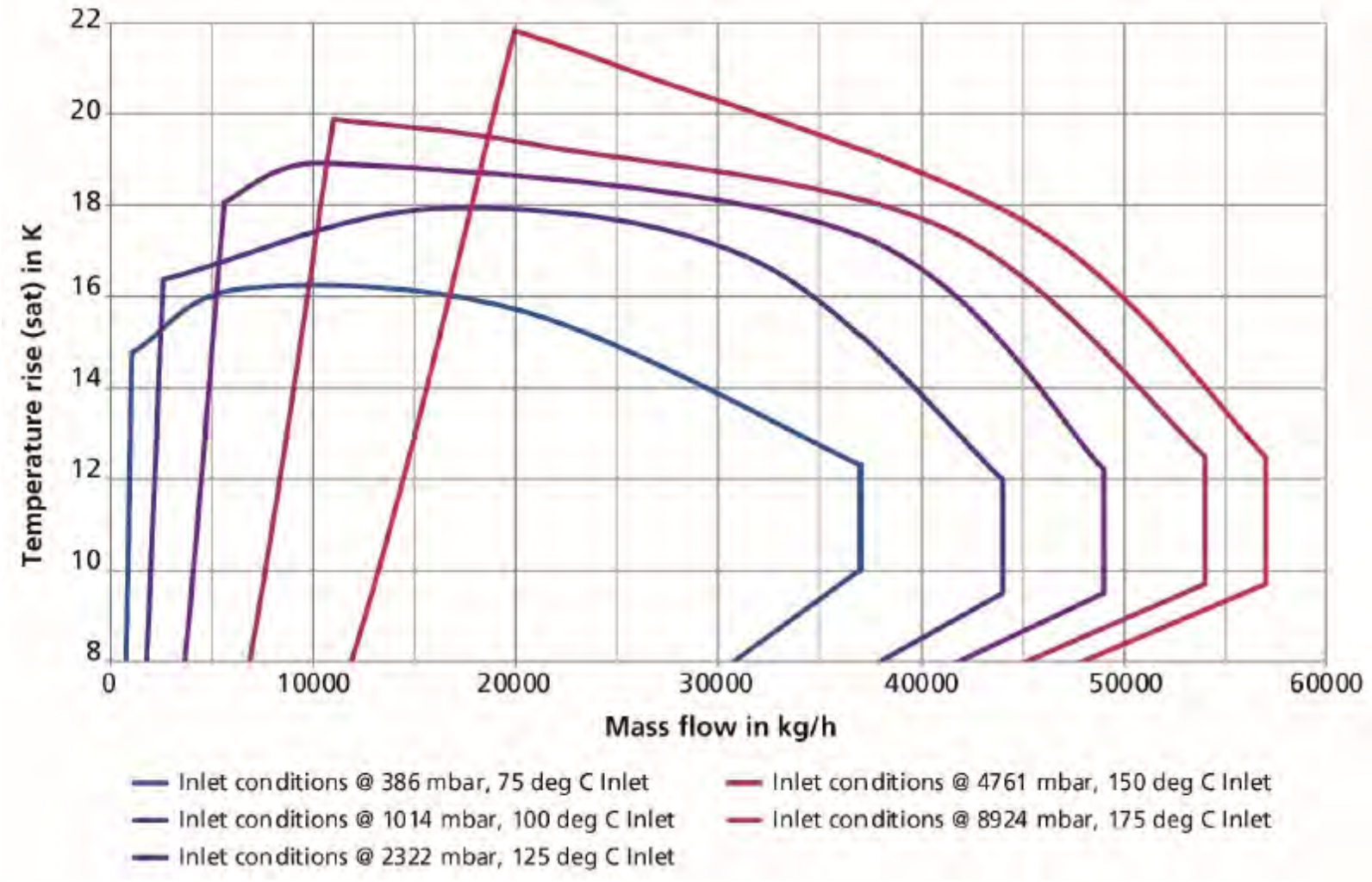
PILLER Steam Compressors – VapoMaxX

- Up to 20 K temperature rise
- Pressure up to 20 bar(g)
- Temperature up to 215 °C
- Mass flow range up to 57’000 kg/h



Images courtesy by PILLER

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PILLER MVR Blowers & Compressors – Examples

- Recompression of 11.4 t/h steam (80 °C) (head flow of a cumol distillation column) to 5 bar(g), ~14 t/h steam (after injection, slightly superheated) is fed into a steam network
- Electrical power requirement is 2’313 kW

Images courtesy by PILLER

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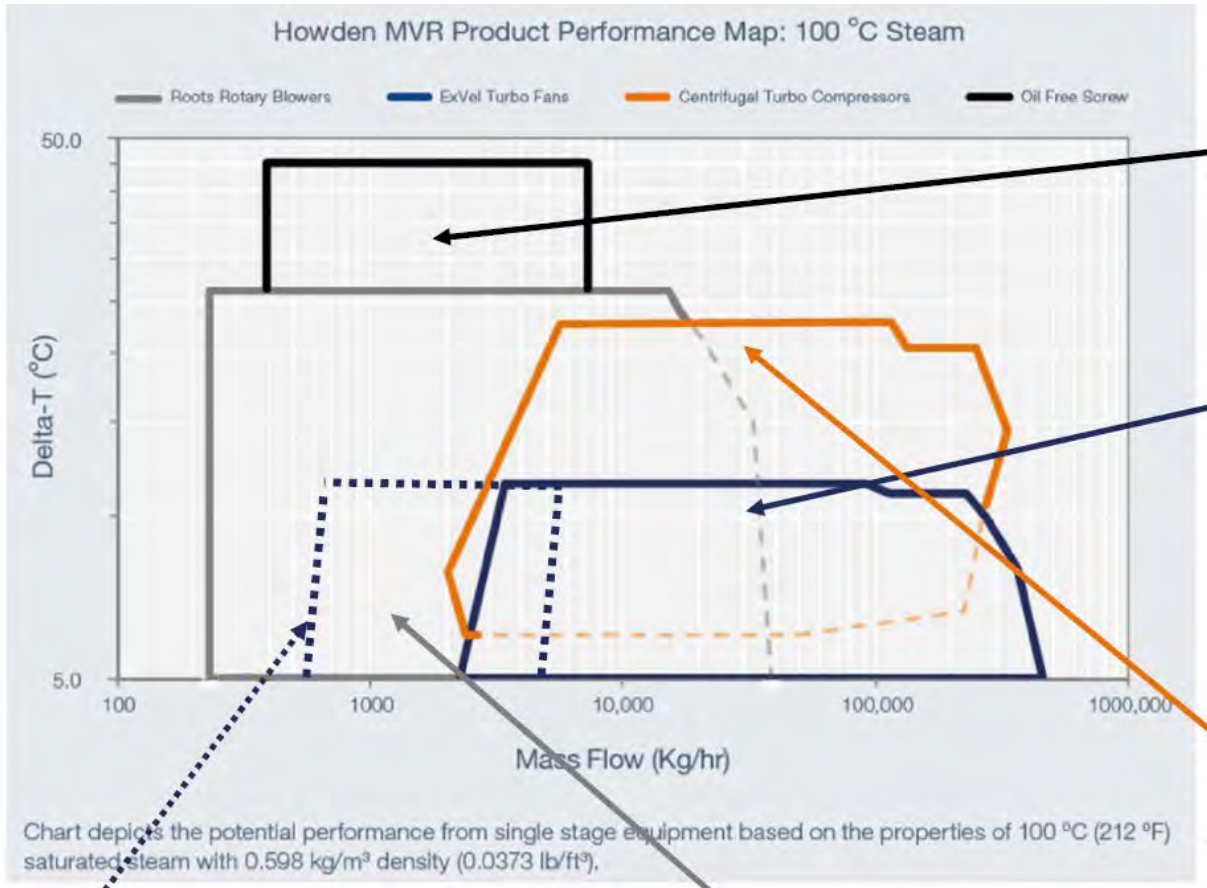
MVR Product Performance Map: 100 °C Steam



Oil Free Screw
Flow: 400-7 000 kg/h
dT: up to 45°C

ExVel Turbo Fan
Flow: 2000-400 000 kg/h
dT: up to 12°C single stage
Over 30°C possible with multi-stage configuration

MVR
low: 400-6 000 kg/h
T: >10°C single stage
...introduction to markets in 2022

Roots Rotary Blower
Flow: 200-40 000 kg/h
dT: up to 25°C

Turbo Compressor
Flow: 2000-350 000 kg/h
dT: up to 23°C

Source: Olli Sipinen, Howden Turbo Fans, 10 November 2021

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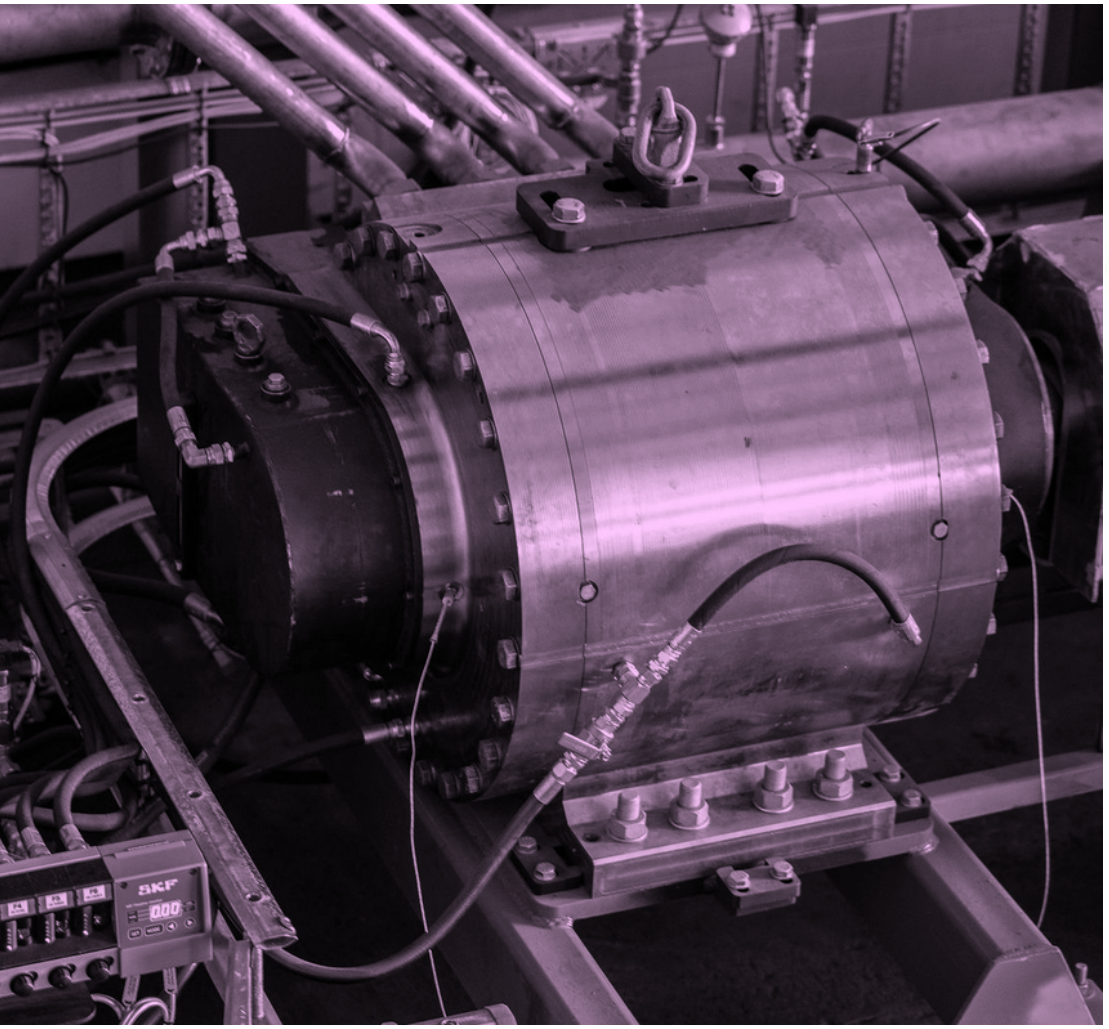
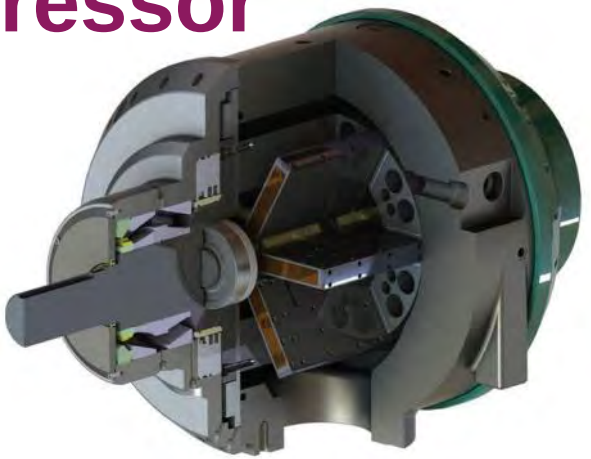
Tocircle Two-Phase Compressor

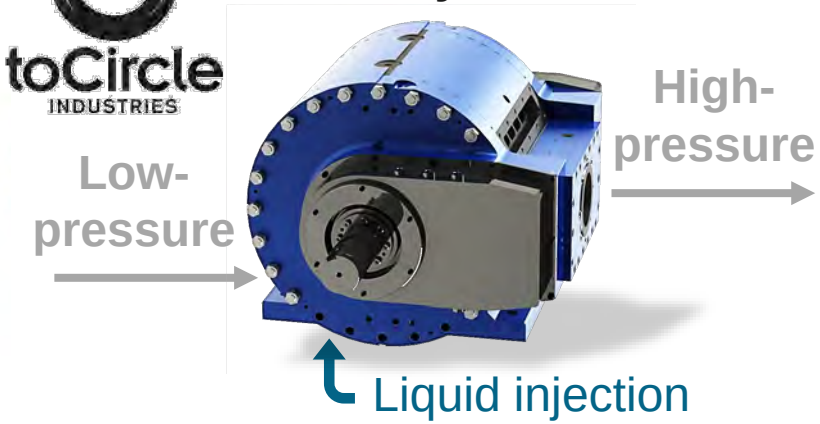


Images courtesy by Tocircle Industries AS



toCircle INDUSTRIES

MVR system



- **Rotary vane compressor** (free of lubrication oils)
- **Handles 2-phase working fluid** (mix of gas and liquid, e.g. pure water or water/ammonia mixture)
- Liquid injection keeps working fluid around saturation line through compression
- High compression ratio of about 5 (compact setup)
- Design temperature 220 °C
- **Delivered so far 12 bar(a) (188 °C) with a 2-stage compressor package (footprint 3 m x 2.5 m)**

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Tocircle High-Temperature MVR System at Scanships drying facility

Image courtesy by Tocircle Industries AS

- Pilot system up to 400 kW developed in **Free2Heat project** (SINTEF, NTNU, Tocircle, Bioretur AS)
- **Recovers waste steam at 100 °C** as heat source **from** a **drying process** and **compresses** it **up to 150 °C** to dry bio waste (which is then used to produce biochar)
- **In 2023** the plant will be moved to Bioretur in a similar drying process (drying fish sludge)

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Heaten's 1.5 MW_{th} Very High-Temperature Heat Pump

Image courtesy by Heaten AS

- **HeatBooster HBL4 1.5 MW**
- **20-foot container (5.6 x 2.3 x 2.4 m)**
- **Pilot by the end of May 2023**
- **Supply temperature up to 165 °C**
- Low-pressure steam production
- R1233zd(E) or R1336mzz(Z)
- Hydrocarbons as working fluids
- 50% to 60% Carnot efficiency
- Upon request: 2-stage heat pump cycle design option
- "Scale-up 6 MW_{th} soon" with piston compressors in V-shape

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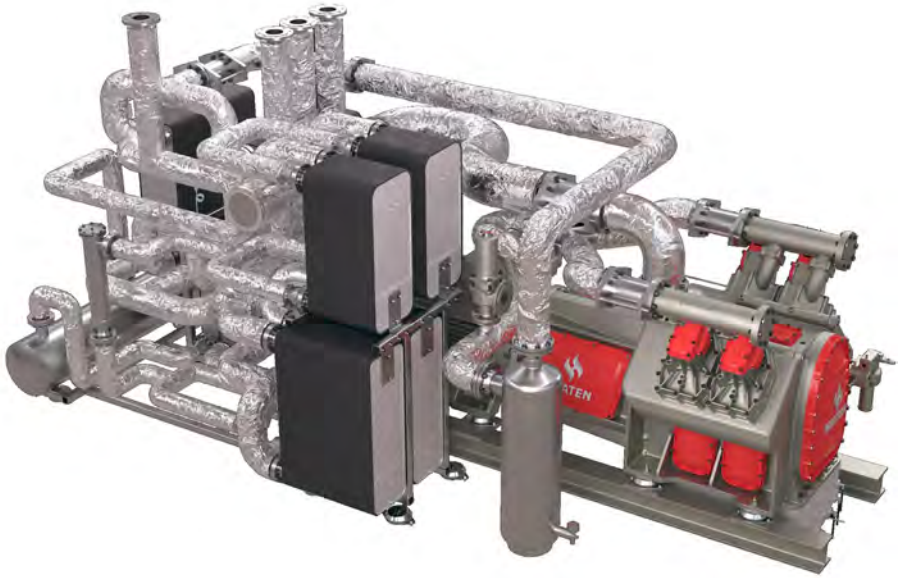
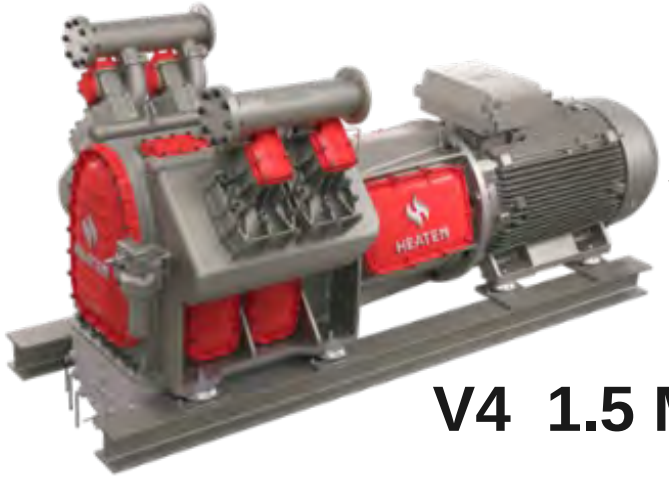
Heaten's HeatBooster Scale-Up Perspective



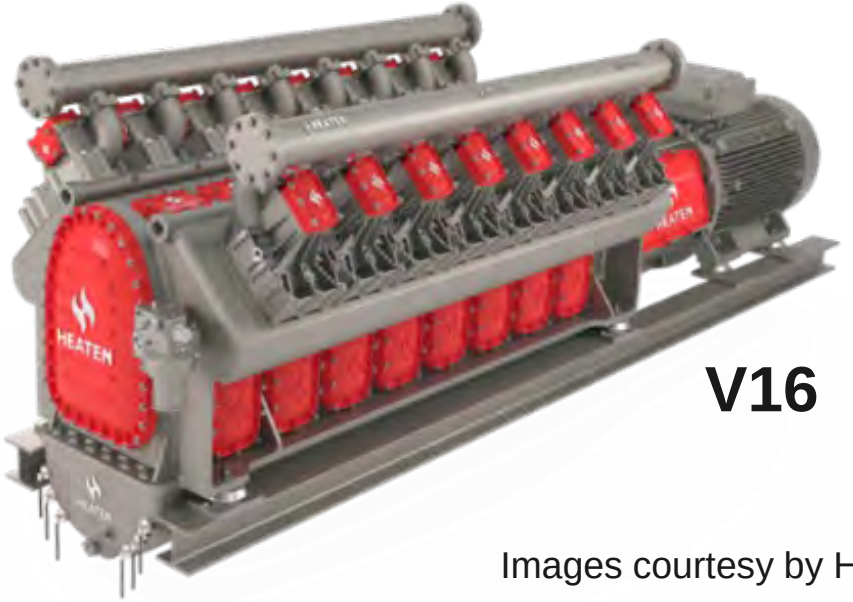
HBL4 W/W

HEATEN



V4 1.5 MW_{th}

Scale up



V16 6 MW_{th}

Images courtesy by Heaten AS

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Heaten's HeatBooster Container Solutions

Images courtesy by Heaten AS

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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

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Laboratory for testing the ThermBooster™

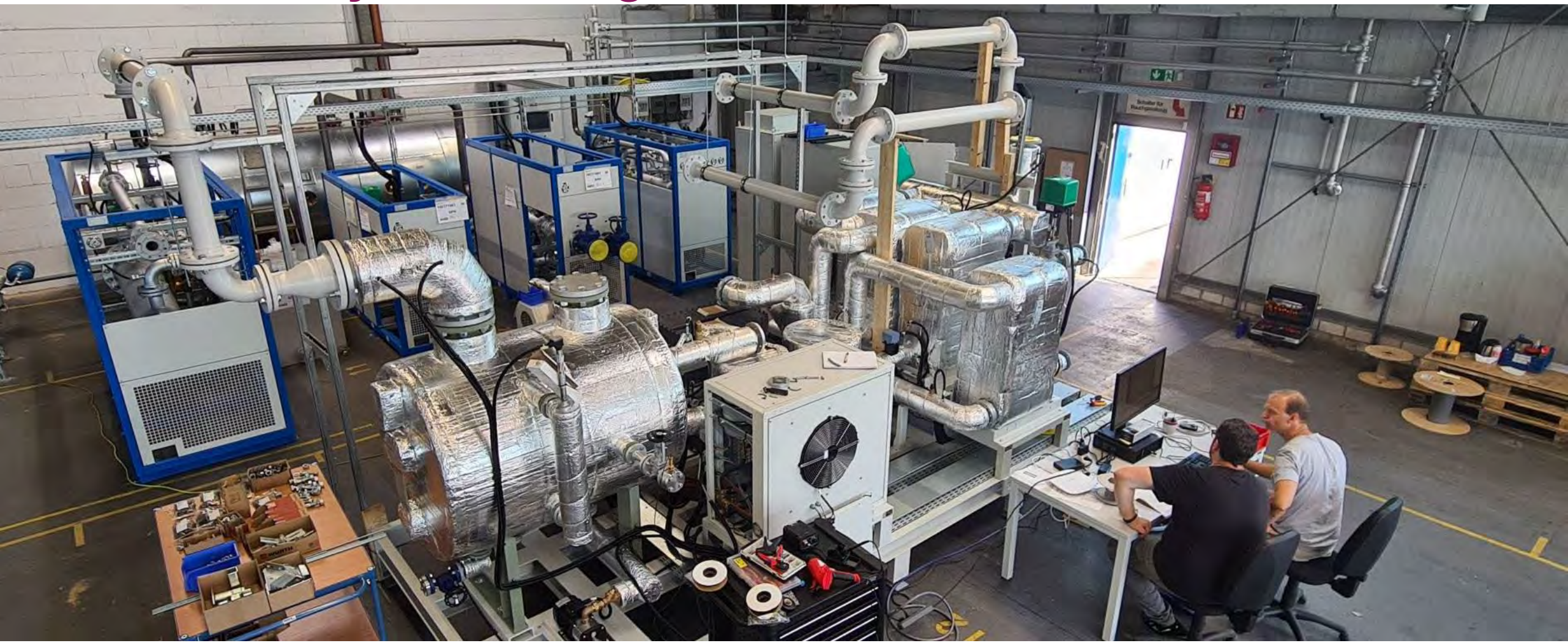

Image courtesy by SPH Sustainable Process Heat GmbH

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Applications of the ThermBooster™

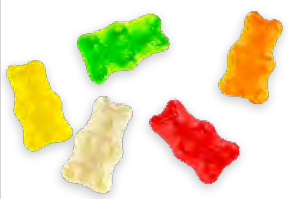
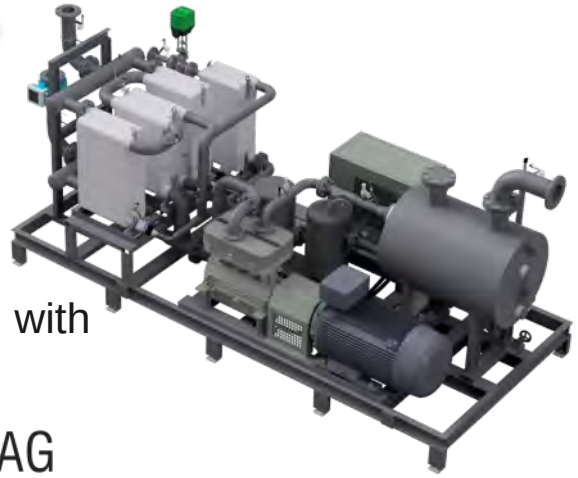
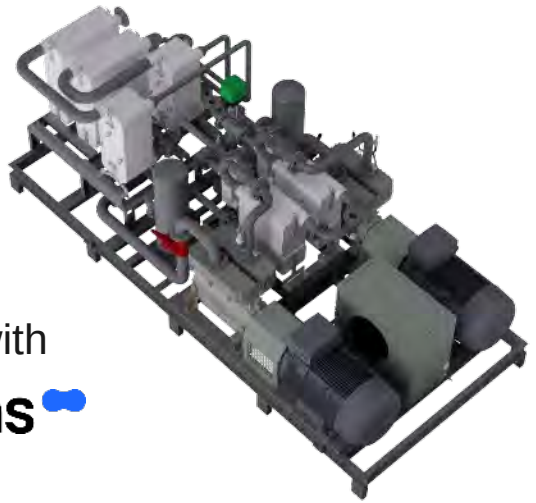
Application	Gelatine	Thermoplastic from waste
Heat source	85/70 °C	75/65 °C (water)
Heat sink	812 kg/h steam at 2 bar	90/130 °C (hot water) for drying process
Heating capactiy	514 kW	1’017 kW (2 cycles)
Cooling capacity	407 kW	809 kW
Electrical power	118 kW	229 kW (2 compressors)
COP	4.4	4.4
Energy savings	4.1 GWh_{th}/a	1.25 Mio. m^3 gas/a
CO_2 emission reduction	550 t CO_2/a	~2’400 t CO_2/a
	  In cooperation with 2G Energy AG	 In cooperation with technotrans 

Image courtesy by SPH Sustainable Process Heat GmbH

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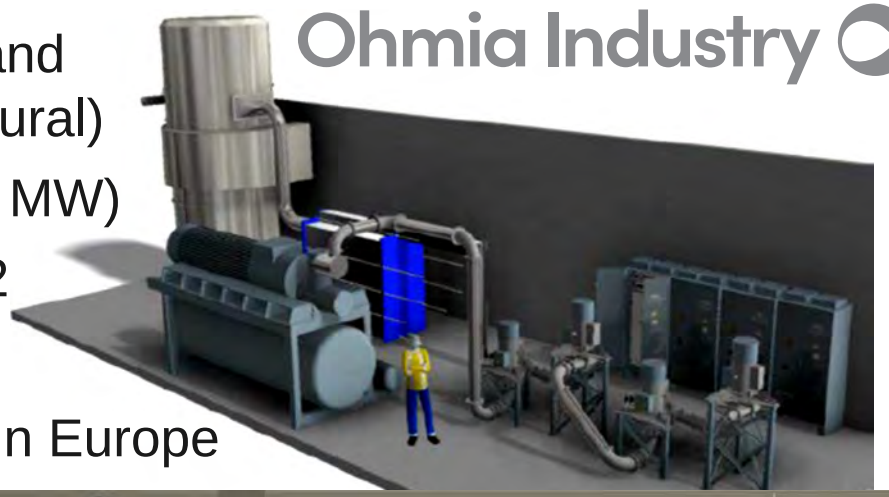
New Developments and Products for Supply Temperatures above 100 °C

Steam producing heat pump (SPHP) with MVR

- Ammonia (R717) (bottom cycle) and water (R718) (top cycle) (only natural)
- Capacity 2 to 10 t steam/h (1 to 5 MW)
- 1.5 MW pilot start-up by end 2022
- Currently available in Norway
- From 2023 also other customers in Europe

Ohmia Industry



- Humid air (or other sources) used as heat source
- Dew point determines COP
- Max. pressure 5 bar(a)

$T_{source,in}$ [°C]	$T_{source,out}$ [°C]	$T_{sink,latent}$ [°C]	p_{steam} [bara]	$COP_{heating}$* [-]
40	30	120	2.0	2.9
40	30	150	5.0	2.3
60	40	120	2.0	3.6
60	40	150	5.0	2.7
70	50	120	2.0	4.2
70	50	150	5.0	3.0

*The given COP values are indications of the possible onsite performance based on an assumed excess heat recovery temperature and will vary depending on the best suited integration concept.

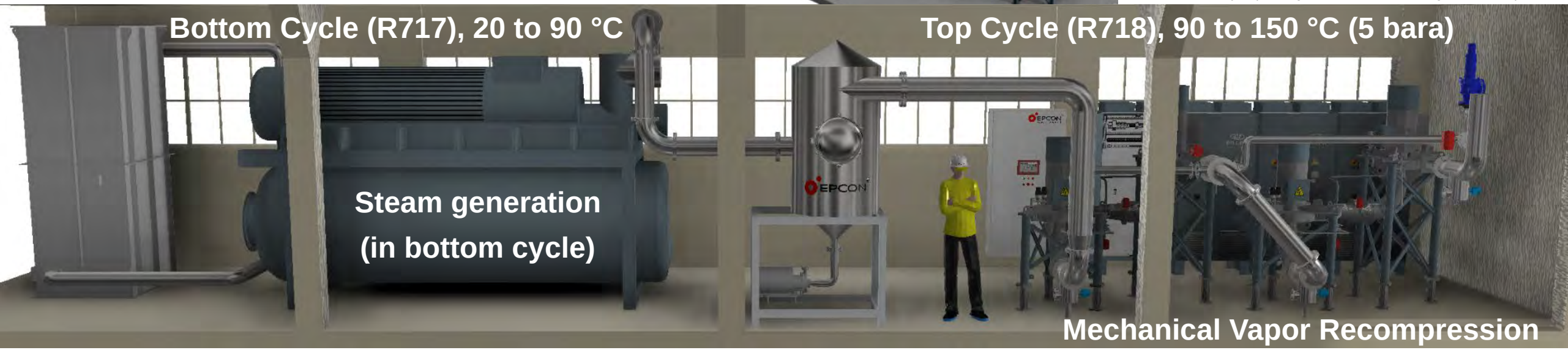


Image courtesy by Ohmia Industry AS

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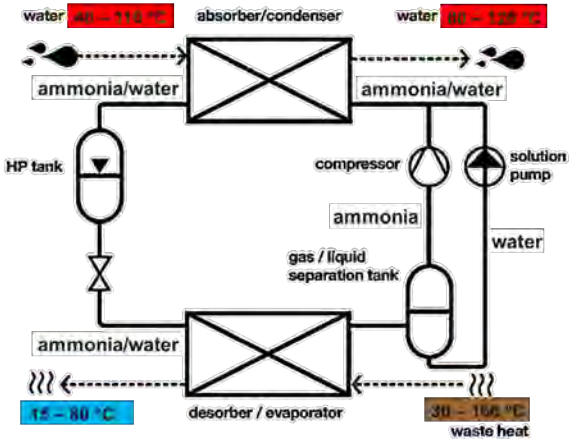
New Developments and Products for Supply Temperatures above 100 °C

HTHP with hybrid technology (Water/Ammonia)

Image courtesy by Hybrid Energy AS



HybridEnergy
HIGH TEMPERATURE HEAT PUMPS

Fruit processing	Dairy
	
• *Confidential* • GreenPAC-R / 1,9MW • Source: 67°C / 60°C • Sink: 80°C / **100°C** • COP: 5.0	• Q–Dairy Stavanger • HyPAC-R / 1.5MW • Source: 67°C/62°C • Sink: 90° / **102°C** • COP: 4,4

Natural refrigerants: H_2O + NH_3
→ zero GWP

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R717/R600 heat pump for district heating

- **R717 in the bottom cycle (Sabroe HeatPAC) and R600 in top cycle**
- Ventilated in case of leak detection
- Heated ATEX-compliant enclosure to avoid frosting in winter during standstill periods
- Tested and shipped to the client
- Tested with **n-butane (R600) and iso-butane (R600a)**
- FAT test done online
- Final test at site: start of 2023
- COP is 5.7 at 40 °C/90 °C, 500 kW

Image courtesy by Johnson Controls

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Butane (R600) Heat Pump from Mayekawa Europe NV

Image courtesy by Mayekawa Europe NV

- Heating capacity around 750 kW
- Reciprocating compressor
- 18 m^2 footprint
- Hot brine up to 120 °C (70 °C inlet) for district heating applications
- Heat source: 72 °C (in), 45 to 65 °C (out)
- COP 3.2 to 4.8

$T_{source,in}$ [°C]	$T_{source,out}$ [°C]	$T_{sink,in}$ [°C]	$T_{sink,out}$ [°C]	$COP_{heating}$ [-]
72	65	70	120	4.8
72	60	70	120	4.4
72	55	70	120	4
72	50	70	120	3.7
72	45	70	120	3.2

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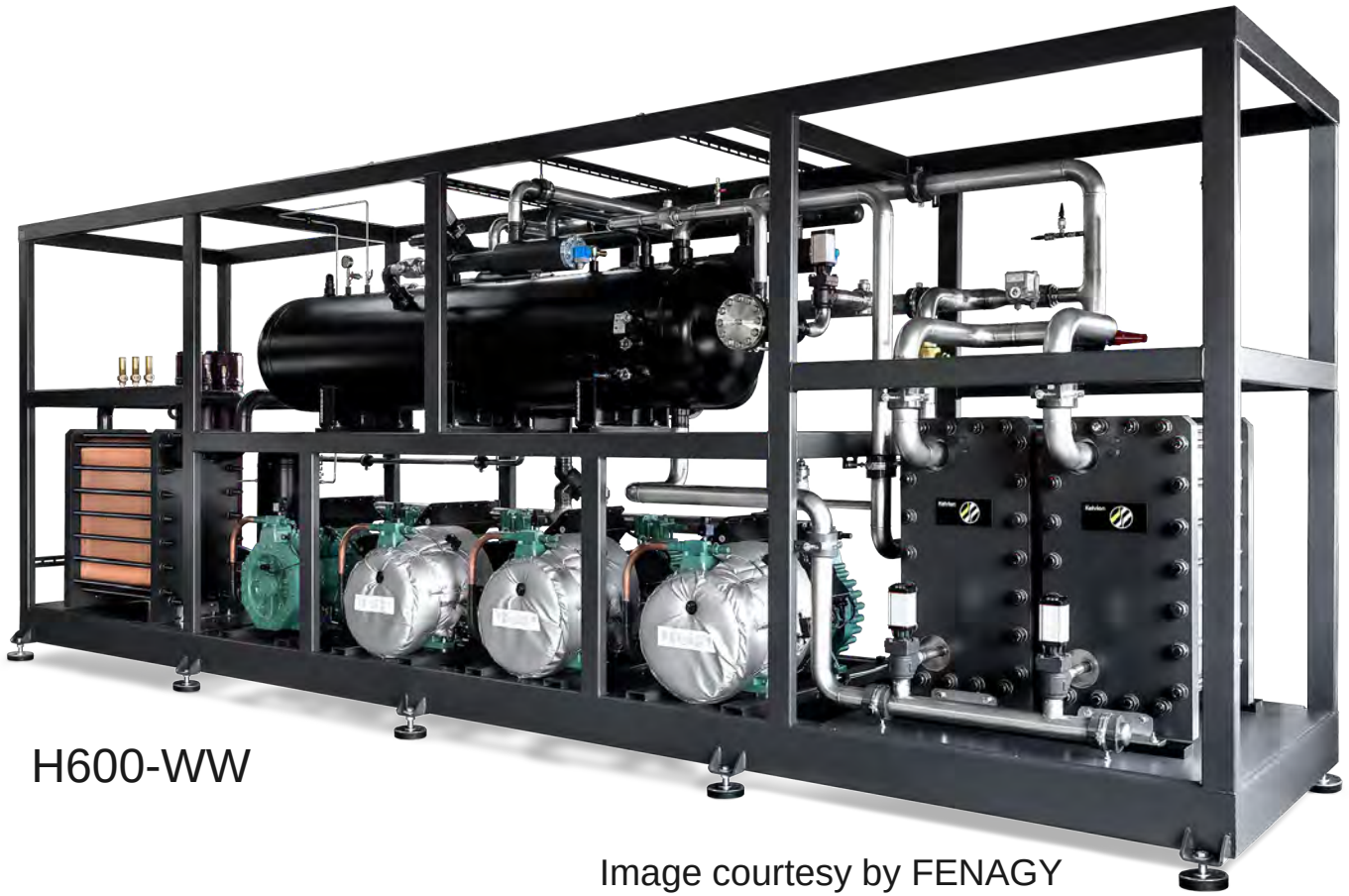
CO_2 Heat Pump System for Hot Water Production



H600-WW

Image courtesy by FENAGY

FENAGY®
FUTURE ENERGY SOLUTIONS

- Heating capacity from 0.3 to 1.8 MW
- Hot water heating from 30 to 120 °C
- Heat source: air (AW) or water (WW)
- Reciprocating compressors (Dorin or Bitzer)
- Low heat sink inlet temperature needed to increase efficiency in CO_2 cycle

Estimated performance

$T_{source,in}$ [°C]	$T_{source,out}$ [°C]	$T_{sink,in}$ [°C]	$T_{sink,out}$ [°C]	$COP_{heating}$ [-]
0	-5	30	120	2,46
0	-5	30	120	2,61*
5	0	30	120	2,63
5	0	30	110	2,91*

*including expander

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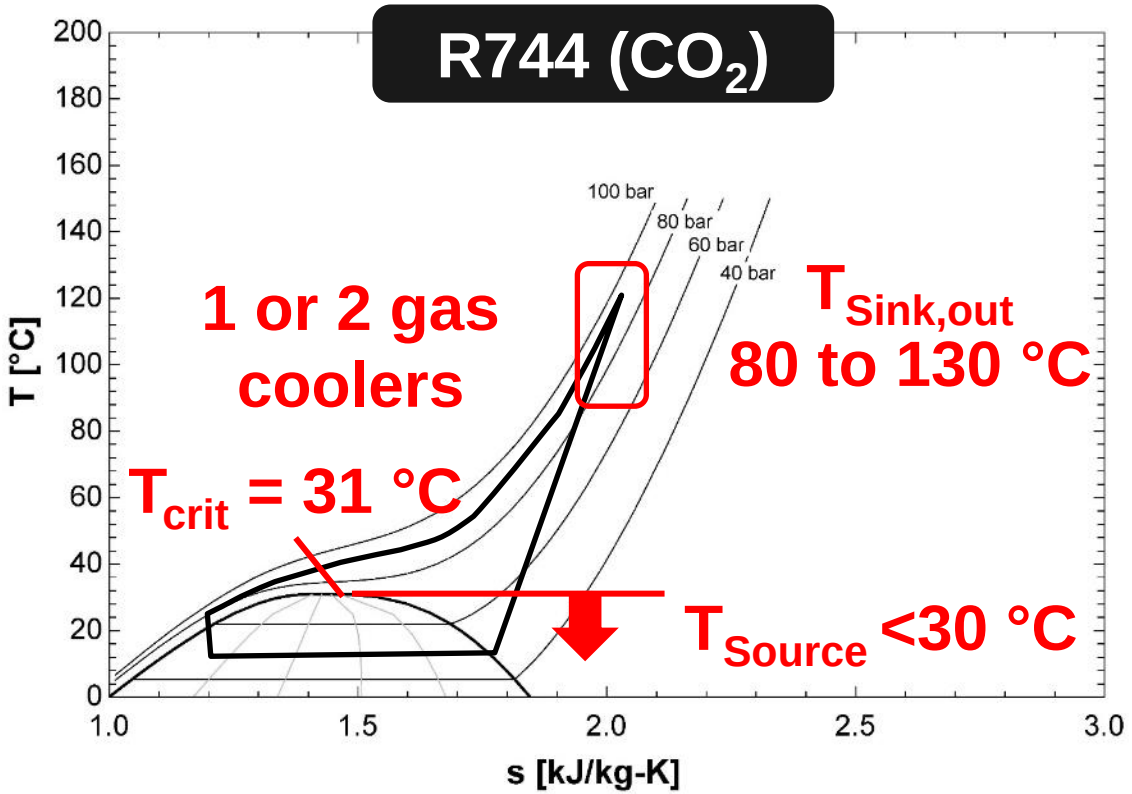
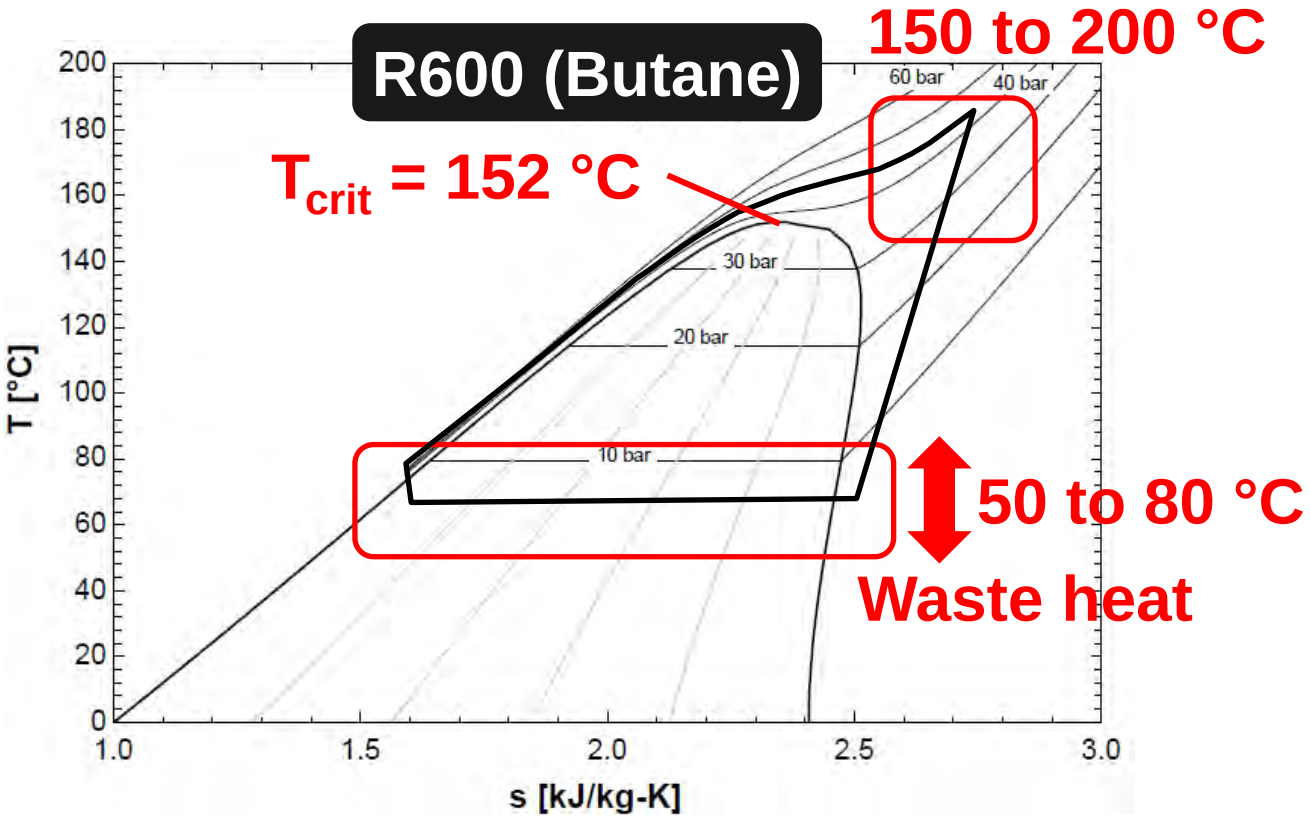
Comparison of Transcritical CO_2 and Butane cycles





Suitable for simultaneous heating (e.g., water or air from 30 to 120 °C) and cooling (<30 °C)

Suitable for producing hot air (water) of 150 to 200 °C using heat sources of 50 to 80 °C (e.g., exhaust air)

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Dorin – R600 (Butane) ATEX Piston Compressor for HTHPs

Oil pump

Lubrication channel

DLC coated wrist pin

Anodized aluminum pistons

Teflon coated bushing

DORIN 100 1918 2018 A LEGEND IN PROGRESS

EXTERNAL DISCHARGE MANIFOLD

160°C MAX DISCHARGE TEMPERATURE

SUCTION SERVICE VALVE ON THE MOTOR COVER

25% LARGER ELECTRIC MOTOR

Ex II 3G c Ex nA IIB T3 Gc

Source: Faralli (2021): R600 Compressor for High Temperature Heat Pump, European Heat Pump Summit 2021, Nuremberg, October 26, 2021

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Oilon ChillHeat P-series (High temperature option) heat pumps

Application example at Carlfors Bruk AS

(producer of metallic pigments)

Image courtesy by Oilon

- Heat source: Recovery and process cooling
- Heat sink: Space and process heating

- **120 °C** water can be produced at full power
- Refrigerant of the future **GWP 1**
- Safety class **A1** (non-toxic and non-flammable)
- **Piston** compressor

- Water temperatures (cooling/**heating**): 20 °C/**110 °C**
- Cooling capacity: 285 kW
- Heating capacity: 0 to 500 kW (very hot water), 10 to 354 kW (warm water)
- **ChillHeat pumps:**
  - 1 x S180 SU HC VFDx1 R1234ze
  - **2 x P300 SU HC VFDx1 High temperature R1233zd**

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Process parameters overview

- Heating setpoint: 105 °C
- Cooling average: 24.3°C (9 to 56 °C)

Produced heating energy	Produced cooling energy	Consumed electrical energy	Average combined COP
131 MWh	91.2 MWh	42.3 MWh	5.26

- **More is yet to come …**

Images courtesy by Oilon

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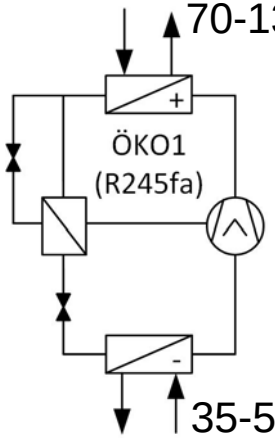
HTHP Case Studies

IWWDS ER3b (1-stage with economizer)

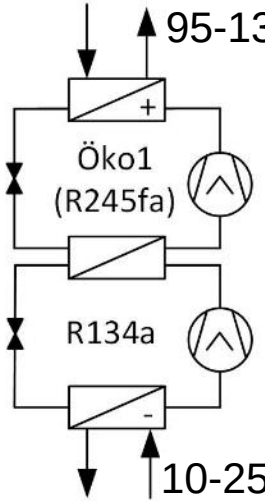
170 to 400 kW



Alternatives:
R1233zd(E)
R513 or
R1234ze(E)

IWWDSS R2R3b (2-stage cascade)

90 to 530 kW

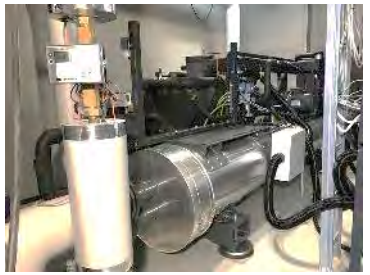


Alternatives:
R1233zd(E)

R513 or
R1234ze(E)

OCHSNER ENERGIE TECHNIK

	Mänttä-Vilpula (FIN)	Leather production Couro Azul (POR)
Heat pump type	IWWDS 120 ER3	IWWDS 270 ER4b
Heating Capacity	158 kW	309 kW
Application	**Local district heating network**	**Hot water for production**
Heat Sink	**120 °C**	**120 °C**
Heat Source	45 to 55 °C	55 °C
Source	District heating network return line	Water
Compressor Refrigerant	Screw ÖKO 1 (R245fa)	Screw R1233zd
COP	**2.0**	**2.47**



Images courtesy by OCHSNER Energie Technik GmbH

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Bitzer – CSH2T Prototype Screw Compressor

(CSH9583-280Y,R1233zdE,+35/+122°C,10/0K, ECO, 60Hz)

+++ DEVELOPMENT STATUS +++

Evap. temp. up to **50/70°C**

Condensing temp. up to **125°C**

SH max ~ 20K
SGT max ~100°C
SDT max ~140°C

Heating Cap. up to **410 kW**

PROCESS& DISCTRICT HEATING

Design pressure **19/28 bar**

R1233zd(E)

Selected models **700/805 m³/h** (50 Hz)

→ ~ **25 parts** need to be **evaluated**, **requalified** and / or **replaced**

Source: Schiendorfer (2021): Challenges in the development of positive displacement compressors for high temperature heat pumps, European Heat Pump Summit 2021, Nuremberg, October 26, 2021

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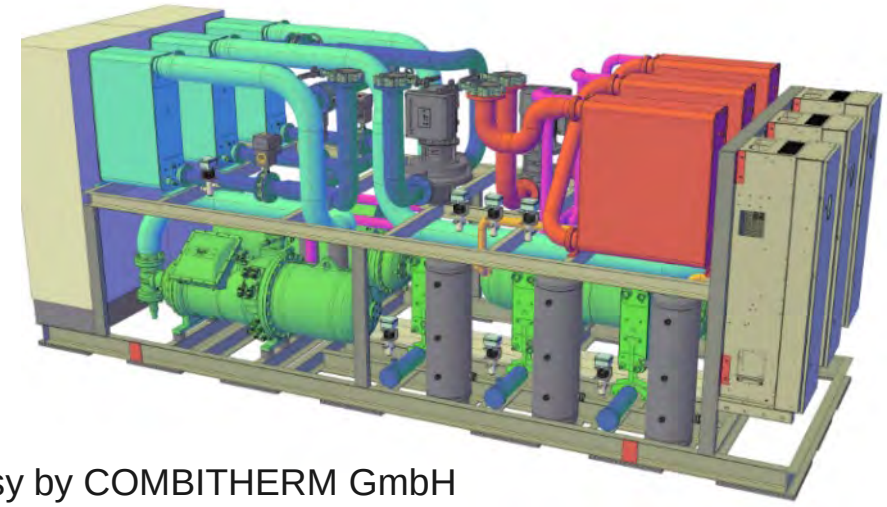
Application Examples of HTHPs from Combitherm

APPARATE- UND ANLAGENBAU

Animal Feed Production
Max. 120 °C (hot water)
2 x 750 kW (heating capacity)
Waste air from dryers
(heat source)

Aqua Feed Production
Max. 120 °C
3.5 MW
Waste air from dryers

HWW 3/9573
Max. 120 °C
1’060 kW
R1233zd(E)



Cleaning Technology
Max. 100 °C
400 kW
Waste heat

Images courtesy by COMBITHERM GmbH

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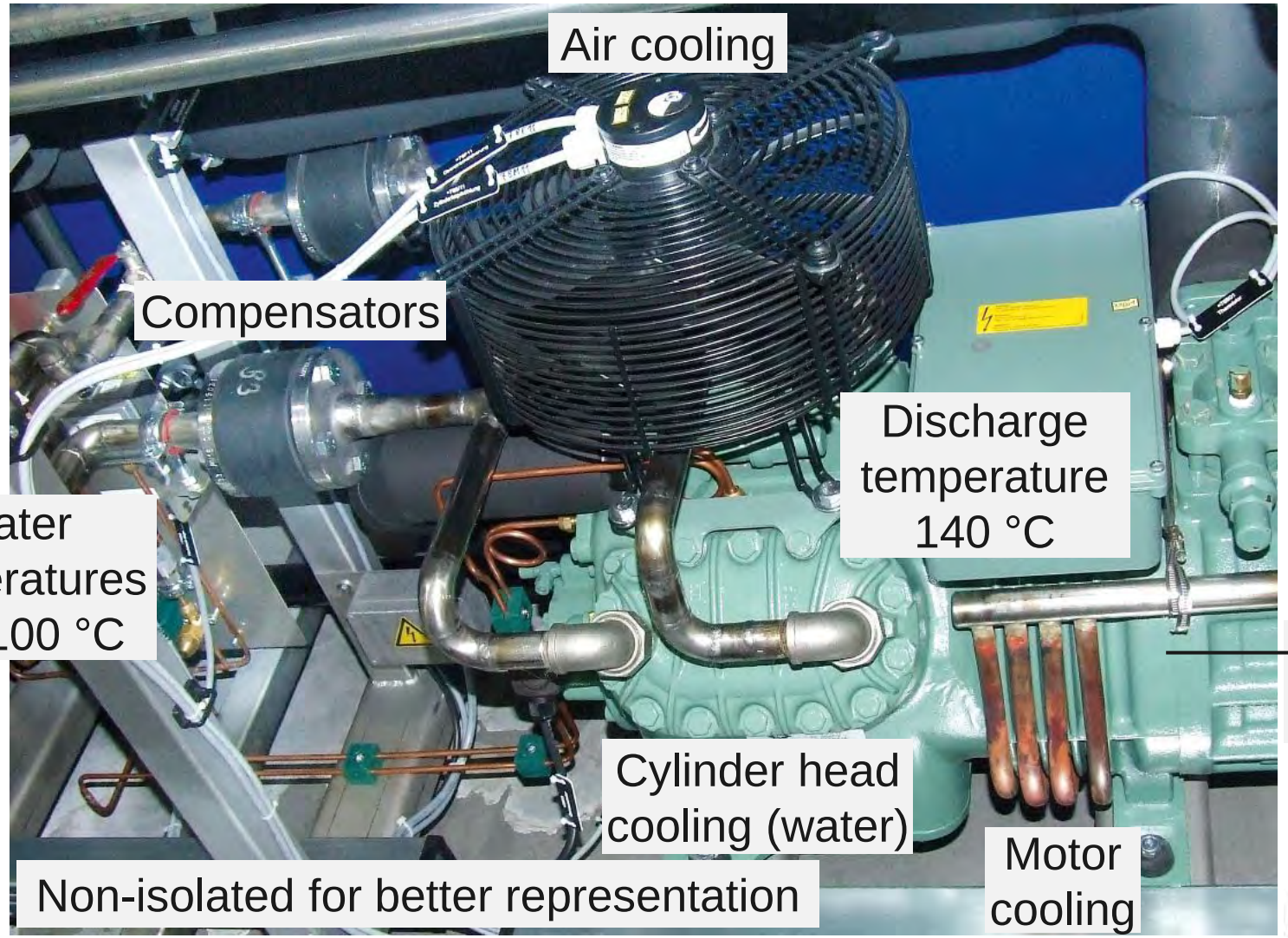
Example of compressor cooling and waste heat recovery



- Cylinder head cooling and motor cooling (water loops)
- Heat recovery ~6% (~4 kW) of heating capacticy (65 kW)
- Air cooling is also installed for demonstration purposes (normally either air or water cooling would be installed)

Surface temperature of motor housing max. 120 °C

Image courtesy by COMBITHERM GmbH

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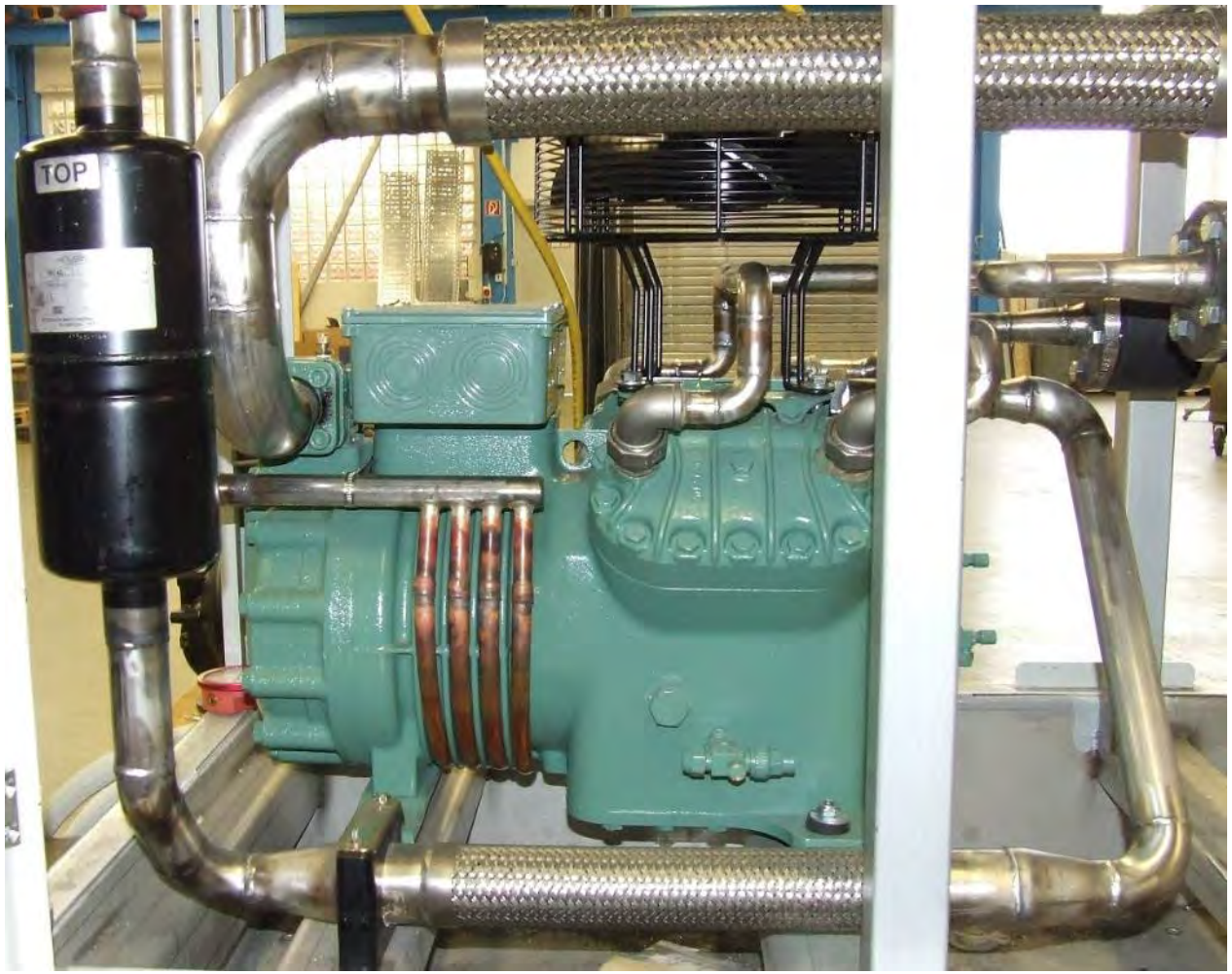
Example of compressor cooling and waste heat recovery



Semi-hermetic
Reciprocating Compressor
(Bitzer Model 4J-22.2Y)

Images courtesy by COMBITHERM GmbH

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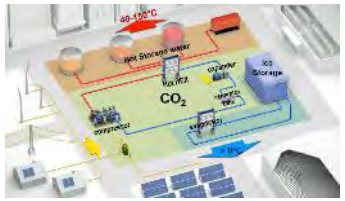
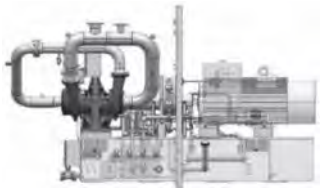
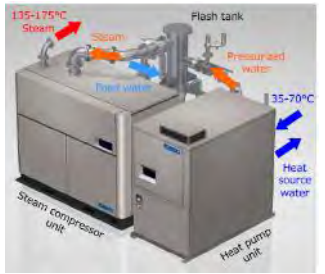
Examples of Large Scale HTHPs (>1 MW heating capacity) for district heating and industrial applications

Friotherm (CH)	Turboden (IT)	MAN Energy Solutions (CH)	Mitsubishi MHPS (DE)	Siemens (DE)	Ochsner (AT)	Kobelco (JP)
FRIOTHERM Heat Pump	LHP30 LHP150	ETES Electro-thermal energy storage	D-GWP	Large-scale	IWWDSS R2R3b IWWHS ER3b TWIN	SGH 120/165
R1233zd(E) + R718 (Water)	R601 + R718 (n-Pentane + Water)	R744 (CO_2)	R600a + R718 (Iso-Butane + Water)	HFOs	Öko (R245fa) R1233zd(E) (HFOs)	R245fa + R718 (water)
25 MW	**2.7 MW 14.4 MW**	**5 to 100 MW**	**4.3 MW**	**4 to 70 MW**	**Up to 750 kW TWIN 2.4 MW**	**Up to 624 kW Cascade 2.5 MW**
137 °C	115 °C	150 °C	174 °C	150 °C	130 °C	165 °C







FRIOTHERM

clean energy ahead TURBODEN

MAN

MITSUBISHI POWER

SIEMENS energy

OCHSNER ENERGIE TECHNIK

KOBELCO

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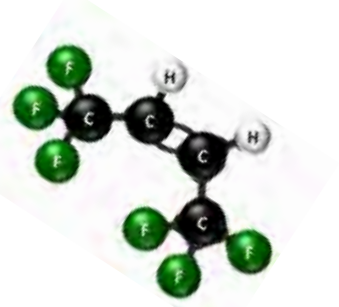
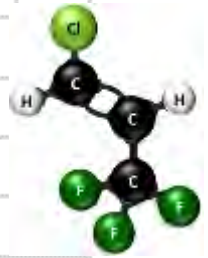
Suitable refrigerants for HTHPs

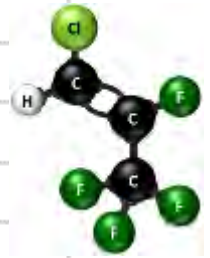
Selection criteria :
- low GWP
- short atm. lifetime
- zero/low ODP
- low flammability
- high efficiency
- high T_{crit}



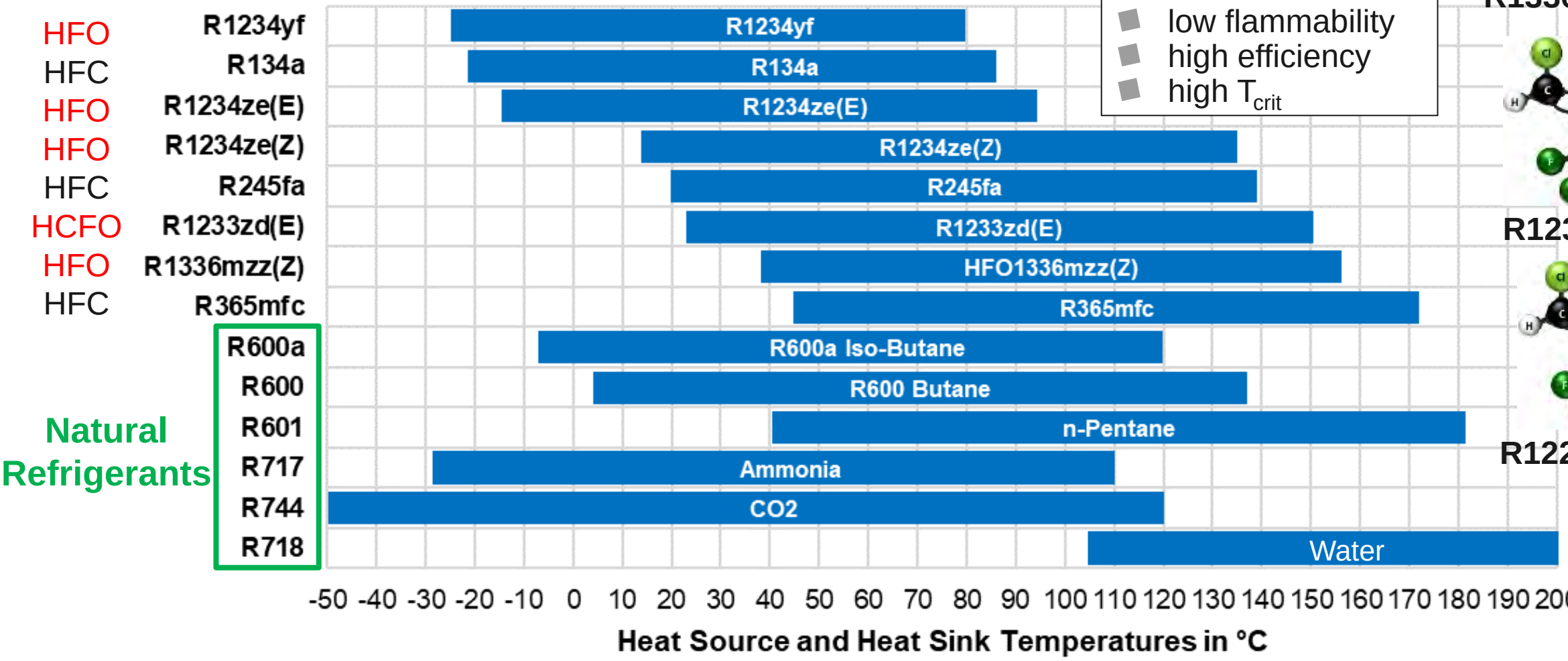
R1336mzz(Z)



R1233zd(E)



R1224yd(Z)



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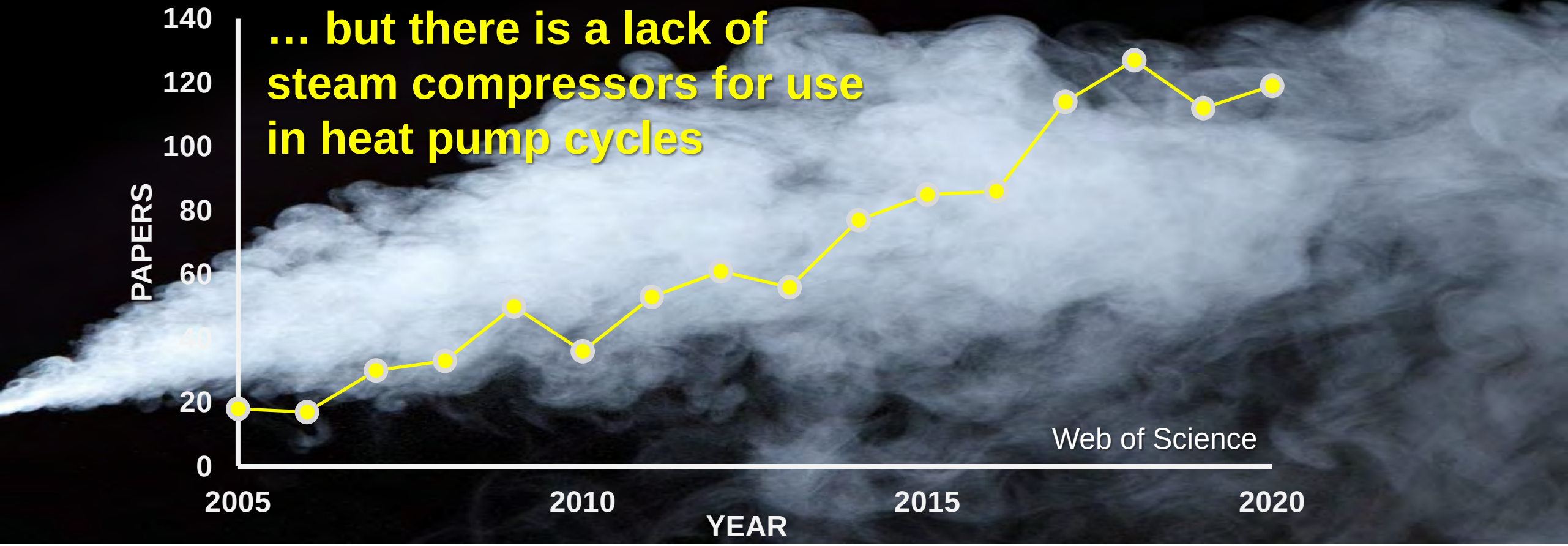
Steam Generating Heat Pumps

STEAM

Publications with keywords «steam + heat pump» are increasing

… but there is a lack of steam compressors for use in heat pump cycles



Source: Bless F., Arpagaus C., Bertsch S. (2021): Theoretical investigation of HTHP cycles for steam generation, 13th IEA Heat Pump Conference, Jeju, Korea, April 26-29, 2021

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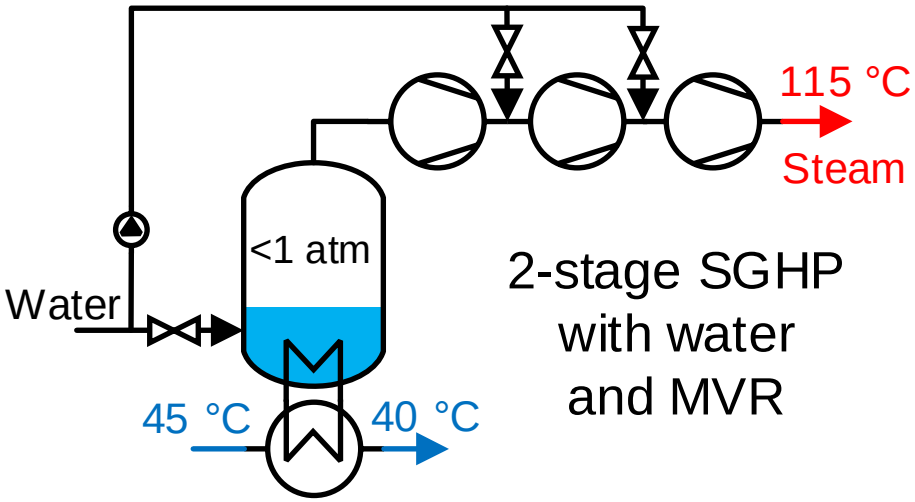
STEAM

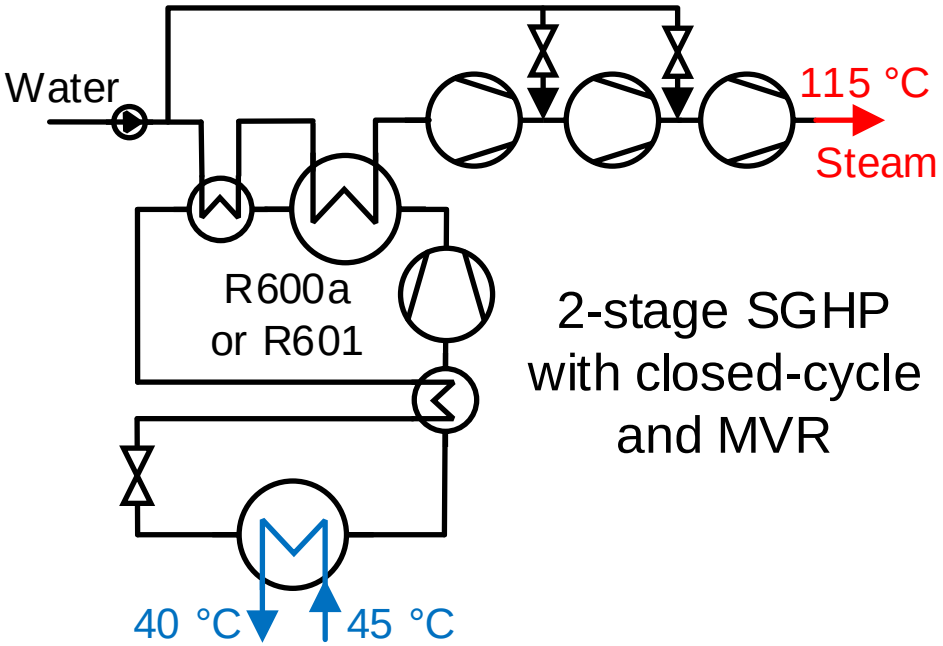
Design concepts of Steam-Generating Heat Pumps

Open cycle with water and MVR



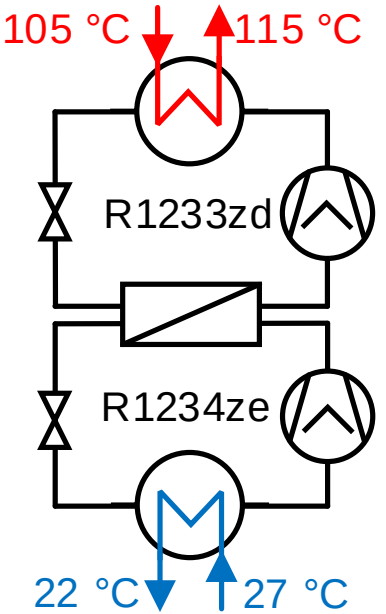
2-stage SGHP with water and MVR

Combined cycle with closed cycle (subcooler) and cycle (MVR)



2-stage SGHP with closed-cycle and MVR

2-stage cascade with flash tank



Source: Arpagaus C., Bless F., Bertsch,S. (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

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Research on Steam Generating Heat Pumps

STEAM

Country, organization	Heating capacity (kW)	Heat source temperature (°C)	Steam temperature (°C) (flow rate kg/h)	Heat pump cycle, compressor	Refrigerant	COP (source/sink temperature °C)
Korea Institute of Energy Research (KIER)	300	60	128 (422)	HTHP + flash tank, piston	R245fa	n.a.
	100	70	120	HTHP + flash tank, open screw	R245fa	3.05 (70/120)
	25	60	104 - 123	HTHP + IHX + flash tank + valve	R245fa	~ 3.5 (60/105)
Seoul National University, Korea	6 - 8	60 - 70	115 - 125 (10.8)	HTHP, piston	R245fa	2.95 (60/125) 3.59 (60/115)
	6 - 12	60 - 80	115 - 125	HTHP + steam reservoir + MVR	R245fa	3.39 (80/125) 2.72 (60/115)
Tokyo Electric Power, Mayekawa, Japan	400	80 - 90	130	HTHP, screw	R601 (pentane)	4.5 (80/130)
Kobe Steel, Ltd., CRIEPI, electric companies, Japan	660 380	35 - 70 25 - 65	165 (890) 120 (20)	HTHP + MVR, screw	R134a/R245fa (SGH165) R245fa (SGH120)	2.5 (70/165) 3.2 (65/120)
Mayekawa, Waseda University, Japan	300	80	100 - 180 (thermal oil)	Transcritical HTHP, centrifugal	R600 (butane)	3.5 (80/180) calculated
Shanghai Jiao Tong University, China	285	75 - 85 (evaporation)	111 - 150 (condensation)	VHTHP + flash tank, twin-screw	R718 (water)	6.10 (85/117) 1.96 (85/150)
ECN, IBK, Bronswerk, Smurfit-Kappa, Netherlands	160	60	125 (2.4)	HTHP + IHX + subcooler, piston	R600 (butane)	1.9 (60/125)
Olvondo Technology, TINE dairy, Norway	449	80 - 90	184 (10)	HTHP (reversed Stirling cycle), piston	R704 (helium)	2.1 (85/183)
NTNU, SINTEF, Norway	20	25 - 35	115	HTHP cascade + IHX	R290/R600 (propane/butane)	2.1 (25/115)
AlterECO project, EDF, France	200	35 - 60	80 -140 (condensation)	HTHP + IHX + subcooler, two scroll	ECO3 containing R245fa	2 - 3 (50-60/125) (evap/cond)
PACO project, Uni Lyon, EDF, France	380	85 - 95	130 -140 (condensation)	HTHP + flash tank, twin-screw	R718 (water)	~5.5 (94/121)
National Research Council Canada	45	55 - 80	103.5 - 135.5	HTHP + IHX, piston	R113 & R123 (ozone depleting)	2.7 (75/135, R113) 3.6 (60/120, R123)

Source: Bless F., Arpagaus C., Bertsch S. (2021): Theoretical investigation of HTHP cycles for steam generation, 13th IEA Heat Pump Conference, Jeju, Korea, April 26-29, 2021

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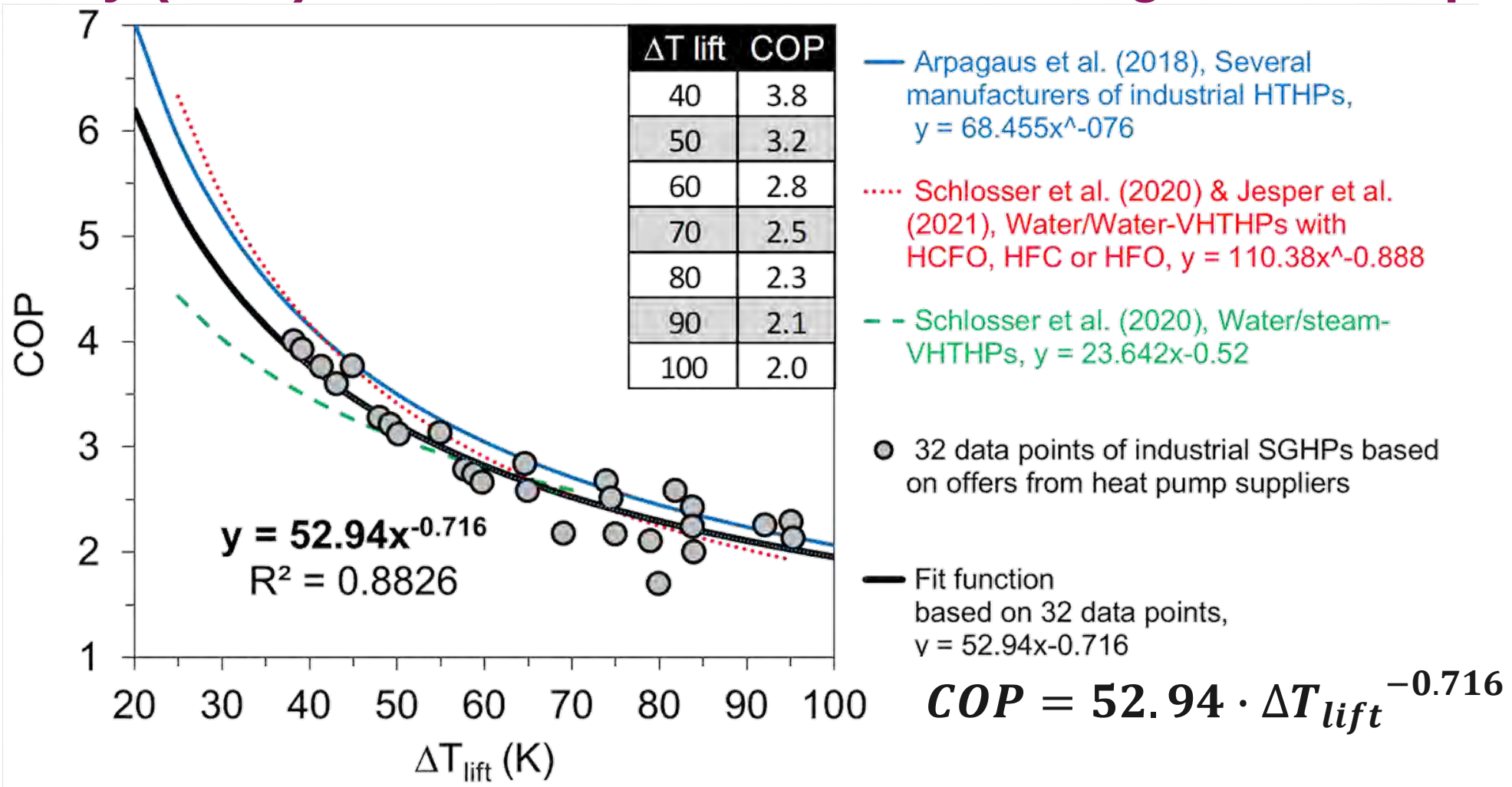
STEAM

Efficiency (COP) of industrial Steam Generating Heat Pumps (SGHP)



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

Source: Arpagaus C., Bless F., Bertsch,S. (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

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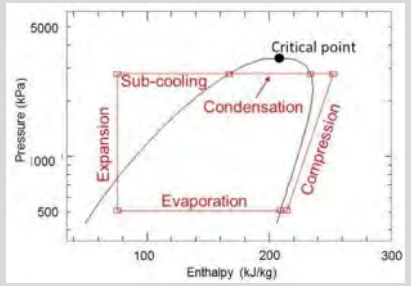
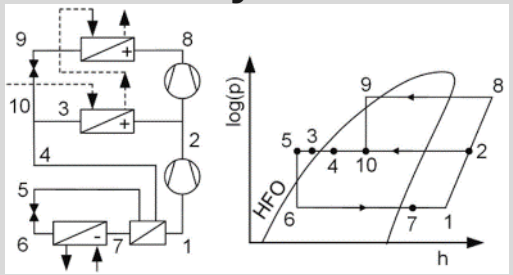
New Developments and Products for Supply Temperatures above 100 °C

HTHP Technologies for Large Temperature Glides

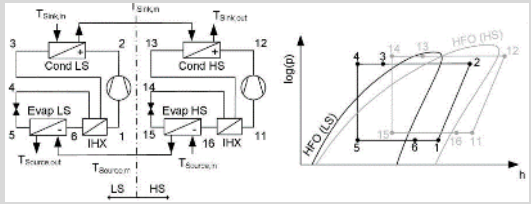
Subcritical cycle with subcooler



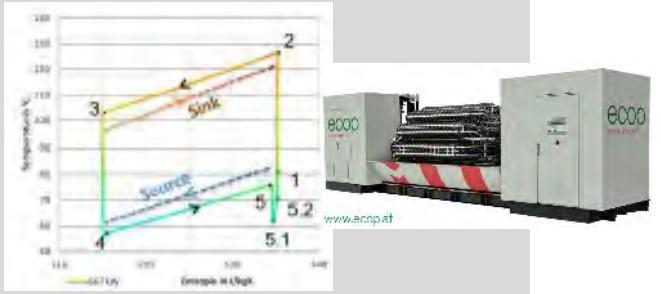
Two-stage extraction cycle



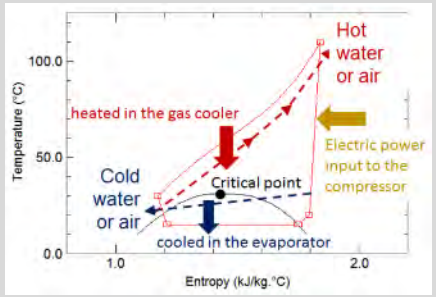
Two parallel subcritical cycles



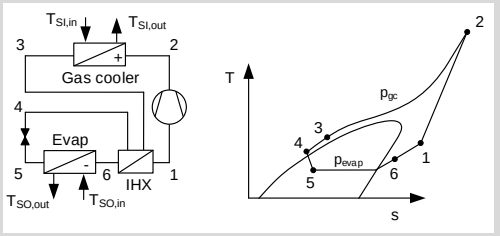
Reverse Brayton cycle



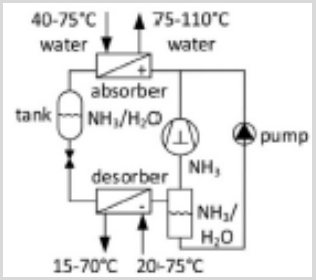
Transcritical CO_2 cycle



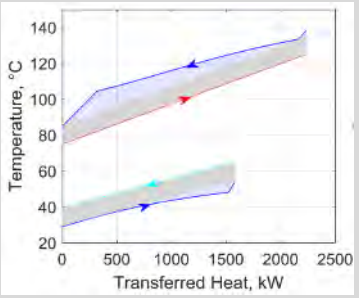
Transcritical cycles with hydrocarbons or HFOs



Hybrid heat pump with NH_3/H_2O



Refrigerant mixtures



to produce

HOT WATER or HOT AIR

Source: Arpagaus C., Bless F., Bertsch S. (2021): Lunch Talk - Industrial Heat Pumps, SWEET DeCarbCH, November 9, 2021

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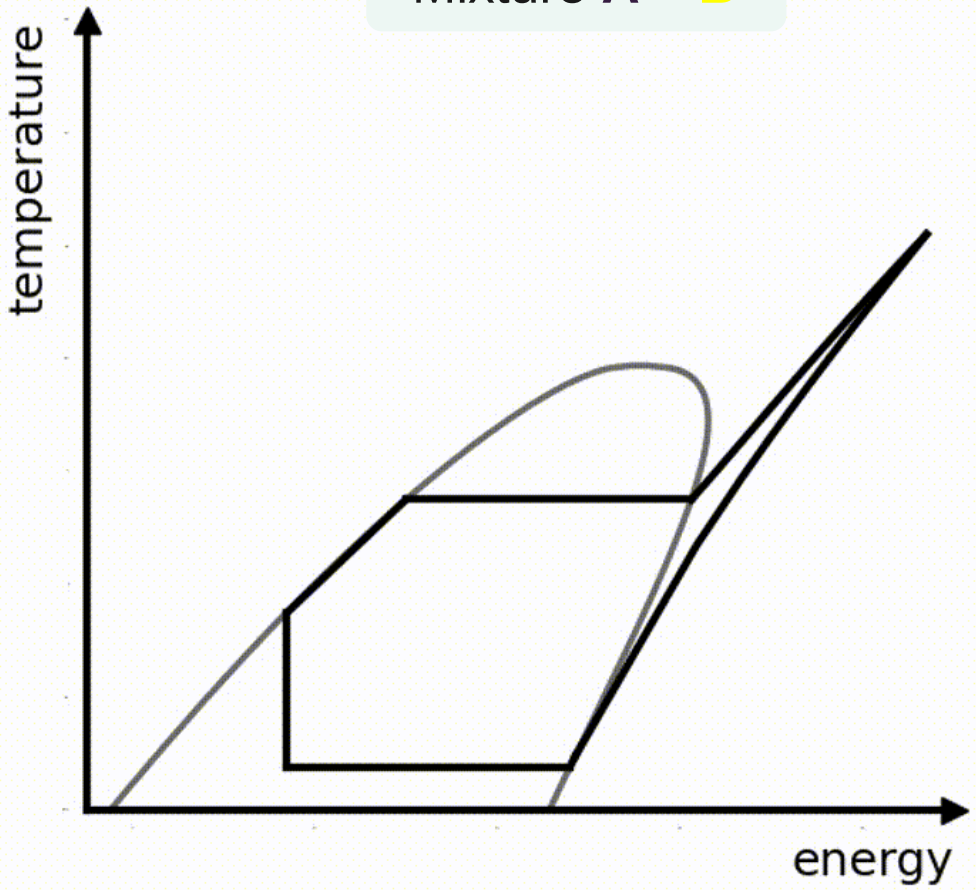
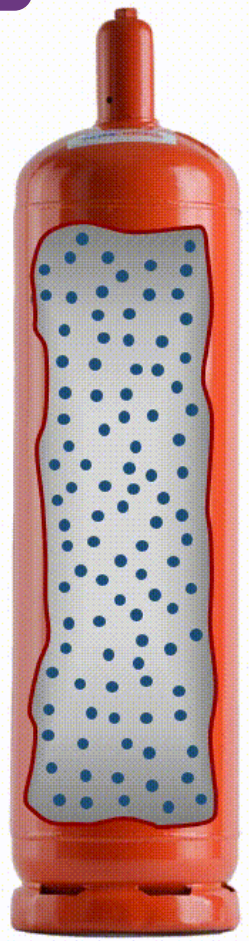
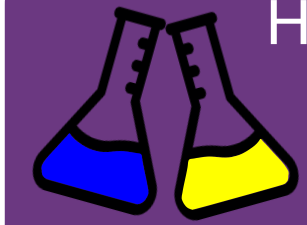
Refrigerant mixtures for Large Temperature Glides

One mixture → **many** options

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







High **flexibility** in **T-levels** and **T-glide**

Animation from Swiss Bridge Project: High-efficiency high-temperature heat pumps with temperature glide

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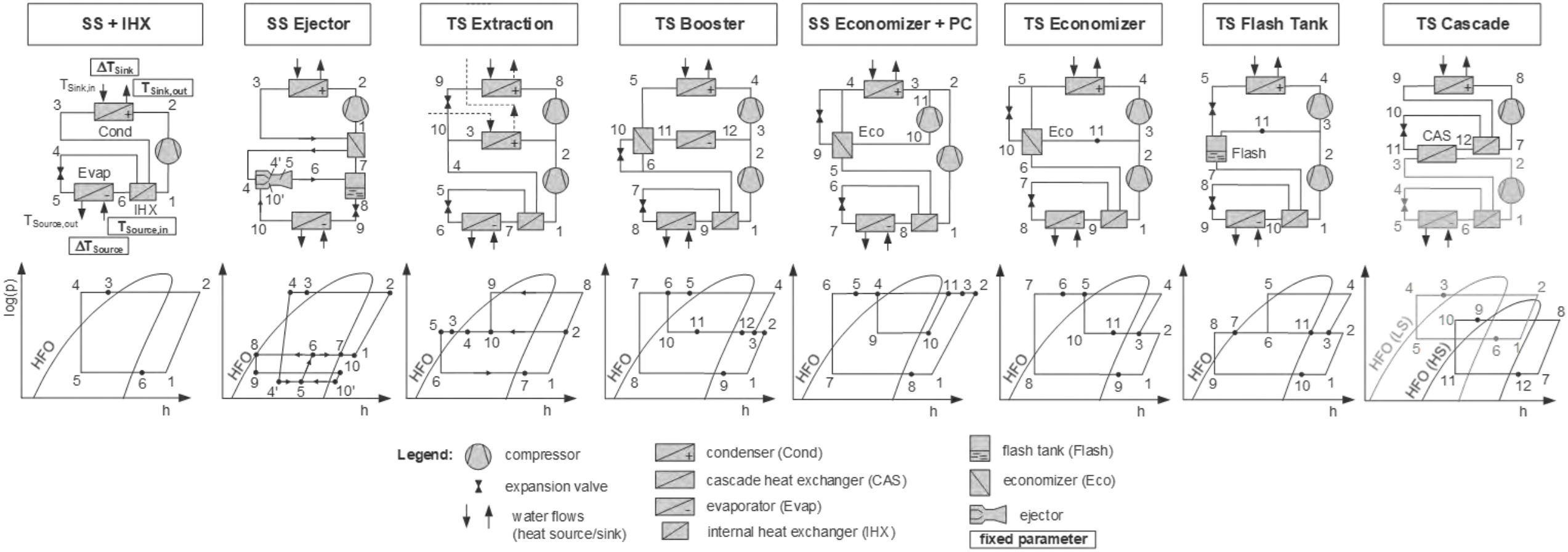
Optimization of HTHP cycle design



Mateu-Royo C., Arpagaus C., Mota-Babiloni A., Navarro-Esbrí J., Bertsch S.S. (2021): Advanced high temperature heat pump configurations using low GWP refrigerants for industrial waste heat recovery: A comprehensive study, https://doi.org/10.1016/j.enconman.2020.113752

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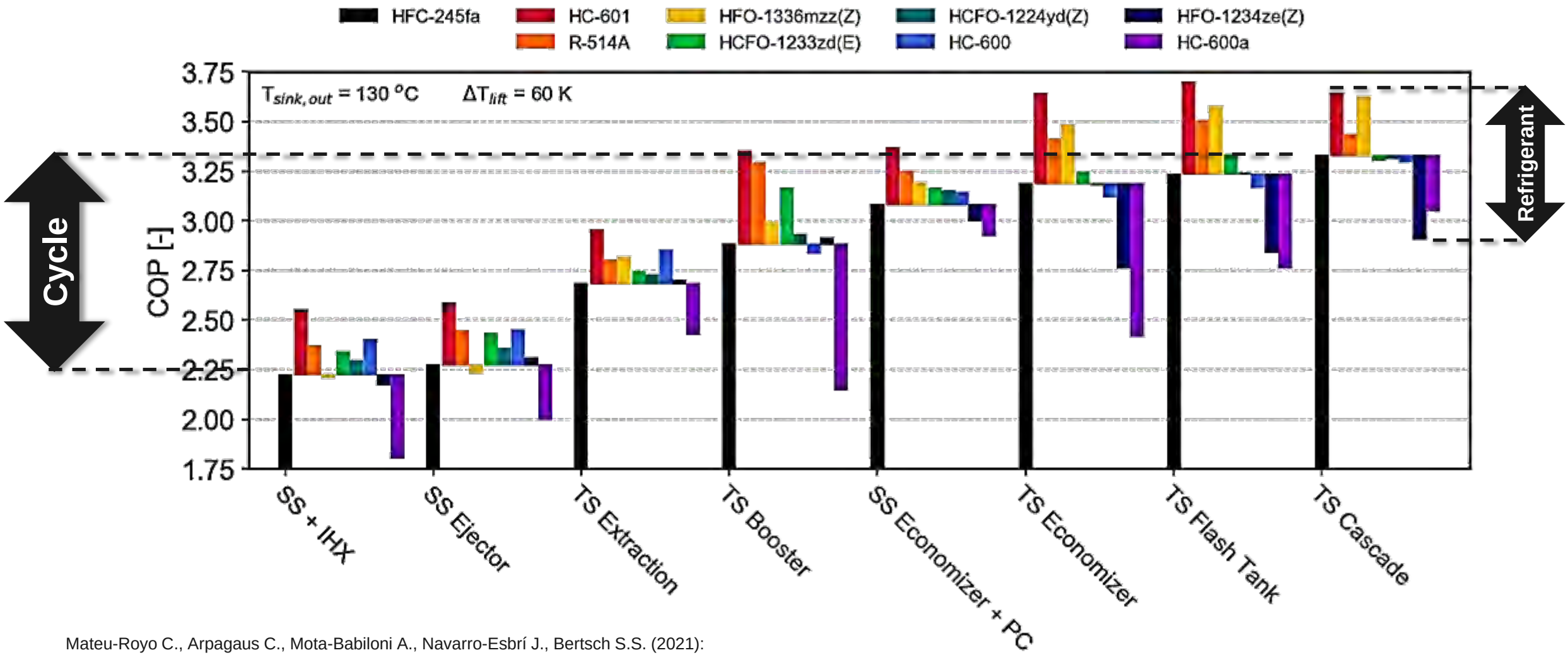
Influence of cycle design and refrigerant on efficiency (COP)



Mateu-Royo C., Arpagaus C., Mota-Babiloni A., Navarro-Esbrí J., Bertsch S.S. (2021): Advanced high temperature heat pump configurations using low GWP refrigerants for industrial waste heat recovery: A comprehensive study, https://doi.org/10.1016/j.enconman.2020.113752

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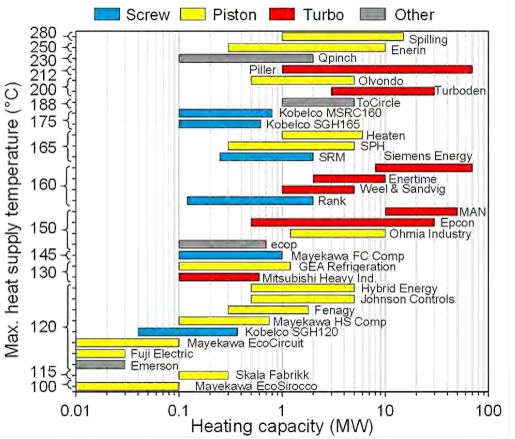
Summary and conclusions

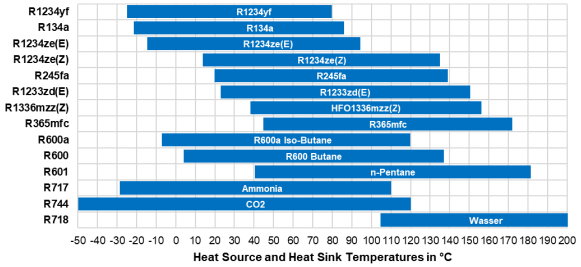
- **Commercial HTHP products and technologies with supply temperature >100 °C are increasingly available on the market** (various manufacturers, >100 kW to >10 MW heating capacity) → IEA HPT Annex 58 overview
- **Various successful case studies, demonstration projects, and HTHP process integrations** presented (hot water, hot air, steam)
- **Future developments about specific HTHP cycle designs** to precisely match temperature requirements → for large temperature glides, steam generation, and large-scale HTHPs
- **HTHP integration concepts** vary from case to case → **tailor-made**
- **Significant energy savings and CO_2 emission reductions** are possible
- **High research activity** worldwide
- **Refrigerants trend** towards **natural** R600 (butane), R601 (pentane), R744 (CO_2), R718 (H_2O), R717 (NH_3), and **synthetic HFOs with low GWP**, like R1336mzz(Z), R1233zd(E), R1336mzz(E), R1224yd(Z), R1234ze(E), etc.



HOT WATER

HOT AIR

STEAM



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Thank you for your attention!

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(SI/502336-01)

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