Industrial Heat Pumps – Research and Market

DeCarbCH Lunch Talk

November 9, 2021

Dr. Cordin Arpagaus, Prof. Stefan Bertsch, Dr. Frédéric Bless, OST, Institute for Energy Systems IES

Agenda

- **Market Overview**
- **Technologies**
- **Research Update**
- **Application examples**

CORE MESSAGES

Industrial Partners:

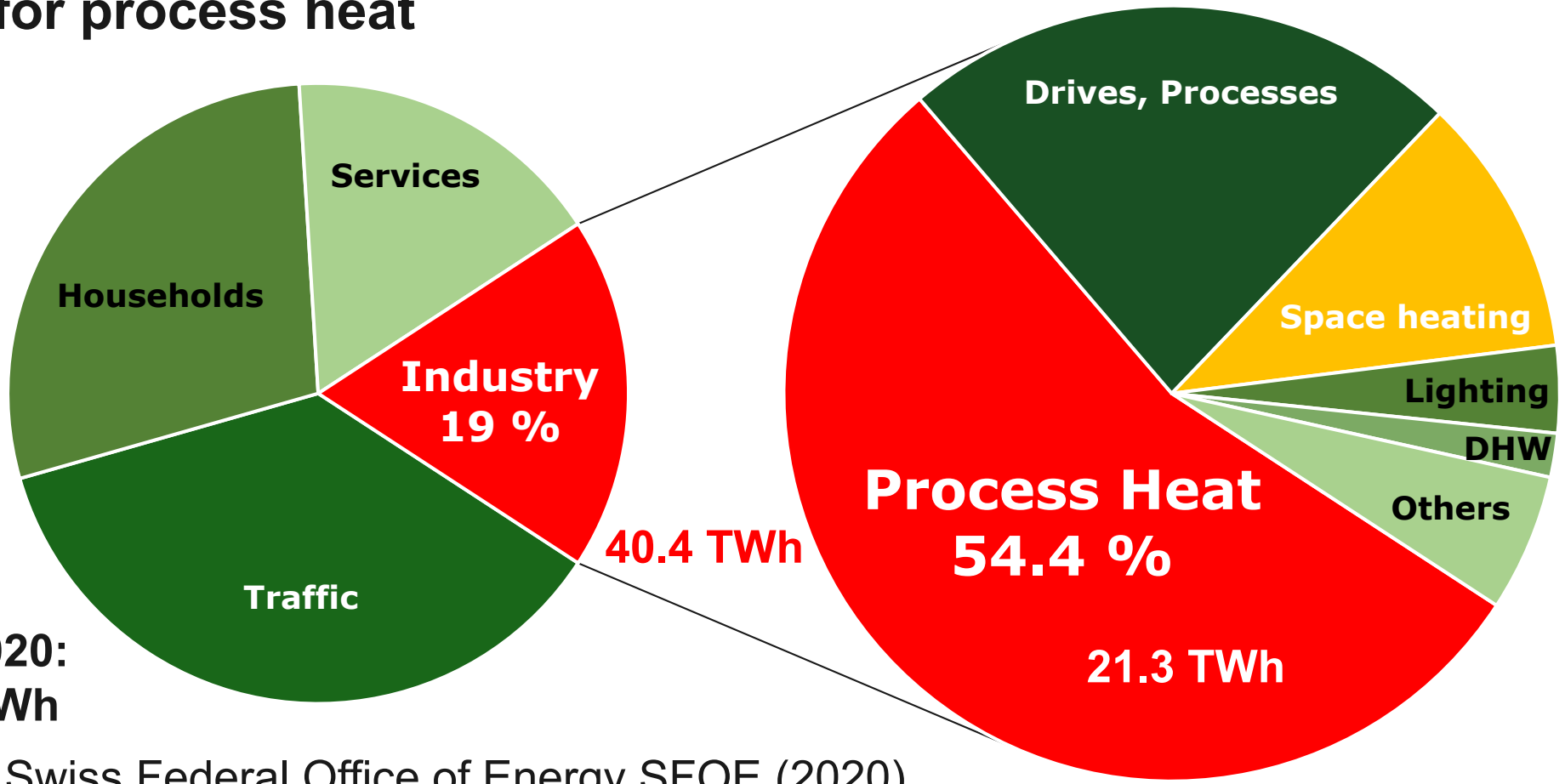
- What technologies are available?
- What to consider when selecting Industrial Heat Pumps?

Researchers:

- Where is OST working on this topic?
- How to implement the technologies?

Energy use in Swiss industry

Approximately **19%** of Switzerland's total energy use is for industry, of it **54.4% for process heat**



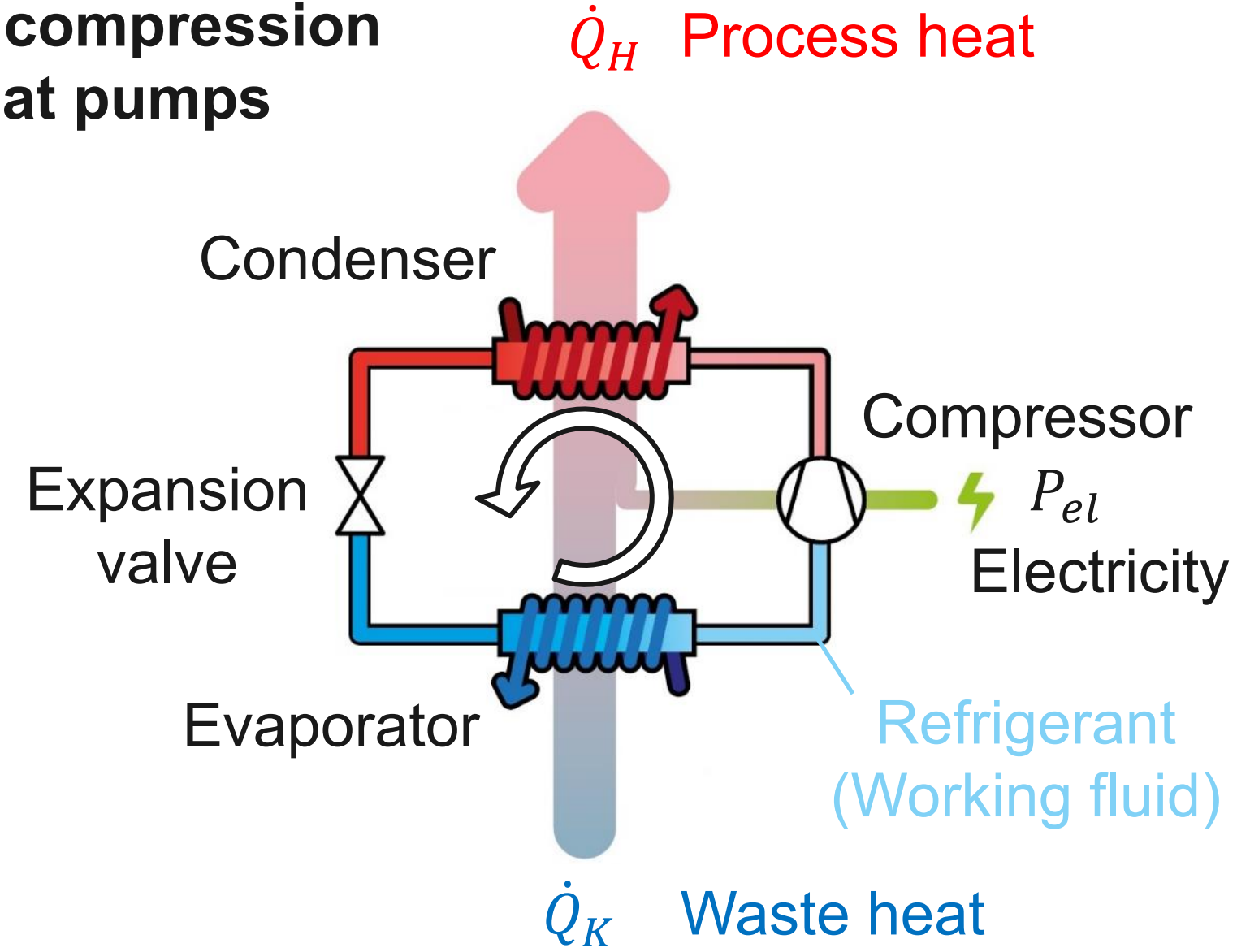
Total 2020:
207.6 TWh

Source: Swiss Federal Office of Energy SFOE (2020)

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.

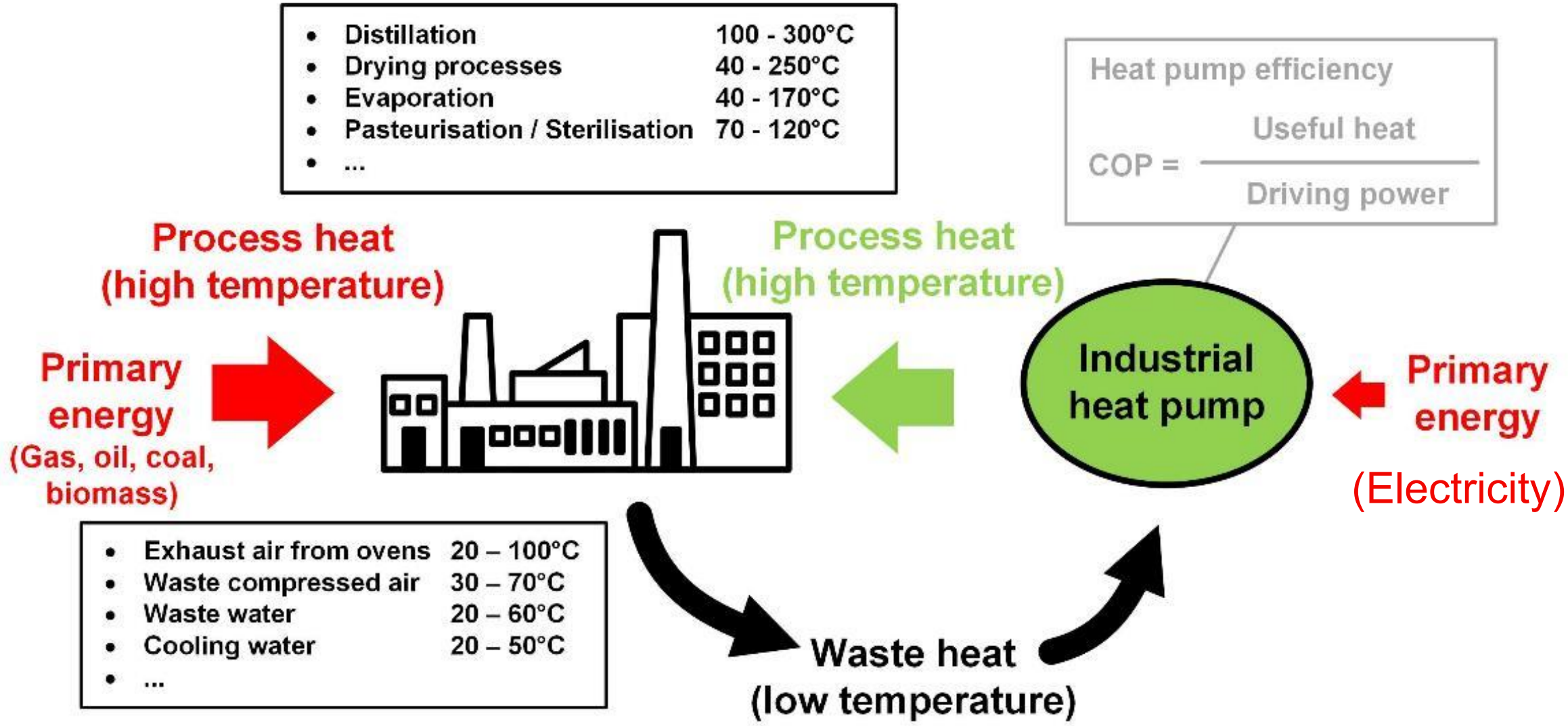
Focus is on vapor compression heat pumps



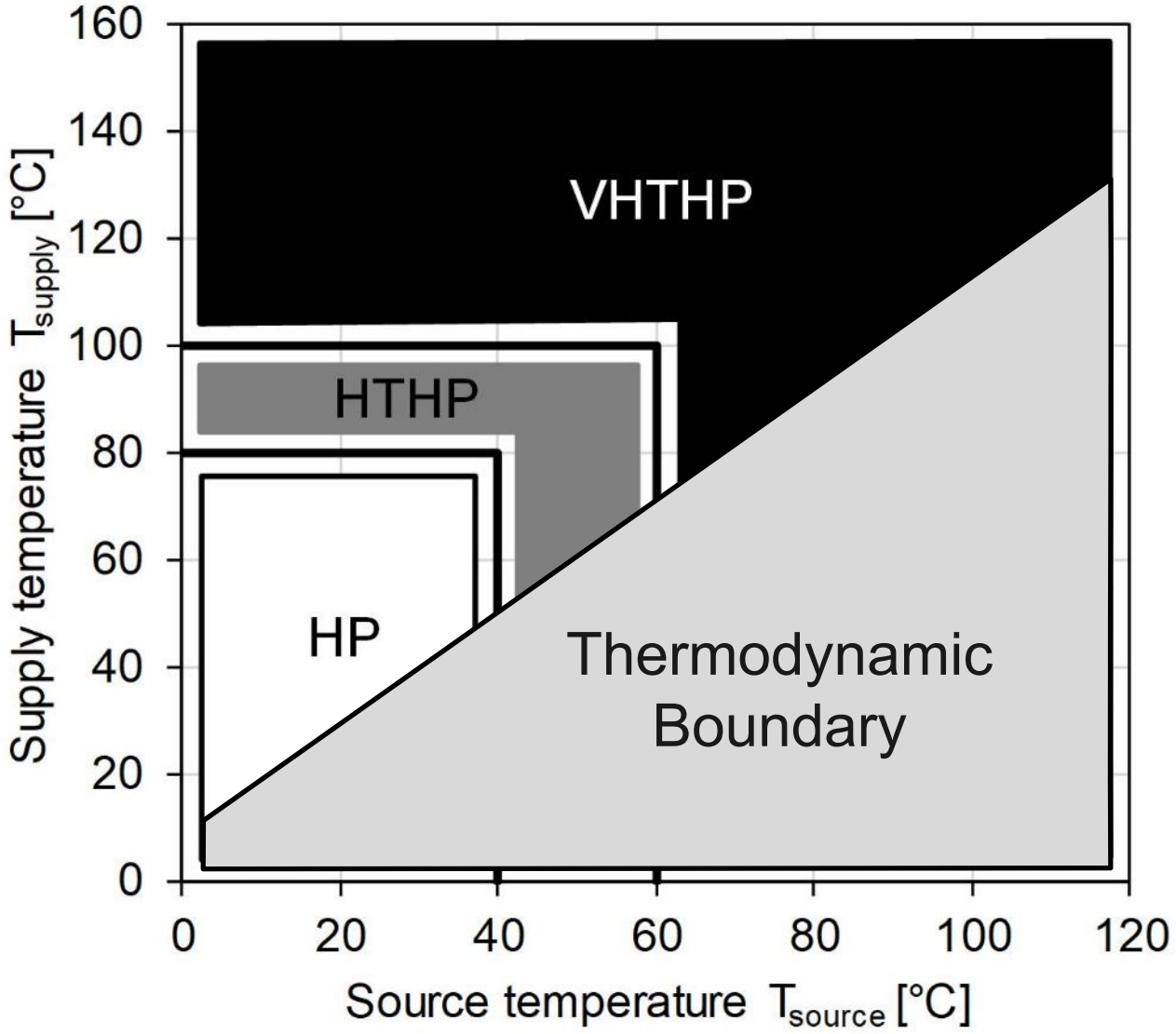
COP (Coefficient of Performance)

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

Industrial Heat Pumps for Waste Heat Recovery



Temperature Ranges and Heat Pump Classification



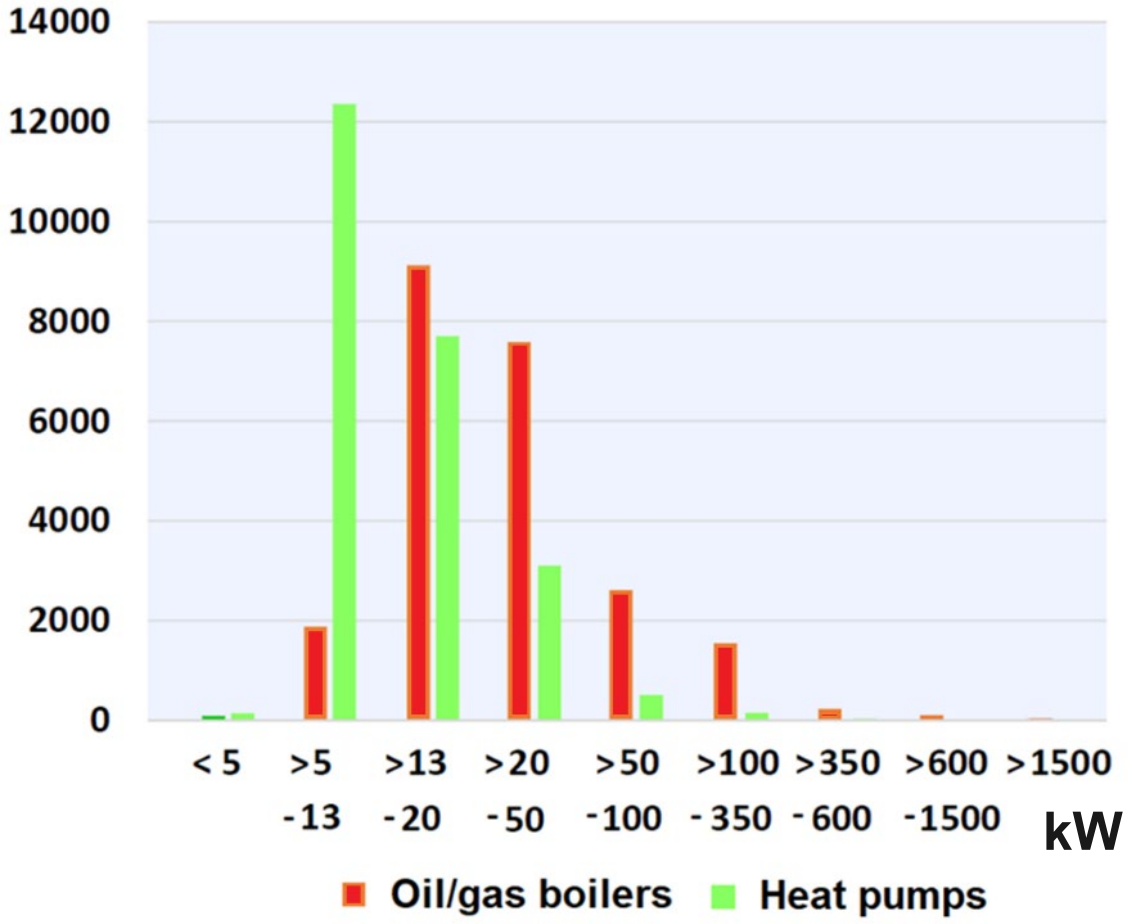
VHTHP: Very High Temperature Heat Pump

HTHP: High Temperature Heat Pump

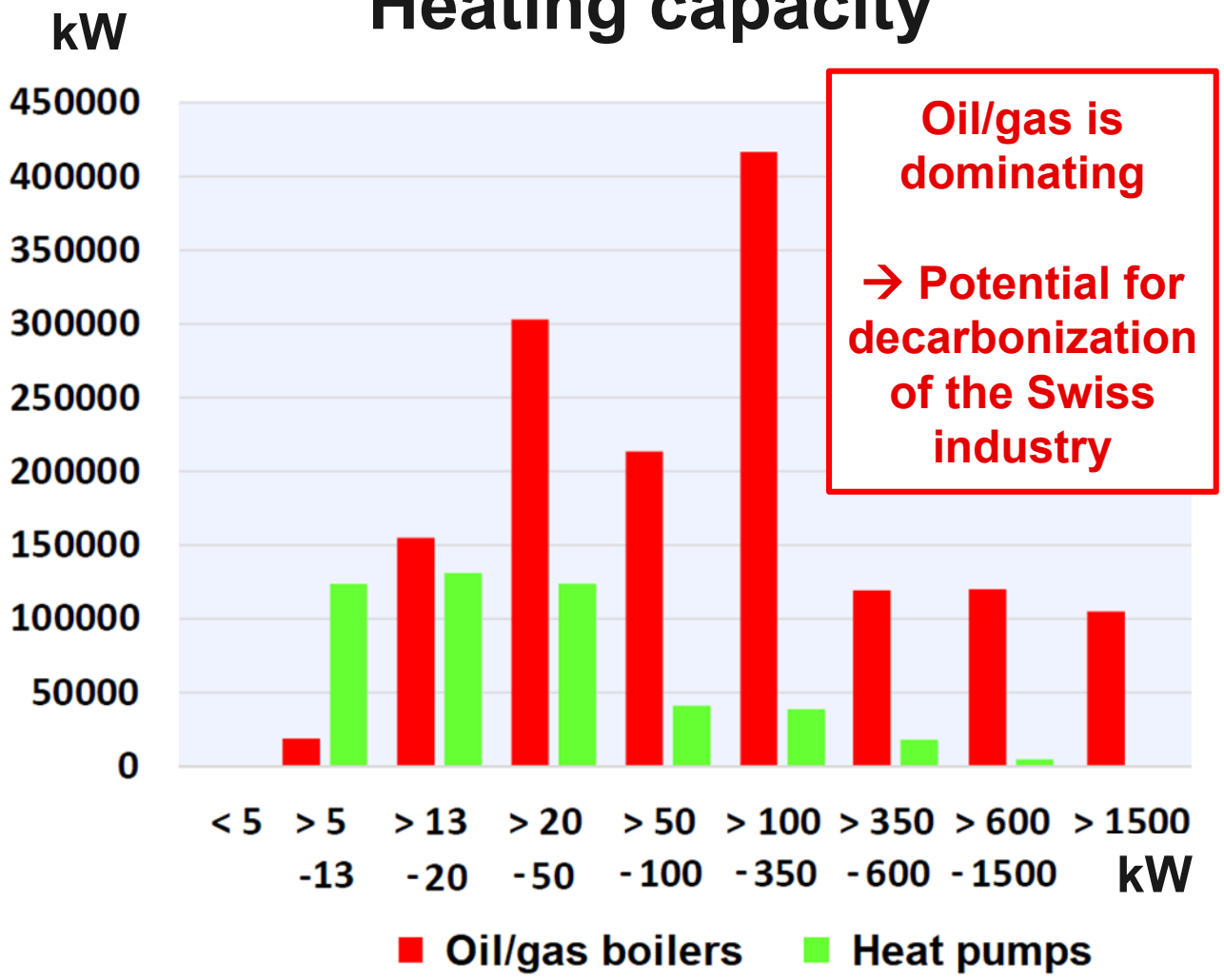
HP: Conventional Industrial Heat Pump

Comparison of Heat Pumps and Oil/Gas Boilers

Units



Heating capacity

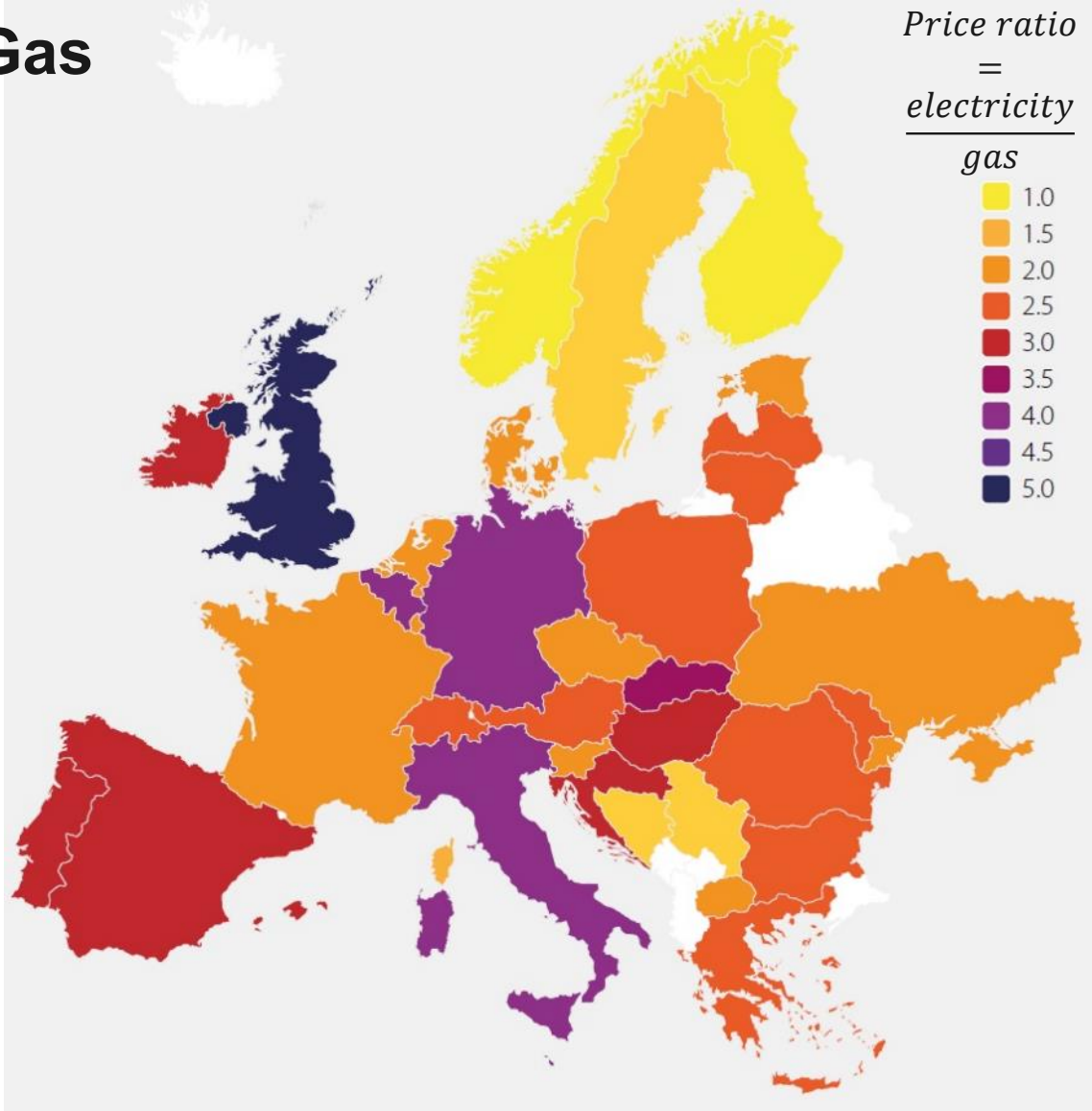


Oil/gas is dominating

→ Potential for decarbonization of the Swiss industry

Market Attractiveness depends on Price Ratio between Electricity and Gas

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



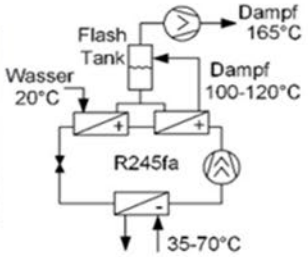
For small scale industrial end-users with
2-20 GWh/a electricity
3-28 GWh/a gas

Challenges to further spread Industrial Heat Pumps into the market

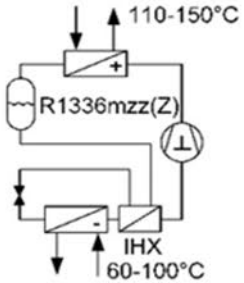
1. **Low level of awareness** of the technical possibilities and economically feasible application potential among users, consultants, investors, planners, manufacturers and installers
2. **Lack of knowledge** about the integration of heat pumps into existing industrial processes (retrofit)
3. **Factory-built 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)

Industrial Heat Pumps with cycles

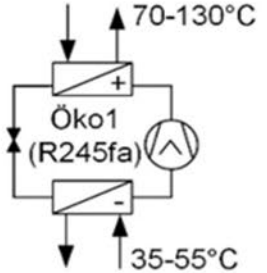
Kobe Steel
Kobelco SGH 120/165



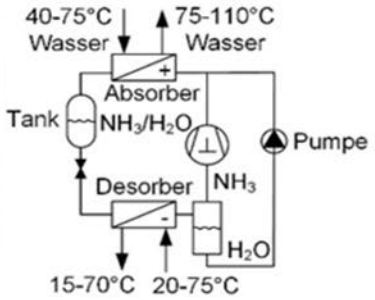
Viking Heat Engines
HeatBooster S4



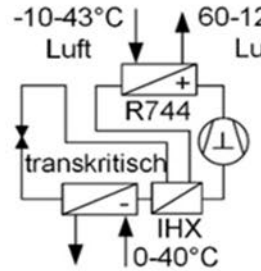
Ochsner
IWWDS ER3c4



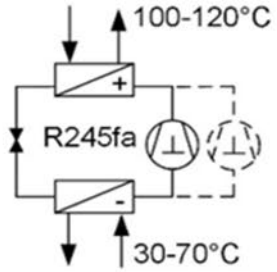
Hybrid Energy
Hybrid Heat Pump



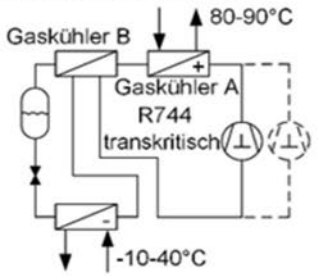
Mayekawa
Eco Sirocco



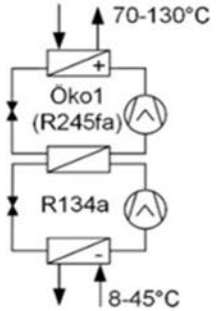
Combitherm
HWW R245fa



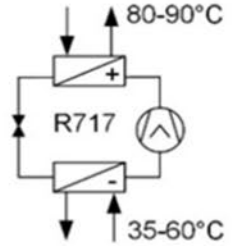
ENGIE (ex-Dürr Thermea), thermeco$_2$ HHR1000
mit 6 Hubkolbenverdichtern bis 1100 kW



Ochsner
IWWDSS R2R3b

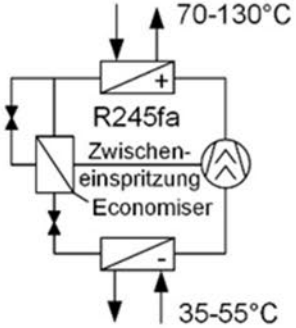


Star Refrigeration, Neatpump NP601,
Vilter VSSH Schraubenkompressor 76 bar

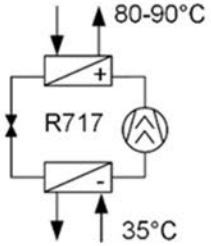


Industrial Heat Pumps with cycles

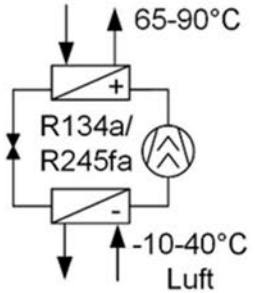
Ochsner IWWDS ER3b



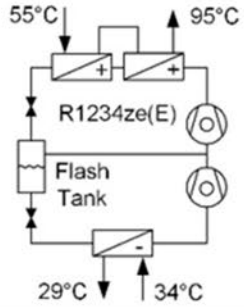
GEA Grasso FX P Heat Pump
Doppelschraubenkompressor bis 63 bar



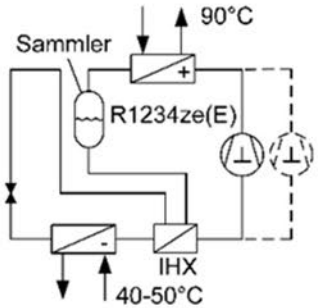
Kobe Steel
Kobelco HEM-HR90



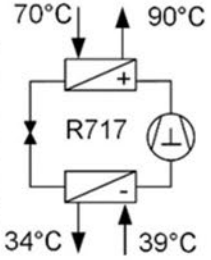
Friotherm
Unitop 22/22, 3'300 kW, zweistufiger Turbokompressor



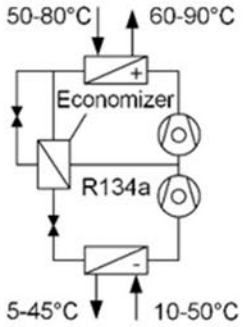
Viessmann
Vitocal 350-HT Pro



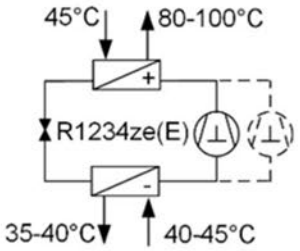
Johnson Controls, SABROE HeatPAC HPX
Hubkolbenkompressor bis 60 bar



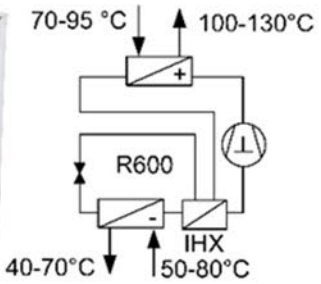
Mitsubishi ETW-L



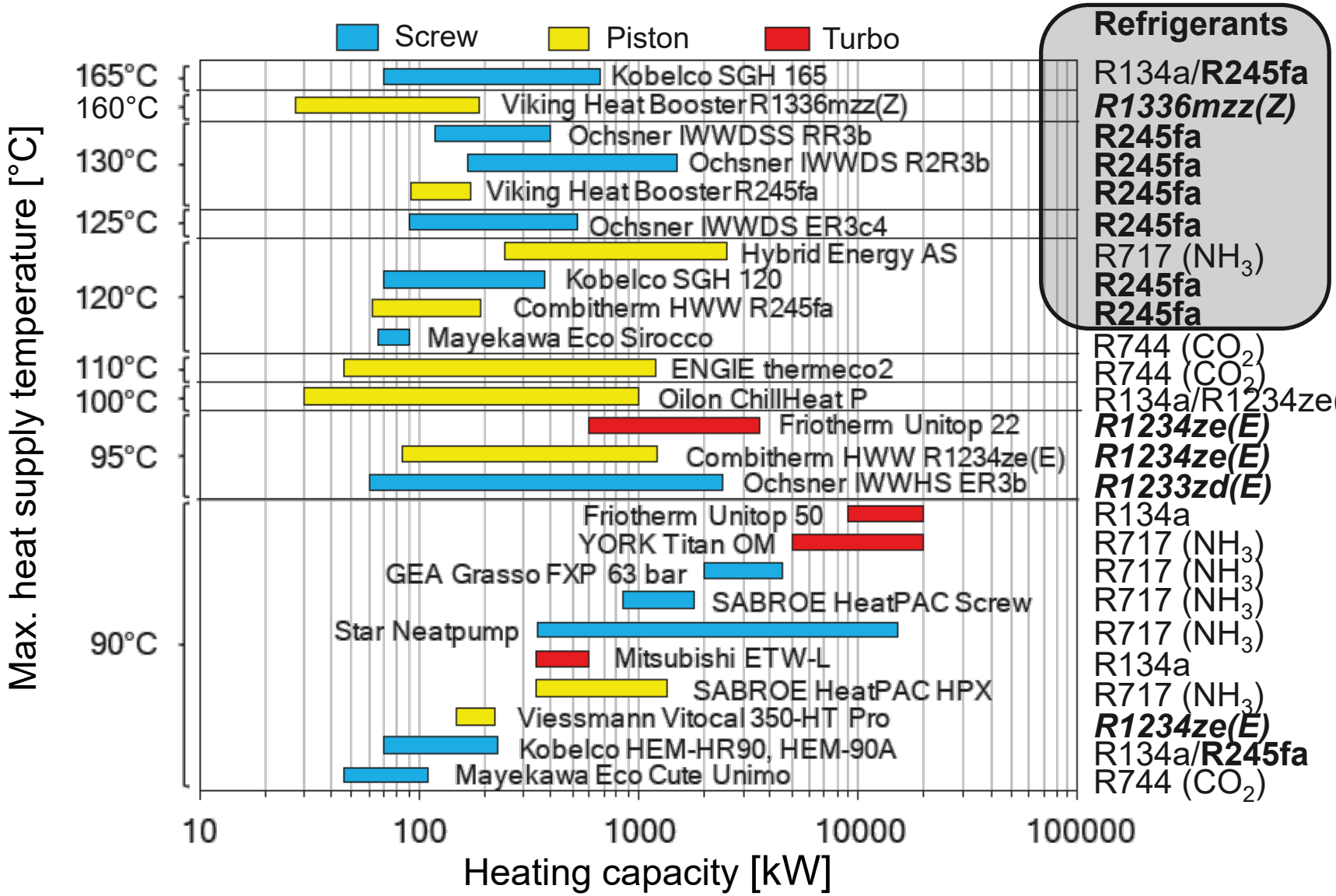
Oilon ChillHeat P300 SU HC+ R1234ze
mit 4 parallel geschalteten Kolbenverdichtern



Frigopol HighButane 2.0



Commercial Industrial HPs (suppliers/products)

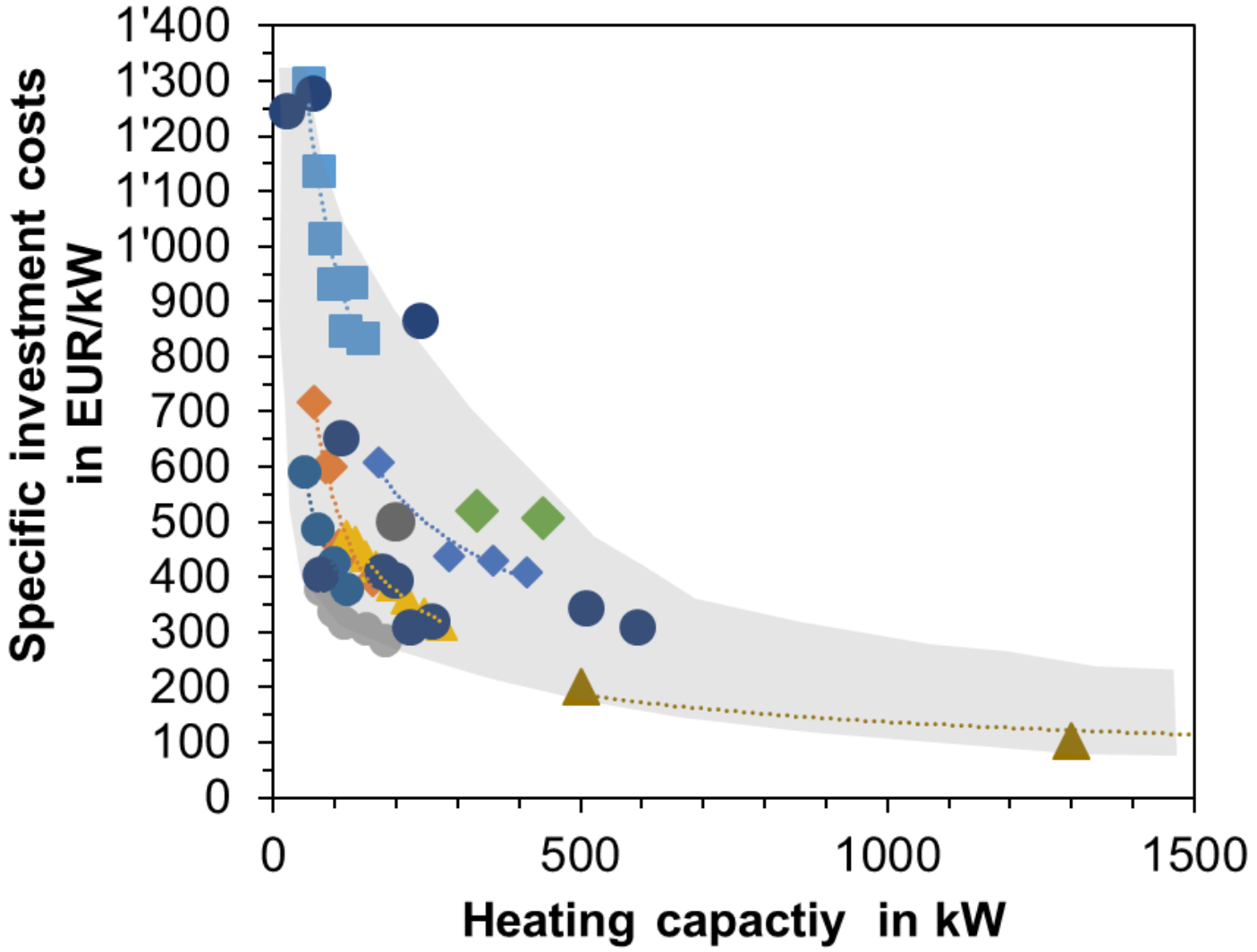


Kobelco SGH 120/165
(Steam Grow Heat Pump)

HeatBooster S4
(Viking Heat
Engines AS)

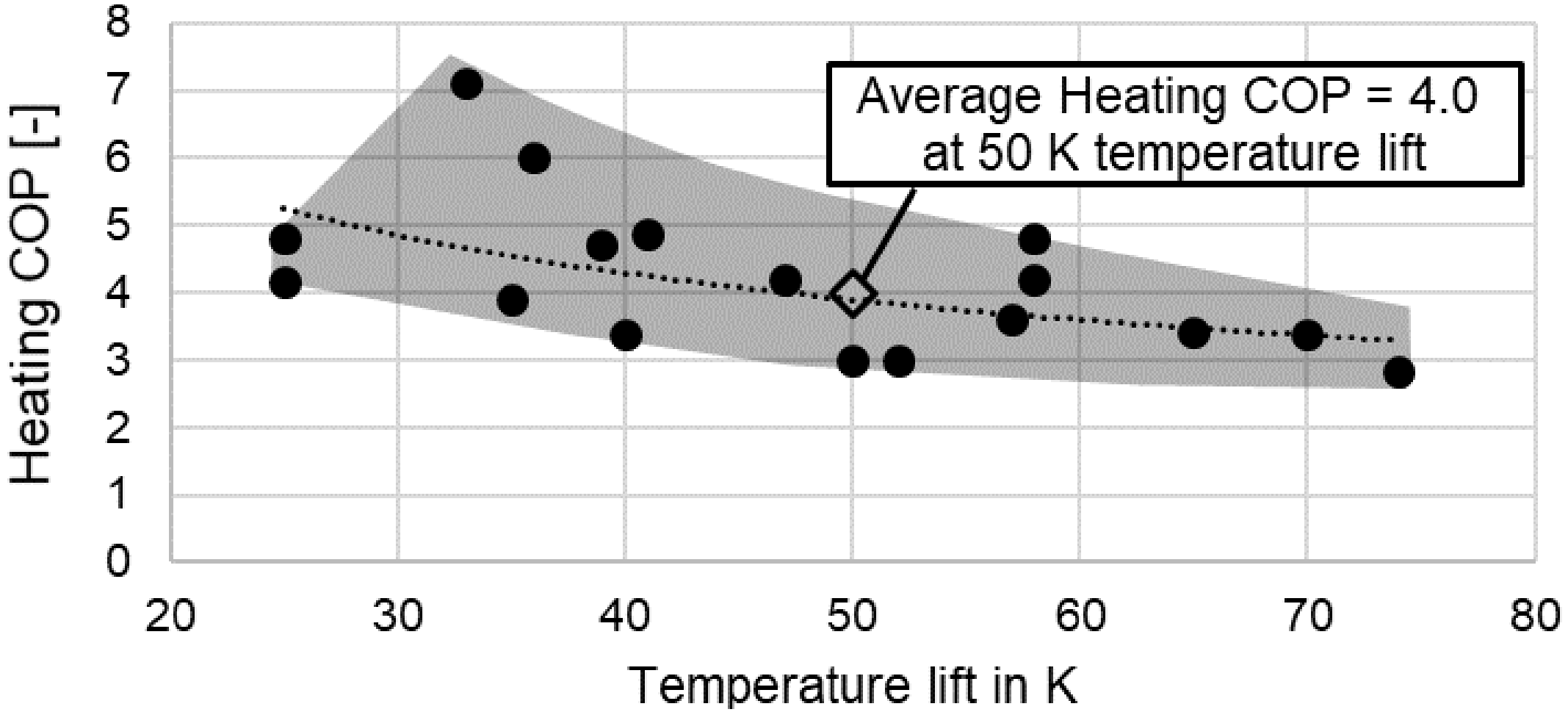
OCHSNER
ENERGIE TECHNIK

Specific investment costs per kW of heating



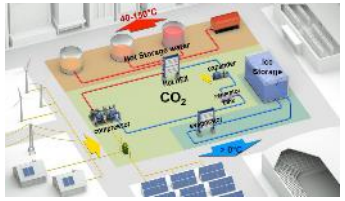
Data based on price information from European heat pump suppliers

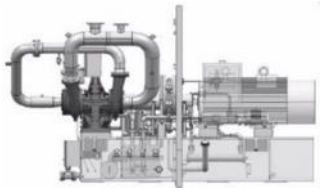
Efficiency in the field: Heating COP vs. temperature lift

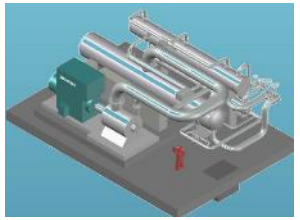


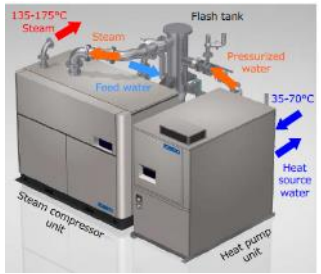
Examples of Large Scale HTHPs (>1 MW) for district heating and industrial applications

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







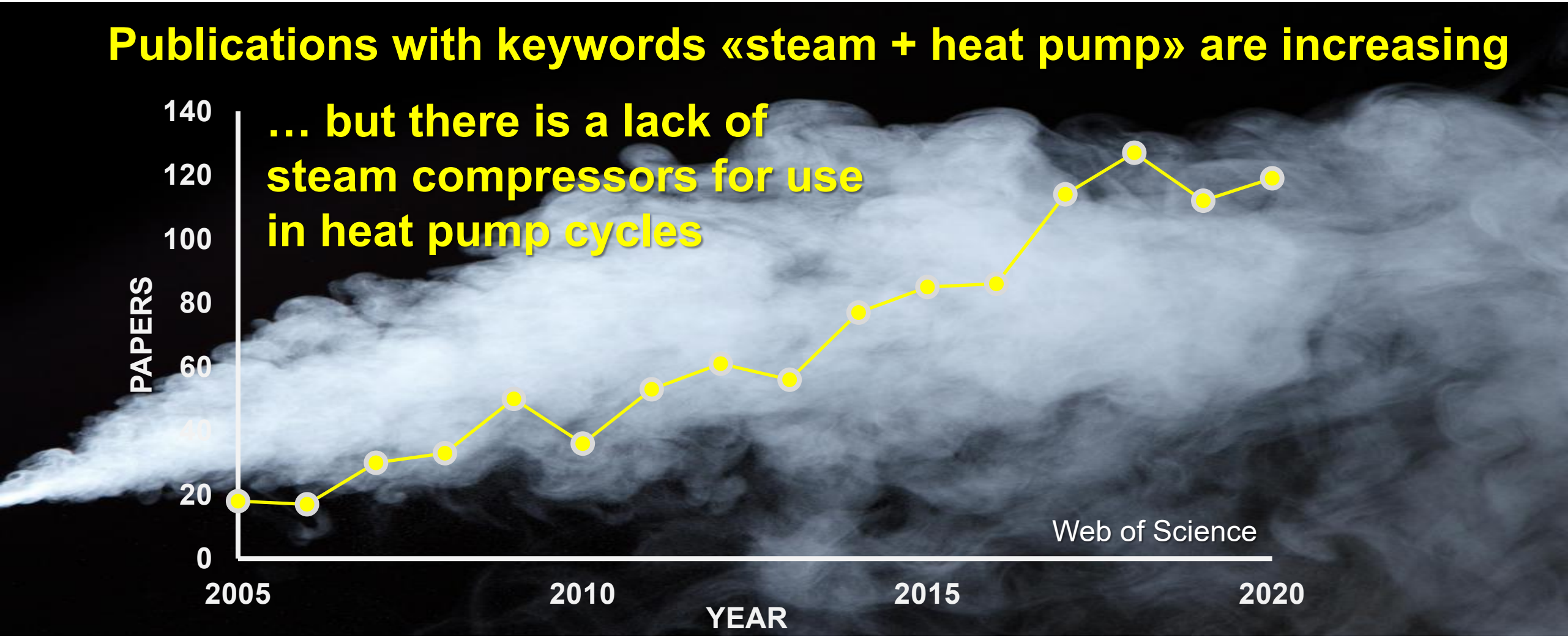


Steam Generating Heat Pumps

STEAM

sweet swiss energy research for the energy transition
DeCarbCH

Publications with keywords «steam + heat pump» are increasing



Steam Generating Heat Pumps

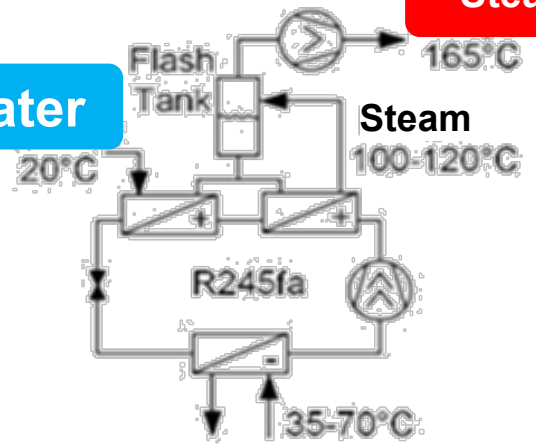
STEAM

sweet swiss energy research for the energy transition
DeCarbCH

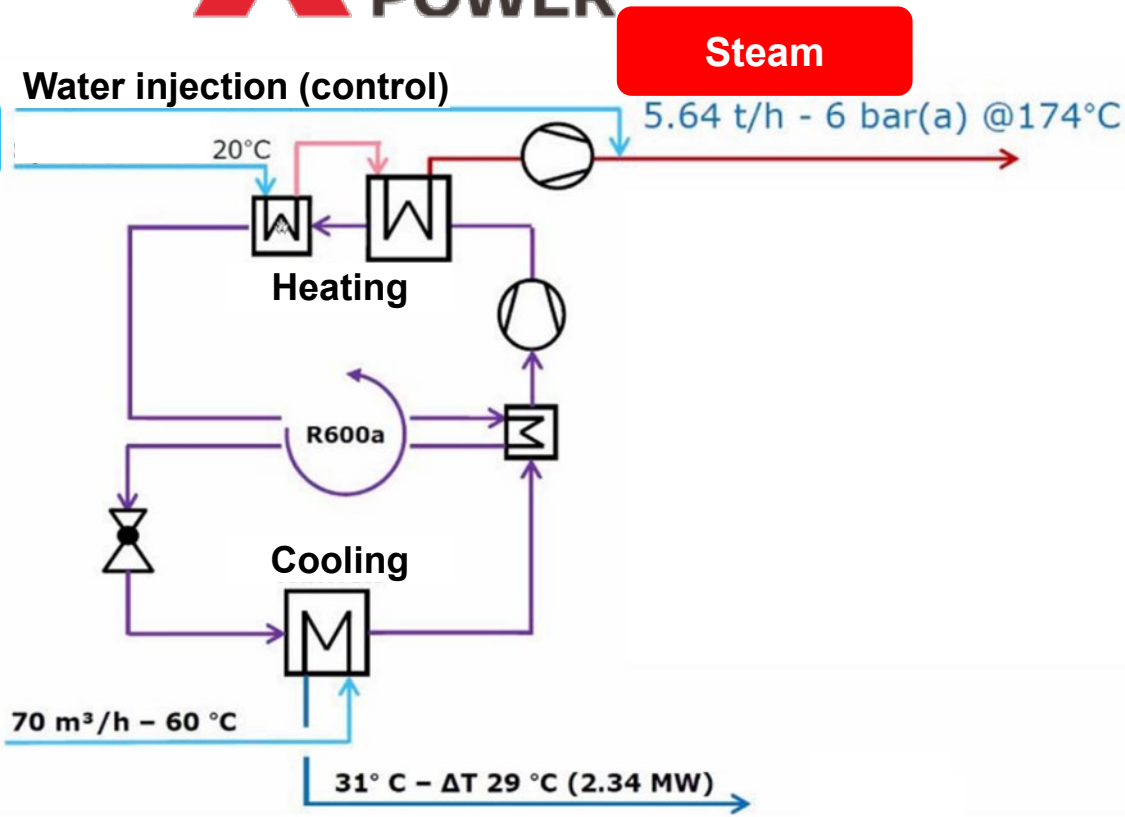
- Cycle with Condenser/Subcooler (R245fa) + Flash Tank + MVR
- Combined closed cycle (R600a) + open cycle (R718 water)

KOBELCO

Kobe Steel
Kobelco SGH 120/165



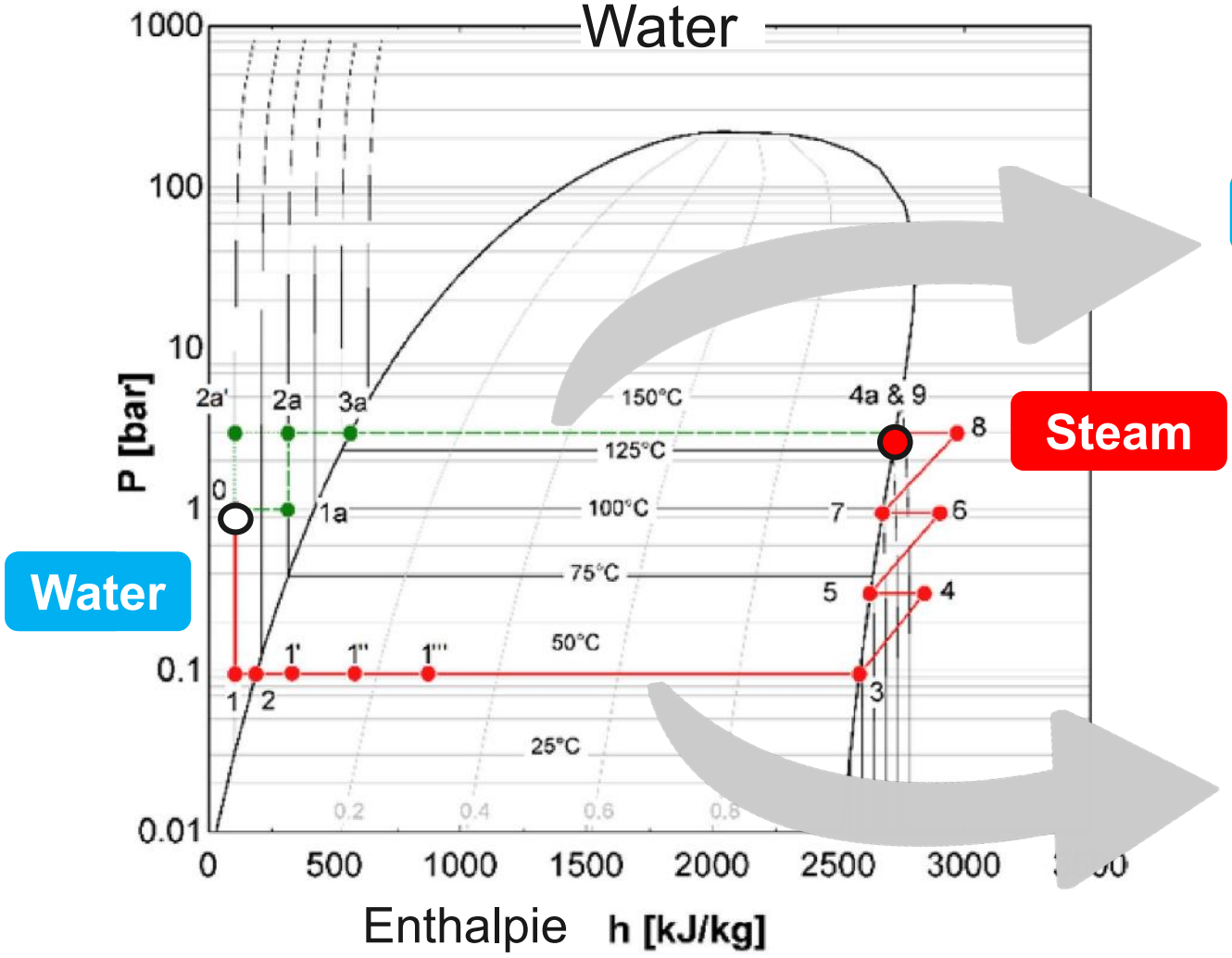
MITSUBISHI POWER

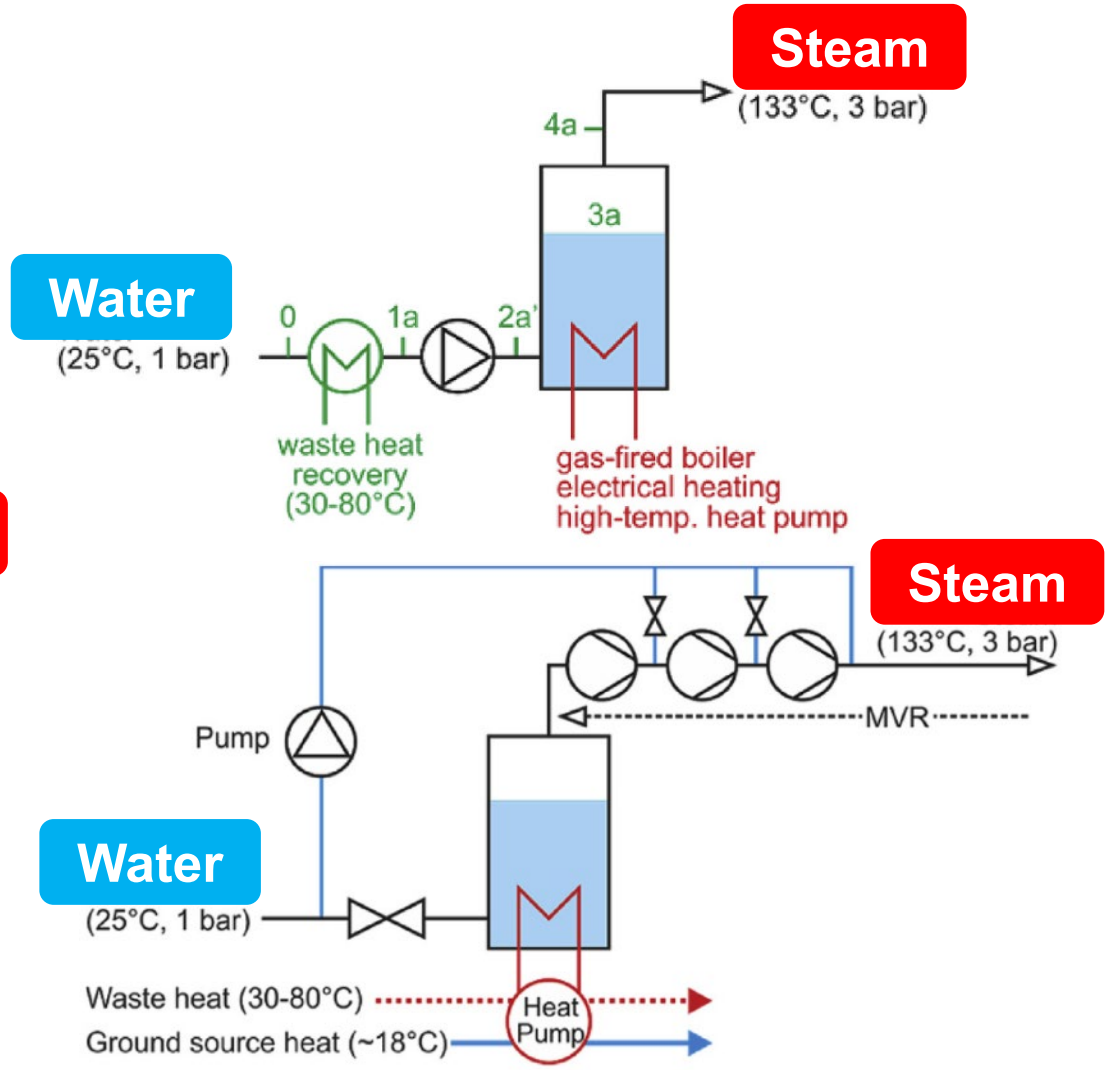


Open-cycle – highly efficient

STEAM

sweet swiss energy research for the energy transition
DeCarbCH





Energy Savings and CO_2 Emissions Reduction

sweet swiss energy research for the energy transition
DeCarbCH

Energy consumption, CO2 emission, and operating cost per kilo of steam

	Steam generation method	without waste heat kJ	without waste heat CO_2 [g]	without waste heat OC [¢]	with waste heat (55°C) kJ	with waste heat (55°C) CO_2 [g]	with waste heat (55°C) 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

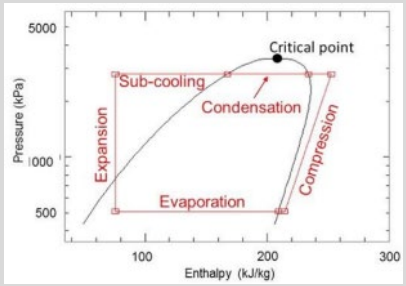
STEAM

CO_2 emissions factor **20** x

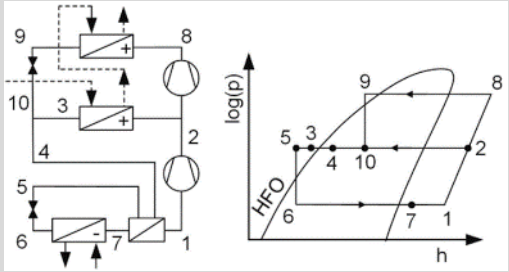
Energy consumption factor **4** x

HTHP Technologies for Large Temperature Glides

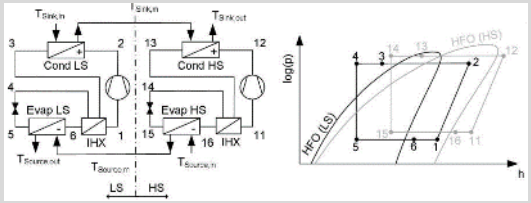
- **Subcritical Cycle with Subcooler**



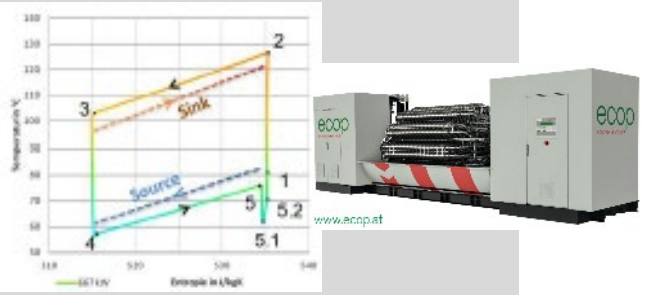
- **Two-stage Extraction Cycle**



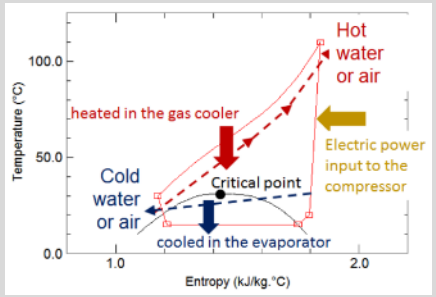
- **Two Parallel Subcritical Cycles**



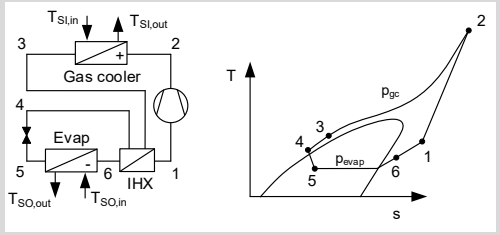
- **Reverse Brayton Cycle**



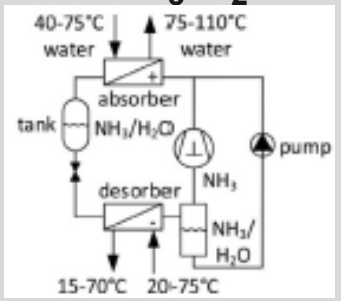
- **Transcritical CO_2 Cycle**



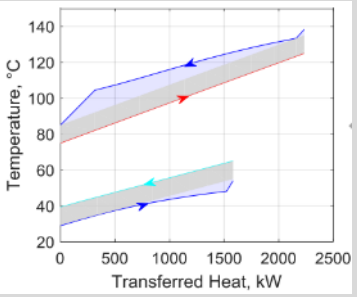
- **Transcritical Cycles with Hydrocarbons or HFOs**



- **Hybrid Heat Pump with NH_3/H_2O**



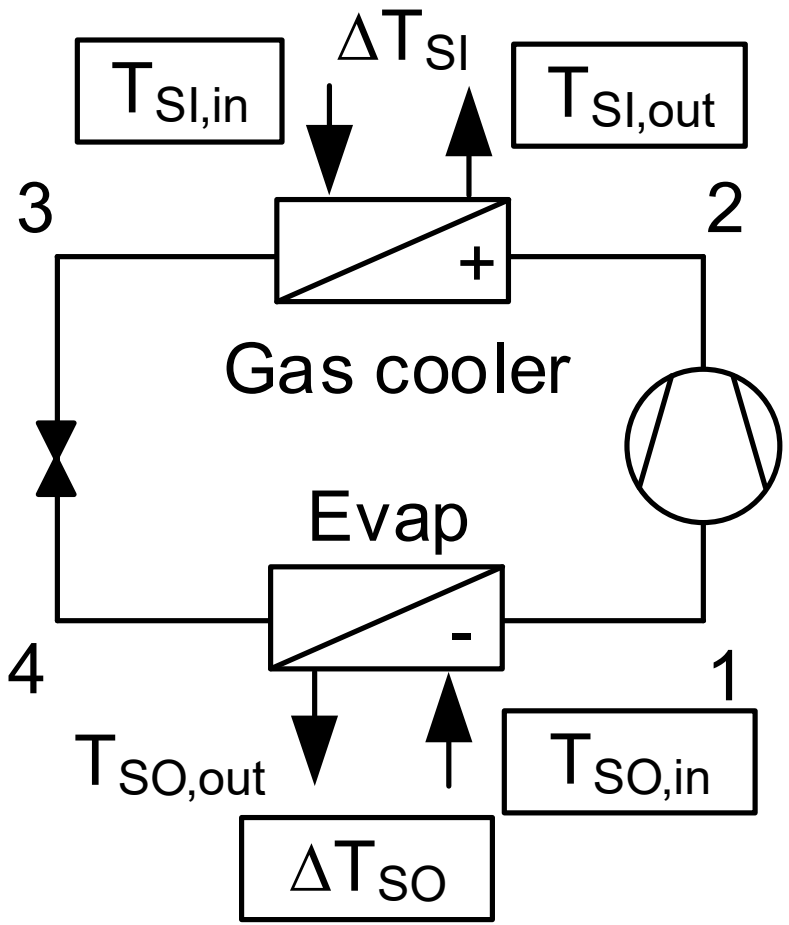
- **Refrigerant Mixtures**

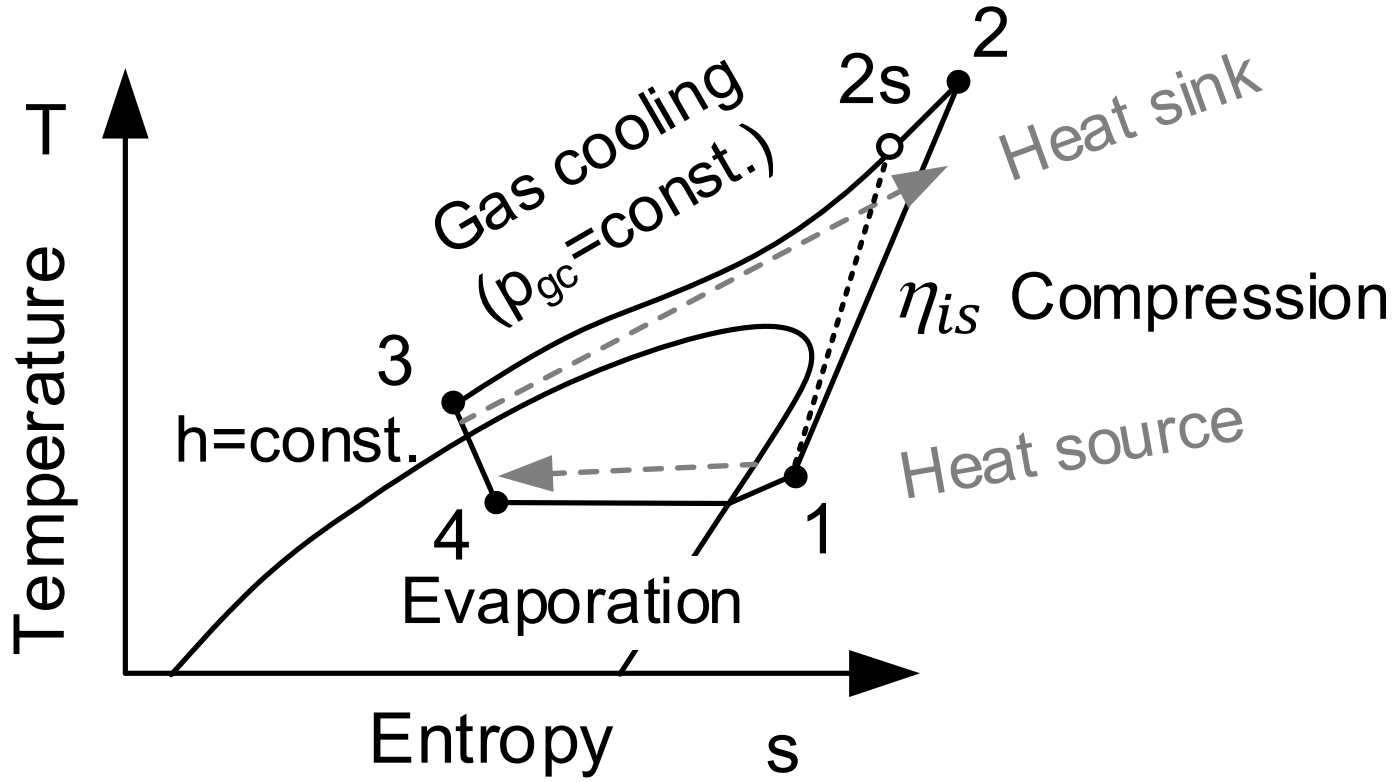


to produce

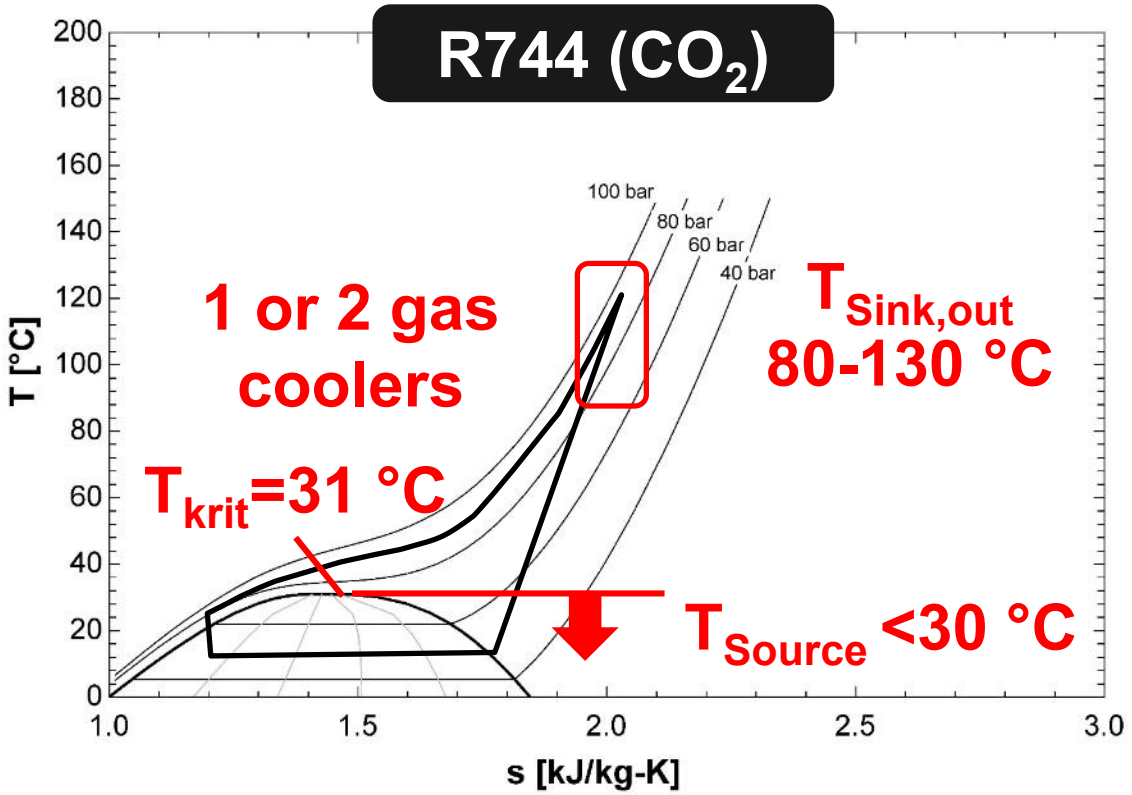
HOT WATER or HOT AIR

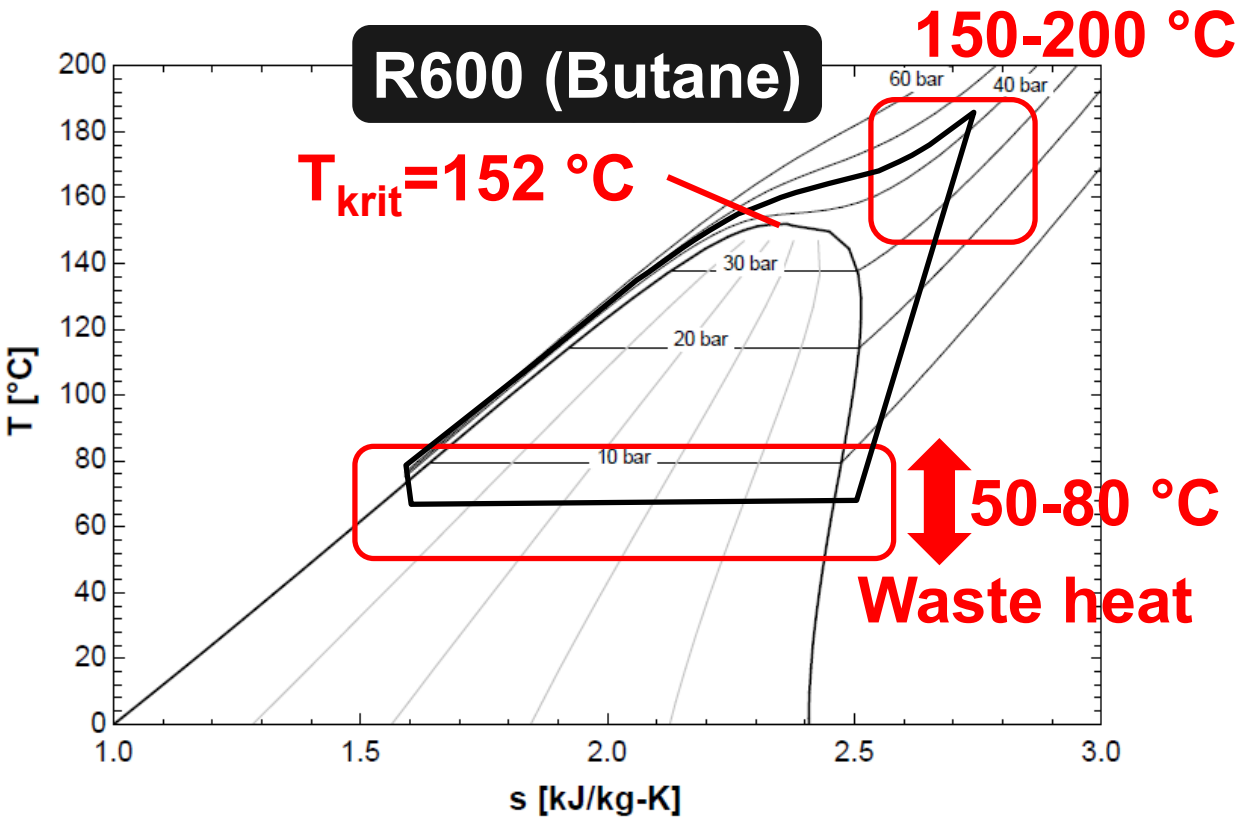
Process Heat with Transcritical Heat Pumps





Transcritical CO_2 vs. Butane cycles



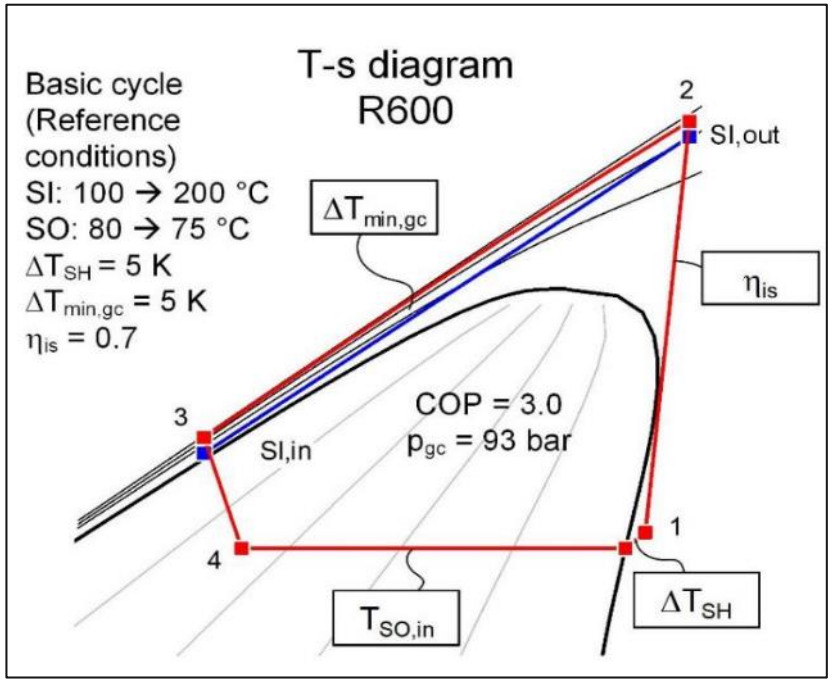


Suitable for simultaneous cooling (<30 °C) and heating (e.g. water or air from 20 to 90 °C)

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

High heat supply temperatures are possible with transcritical cycles and various refrigerants

Refrigerant	Case study 1 (SI: 100 → 200 °C, SO: 80 → 75 °C)										
	p_{gc} [bar]	COP [-]	p_{ratio} [-]	VHC [kJ/m^3]	$T_{gc,in}$ [C]	$T_{gc,out}$ [C]	η [-]	ΔT_{SH} [C]	p_{evap} [bar]	p_{int} [bar]	$p_{ratio,2nd}$ [-]
											Basic cycle
R601	36	3.3	12.6	2'922	204	105	0.53	25	2.8	-	-
R514A	44	3.3	12.0	3'710	205	105	0.54	10	3.7	-	-
R1234ze(Z)	56	3.3	8.3	6'071	208	105	0.52	5	6.7	-	-
R1233zd(E)	56	3.2	11.0	4'714	205	105	0.51	5	5.1	-	-
R1224yd(Z)	73	3.1	12.8	5'069	205	105	0.50	5	5.7	-	-
R245fa	89	3.1	14.5	5'598	205	105	0.49	5	6.1	-	-
R600	93	3.0	11.4	6'451	205	105	0.48	5	8.1	-	-



Further research on transcritical HPs is needed

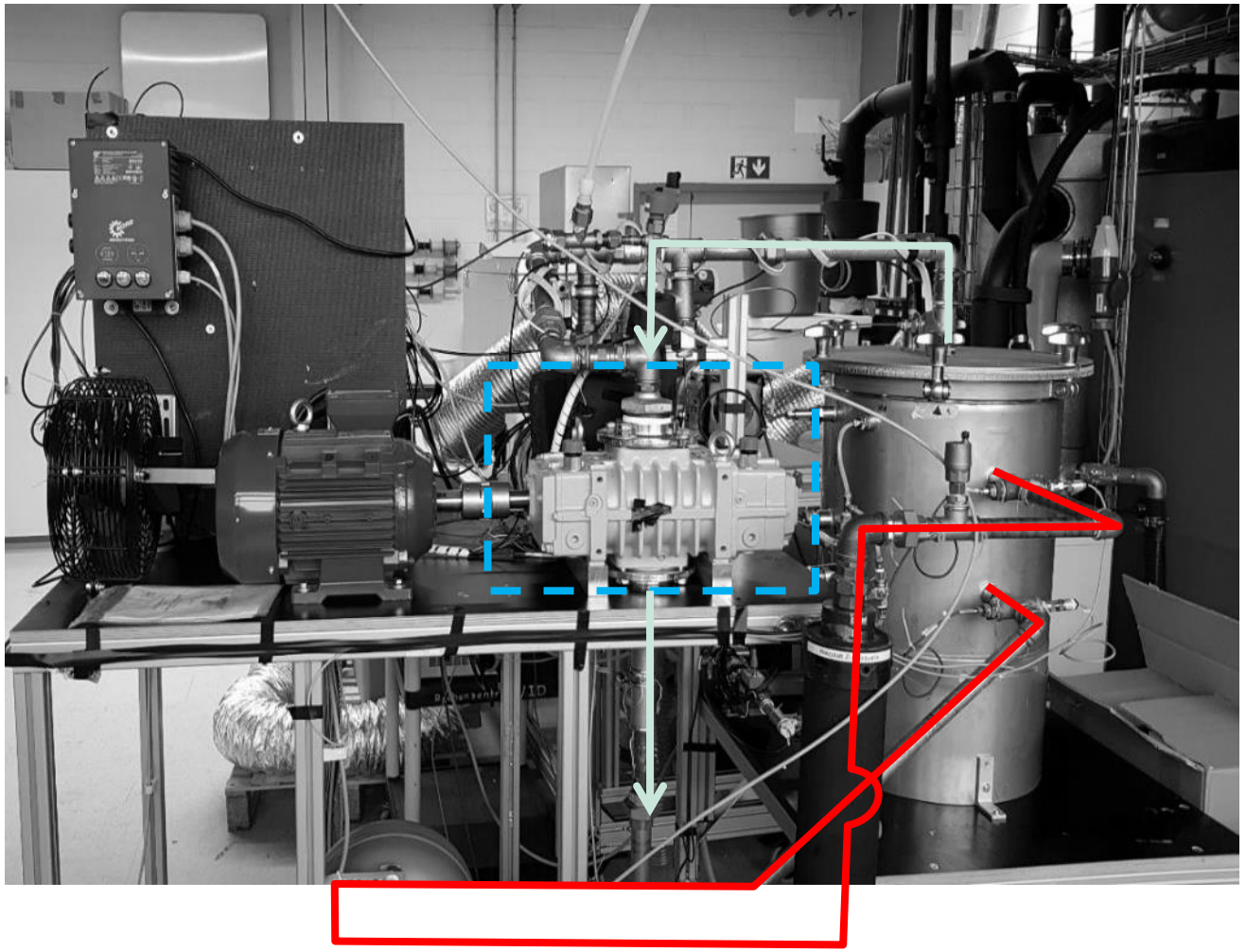
OST
Eastern Switzerland
University of Applied Sciences

sweet swiss energy research for the energy transition
DeCarbCH

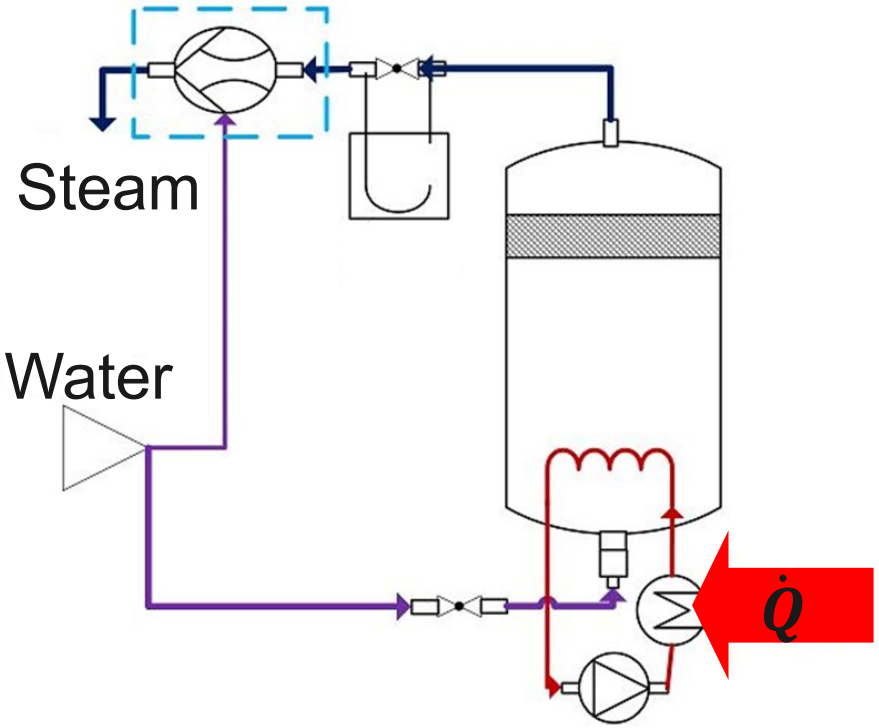
Current work at OST, Institute for Energy Systems (IES)

- **Case studies** of successful Industrial HP integrations
- **Demonstration** of steam generating heat pumps
- **Testing HFO refrigerants** for high temperatures
- HP technologies fitting the **temperature demands**

Steam Generating HP in the Lab



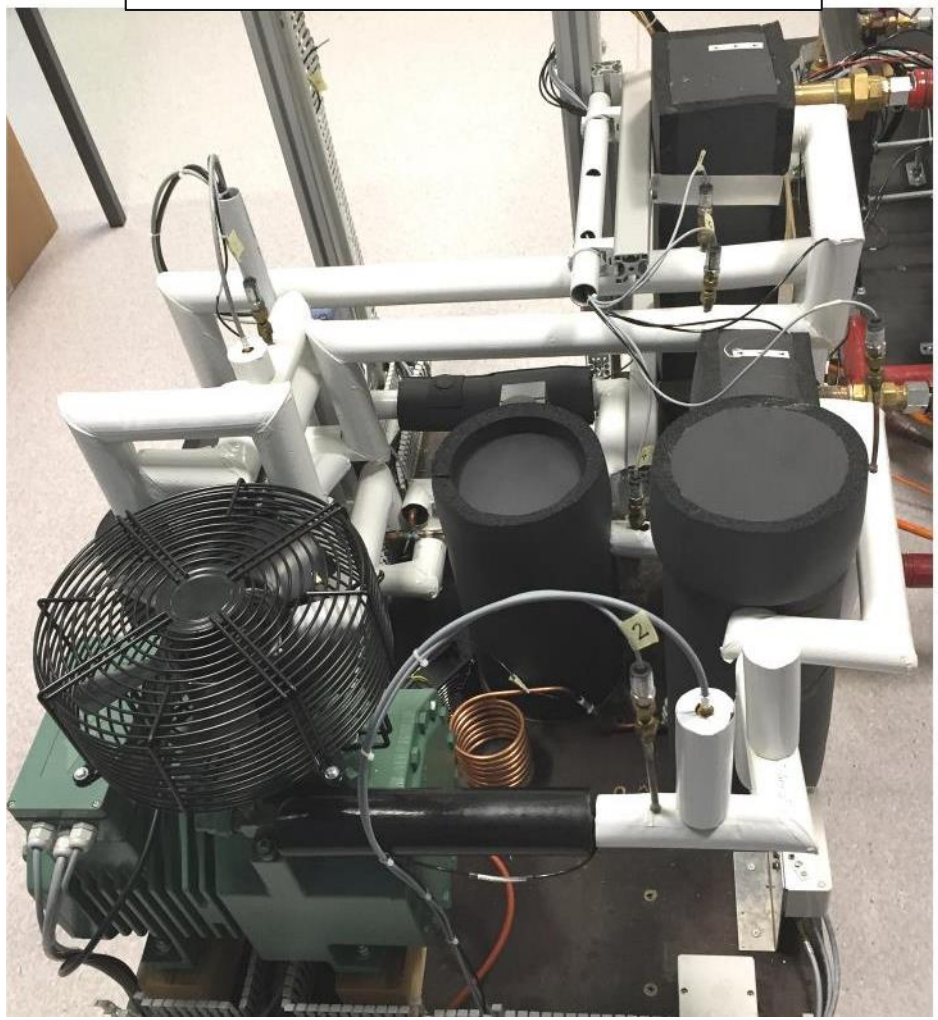
- 34.2 kg/h steam at 115 °C
- Proof of concept



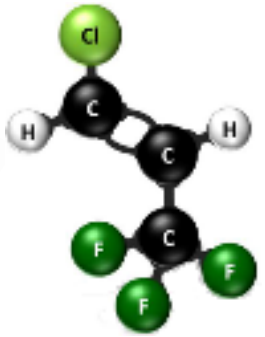
HTHP up to 150 °C testing HFO/HCFO refrigerants

sweet swiss energy research for the energy transition
DeCarbCH

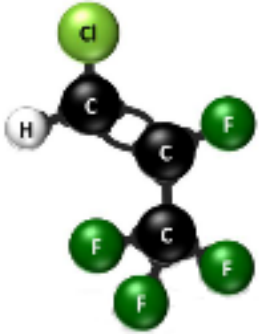
5 to 10 kW heating capacity



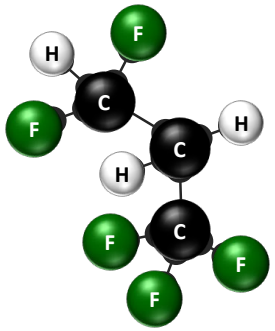
R1336mzz(Z)



R1233zd(E)



R1224yd(Z)



R245fa

HFO: Hydrofluorolefine, HCFO: Hydrochlorfluorolefine

Properties:

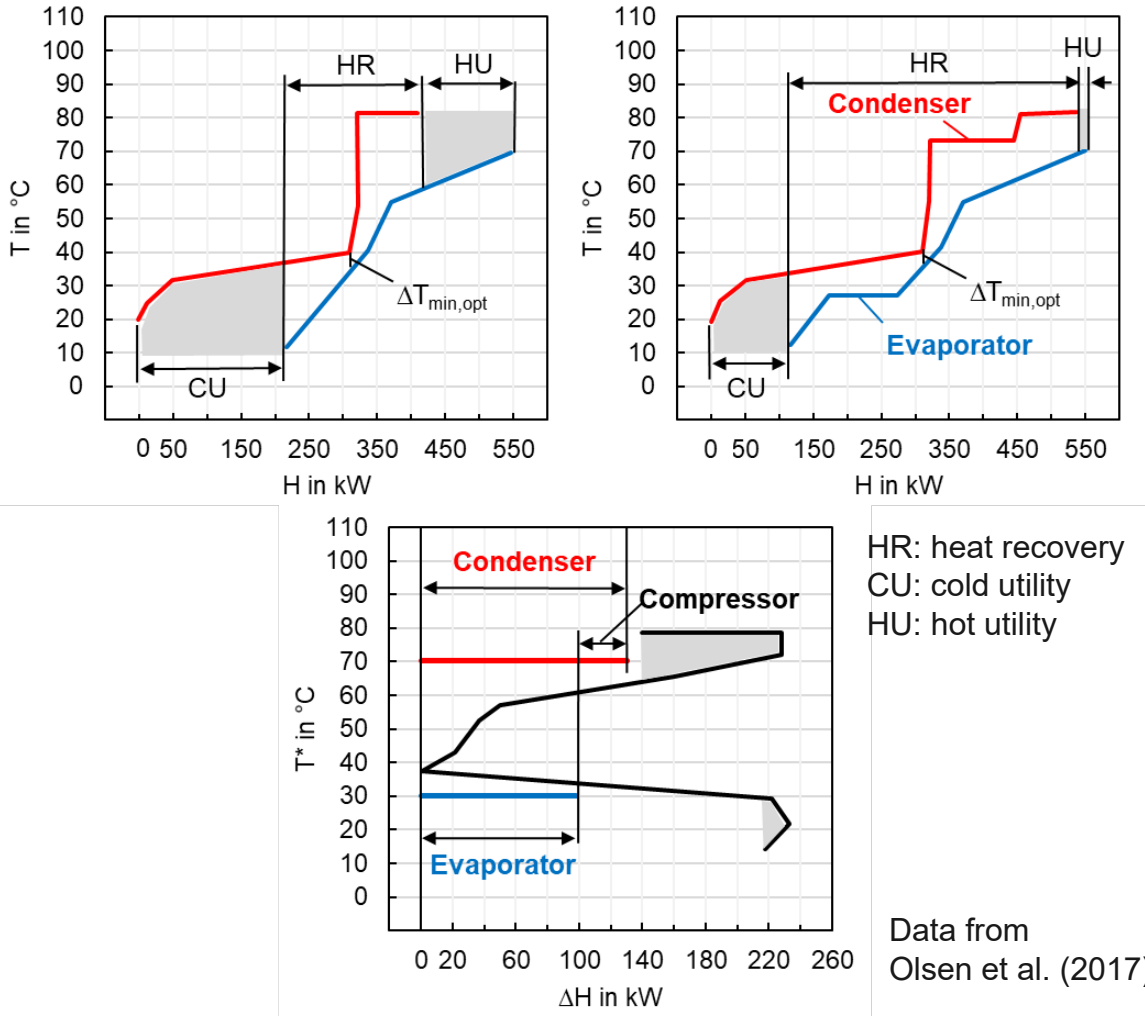
- Low GWP
- Zero/near zero ODP
- Short atmospheric life
- Not flammable
- Not toxic

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

- Heat pump integration -
Questions to be answered

1. Are there processes with **heat demand**?
2. Are there processes with **cooling demand**?
3. What is the required **heat supply temperature**?
4. Are **sufficient heat sources** available for high heat supply temperatures?
5. Is the heat source approx. in the **same order of magnitude** as the heat demand?
6. Is the heat source available at about the **same time** as the heat sink?
7. What is the **heat recovery potential**?
8. What is the **operation profile** of the heat pump (part-load, fluctuations)?

Pinch Analysis
Case Study - Candy Production



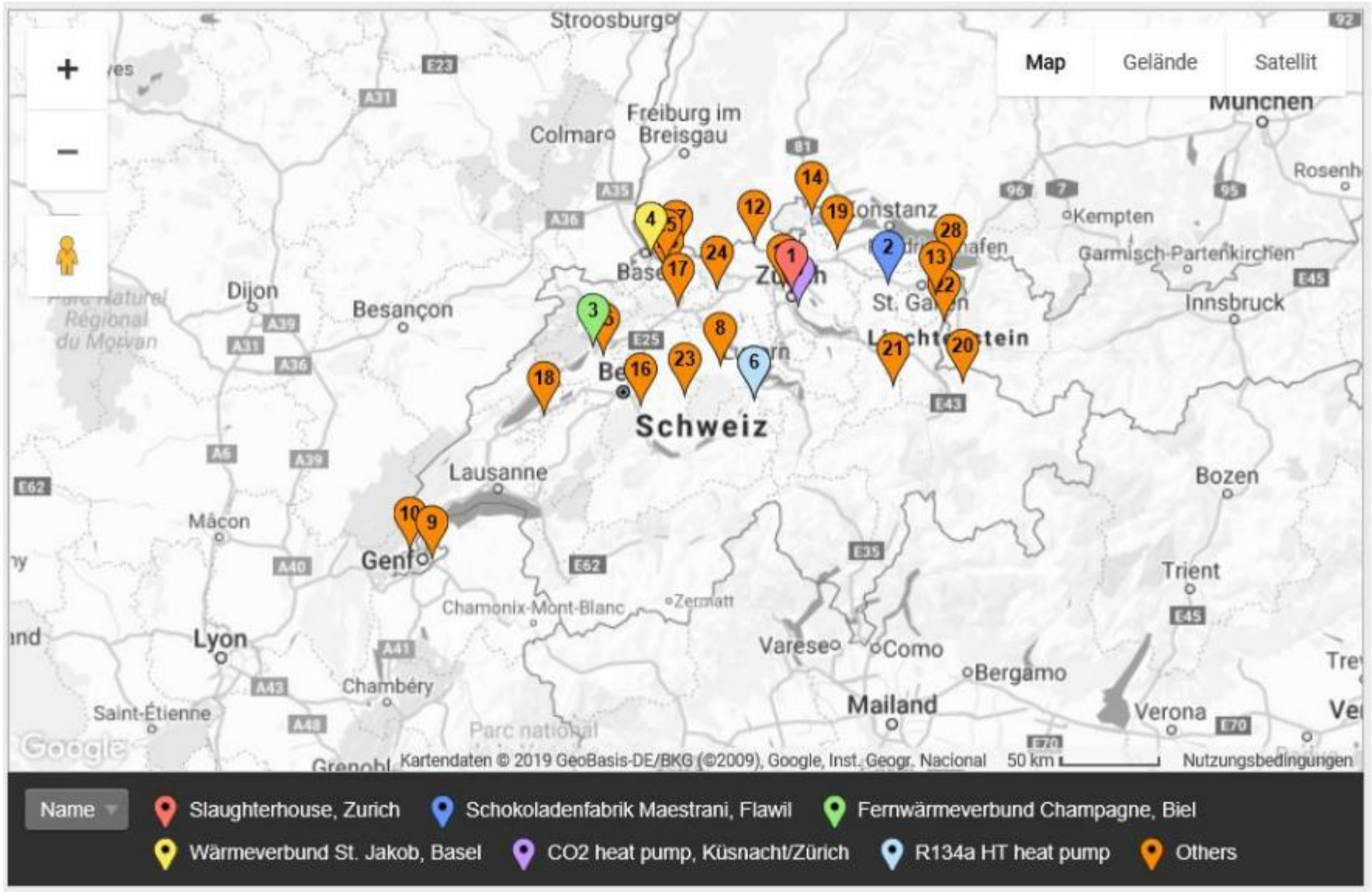
HR: heat recovery
CU: cold utility
HU: hot utility

Data from
Olsen et al. (2017)

Industrial Heat Pumps in Switzerland
Application Potentials and Case Studies

Final report: https://www.aramis.admin.ch/Dokument.aspx?DocumentID=66033

Locations of the Industrial Heat Pumps



Note: The graph does not represent the actual range of heat pump installations in Switzerland, but refers to the contact network.

Final report: https://www.aramis.admin.ch/Dokument.aspx?DocumentID=66033

IEA HPT Annex 48: 25 Case Studies of Industrial Heat Pumps

Company, Location	Industry / Sector	Application	Integration level	Capacity (kW)	Temperature range (°C)		No.
Slaughterhouse, Zurich	Food	Hot water, cleaning water	Process	800	20	90	CH01
Chocolate factory Maestrani, Flawil	Food	Hot water, heating, cooling	Process	276	17	70	CH02
Cheese factory, Gais Appenzell	Food	Hot water, heating	Process	520	18	92	CH13
Kambly SA, Trubschachen	Food	Hot water for biscuit production	Process	471	20	65	CH23
Kellermann AG, Ellikon an der Thur	Food	Hot water for greenhouse heating	Plant	1'000	6	65	CH19
Hilcona AG, Schaan	Food	Hot water for fresh convenience foods	Plant	507	31	67	CH29
Nutrex, Busswil bei Büren	Food & Beverages	Vinegar fermentation and pasteurization	Process	194	30	70	CH15
GVS Schaffhausen Landi	Food & Beverages	Process/hot water, heating, cooling	Plant	63	37	95	CH14
Bachem AG, Bubendorf	Pharma	Heating and cooling of peptides	Process	480	14	70	CH26
R134a heat pump, Geistlich Wolhusen	Pharma	Hot water, heating	Plant	606	2	67	CH08
Mifa AG Mibelle Group, Frenkendorf	Home Care and Nutrition	Hot/cold water, heating, cooling	Plant	885	35	70	CH25
Härterei Gerster AG, Egerkingen	Metals	Process heat for hardening process	Plant	260	17	65	CH17
Georg Fischer AG, Grüsch	Machinery	Heating for production of plastic valves	Plant	382	8	65	CH20
Feldschlösschen, City of Rheinfelden	District heating, brewery	Hot water, district heating	Plant/Network	1'350	16	81	CH27
Champagne, Biel	District heating	Hot water, heating	Network	650	11	63	CH03
St. Jakob, Basel	District heating	Hot water, heating	Network	181	0	65	CH04
Laurana, Thônex	District heating	Hot water, heating	Network	338	14	63	CH09
Les Vergers, Meyrin	District heating	Heating of residential buildings	Network	5'000	12	50	CH10
City of Lausanne	District heating	Hot water for residential buildings	Network	4500	6	68	CH16
Casino Aarau	District heating/cooling	District heating and cooling network	Network	1'975	9	70	CH24
Kokon Corporate Campus, Ruggell	Wellness and restaurant	Hot water, heating	Building	341	10	35	CH22
Swiss Army, CO_2 HP Payerne	Military	Tap water and facility heating	Building	60	9	45	CH18
Swiss Army Troop building, Matt	Military	Hot water, heating	Building	270	8	60	CH21
ARA Altenrhein	Waste water treatment	Hot water for sewage sludge drying	Plant	2'840	8	65	CH28
Waste water treatment plant, Zürich	Waste water treatment	Hot water	Plant	410	7	50	CH11
Bad Zurzach	Thermal bath	Hot water	Plant	550	29	55	CH12

Energy savings and CO_2 emissions reduction

Replacement of gas and oil boilers with heat pumps leads to significant energy Savings (20 to 80%) and reduction of CO_2 emissions (30 to 90%)

Case study	Energy savings	CO_2 emission reductions
Slaughterhouse Zurich hot water	2'560 MWh fossil fuels	**30%** (510 t CO_2/a) *(520 t CO_2/a*)*
Chocolate factorz Maestrani	*882 MWh gas**	179 t CO_2/a (2013 to 2020)
District heating Champagne	*3'054 MWh gas**	620 t CO_2/a
District heating Laurana	1'435 MWh fossile	**42%** (1'746 t CO_2/a)
Cheese factory Gais Appenzell	1'500 MWh gas	*305 t CO_2/a**
GVS Landi beverages	26'000 L oil/a	**40%** *(69 t CO_2/a*)*
Nutrex AG fermentation	bis zu 65'000 L oil/a	310 t CO_2/a *(up to 172 t CO_2/a*)*
Härterei Gerster AG metals	**80%** (800 MWh gas)	160 t CO_2/a *(162 t CO_2/a*)*
Kellermann vegetables	*4'729 MWh gas**	960 t CO_2/a
Kambly SA biscuits	**25%** *(493 MWh gas*)*	**90%** (100 t CO_2/a)
District heating casino Aarau	**40%** by 2035	n.a.
Mifa AG home care and nutrition	**20%** *(4'729 MWh gas*)*	**60%** (960 t CO_2/a)
Bachem AG biotech peptides	*1'478 MWh Gas**	300 t CO_2/a
Feldschlösschen brewery	**75%** (11'160 MWh fossil)	*2'265 t CO_2/a**
ARA Altenrhein waste water	*14'778 MWh gas**	3'000 t CO_2/a

**values calculated assuming CO_2 emission factors of 0.203 t CO_2/MWh gas and 0.00265 t CO_2/L oil (BAFU, 2019)*

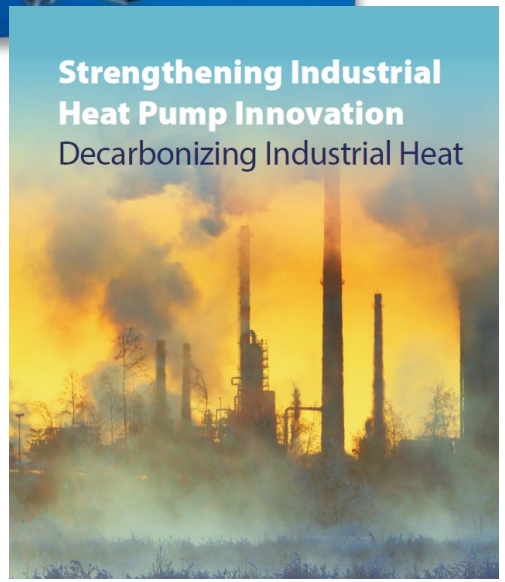
More detailed analysis of operating data from selected Industrial Heat Pumps

Object, location	GVS Landi, Schaffhausen-Herblingen	Resilux Schweiz AG, Bilten	Bachem AG, Bubendorf
Application, temperatures, heating capacity	Cleaning of bottles and wine tanks, heating/hot water 37 °C/ 80 to 95 °C, heating capacity 63 kW	Production of PET blanks 50 °C / 90 to 95 °C (hot water), heating capacity 400 kW	Space heating/hot water up to 70 °C, cooling capacity 480 kW, heating capactiy 640 kW
Operating data	Over 3 years of operating data via online software at 1-min resolution, remote access, hydraulic integration	Operating data of 2 units with integration into extruder process and cooling systems	Operating data from process control system (reference is refrigeration), trending data since 2020
Heat pump	Ochsner ISWHS 60ER3, economizer cycle, screw compressor, ÖKO 1 (R245fa)	2x Viking HeatBooster HBS4, piston, R245fa	Sabroe HPO 28 VSD, Ammonia (NH_3)

Summary – Industrial Heat Pumps

- **Industrial Heat Pump applications**
- **Numerous products and technologies from various manufacturers are available on the market** (90 to 165°C, >100 kW to MW capacity range)
- **COP of about 4.0 at 50 K temperature lift**
- **Specific HP Technologies and Cycles** for large temperature glides, steam generation, and large heat pumps
- **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)

Literature References



Mateu-Royo, C.; Arpagaus, C.; Mota-Babiloni, A.; Navarro-Esbrí, J.; Bertsch, S.: Advanced High Temperature Heat Pump Configurations using low GWP Refrigerants for Industrial Waste Heat Recovery: A Comprehensive Study, Energy Conversion and Management, Vol. 229, 1 February 2021, 113752, https://doi.org/10.1016/j.enconman.2020.113752

Kosmadakis, G.; Arpagaus, C.; Neofytou, P.; Bertsch, S.: Techno-Economic Analysis of High-Temperature Heat Pumps with low-GWP Refrigerants for upgrading Waste Heat up to 150 °C, Energy Conversion and Management, Vol. 226, 113488, pp. 1-19, https://doi.org/10.1016/j.enconman.2020.113488

Schiffmann, J.; Kontomaris, K.; Arpagaus, C.; Bless, F.; Bertsch, S.: Scale Limitations of Gas Bearing Supported Turbocompressors for Vapor Compression Cycles, International Journal of Refrigeration, Vol. 109, pp. 92-104, 2020, https://doi.org/10.1016/j.ijrefrig.2019.09.019

Schlosser, F.; Jesper, M.; Vogelsang, J.; Walmsley, T.G.; Arpagaus, C.; Hesselbach, J.: Large-Scale Heat Pumps: Applications, Performance, Economic Feasibility and Industrial integration, Renewable and Sustainable Energy Reviews, Vol. 133, 1102019, pp. 1-20, 2020, https://doi.org/10.1016/j.rser.2020.110219

Arpagaus, C.; Bertsch, S.: Industrial Heat Pumps in Switzerland – Application Potentials and Case Studies, Final Report, on behalf of the Swiss Federal Office of Energy, SFOE contract number: SI/501782-01, Bern, 23 July 2020.

De Boer, R.; Marina, A.; Zühlsdorf, B.; Arpagaus, C.; Bantle, M.; Wilk, V.; Elmegaard, B.; Corberán, J.; Benson, J.: Strengthening Industrial Heat Pump Innovation, Decarbonizing Industrial Heat, White Paper, 14 July 2020.

Arpagaus, C.; Bertsch, S.: Experimental Comparison of R1224yd(Z) and R1233zd(E) in a High Temperature Heat Pump, 13th IEA Heat Pump Conference, Jeju, Korea, 26-29 April 2021.

Arpagaus, C.; Bertsch, S.: Successful Application Examples of Industrial Heat Pumps in Switzerland, IIR International Rankine 2020 Conference, 27-31 July 2020, Glasgow, UK, https://doi.org/10.18462/iir.rankine.2020.1183

Arpagaus, C.; Bertsch, S.: Experimental Comparison of HCFO R1233zd(E) and R1224yd(Z) in a High Temperature Heat Pump up to 150 °C, IIR International Rankine 2020 Conference, 27 to 31 July 2020, Glasgow, UK, https://doi.org/10.18462/iir.rankine.2020.1129

Arpagaus, C.; Bertsch, S.: Experimental Comparison of HCFO and HFO R1224yd(Z), R1233zd(E), R1336mzz(Z), and HFC R245fa in a High Temperature Heat Pump up to 150 °C Supply Temperature, 18th International Refrigeration and Air Conditioning Conference at Purdue, 23-27 May 2021.

Arpagaus, C.; Bless, F.; Bertsch, S.: Theoretical Analysis of Transcritical HTHP Cycles with low GWP HFO Refrigerants and Hydrocarbons for Process Heat Applications up to 200 °C, IIR International Rankine 2020 Conference, 27-31 July 2020, Glasgow, UK, https://doi.org/10.18462/iir.rankine.2020.1168

Bless, F.; Arpagaus, C.; Bertsch, S.: Theoretical Investigation of High-Temperature Heat Pump Cycles for Steam Generation, 13th IEA Heat Pump Conference, Jeju, Korea, 26 -29 April 2021.

Diewald, K; Arpagaus, C.; Hebenstreit, B.: Thermodynamic Analysis of low GWP HFO and HCFO Refrigerants in HTHP with Large Temperature Glides on the Heat Sink, IIR International Rankine 2020 Conference, 27-31 July 2020, Glasgow, UK, https://doi.org/10.18462/iir.rankine.2020.1166

OST
Eastern Switzerland
University of Applied Sciences

sweet swiss energy research for the energy transition
DeCarbCH

Thank you for your attention!

Dr. Cordin Arpagaus

Eastern Switzerland University of Applied Sciences
Institute for Energy Systems IES

cordin.arpagaus@ost.ch
Tel. +41 58 257 34 94
www.ost.ch/ies