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Industrial Heat Pumps: Market Overview and Applications

ESB Leading Lights Series |
The Role of Industrial Heat Pumps,
Webinar, September 14, 2021

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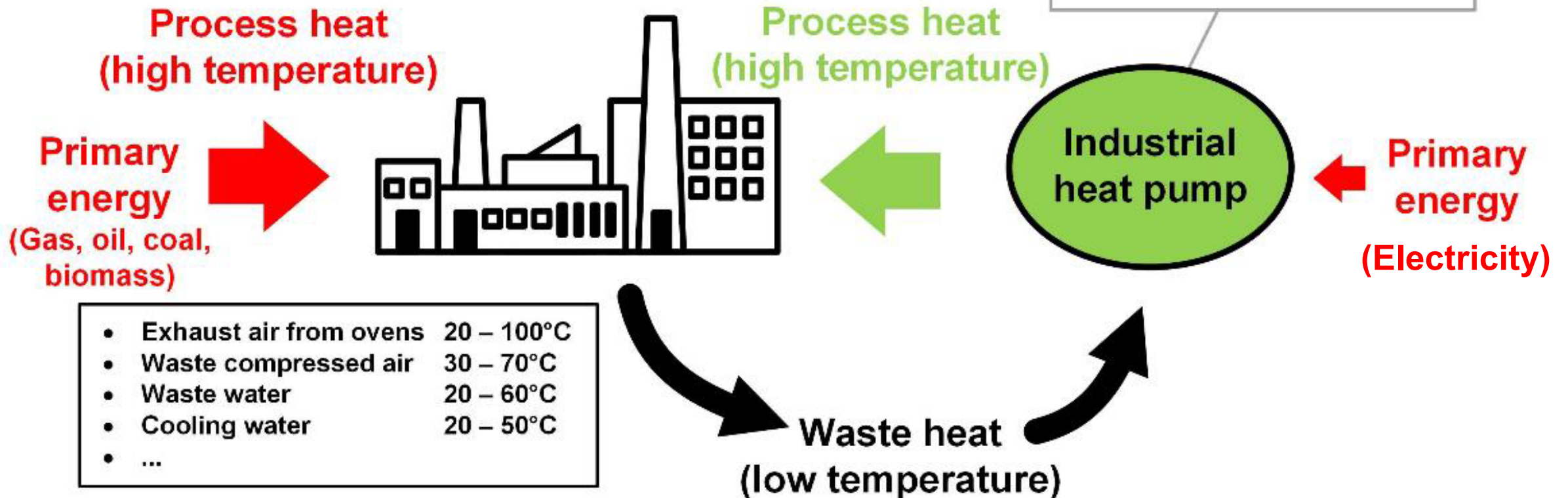


Motivation = Upgrading useful (waste) heat to higher temperatures

- Distillation 100 - 300°C
- Drying processes 40 - 250°C
- Evaporation 40 - 170°C
- Pasteurisation / Sterilisation 70 - 120°C
- ...

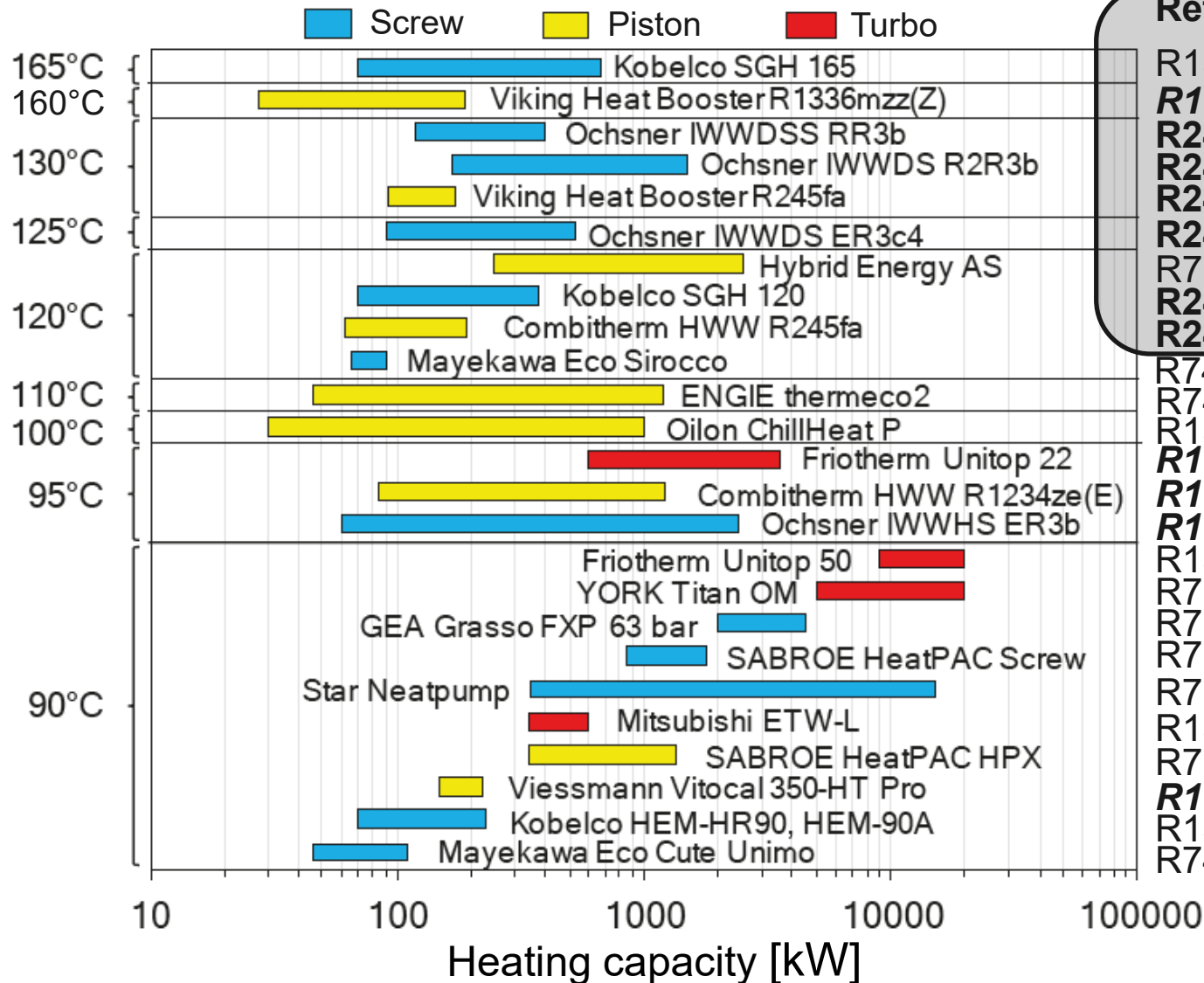
Heat pump efficiency

$$\text{COP} = \frac{\text{Useful heat}}{\text{Driving power}}$$



More than 26 industrial heat pumps with heat supply $\geq 90^\circ\text{C}$

Max. heat supply temperature [$^\circ\text{C}$]



Refrigerants

R134a/R245fa

R1336mzz(Z)

R245fa

R245fa

R245fa

R245fa

R717 (NH₃)

R245fa

R245fa

R744 (CO₂)

R744 (CO₂)

R134a/R1234ze(E)

R1234ze(E)

R1234ze(E)

R1233zd(E)

R134a

R717 (NH₃)

R717 (NH₃)

R717 (NH₃)

R717 (NH₃)

R134a

R717 (NH₃)

R1234ze(E)

R134a/R245fa

R744 (CO₂)

OCHSNER
ENERGIE TECHNIK





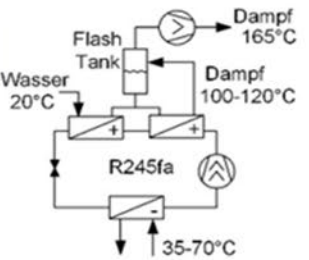


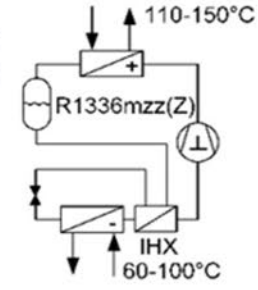


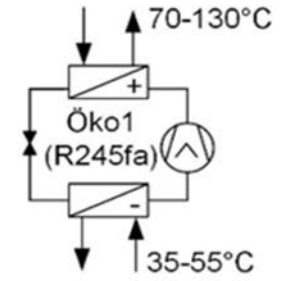


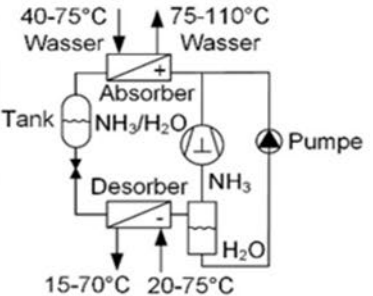


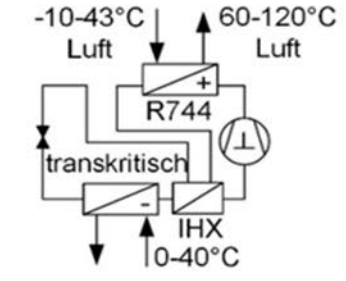


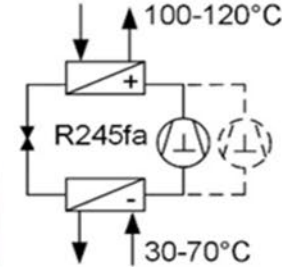


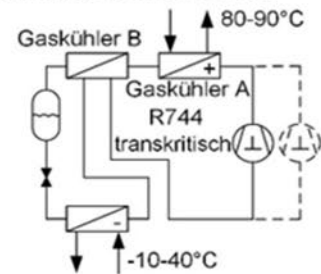


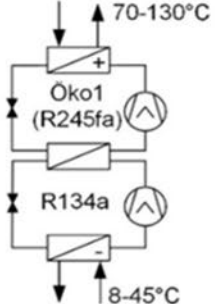


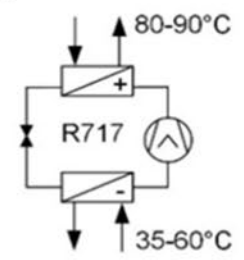
HeatBooster S4
(Viking Heat Engines AS)




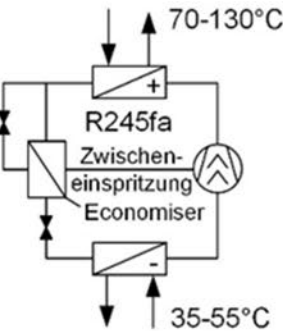


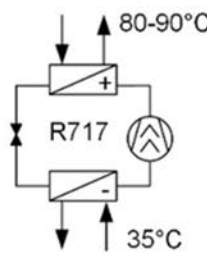


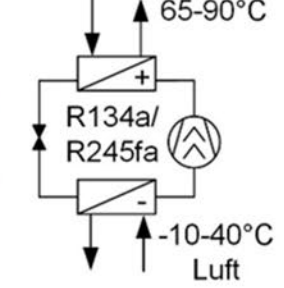


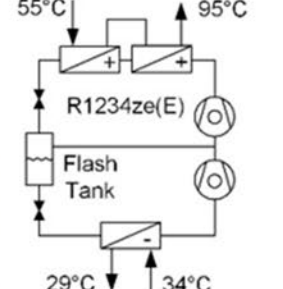


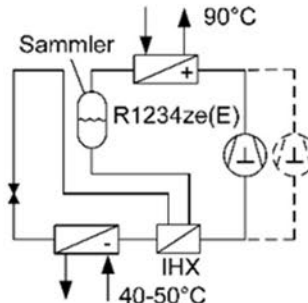


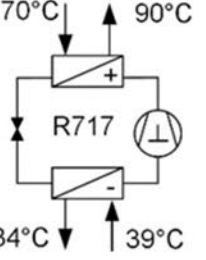


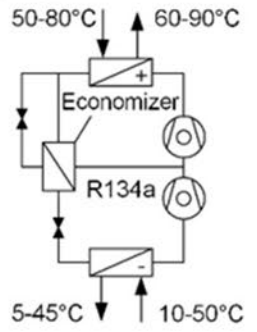


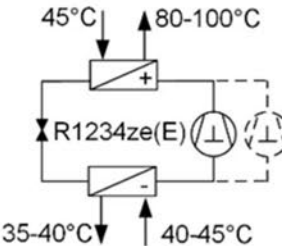

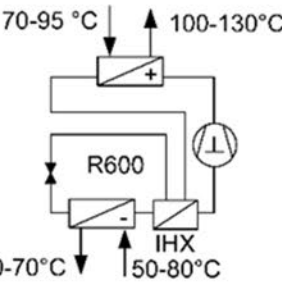
Kobelco SGH 120/165
(Steam Grow Heat Pump)



Selection of industrial heat pumps with heat pump cycles

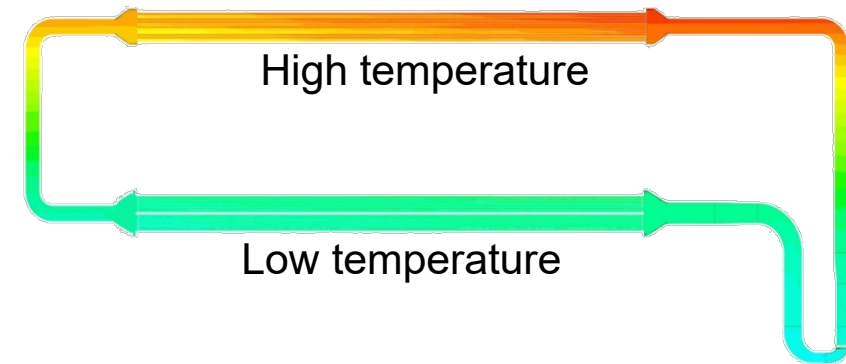
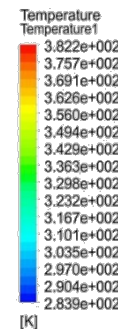
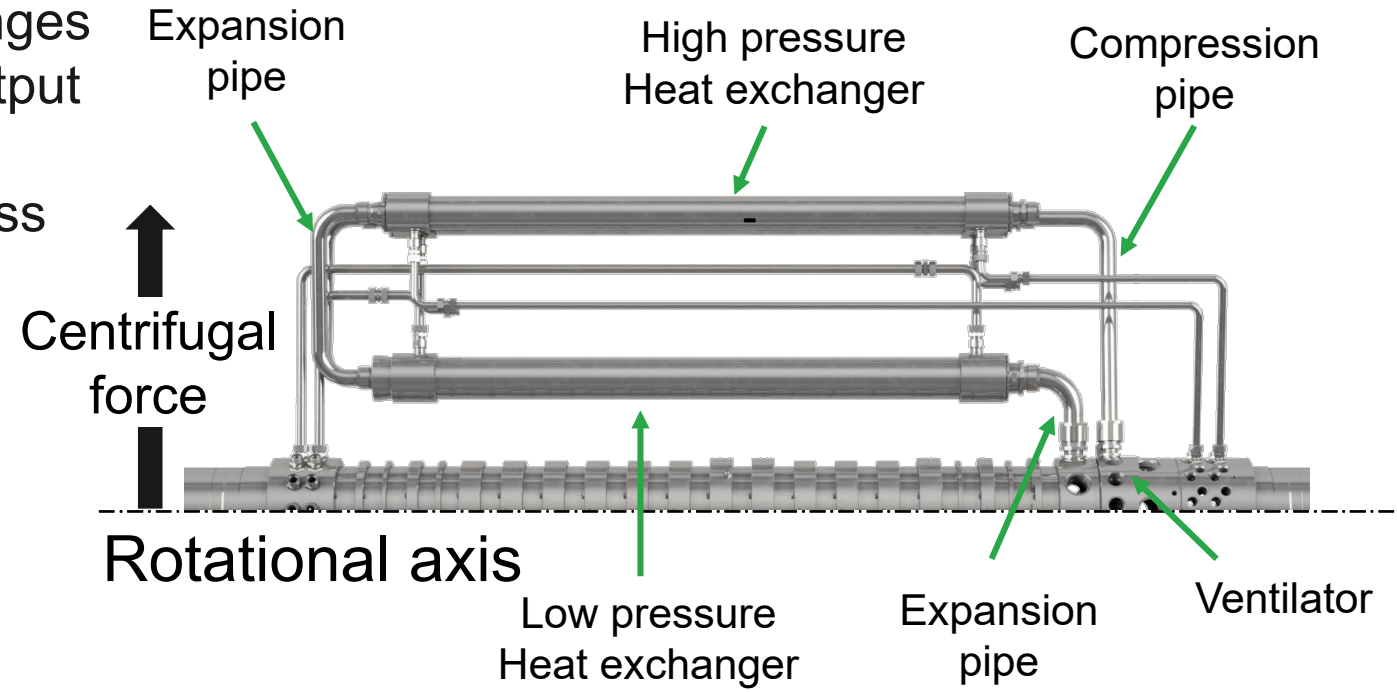
<p></p> <p>Kobe Steel Kobelco SGH 120/165</p>  	<p></p> <p>Viking Heat Engines HeatBooster S4</p>  	<p></p> <p>Ochsner IWWDS ER3c4</p>  
<p></p> <p>Hybrid Energy Hybrid Heat Pump</p>  	<p></p> <p>Mayekawa Eco Sirocco</p>  	<p></p> <p>Combitherm HWW R245fa</p>  
<p></p> <p>ENGIE (ex-Dürr Thermea), thermeco₂ HHR1000 mit 6 Hubkolbenverdichtern bis 1100 kW</p>  	<p></p> <p>Ochsner IWWDS R2R3b</p>  	<p></p> <p>Star Refrigeration, Neatpump NP601, Vilter VSSH Schraubenkompressor 76 bar</p>  

Selection of industrial heat pumps with heat pump cycles

 <p>Ochsner IWWDS ER3b</p>  <p>70-130°C R245fa Zwischen-einspritzung Economiser 35-55°C</p>	 <p>GEA Grasso FX P Heat Pump Doppelschraubenkompressor bis 63 bar</p>   <p>80-90°C R717 35°C</p>	 <p>Kobe Steel Kobelco HEM-HR90</p>   <p>65-90°C R134a/ R245fa -10-40°C Luft</p>
 <p>Friotherm Unitop 22/22, 3'300 kW, zweistufiger Turbokompressor</p>   <p>55°C 95°C R1234ze(E) Flash Tank 29°C 34°C</p>	 <p>Viessmann Vitocal 350-HT Pro</p>   <p>90°C Sammler R1234ze(E) IHX 40-50°C</p>	 <p>Johnson Controls, SABROE HeatPAC HPX Hubkolbenkompressor bis 60 bar</p>   <p>70°C 90°C R717 34°C 39°C</p>
 <p>Mitsubishi ETW-L</p>   <p>50-80°C 60-90°C Economizer R134a 5-45°C 10-50°C</p>	 <p>Oilon ChillHeat P300 SU HC+ R1234ze mit 4 parallel geschalteten Kolbenverdichtern</p>   <p>45°C 80-100°C R1234ze(E) 35-40°C 40-45°C</p>	 <p>Frigopol HighButane 2.0</p>  <p>70-95 °C 100-130°C R600 IHX 40-70°C 50-80°C</p>

Rotation Heat Pump of ecop Technologies GmbH (Austria)

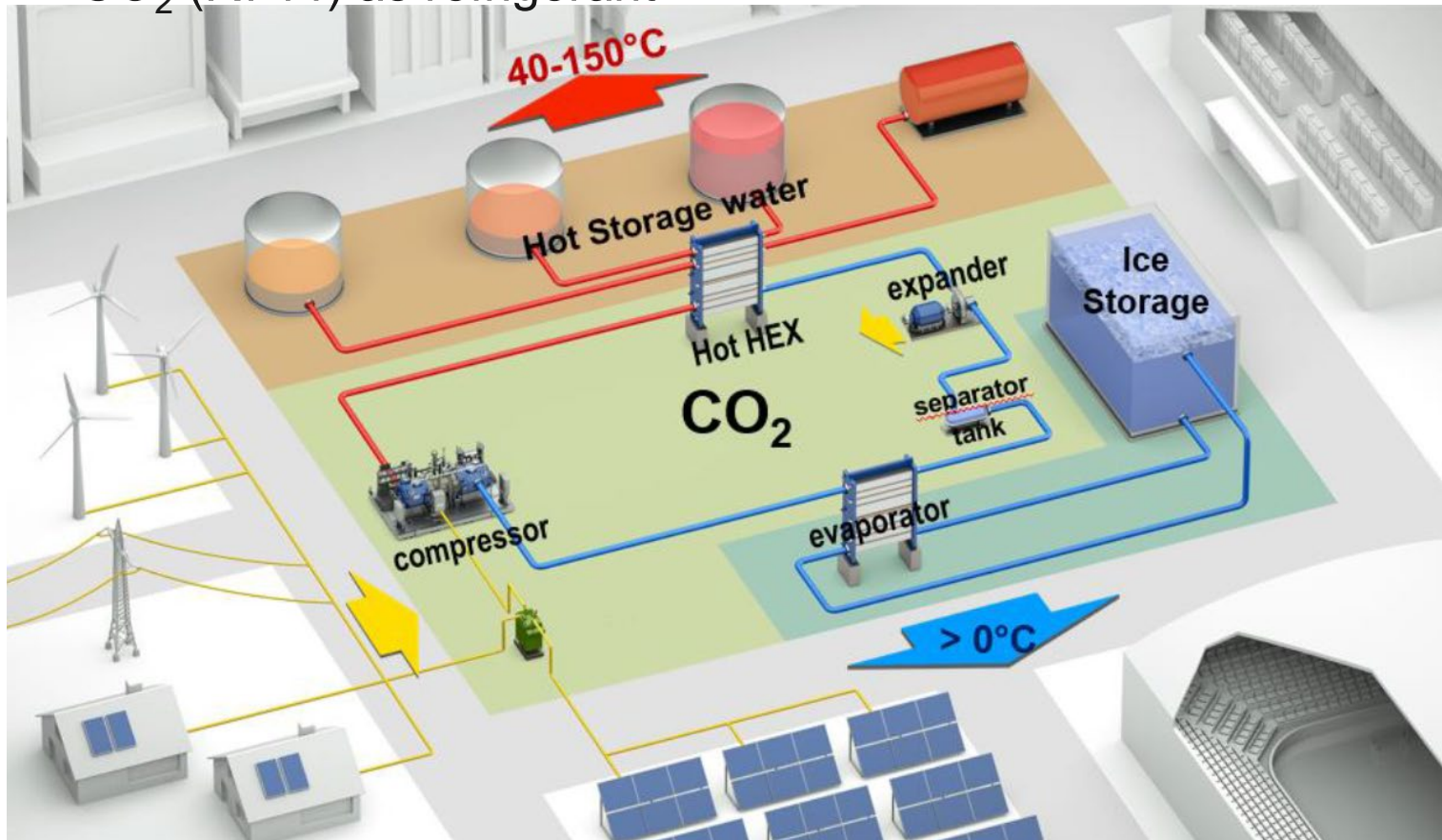
- up to 150 °C, flexible temperature ranges
- (-20 °C to +150 °C), 700 kW heat output
- High COP, high temperature glides
- Noble gas as refrigerant, Joule process



Large scale high-temperature CO₂ heat pump

Electro-thermal energy storage (ETES)

- Trigeneration (heat, cold, electricity), with storage possibilities
- 0 °C to 150 °C, modular from 5 to 100 MW_{th}
- CO₂ (R744) as refrigerant

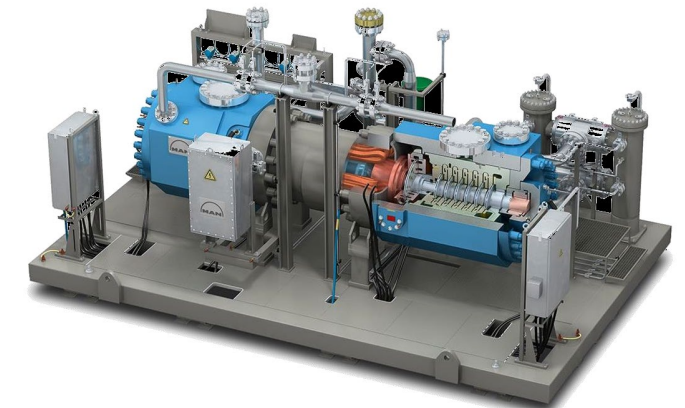


Decorvet & Jacquemoud: 2nd Conference on High Temperature Heat Pumps, Copenhagen, 2019

MAN Energy Solutions
Schweiz AG

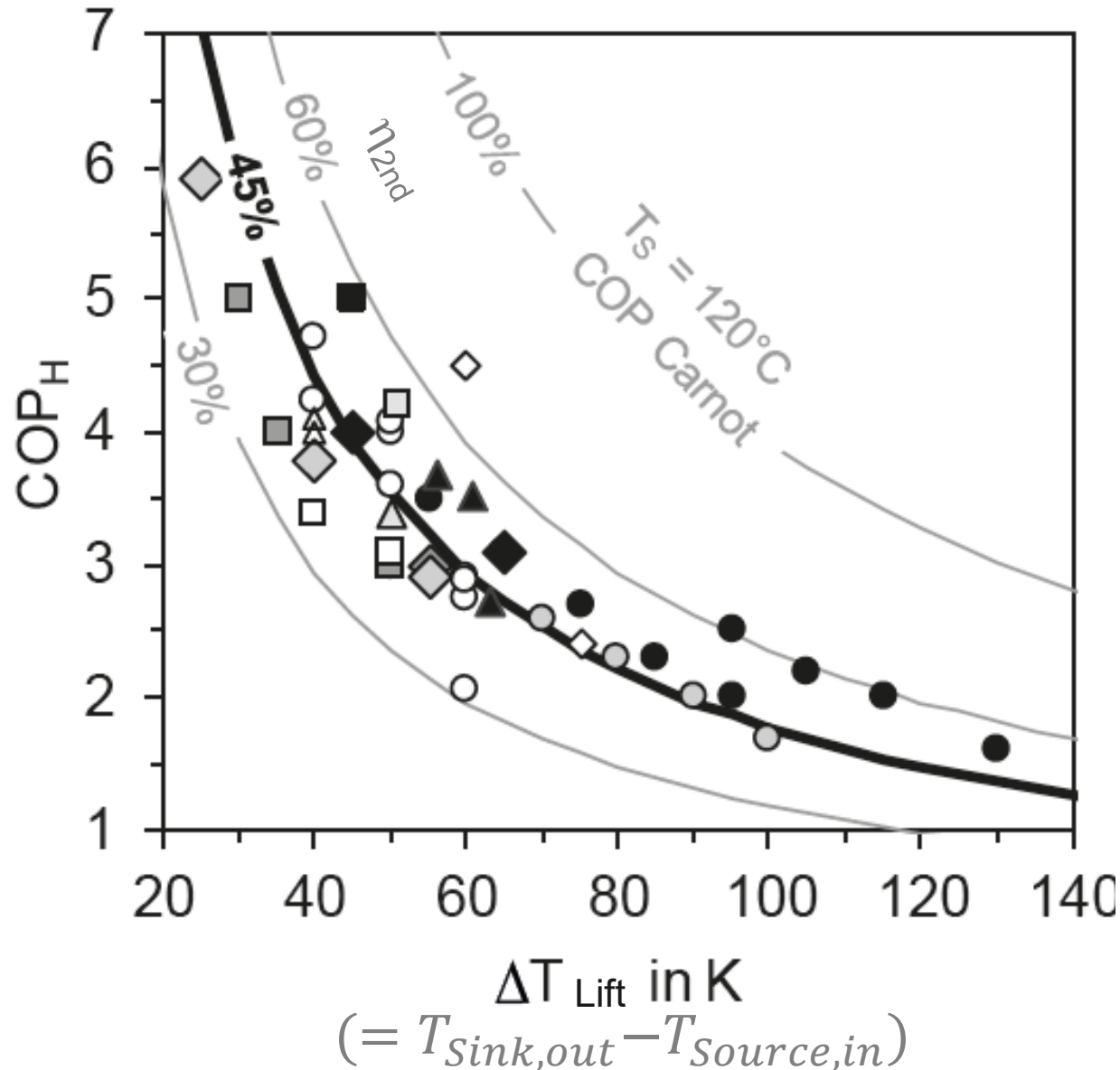


HOFIM™ Kompressor
(High speed Oil Free Integrated Motor compressor)



Efficiency (COP – Coefficient of Performance)

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



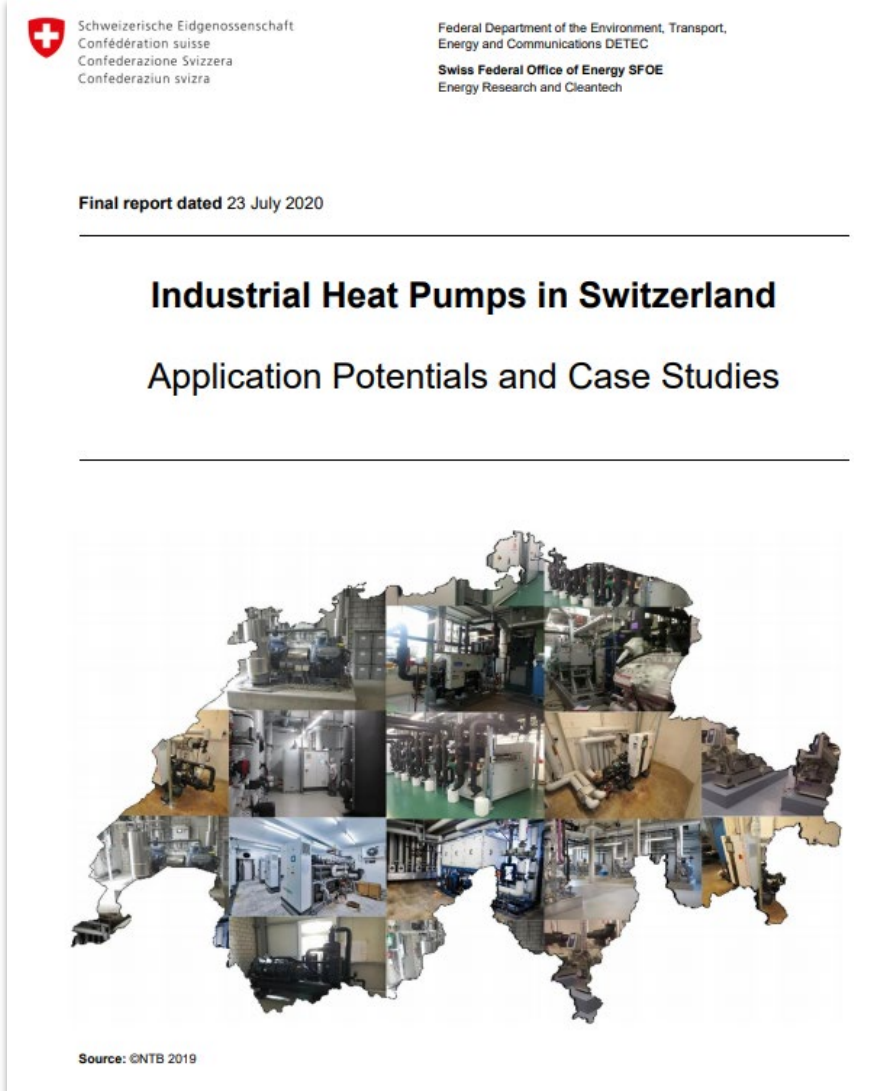
- Kobelco SGH 120/165
- Kobelco HEM-HR90
- Viking HeatBooster S4 R1336mzz(Z)
- ◆ Ochsner IWWDS R2R3b
- ◆ Ochsner IWWDS ER3b
- ◆ Ochsner IWWDS ER3c4
- ◇ Hybrid Heat Pump
- ▲ Friotherm Unitop 22/22
- △ Combitherm
- GEA Grasso FX P
- Star Refrigeration Neatpump
- SABROE HeatPAC HPX
- Viessmann Vitocal 350-HT Pro
- △ Mitsubishi ETW-L

2nd Law efficiency:
 $\eta_{2nd} = COP_H / COP_{Carnot}$

$$COP_{Carnot} = \frac{T_{Sink,out}}{T_{Sink,out} - T_{Source,in}}$$

Fit-curve (45% 2nd Law efficiency η_{2nd}):
 $COP_H = 68.455 \cdot \Delta T_{Lift}^{-0.76}$, $R^2=0.78$

25 Case Studies of Industrial Heat Pumps in Switzerland



- Presents case studies of successful applications of industrial heat pumps in Switzerland
- Promotes further market penetration of industrial heat pumps
- Highlights typical applications in large-scale
- Establishes a framework for comparison

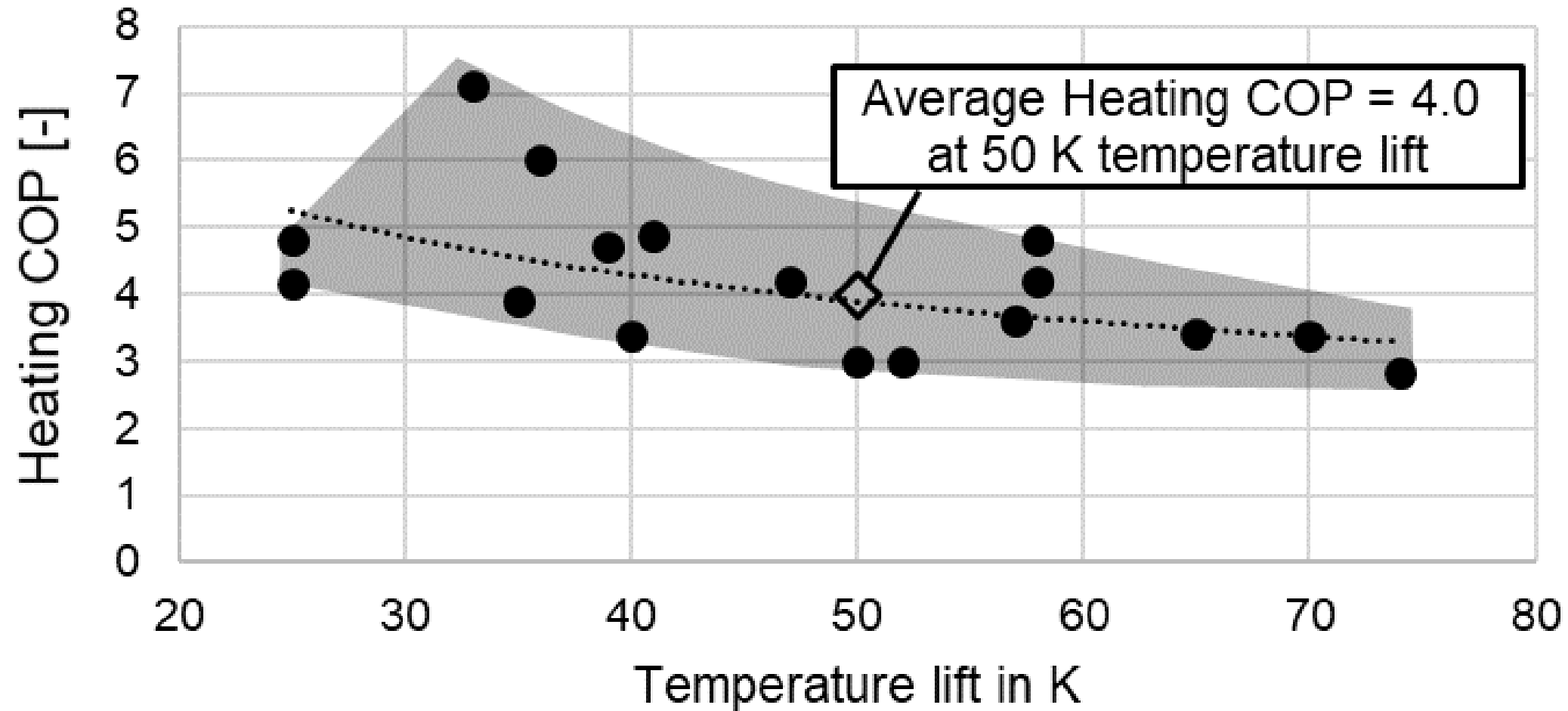
Download Link: <https://www.aramis.admin.ch/Dokument.aspx?DocumentID=66033>

Overview of 25 Case Studies of Industrial Heat Pumps

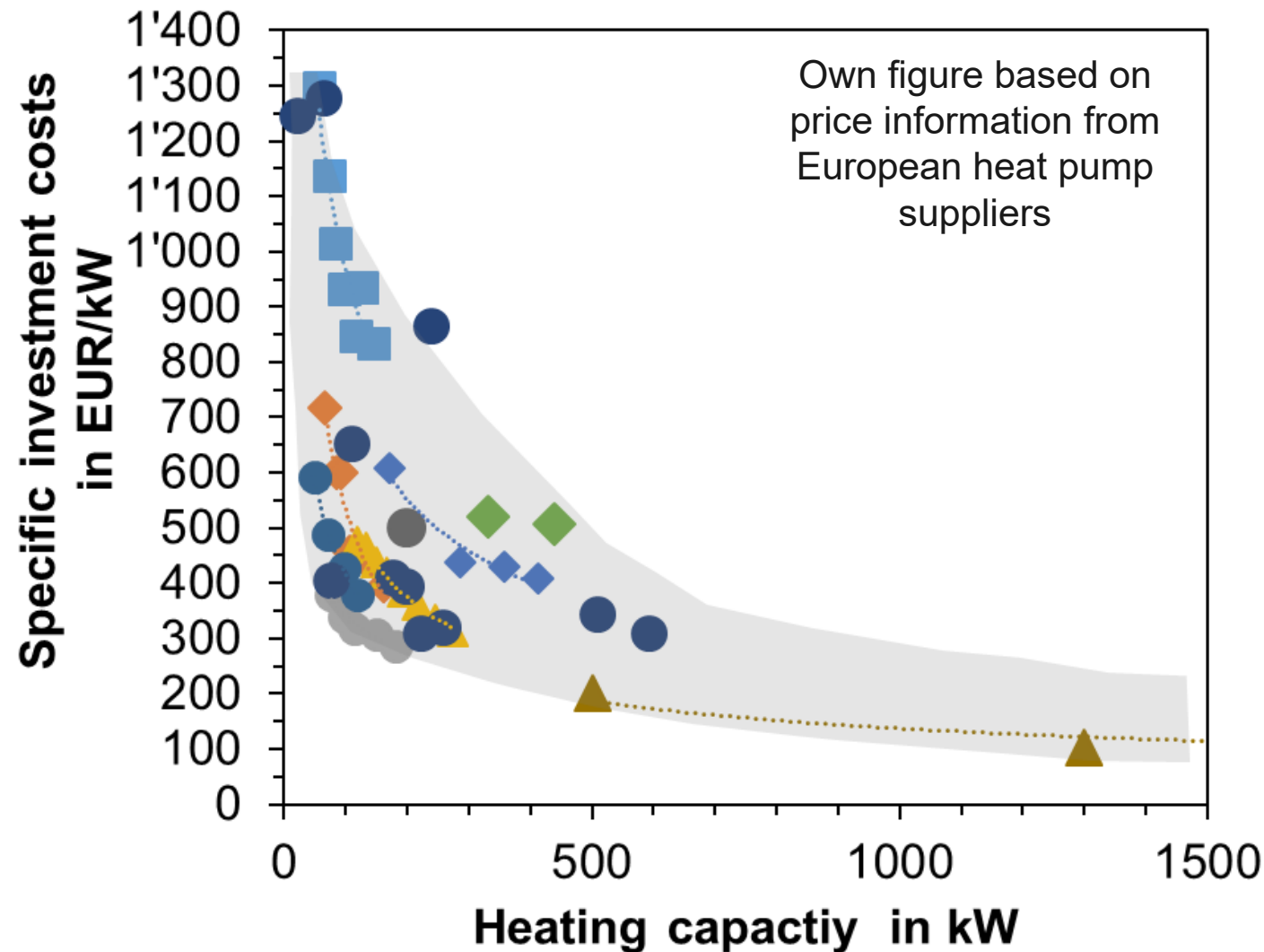
Company, Location	Industry / Sector	Application	Integration level	Capacity (kW)	Temperature range (°C)		No.
Slaughterhouse, Zurich	Food	Hot water, cleaning water	Process	800	20	90	CH01
Chocolate factory Maestrani, Flawil	Food	Hot water, heating, cooling	Process	276	17	70	CH02
Cheese factory, Gais Appenzell	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, Grösch	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

Efficiency of industrial heat pumps in the field

Database: Case Studies in Switzerland



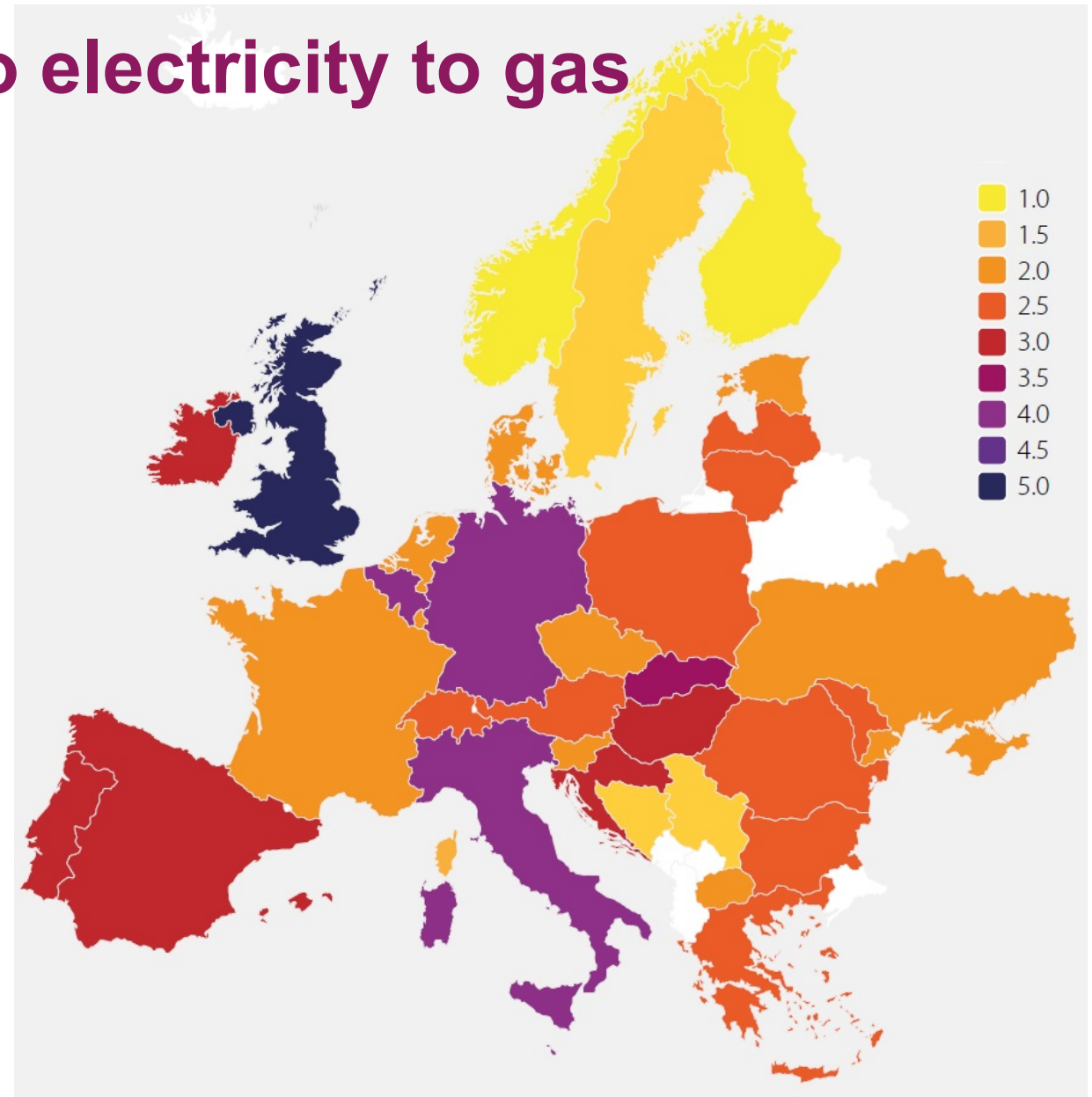
Specific investment costs (incl. installation) per kW of heating



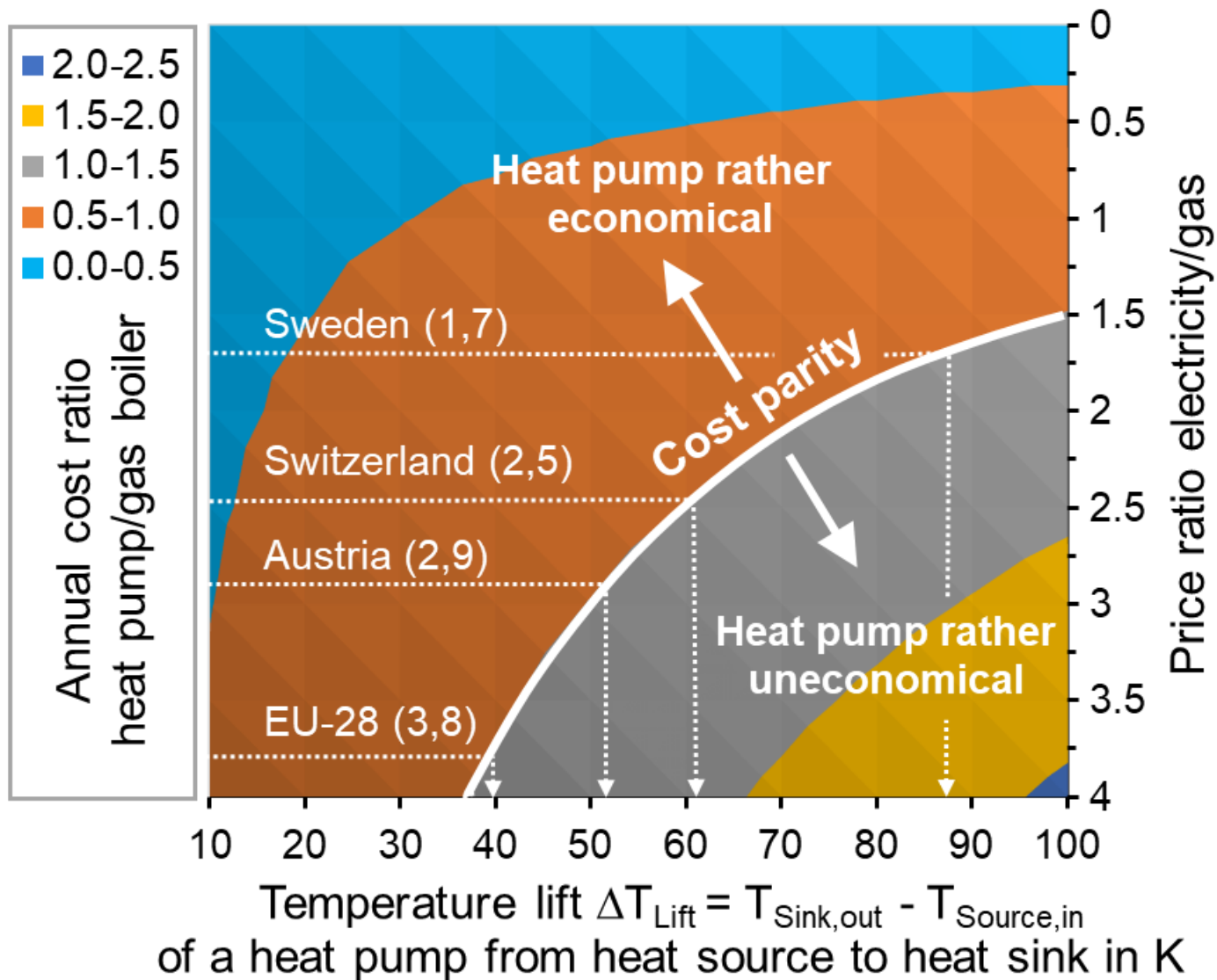
Market challenge – price ratio electricity to gas

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

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



Economic evaluation – heat pump vs. gas boiler



Parity of annual costs
with a heat pump and a gas boiler

Assumptions:	Heat pump	Gas boiler
Investment costs:	420 EUR/kW	60 Euro/kW
Interest on capital:	5%	5%
Useful life:	15 years	15 years
Annuity:	40.5 EUR/kW	5.8 EUR/kW
Maintenance costs:	2.5%	3% (Investition)
	15 EUR/kW	4,2 EUR/kW
2 nd law efficiency (η_{HP}): ¹⁾	45%	
Gas boiler efficiency (η_{Boiler}):		80%
Operating hours: ²⁾	3'504 h/year	3'504 h/year
Gas price: ³⁾		0,0301 Euro/kWh

¹⁾ $\text{COP}_H = \eta_{\text{HP}} \cdot T_{\text{Sink,out}} / \Delta T_{\text{Lift}}$; $T_{\text{Sink,out}} = 393,15$ (120°C)
²⁾ 40% x 365 days x 24 h = 3'504 h
³⁾ Eurostat, EU-28, 2016

Source: Arpagaus (2018)

Application examples

HOT WATER

HOT AIR

STEAM

- **Hot water generation for washing and cleaning processes** (e.g. food, meat, bottles, wine tanks, product washing) in combination with cooling generation
- **Hot air generation and air preheating for drying processes** (e.g. starch, pet food) by waste heat recovery
- **Process steam generation** (i.e. low pressure steam) **for the sterilization and pasteurization of food** (e.g. milk, fruit juice) using cooling water or humid exhaust air

Temperature levels of processes in the food industry

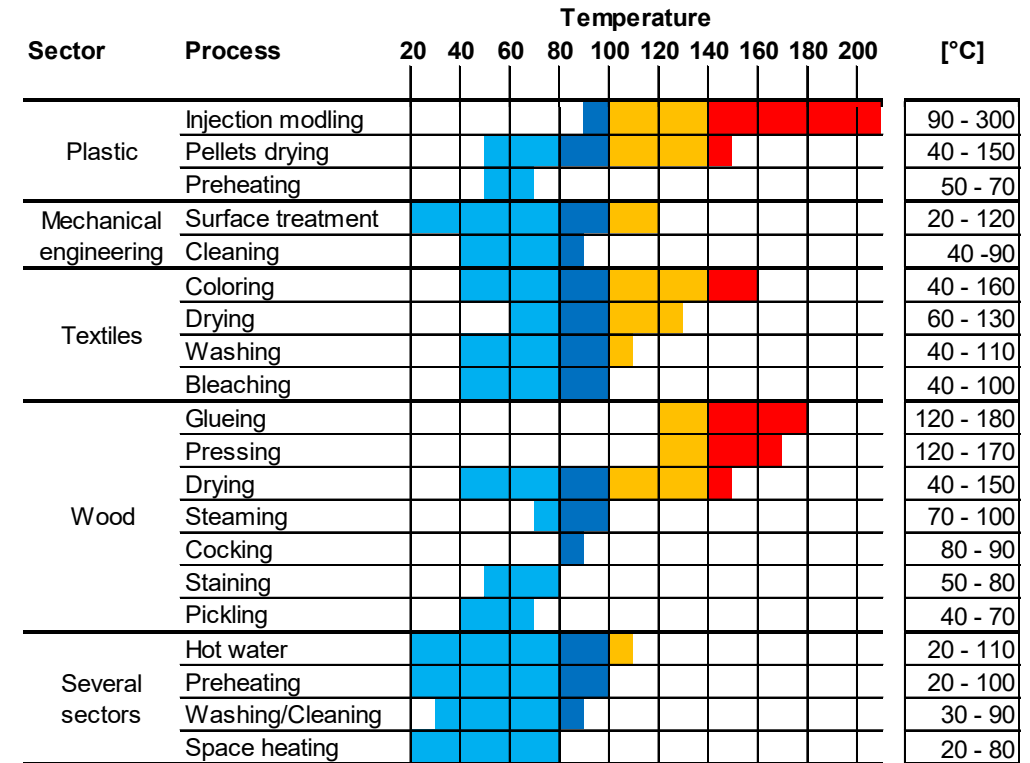
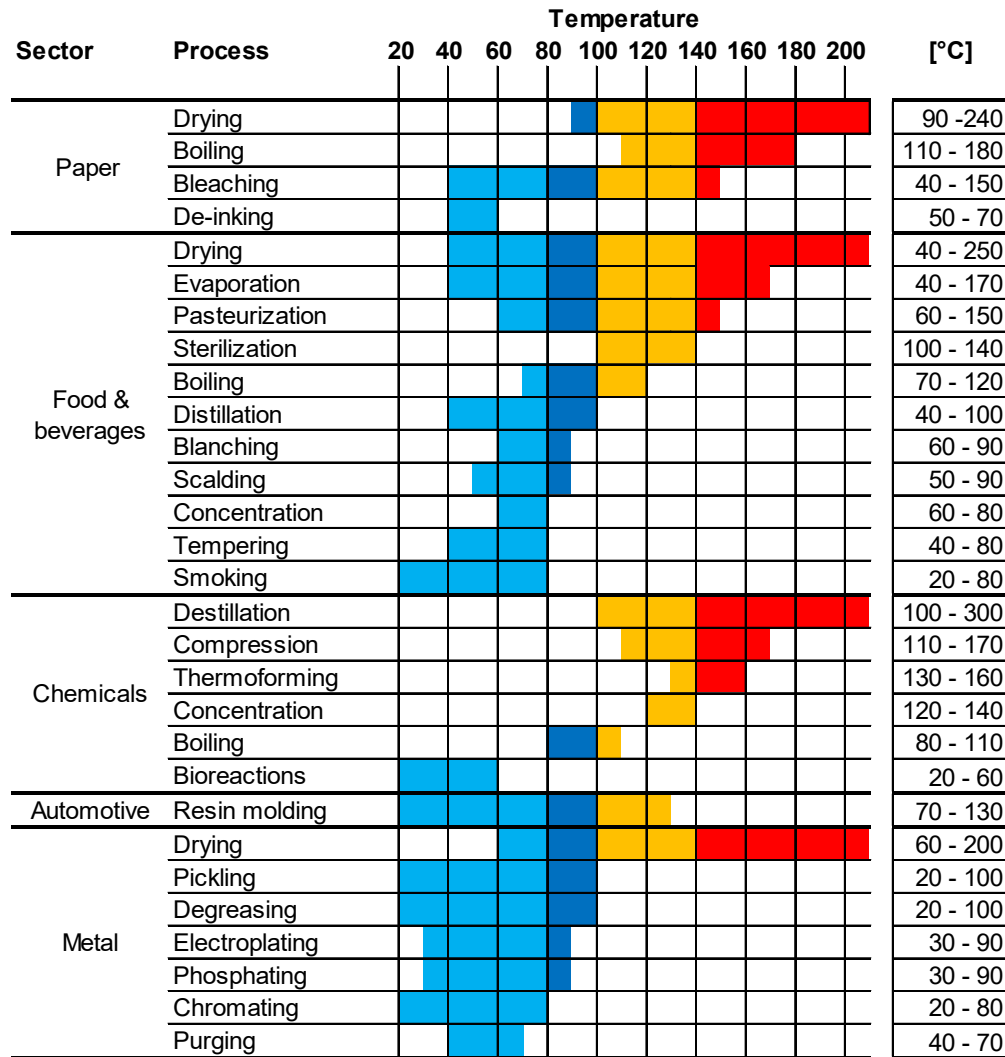


Sector	Process	Temperature										
		20	40	60	80	100	120	140	160	180	200	
Food & beverages	Drying											
	Evaporation											
	Pasteurization											
	Sterilization											
	Boiling											
	Distillation											
	Blanching											
	Scalding											
	Concentration											
	Tempering											
	Smoking											

Technology Readiness Level (TRL):

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

Temperature levels of industrial processes



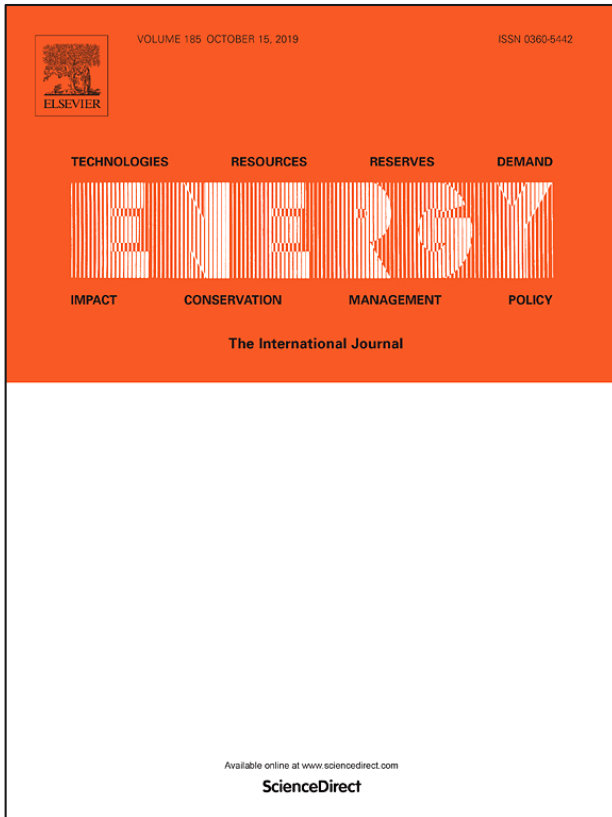
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Data sources: Brunner et al. (2007), Hartl et al. (2015), IEA (2014), Kalogirou (2003), Lambauer et al. (2012), Lauterbach et al. (2012), Noack (2016), Ochsner (2015), Rieberer et al. (2015), Watanabe (2013), Weiss (2007, 2005), Wolf et al. (2014)

Further literature

Arpagaus C., Bless F., Uhlmann M., Schiffmann J., Bertsch S.S.: **Review - High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials**, Energy, 2018, 152, 985-1010



Book «Hochtemperatur-Wärmepumpen»
(in German), Link: <https://www.vde-verlag.de/buecher/494550/hochtemperatur-waermepumpen.html>



Thank you for your attention!



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