AUSTRALIAN ALLIANCE FOR ENERGY PRODUCTIVITY

OST Ostschweizer Fachhochschule

Industrial Heat Pumps: Research and Market Update

A2PH Webinar: High temperature heating solutions
November 10, 2021

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Content

- HTHP Technologies
- Research Update
- Steam Generating Heat Pumps
- Application Examples

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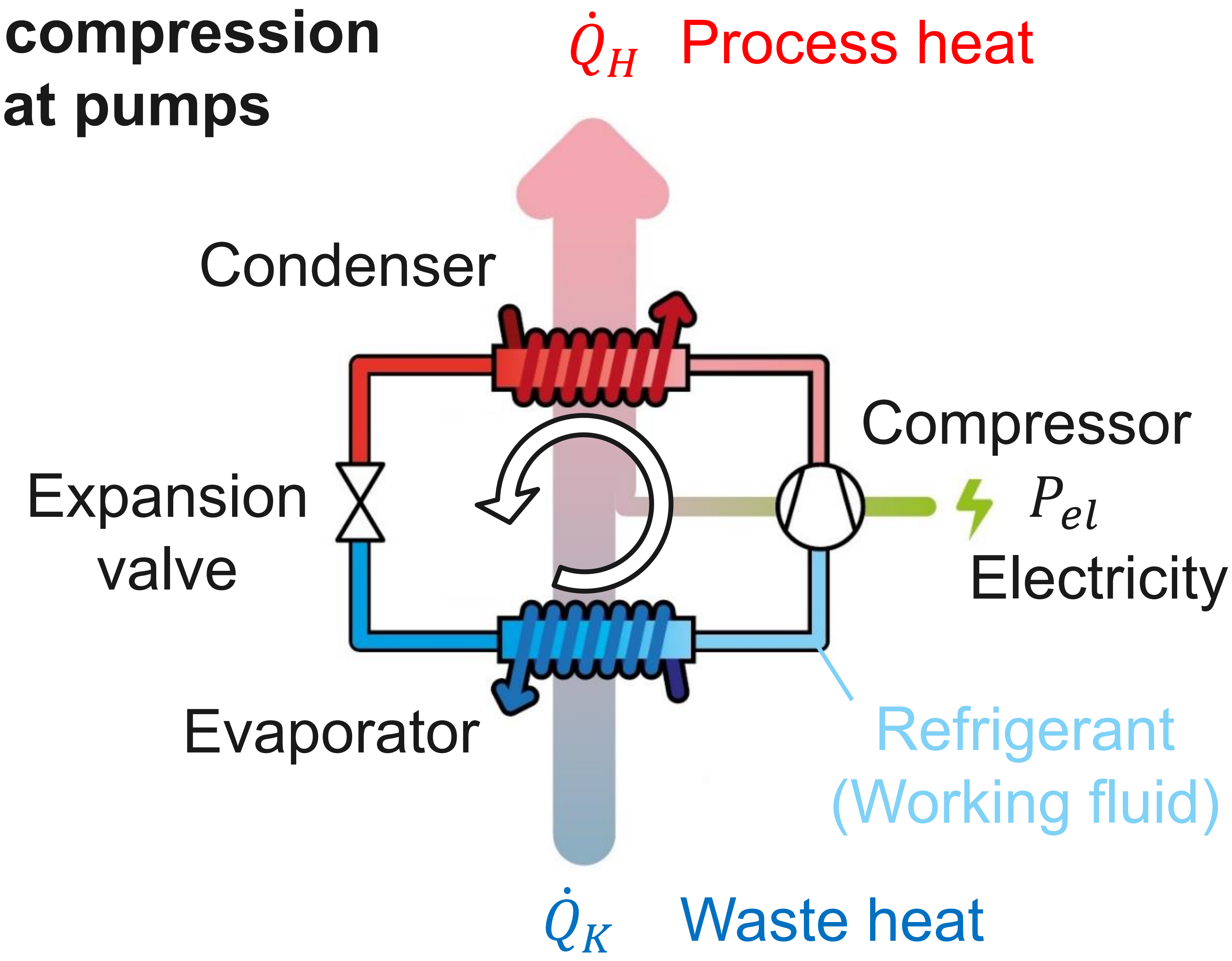
Industrial Heat Pump
Definition of IEA HPT Annex 48 project

Heat pump with
>100 kW heating capacity
applied for industrial processes
but also
for district heating
and large residential buildings.

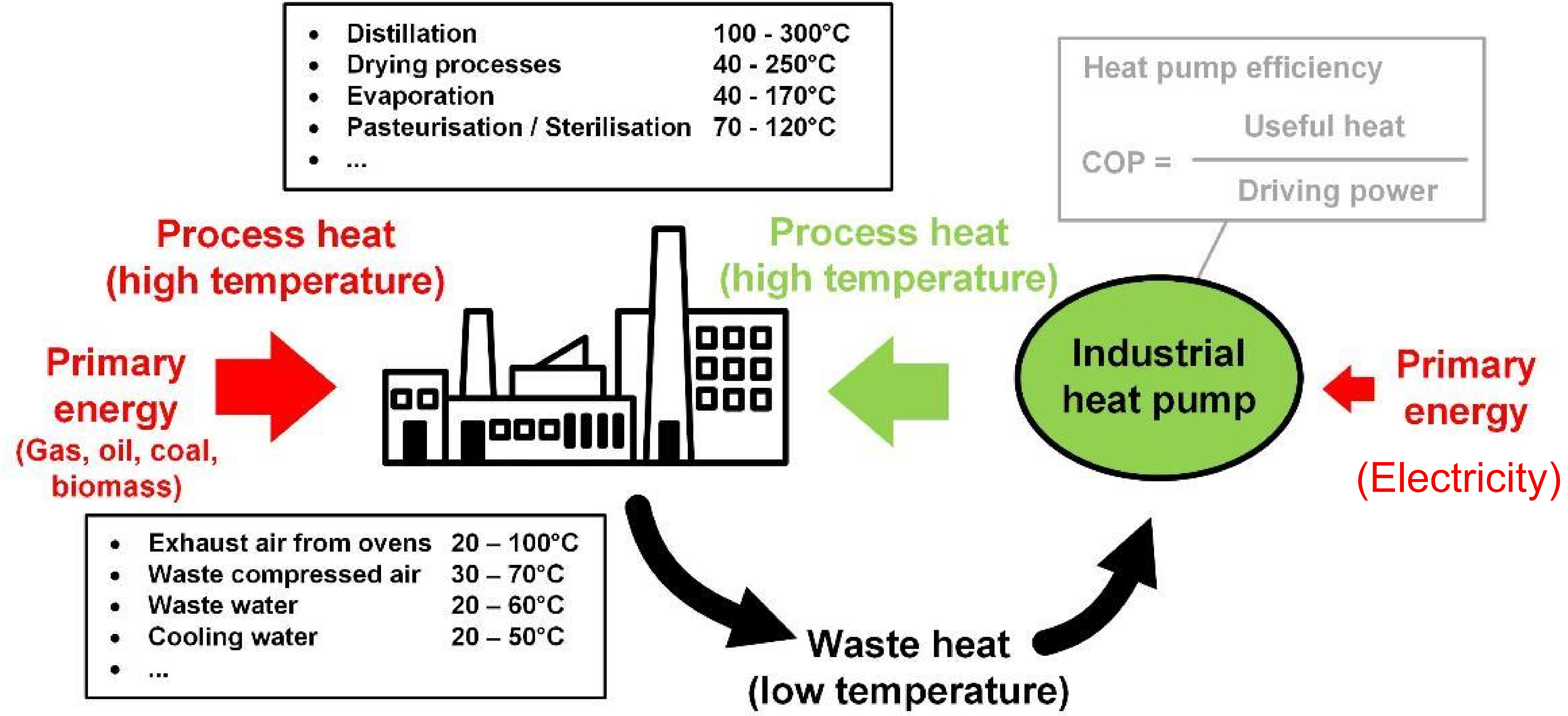
Focus is on vapor compression heat pumps



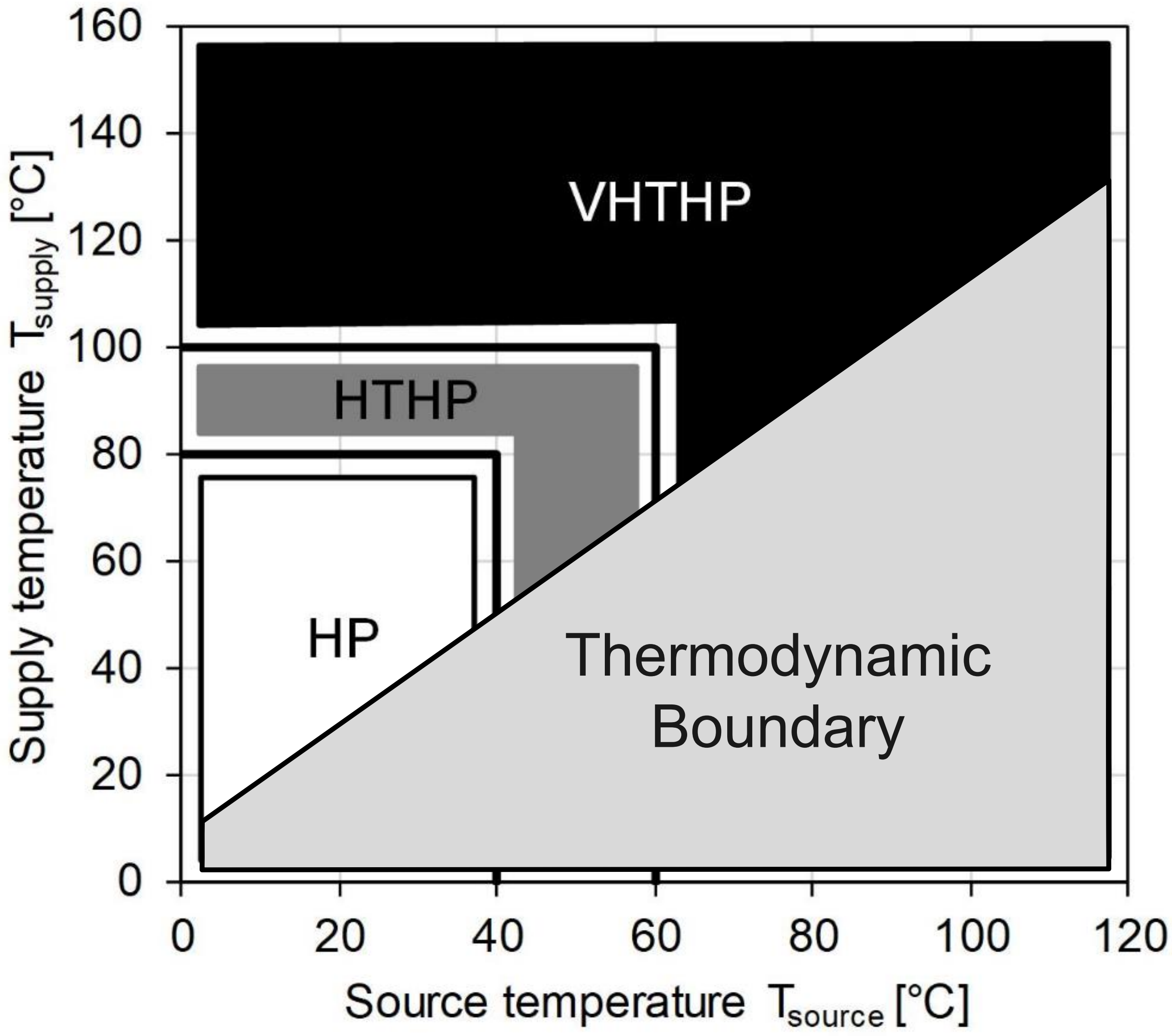
COP (Coefficient of Performance)

$$COP_H = \frac{\dot{Q}_H}{P_{el}}$$

Industrial Heat Pumps for Waste Heat Recovery



Temperature Ranges and Heat Pump Classification



VHTHP: Very High Temperature Heat Pump

HTHP: High Temperature Heat Pump

HP: Conventional Industrial Heat Pump

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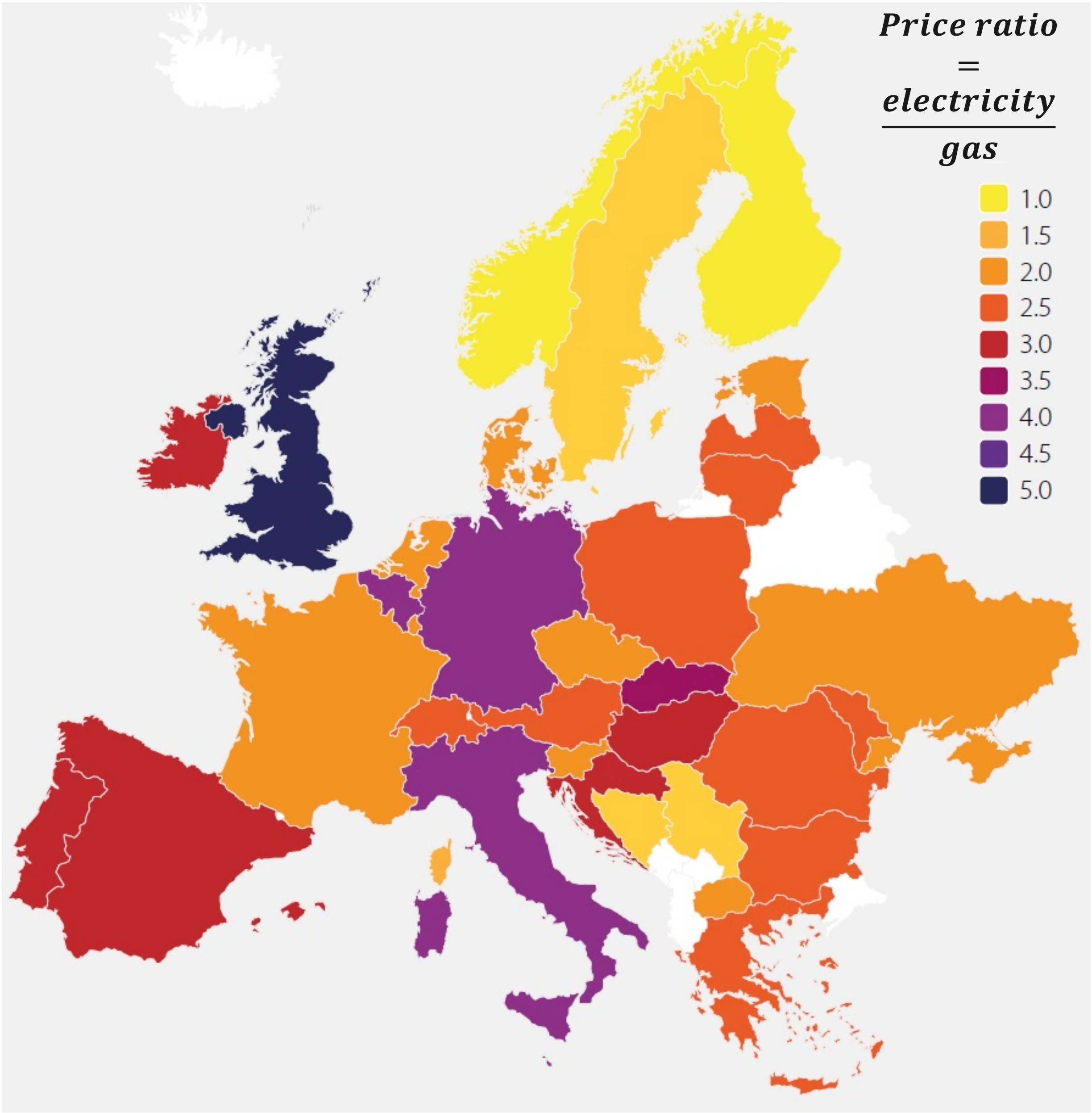
Market Attractiveness depends on Price Ratio between Electricity and Gas

- 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



Source: De Boer et al. (2020): Strengthening Industrial Heat Pump Innovation, Decarbonizing Industrial Heat, White Paper, 14 July 2020.

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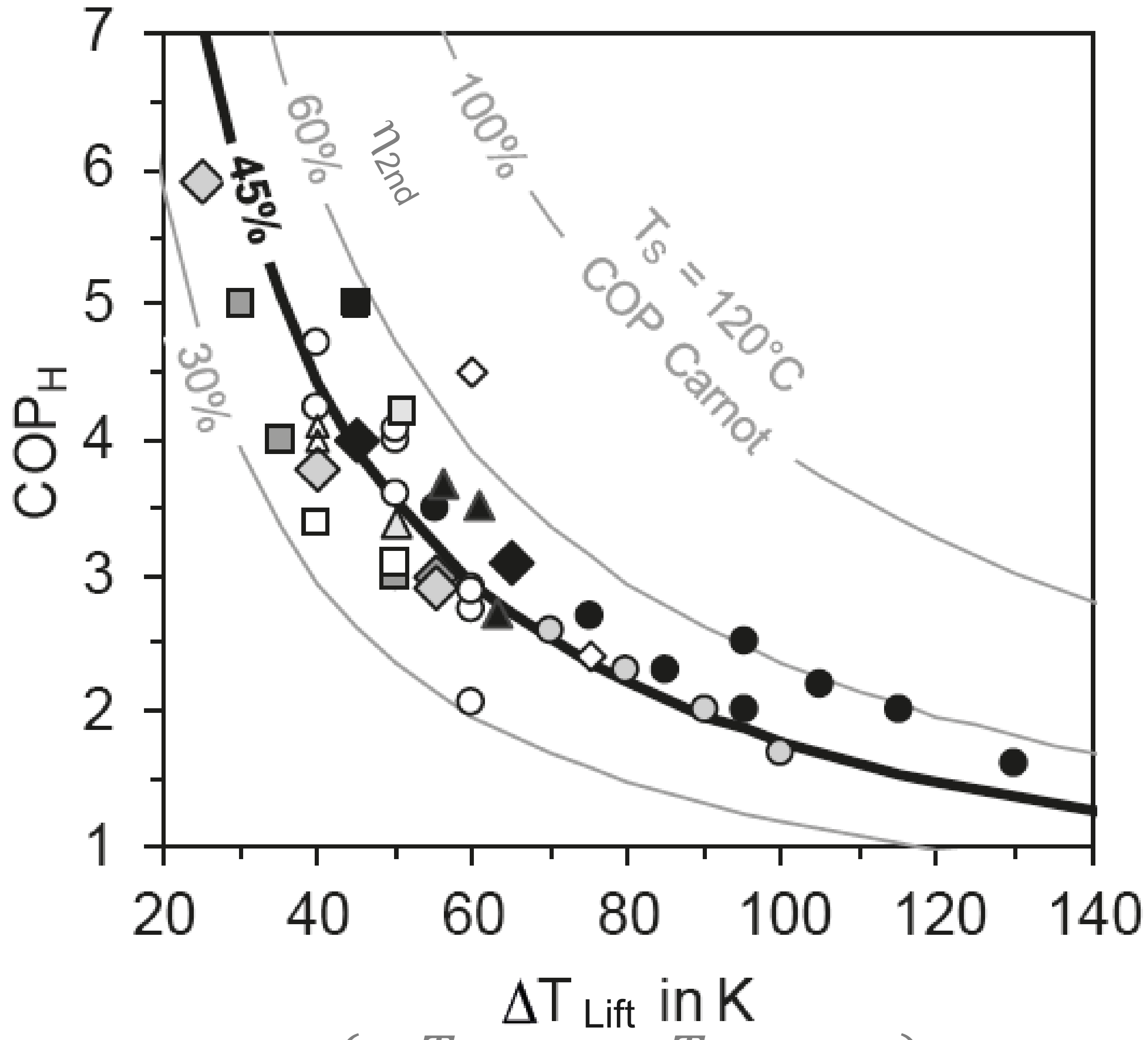
Efficiency (COP) of Industrial Heat Pumps



$(= T_{Sink,out} - T_{Source,in})$

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

Source: Arpagaus et al. (2018): High temperature heat pumps: Market overview, State of the Art, Research Status, refrigerants, and Application Potentials, Energy, 152, 985-1010, https://doi.org/10.1016/j.energy.2018.03.166

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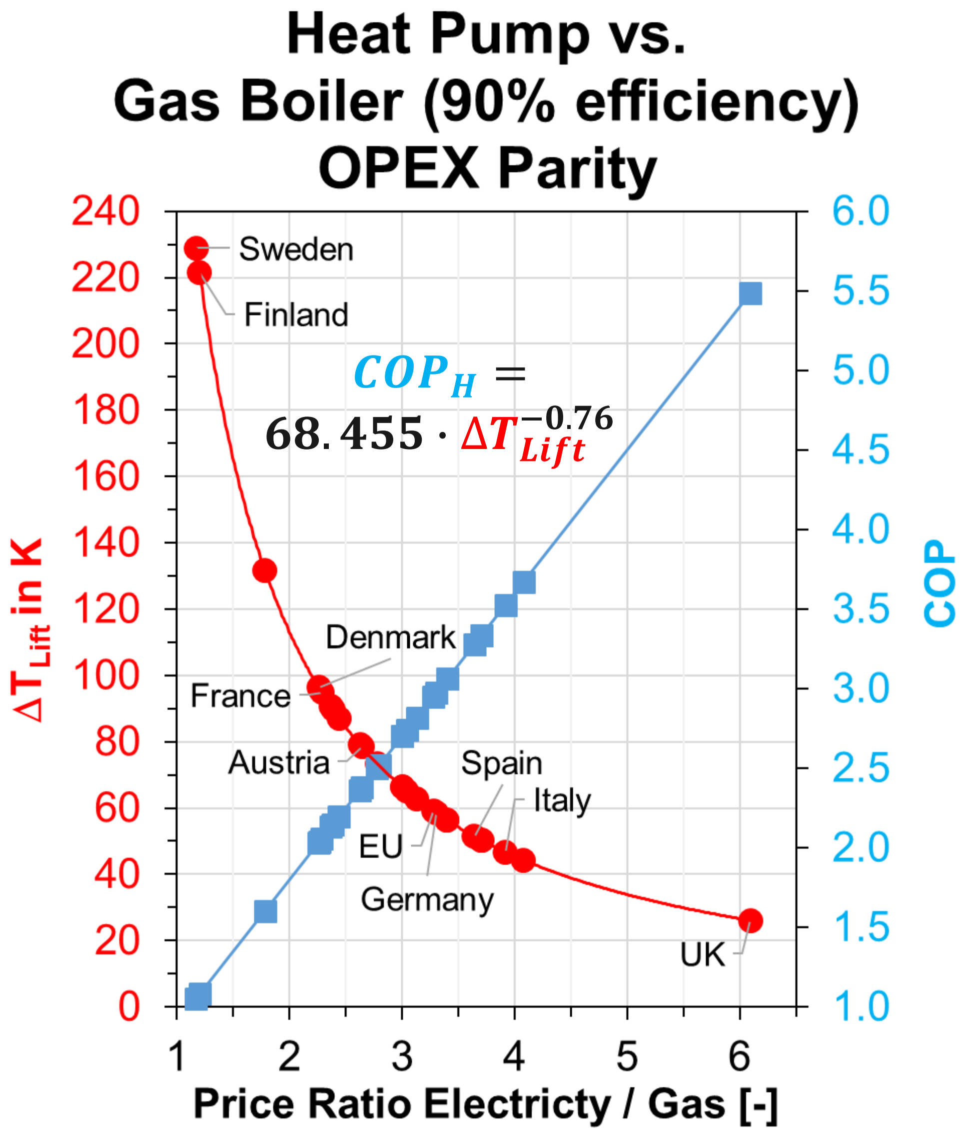
OPEX Parity COP and Temperature Lift

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

90%

Country	Prices without refundable Gas	Electricity	Price Ratio	OPEX Parity COP	ΔT_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



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Decarbonization of the Heat Sector in Europe

Stock of Boilers (Oil, Gas, Coal) in EU28* (Status 2015)

	25 – 100 kw	101 – 250 kw	TOTAL
EU – 28	14,7 Mio.	3,3 Mio.	18 Mio.
Germany	3.915.585	1.307.405	5.222.990
Italy	4.079.424		4.079.424
Spain	3.049.352	274.290	3.323.642
Netherlands	1.177.599	47.808	1.225.407
United Kingdom	646.492	244.231	890.723
France	404.866	375.099	779.965
Poland	186.429	533.109	719.538
Austria	396.392	114.860	511.252
Czech Republic	330.611	59.678	390.289
Belgium	129.175	223.517	352.692
Greece	180.566		180.566
Rest EU-28	291.166	115.712	406.878

*based on European Comission (2016): Mapping and analysis of current and future (2020-2030) heating / cooling fuel development (fossils/renewables)

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Challenges to further spread Industrial HPs into the market

1. **Low level of awareness** of the technical possibilities and economically feasible application potential among users, consultants, investors, planners, manufacturers and installers
2. **Lack of knowledge** about the integration of heat pumps into existing industrial processes (retrofit)
3. **Factory-built vs. tailor-made designs** (economies of scale)
4. **Amortization periods** longer as for gas or oil-fired boilers (price ratio electricity to gas)
5. **Competing heating technologies** (fossil, and renewable energies)
6. **Requirements of heat storage** to compensate for the time lag between demand and supply (e.g. heat pump for band load, gas boiler for heating peaks)
7. **Lack of available compressors** for high temperatures **and refrigerants** with low global warming potential (GWP) and zero ozone depletion potential (ODP)

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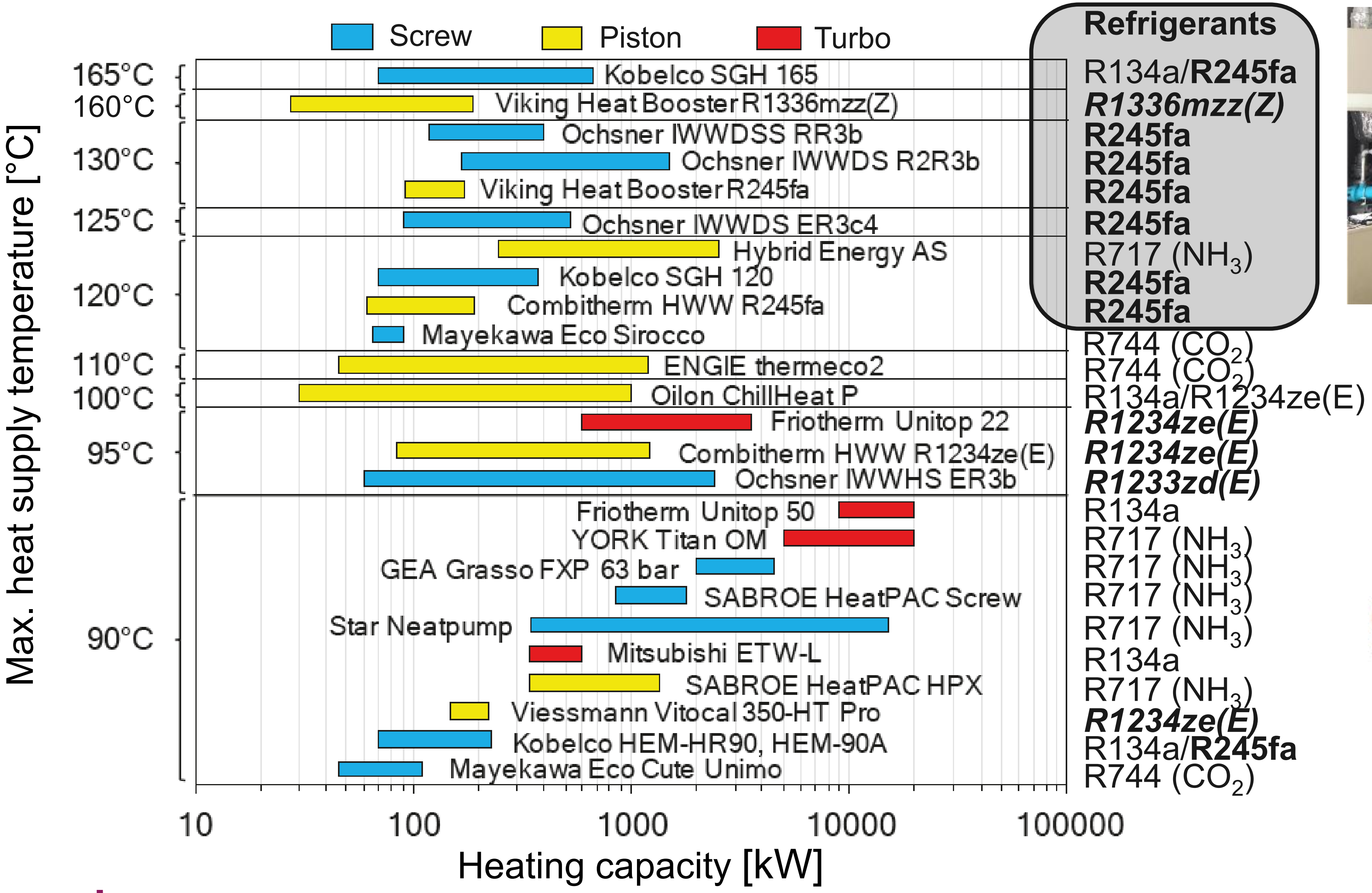
Commercial Industrial HTHPs (Status end of 2018)



Kobelco SGH 120/165 (Steam Grow Heat Pump)

HeatBooster S4 (Viking Heat Engines AS) (now Heaten)

OCHSNER ENERGIE TECHNIK

Source: Arpagaus et al. (2018): High temperature heat pumps: Market overview, State of the Art, Research Status, refrigerants, and Application Potentials, Energy, 152, 985-1010, https://doi.org/10.1016/j.energy.2018.03.166

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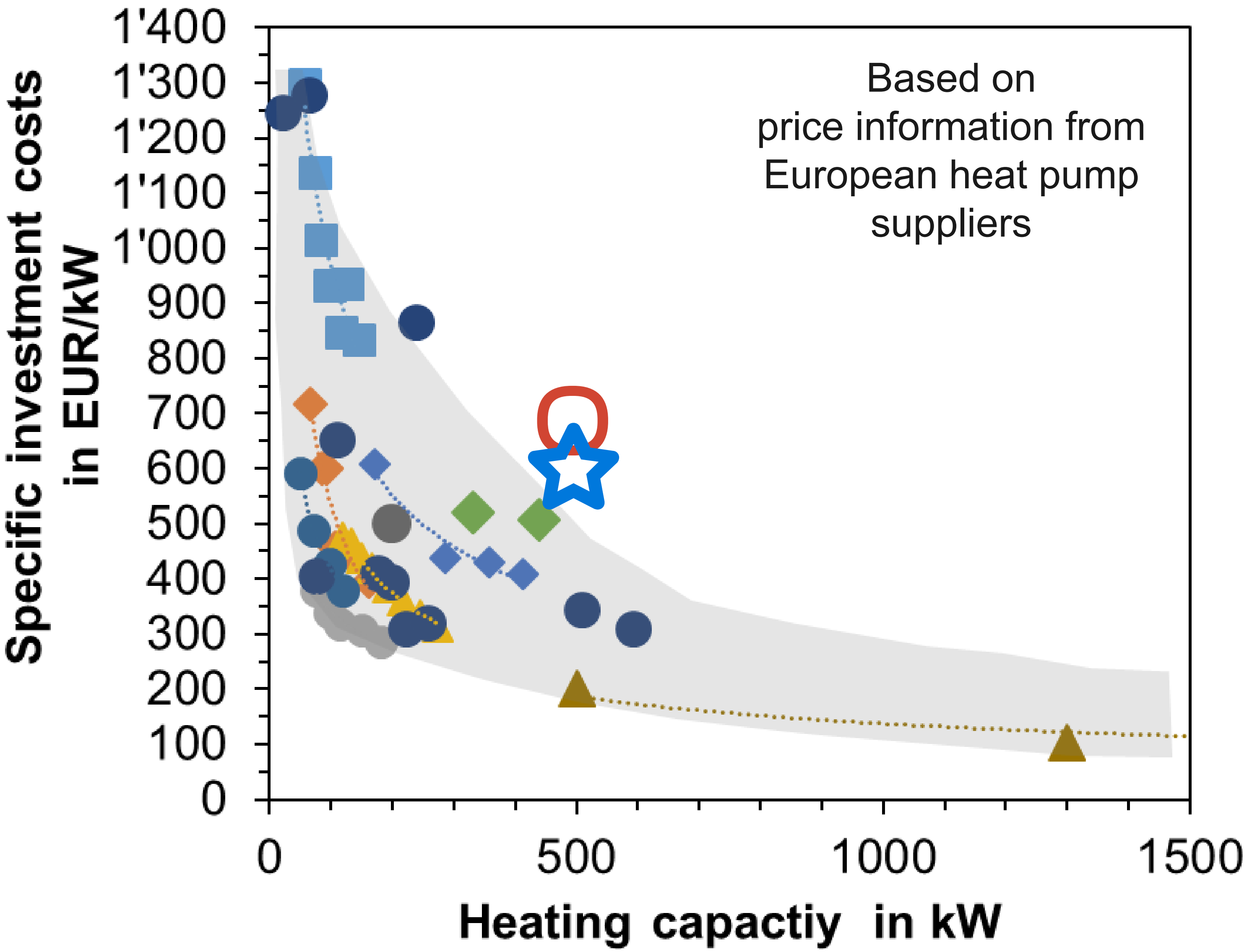
Specific investment costs per kW of heating



OCHSNER ENERGIE TECHNIK
IWWDSS 630 R6R4ab (500 kW)

KOBELCO
SGH120 (370 kW)
SGH165 (624 kW)
(sales and after-service base in Europe)

These prices are rough values. The actual prices depend on the sales channels.

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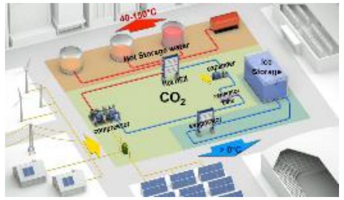
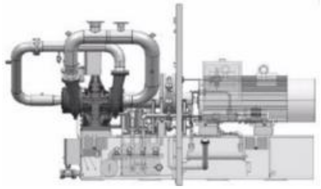
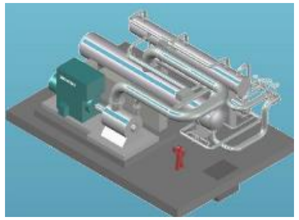
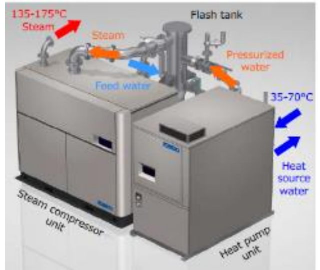
Examples of Large Scale HTHPs (>1 MW) for district heating and industrial applications

Company	Turboden (IT)	MAN Energy (CH)	Mitsubishi MHPS (DE)	Siemens (DE)	Ochsner (AT)	Kobelco (JP)
Product	LHP30 LHP150	ETES	D-GWP	Large-scale	IWWDSS R2R3b IWWHS ER3b TWIN	SGH 120/165
Refrigerant	R601 + R718 (n-Pentane + Water)	R744 (CO_2)	R600a + R718 (Iso-Butane + Water)	HFOs	Öko (R245fa) R1233zd(E) (HFOs)	R245fa + R718
Heating capacity	**2.7 MW** **14.4 MW**	**5 to 100 MW**	**4.3 MW**	**4 to 35 MW**	**Up to 750 kW** **TWIN 2.4 MW**	**Up to 624 kW** **Cascade 2.5 MW**
Max. supply temp.	115 °C	150 °C	174 °C	150 °C	130 °C	165 °C



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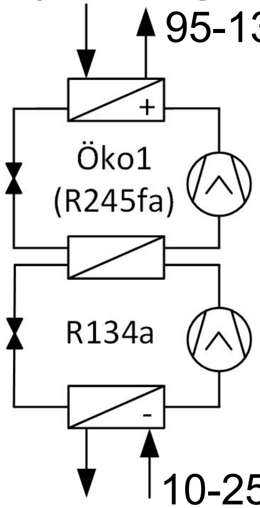
OCHSNER Energie Technik GmbH (Austria)

OCHSNER ENERGIE TECHNIK

IWWDSS R1R3b (2-stage cascade)

- 90 to 530 kW

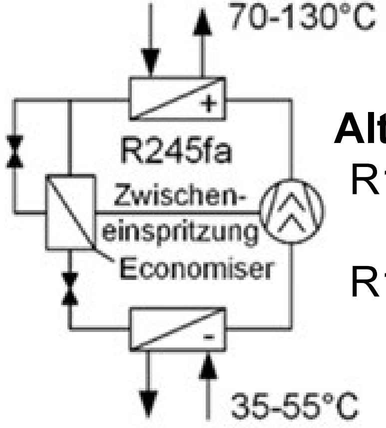


Alternative:
R1233zd(E)

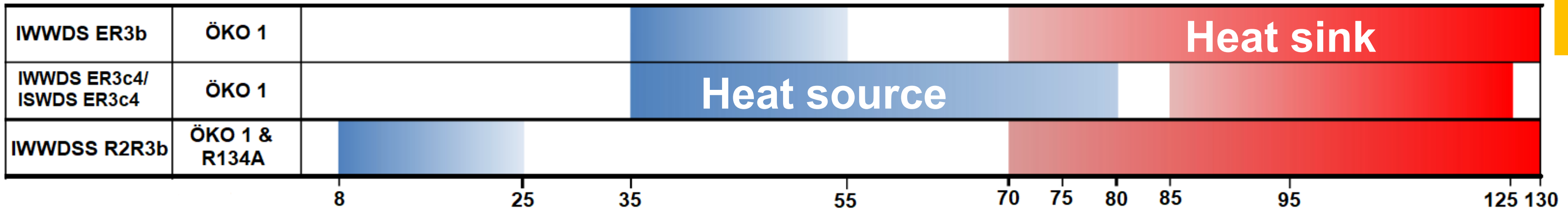
R513 or
R1234ze(E)

IWWDS ER3b (1-stage with economizer):

- 170 to 400 kW

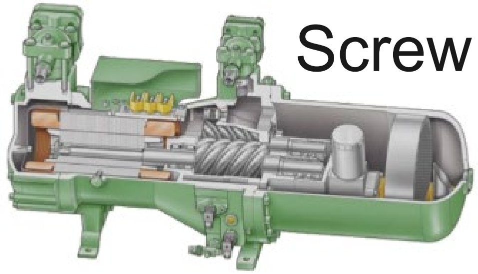


Alternatives:
R1233zd(E)
R513 or
R1234ze(E)

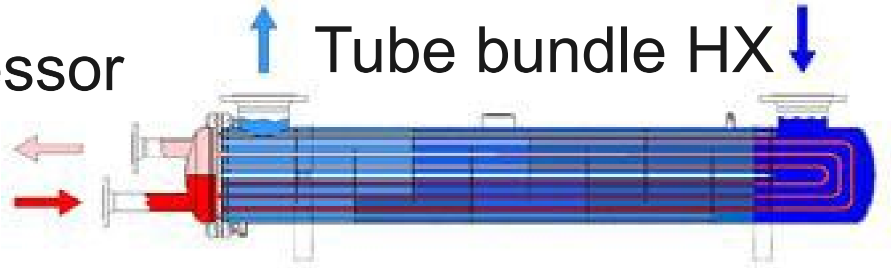


New

IWWHS ER3b TWIN
with R1233zd(E)
up to 2.4 MW



Screw compressor



Tube bundle HX

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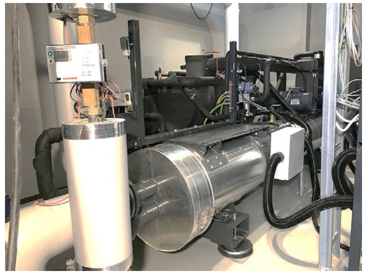
HTHP Case Studies

OCHSNER ENERGIE TECHNIK

	Mänttä-Vilpula (FIN)	Leather production Couro Azul (POR)	Université de Bourgogne, Dijon (FRA)	Plansee Reutte (AUT)	GVS Schaffhausen (CH)
Heat pump type	IWWDS 120 ER3	IWWDS 270 ER4b	IWHSS 430 R2R3	IWHS 400 ER3	ISWHS 60 ER3
Heating Capacity	158 kW	309 kW	420 kW	380 kW	63 kW
Heat Sink	**120 °C**	**120 °C**	**90 °C**	**90 °C**	**80 – 95 °C**
Heat Source	45 – 55 °C	55 °C	10 – 15 °C	45 °C	37 °C
Source	District heating network return line	Water	Water	Waste heat from sintering process	Waste heat from chiller
Compressor Refrigerant	Screw ÖKO 1 (R245fa)	Screw R1233zd	Screw R134a + ÖKO 1 (R245fa)	Screw ÖKO 1 (R245fa)	Screw ÖKO 1 (R245fa)
COP	2.0	2.47	2.6	4.0	4.2
Installation	2017	2021 (Shipment)	2015	2013	2017
Application	**Local district heating network**	**Hot water for production**	**Heating and cooling of computer room and offices**	**Process heat recovery for plant district heating network**	**Warehouse heating and cooling**





Source: Direct information from OCHSNER and https://ochsner-energietechnik.com/referenzen/

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Bitzer – Screw Compressors

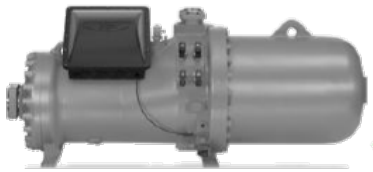
BITZER´S PATH TO HIGH TEMPERATURE HEATING
CSH SCREW COMPRESSORS

// **Step-by-step concept**

CSH-M1 Standard
A1: R134a/R513A/R450A
A2L: R1234yf/R1234ze(E)
to max: +25°C
tc max: +70°C

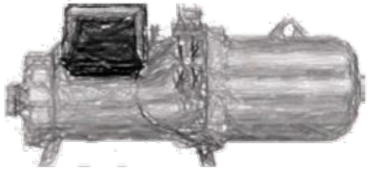
NEW: Ext. Envelope

CSH-M1 Extension
A1:R134a/R513A/R450A
to max: +30°C (Target)
tc max: +80°C
A2L: R1234ze(E)
to max: +50°C
tc max: +95°C
B1: R245fa
tc max: +100°C



CSH2T-M1 Product Variant
B1:R245fa
A1: R1224yd(Z)
R1336mzz(Z)
A2: R1234ze(Z)
to max: + 75°C (Target)
tc max: +125°C

Investigations ongoing



CS – NEW Product
A1: R1336mzz(Z)
R1233zd(E)
A3: Hydrocarbons (HC´s)

to max: tbd°C (Target)
tc max: +160°C

Pre-considerations have started

STANDARD | EXTENSION | MID-TERM | LONG-TERM

Source: Rodríguez and Schlehuber (2019): Bitzer Compressor Solutions from Comfort to High Temperature Heat Pumps, European Heat Pump Summit, Nuremberg, October 22, 2019

Bitzer – Screw Compressors

PROJECT REFERENCE
CSH2T PROTOTYPE

+++ DEVELOPMENT STATUS +++

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

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: Schlehuber (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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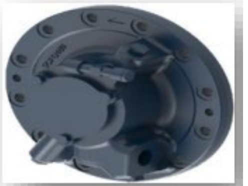
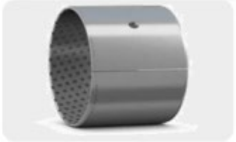
Dorin – R600 (Butane) ATEX Piston Compressor for HTHPs







II 3G c Ex nA IIB T3 Gc

EXTERNAL DISCHARGE MANIFOLD

160°C MAX DISCHARGE TEMPERATURE

SUCTION SERVICE VALVE ON THE MOTOR COVER

25% LARGER ELECTRIC MOTOR

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

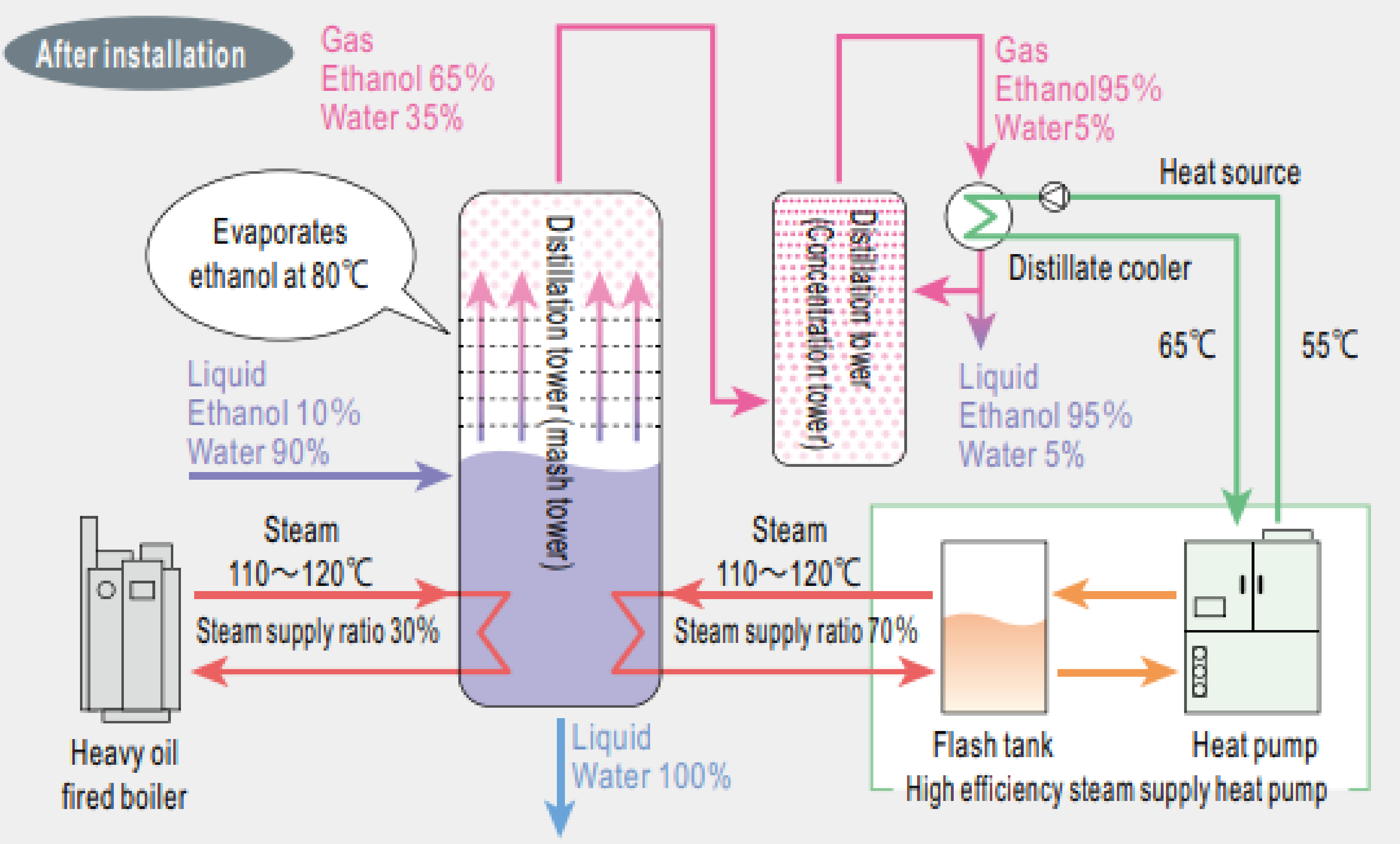
Commercialized Industrial HTHPs over 100 °C in Japan

	MAYEKAWA	KOBELCO	KOBELCO	MHI Thermal Systems	Fuji Electric
External Appearance					
Commercialized Year	2009	2011	2011	2011	2015
Product Name	Eco Sirocco	SGH120	SGH165	ETW-S	–
Heat Source/Sink	Water/Air	Water/Steam	Water/Steam	Water/Water	Water/Steam
Supply Temperature	60-120°C	100-120°C	135-175°C	130°C	100-120°C
Heat Source Temperature	0-40°C	25-65°C	35-70°C	55°C	60-80°C
Heating Capacity (Steam Rate)	110 kW[*1]	370 kW[*2] (0.51 ton/h)	624 kW[*3] (0.89 ton/h)	627 kW[*4]	30 kW[*5] (45 kg/h)
COP	3.7[*1]	3.5[*2]	2.5[*3]	3.0[*4]	3.5[*5]
Refrigerant	R744 (CO_2)	R245fa	R245fa+R134a	R134a	R245fa
Compressor	Reciprocating	Screw	Screw	Centrifugal	Reciprocating
Heat Pump Cycle	Transcritical	Subcritical	Subcritical + Steam Compression	Transcritical	Subcritical

*1 Heat source: 30-25°C, Heat sink: 20-100°C *2 Heat source: 65-60°C, Heat sink: 20-120°C *3 Heat source: 70-65°C, Heat sink: 20-165°C *4 Heat source: 55-50°C, Heat sink: 70-130°C *5 Heat source: 80-75°C, Heat sink: 20-120°C

Source: Kaida (2019): HTHPs in Japan, 2nd Conference on HTHPs, Sept 9, 2019, Copenhagen

Case Study: Distillation of Bioethanol



Hokkaido Bioethanol Co., Ltd.

Installed year	2012

Steam (120°C)

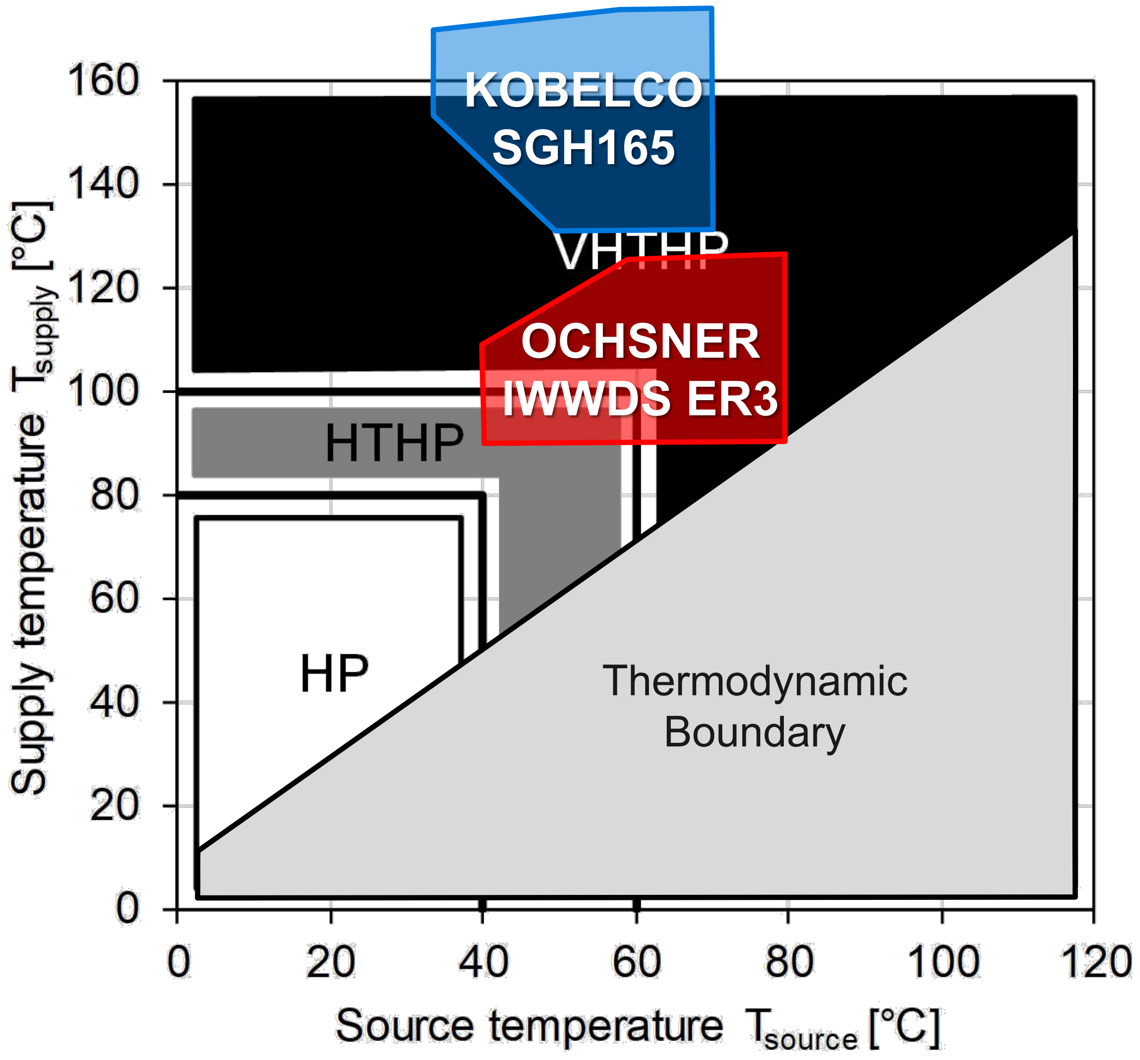
SGH120 (× 5 units)
Refrigerant: R245fa
Steam flow: 2 ton/h

CO_2 reduction: 43%*1
Primary energy reduction: 40%*2
Energy cost reduction: 54%

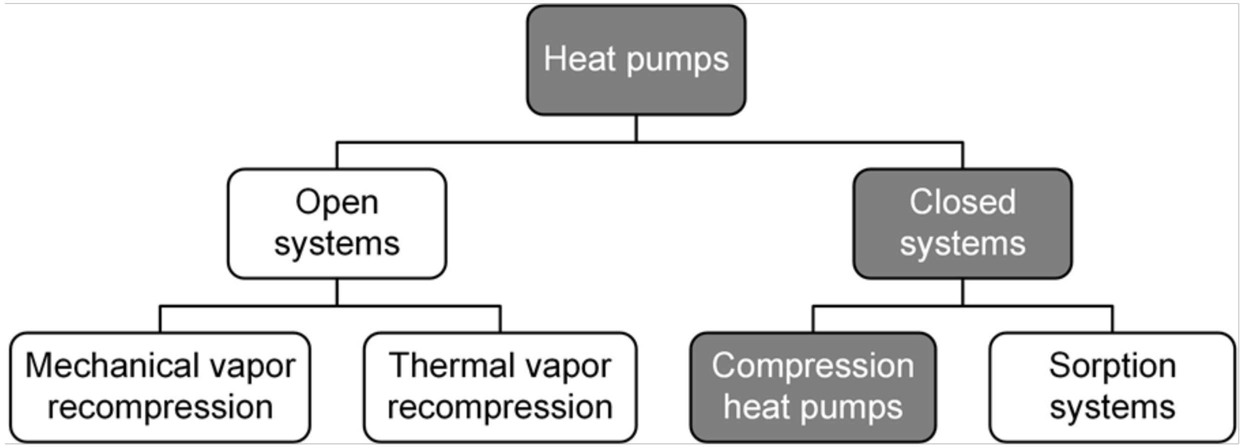
*1 Electricity: 0.681 kg-CO_2/kWh (Hokkaido EPCo, FY2013), Heavy oil: 2.71 kg-CO_2/L
*2 Electricity: 9.76 MJ/kWh, Heavy oil: 39.1 MJ/L

Source: https://www.hptcj.or.jp/Portals/0/english/Learning/HOKKAIDO.pdf

Heat Pump Classification



Focus is on vapor compression heat pumps



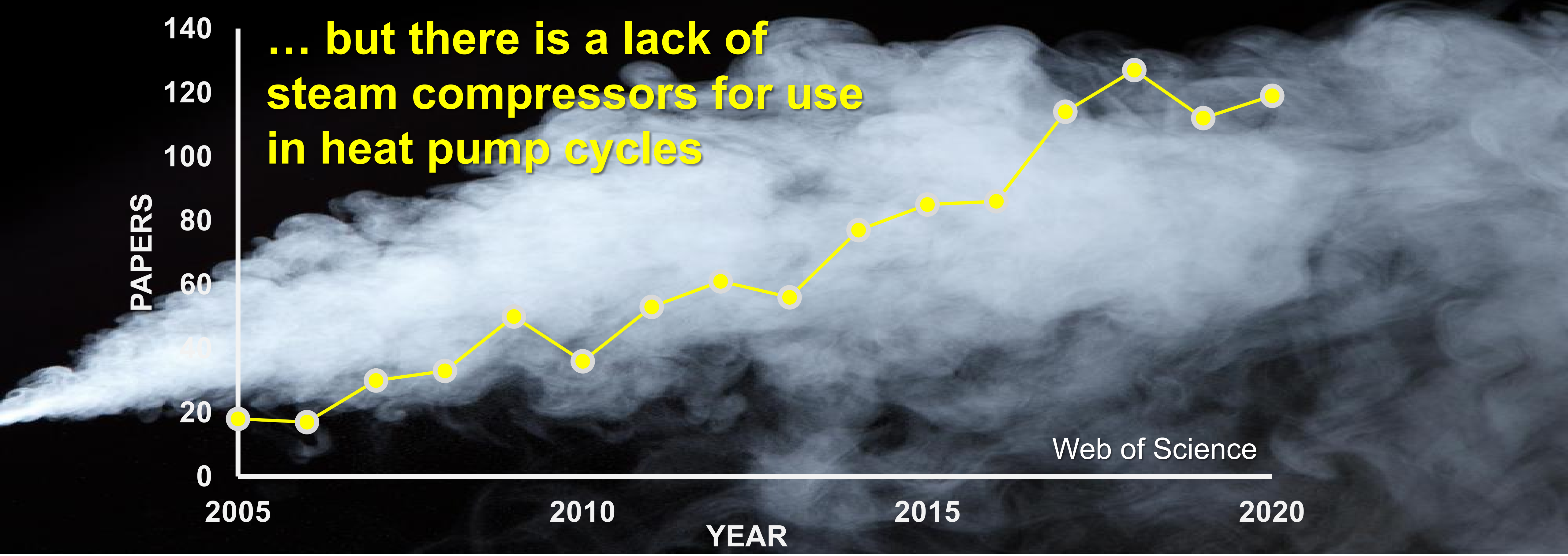
HP: Conventional Industrial Heat Pump
HTHP: High Temperature Heat Pump
VHTHP: Very High Temperature Heat Pump

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

Steam Generating Heat Pumps

STEAM

Publications with keywords «steam + heat pump» are increasing



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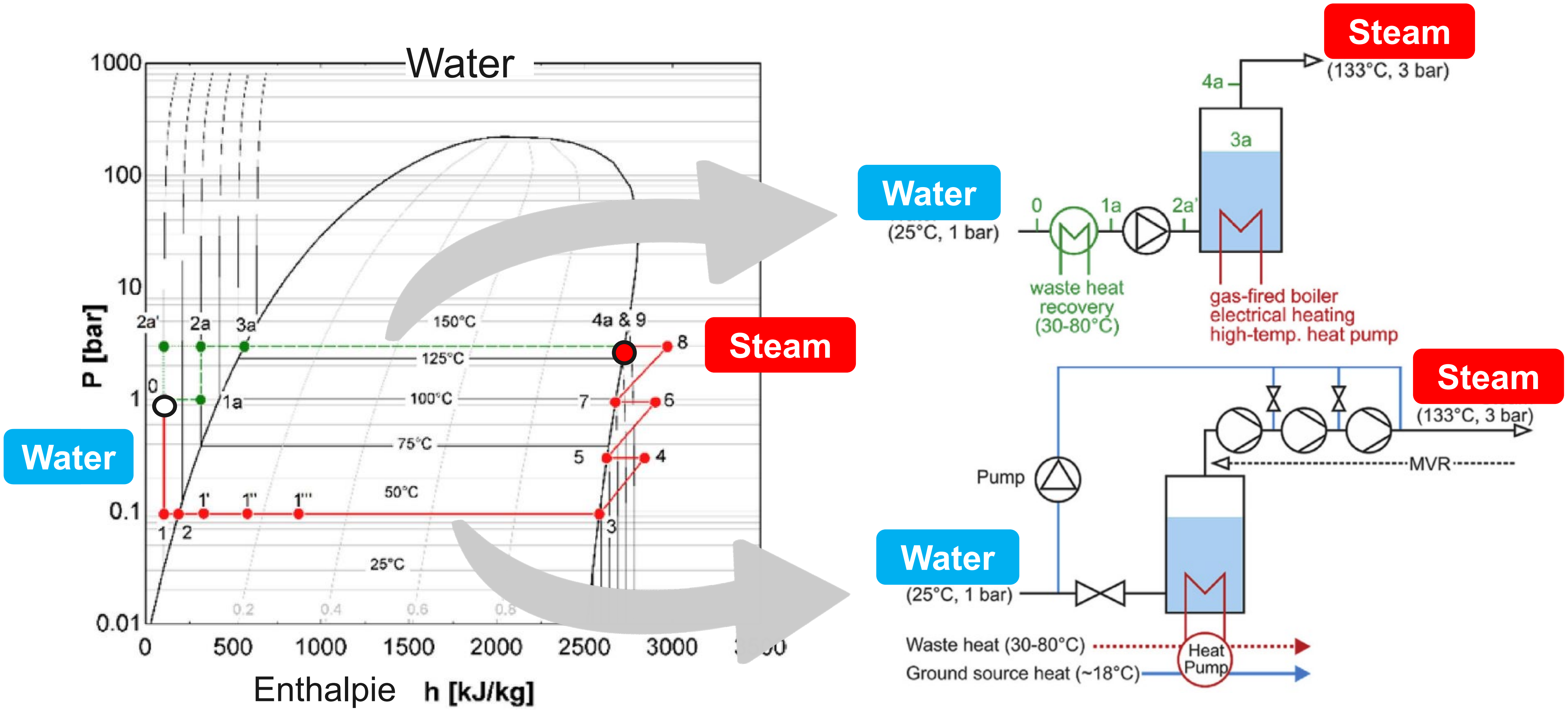
Open-cycle – highly efficient

STEAM



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

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Energy Savings and CO_2 Emissions Reduction

Energy consumption, CO2 emission, and operating cost per kilo of steam							
		without waste heat			with waste heat (55°C)		
	Steam generation method	kJ	CO_2 [g]	OC [¢]	kJ	CO_2 [g]	OC [¢]
direct heating	Natural gas-fired (US)	2758	139	1.8	2648	133	1.8
	Natural gas-fired (CH)			5.1			4.9
	Electrical heating (US)	2620	375	7.4	2516	360	7.1
	Electrical heating (CH)		27	12.0		26	11.5
	High temperature HP (US)	1849	265	5.2	1137	163	3.2
	High temp. HP (CH)		19	8.5		12	5.2
vapour compression	HP using HX cooling (US)	1180	169	3.3	836	120	2.4
	HP using HX cooling (CH)		12	5.4		9	3.8
	HP using WI cooling (US)	1106	158	3.1	755	108	2.1
	HP using WI cooling (CH)		11	5.1		8	3.5
	Waste heat evap. with HX (US)	-	-	-	772	111	2.2
	Waste heat evap. with HX (CH)			-		8	3.5
	Waste heat evap. with WI (US)	-	-	-	661	95	1.9
	Waste heat evap. with WI (CH)			-		7	3.0

STEAM

CO_2 emissions factor **20** x

Energy consumption factor **4** x

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

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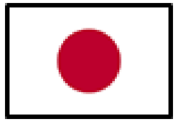
Steam Generating Heat Pumps

STEAM

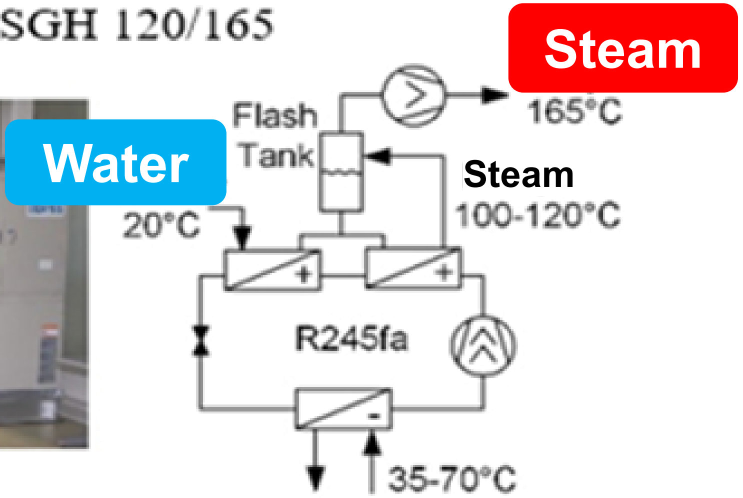
- Cycle with Condenser/Subcooler (R245fa) + Flash Tank + MVR
- Combined closed cycle (R600a) + open cycle (R718 water)

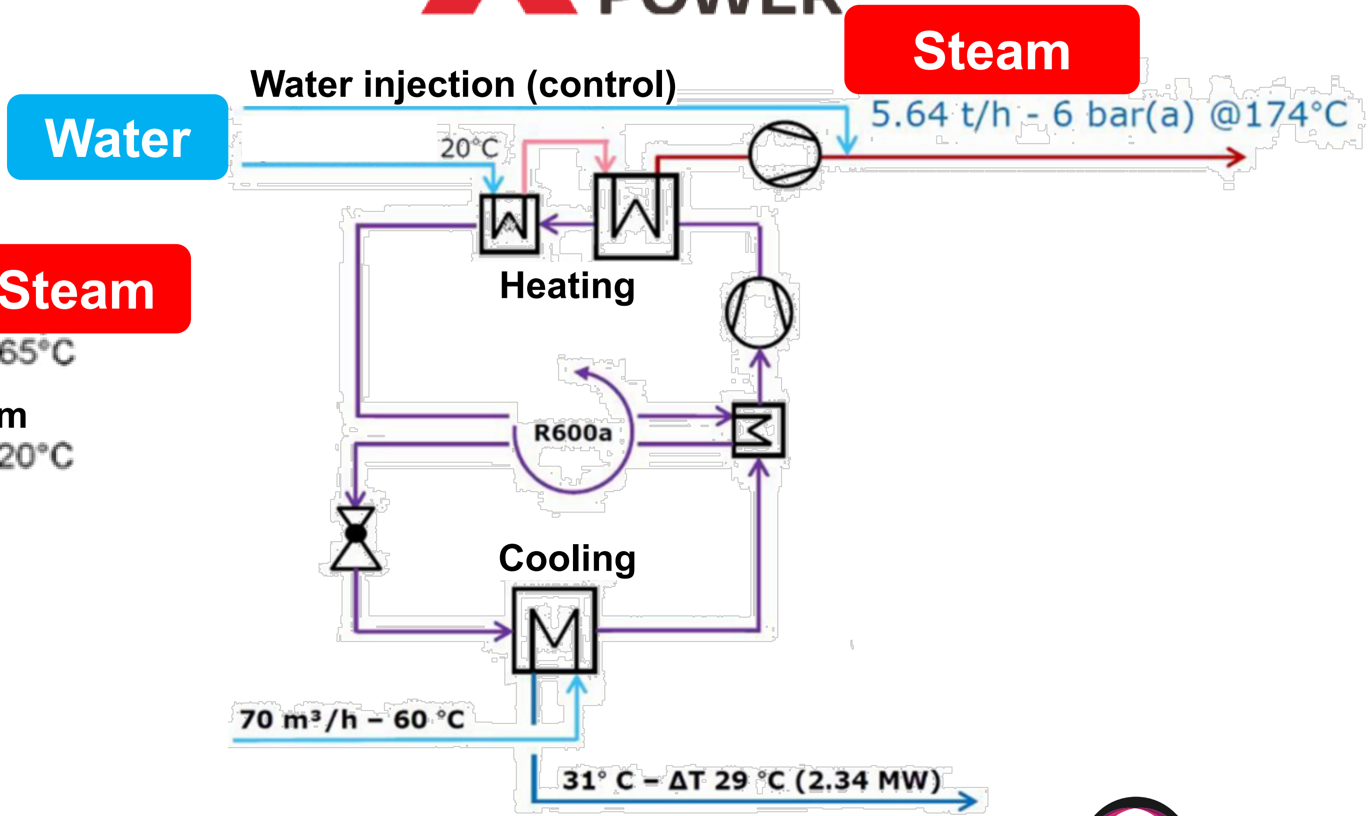
MITSUBISHI POWER

KOBELCO



Kobe Steel
Kobelco SGH 120/165





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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 high-temperature heat pump cycles for steam generation, 13th IEA Heat Pump Conference, Jeju, Korea, April 26-29, 2021

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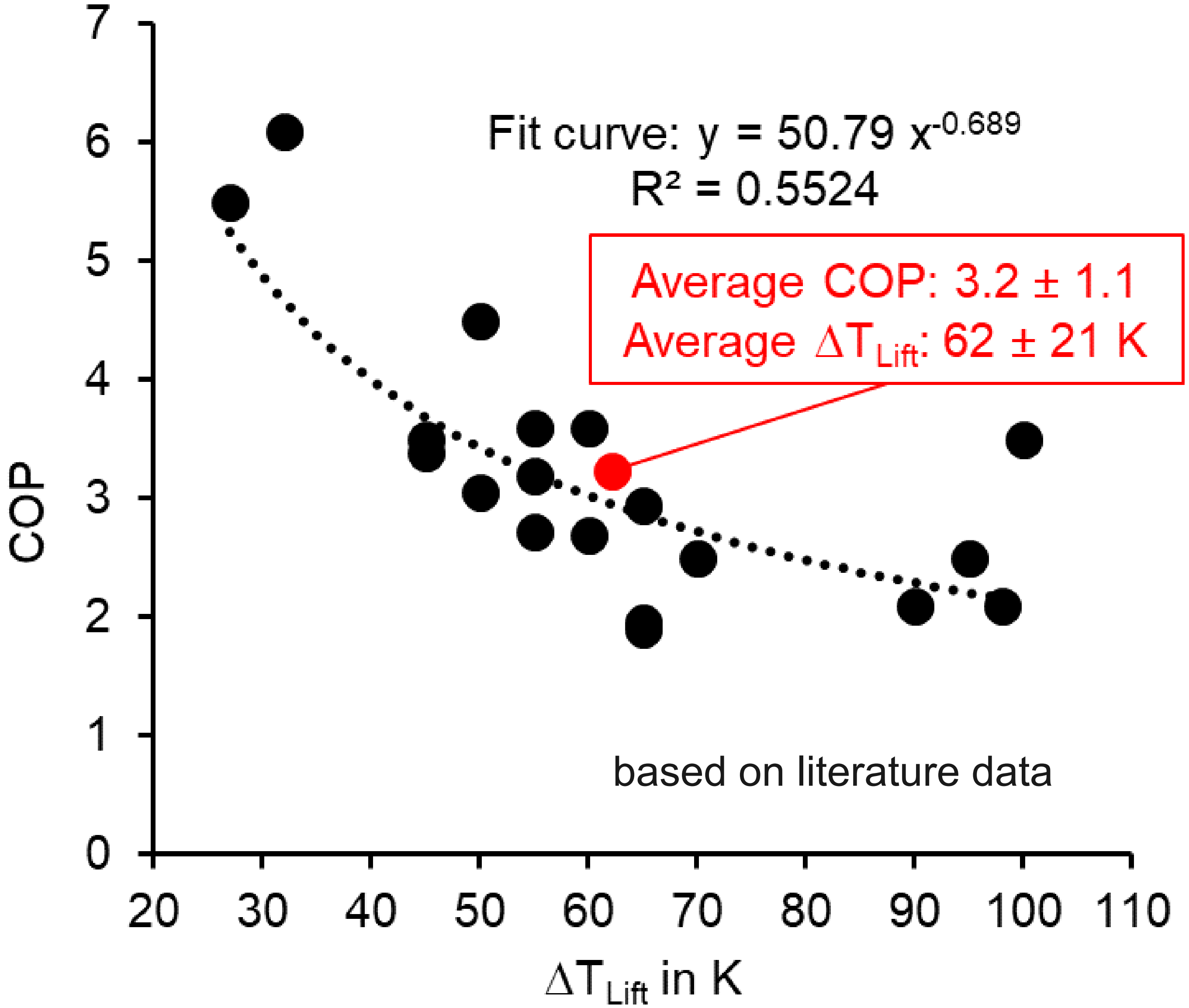
Efficiency of Steam Generating Heat Pumps

STEAM



- Average steam generation temperature: 131 ± 22 °C
- Average source temperature: 69 ± 25 °C

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

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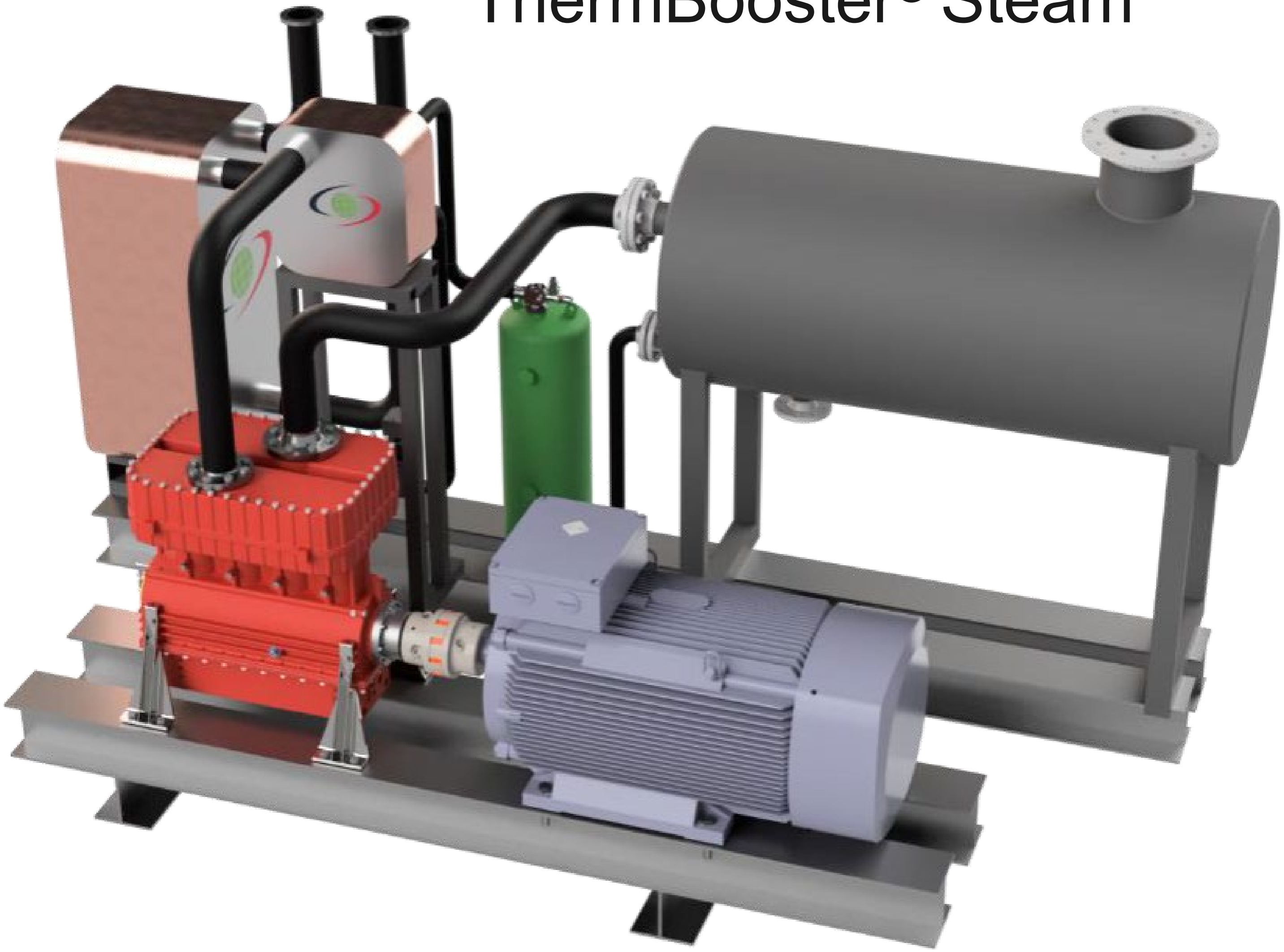
SPH Sustainable Process Heat GmbH

ThermBooster® Steam



SPH Sustainable Process Heat

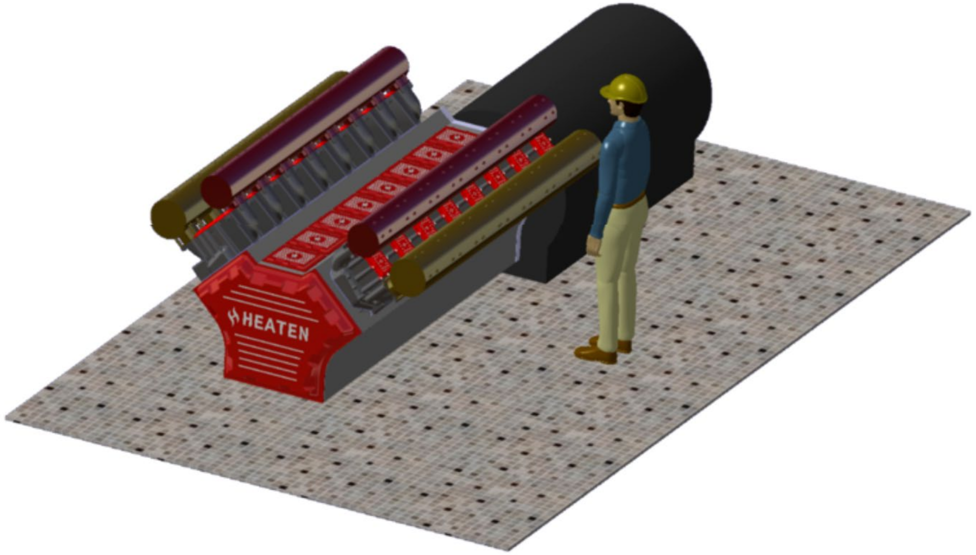
- Based on 1 Compressor (multi compressor arrangement possible)
- Output: 400 – 1000 kW
- Water/Steam or Steam/Steam Type
- Max. Steam Pressure: 6 bar(a), 160°C
- Refrigerants: R1233zd(E), R1336mzz(E), R1336mzz(Z)
- Future: Hydrocarbons like Pentane, Hexane, Ethanol, etc. for temperatures around 200°C

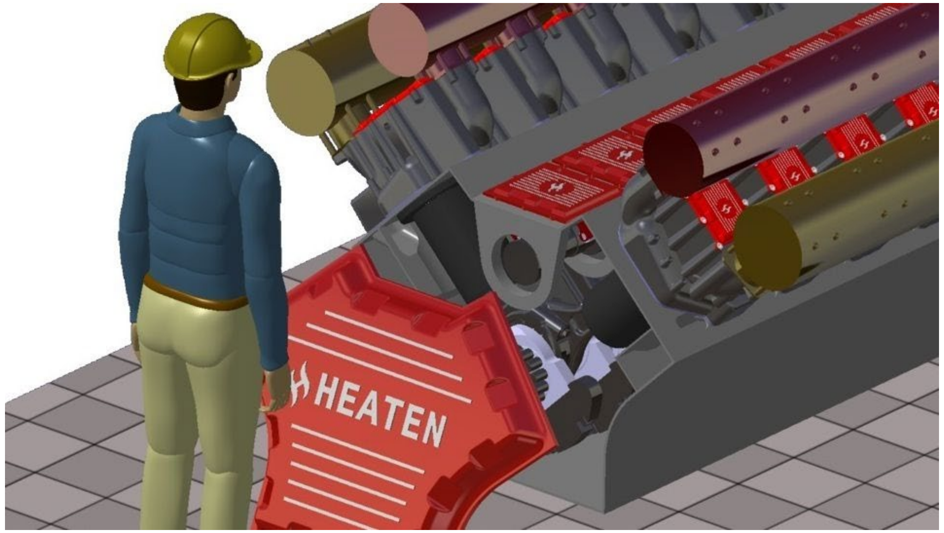
Source: Hamacher (2021): Presentation at the 2nd HTHP IEA HPT Annex 58 Status Meeting, July 8, 2021

HEATEN AS (ex-Viking Heat Engines AS)

HEATEN

- Heaten AS has bought the bankruptcy estate of Viking Heat Engines AS
- 1 MW HeatBooster (pilot end of 2022)
- 6 MW HeatBooster with piston compressors in V-shape
- Supply temperature up to 165 °C
- Direct low-pressure (LP) steam production





Source: https://www.heaten.com/technology

EU Horizon 2020 Projects where the HeatBooster Piston Compressor Technology is demonstrated

DryFiciency (www.dry-f.eu)

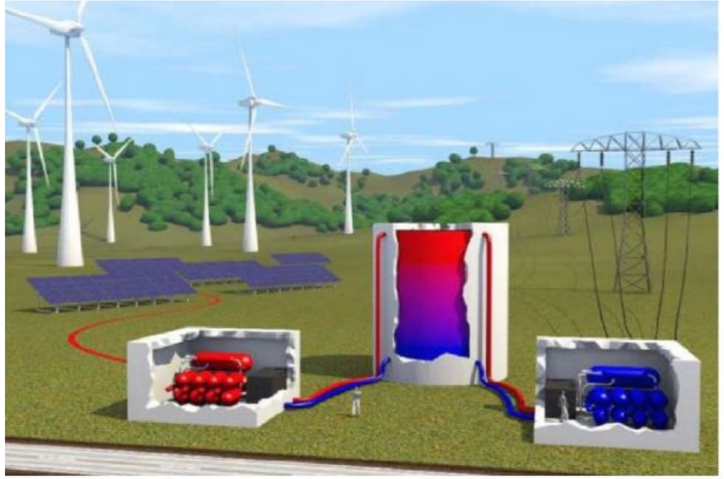
- Hot water generation of up to 160 °C for drying bricks at Wienerberger (AUT)

Bamboo (www.bambooproject.eu)

- Direct steam generation (150 °C) at Arcelor Mittal (steel mill in Spain)

Chester (www.chester-project.eu)

- Storage of surplus renewable electricity in high temperature storage facilities
- Heat pump with R1233zd as working fluid for temperatures up to 150 °C



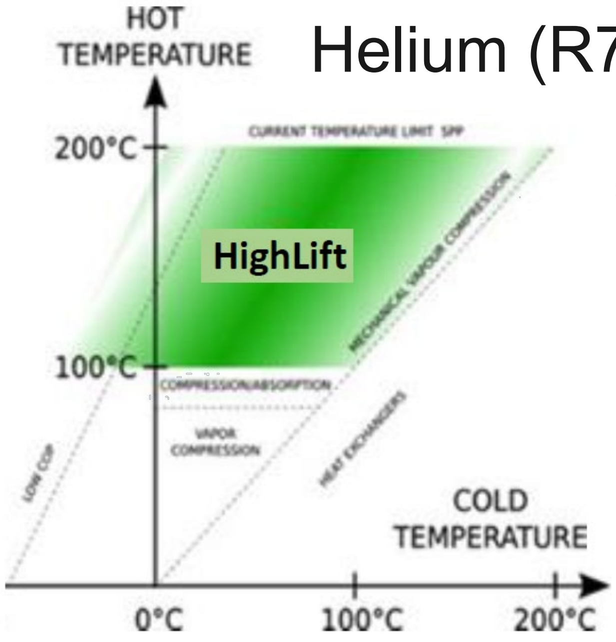
Source: Hamacher (2019): Höchsttemperaturwärmepumpe HeatBooster im industriellen Einsatz, DKV-Tagung 2019, Ulm

Olvondo (Norway)

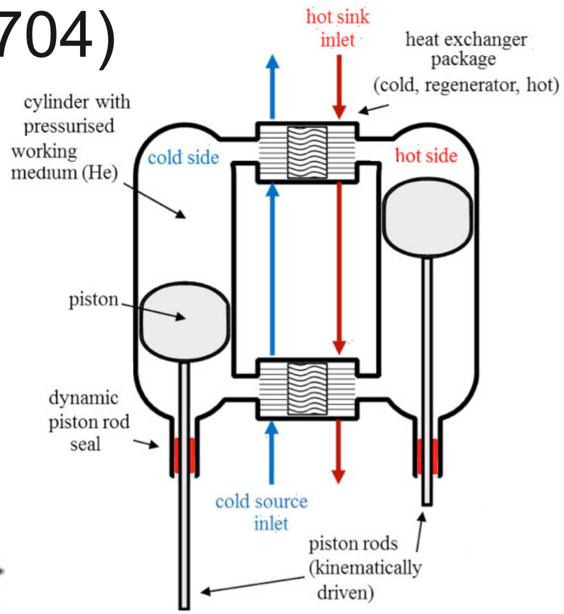
Typical performance		
Typical output (hot)	500	kW
Typical output (cold)	250	kW
Typical power consumption	250	kW
COP_h, typical range	1.5 - 3.0	
Output range	20-100%	

Operation range	
Maximum temperature (hot side)	195 C
Minimum temperature (cold side)	-5 C
Maximum steam pressure	10 bar_g

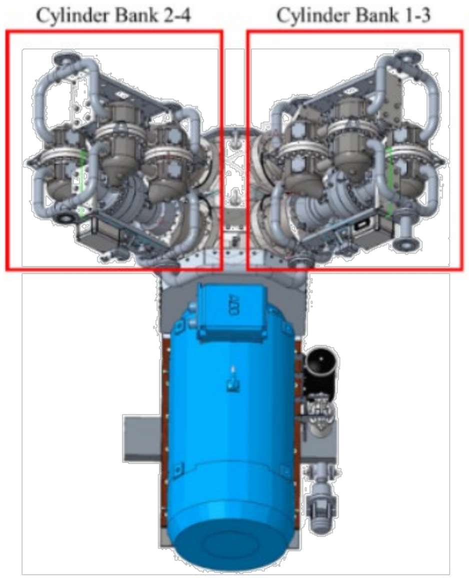
Startup times	cold start	preheated start
hot water production	<10 min	< 5 min
steam production	30-60 min	<10 min

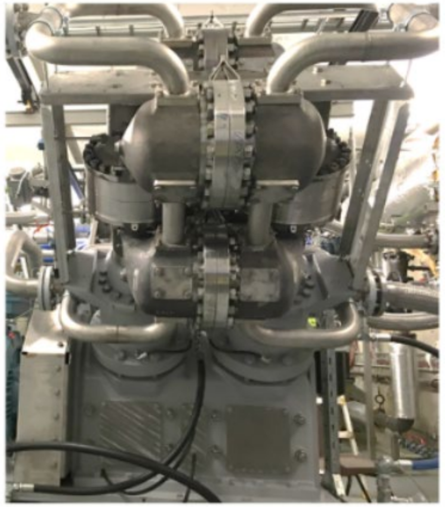


Helium (R704)



4-cylinder-double-acting Stirling engine





Source: https://www.olvondotech.no and Haikarainen et al. (2020): https://doi.org/10.1016/j.enconman.2020.113172

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Case Study for Steam Production at AstraZeneca R&D facility in Gothenburg, Sweden

Performance at design point:

- Steam: 175 to 184 °C
- Waste heat source: 25 to 35 °C (water)
- COP: 1.7
- Heat supply capacity: 1.5 MW
- 3x HighLift heat pumps installed each with a capacity of 500 kW
- Working fluid: Helium (R704)
- Installation year: 2017

Source: Zevenhoven et al. (2020): http://highlift.olvondotech.no/wp-content/uploads/ECOS2020-paper129-Proceedings-p1042-1053.pdf

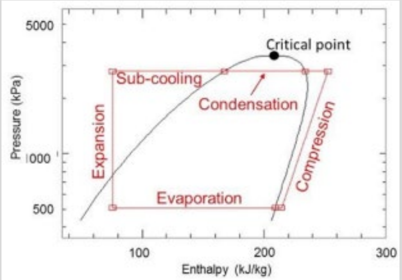
IEA HPT TCP Annex 58 – HTHPs

- **Objective: Providing an overview of High Temperature Heat Pump Technologies with T_{Supply} > 100 °C**
- 20 Leaflets of HTHP supplier technologies are available (30 expected)
- 5 Leaflets of realized installations are available (8 expected)
- Publication planned for 2022, Q1-2
- More details: https://heatpumpingtechnologies.org/annex58/

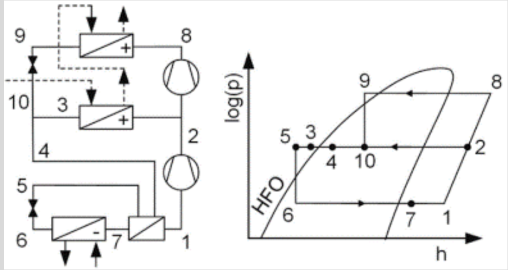
Source: Zühlsdorf (2021): High-Temperature Heat Pumps – Developments and Perspectives, European Heat Pump Summit 2021, Nuremberg, October 27, 2021, Contact Information: Benjamin Zühlsdorf, bez@dti.dk, +45 7220 12 58

HTHP Technologies for Large Temperature Glides

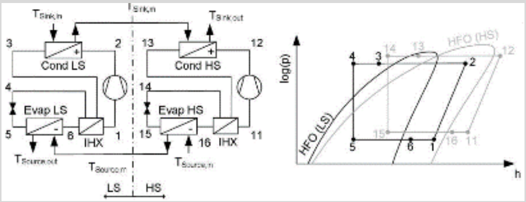
- **Subcritical Cycle with Subcooler**



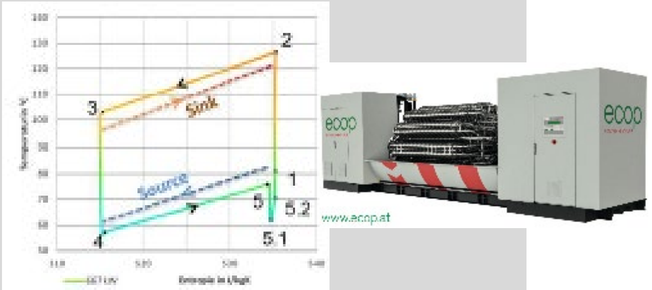
- **Two-stage Extraction Cycle**



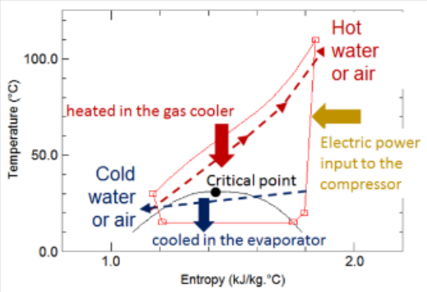
- **Two Parallel Subcritical Cycles**



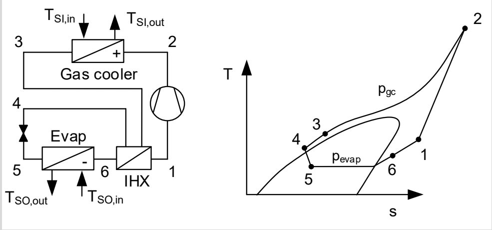
- **Reverse Brayton Cycle**



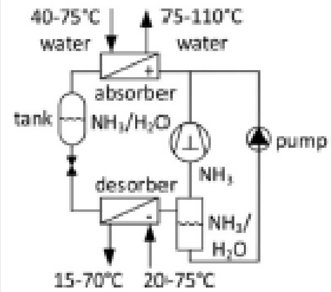
- **Transcritical CO_2 Cycle**



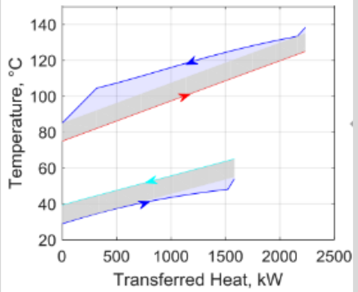
- **Transcritical Cycles with Hydrocarbons or HFOs**



- **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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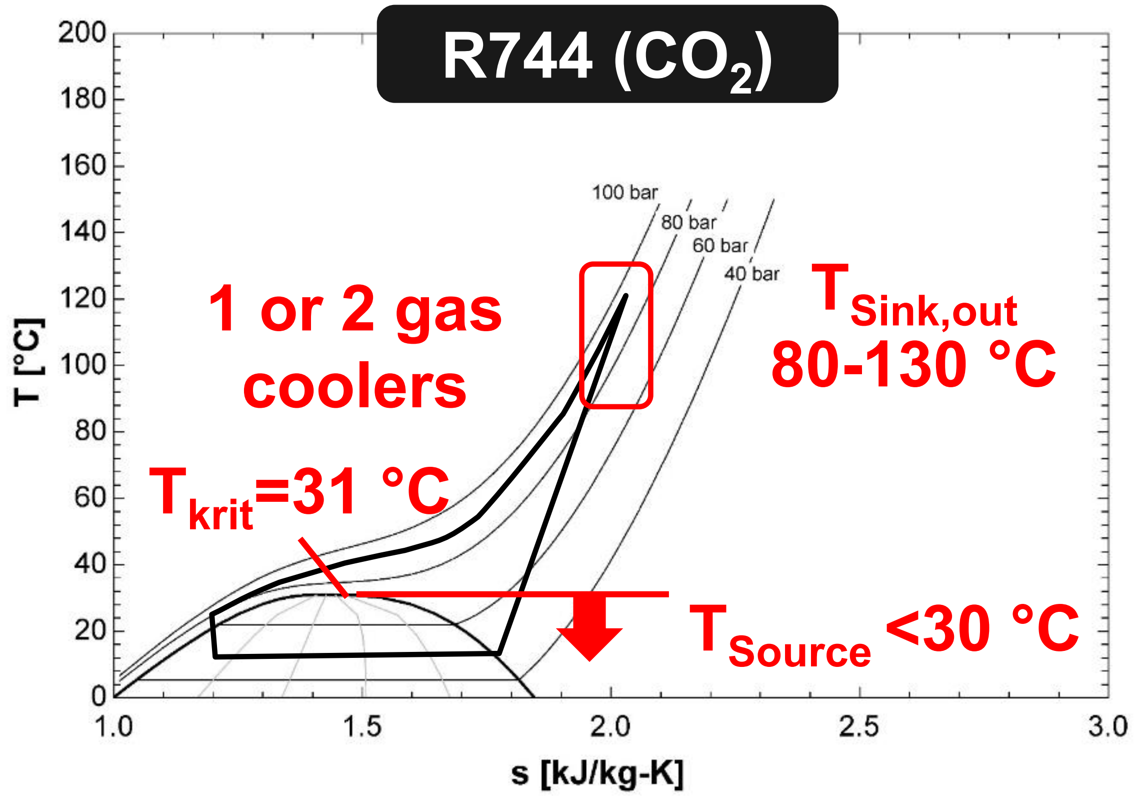
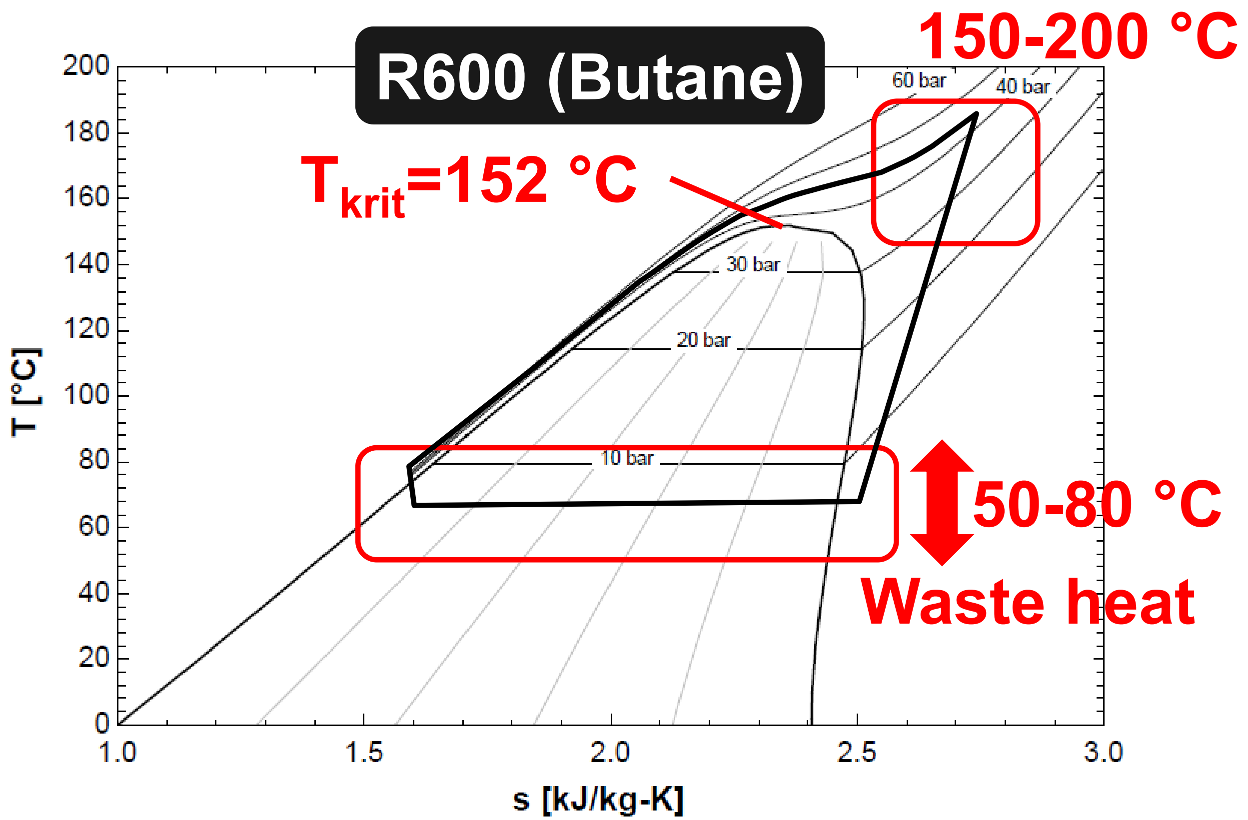
Transcritical CO_2 vs. Butane cycles





Suitable for simultaneous cooling (<30 °C) and heating (e.g. water or air from 20 to 90 °C)

Suitable for heat sources like waste heat (e.g. flue gas 50 to 80 °C) and producing hot air of 150 to 200 °C

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

Summary – Industrial Heat Pumps

HOT WATER
HOT AIR
STEAM

- **Market attractiveness of Industrial HPs depends on price ratio**
- **Various application case studies and demonstration projects**
- **Numerous HP products and technologies from various manufacturers are available on the market** (>100 °C, >100 kW to MW capacity)
- **Steam Generating Heat Pumps (Average COP of 3.2 at 62 K ΔT_{Lift})**
- **Specific HP Technologies and Cycles** for large temperature glides up to 200 °C, steam generation, and large-scale heat pumps (>1 MW)
- **Heat pump integration** varies from case to case
- **High research activity worldwide** (DE, AT, CH, FR, NO, NL, JP, KR, and CN)
- Refrigerants trend towards **natural** R600 (butane), R601 (pentane), R744 (CO_2), R718 (H_2O) and **synthetic HFOs / HCFOs with low GWP**, like R1336mzz(Z), R1233zd(E), R1224yd(Z)

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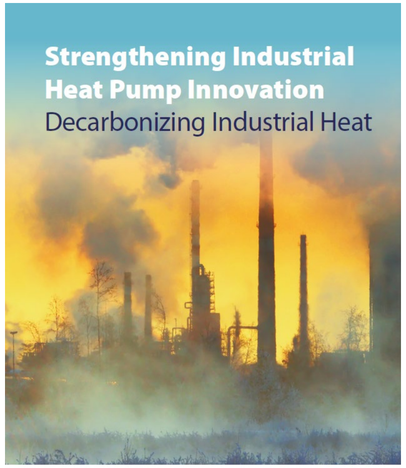
Literature References



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Confédération suisse
Confederazione Svizzera
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Thank you for your attention!

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