SCCER EFFICIENCY OF INDUSTRIAL PROCESSES

WP2 – ENERGY EFFICIENCY (DIRECT)

Future Focus

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WP2- Future Focus

SCCER EFFICIENCY OF INDUSTRIAL PROCESSES

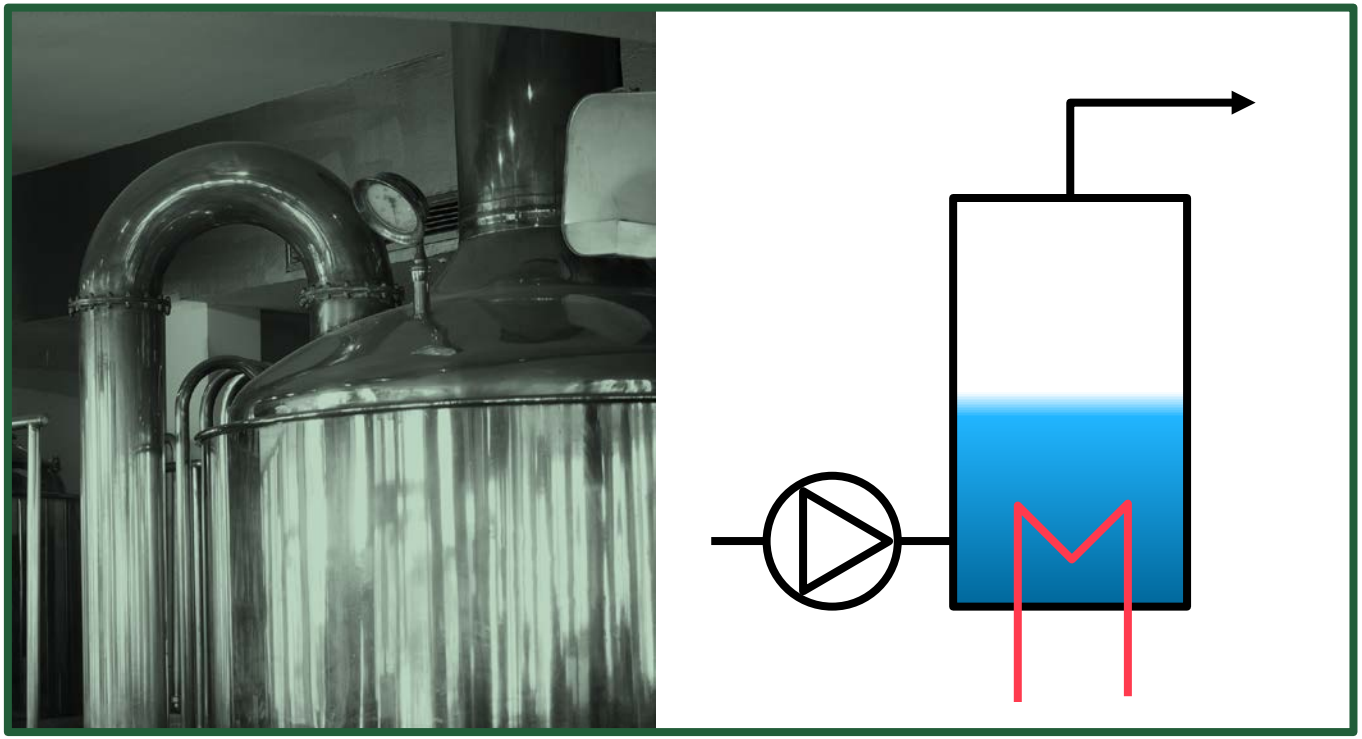
- Steam generation
  - Frédéric Bless, NTB
- High temperature heat pumps
  - Cordin Arpagaus, NTB

WP2- Future Focus

- Steam generation
- USAGE:
  - Heating
  - Distillation
  - Food drying
  - Carbon activation
  - ...

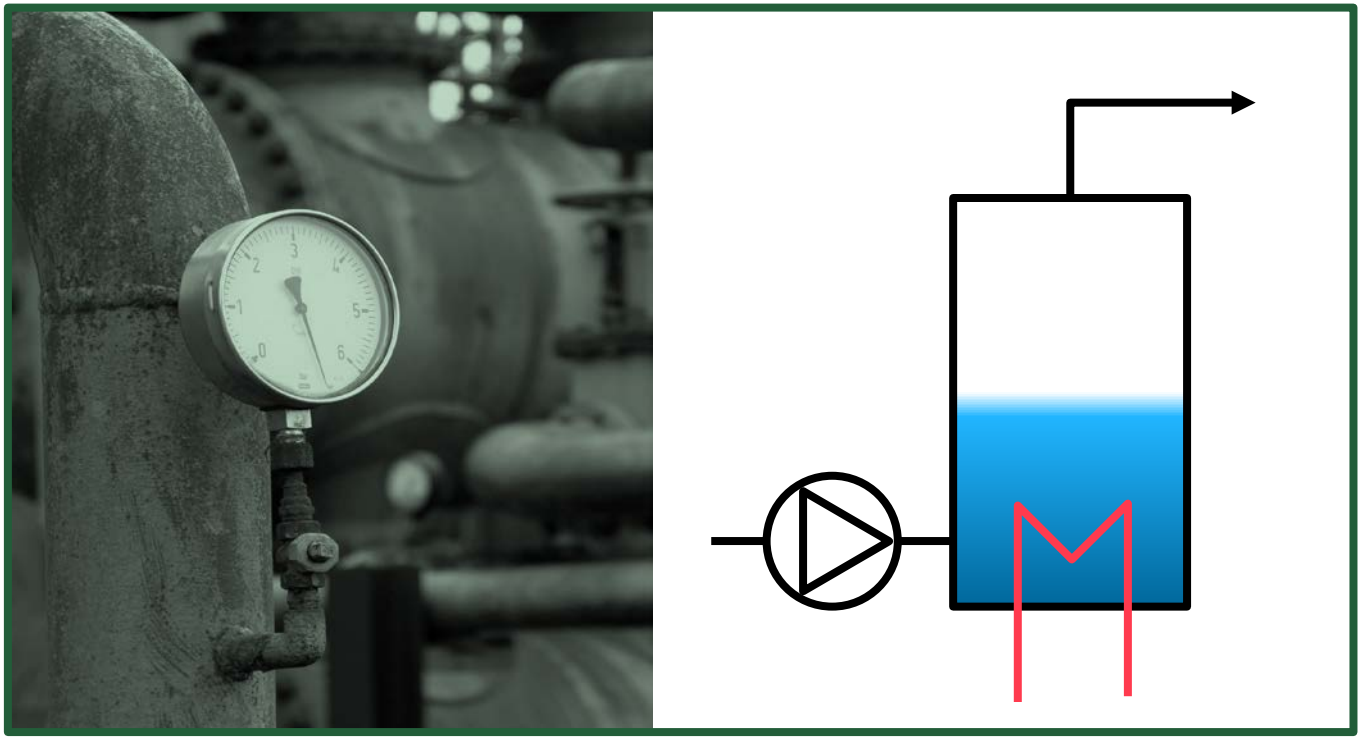
WP2- Future Focus

- Steam generation
- PROCESS: **BOILER**
  - Gas, oil, electricity
  - Efficient



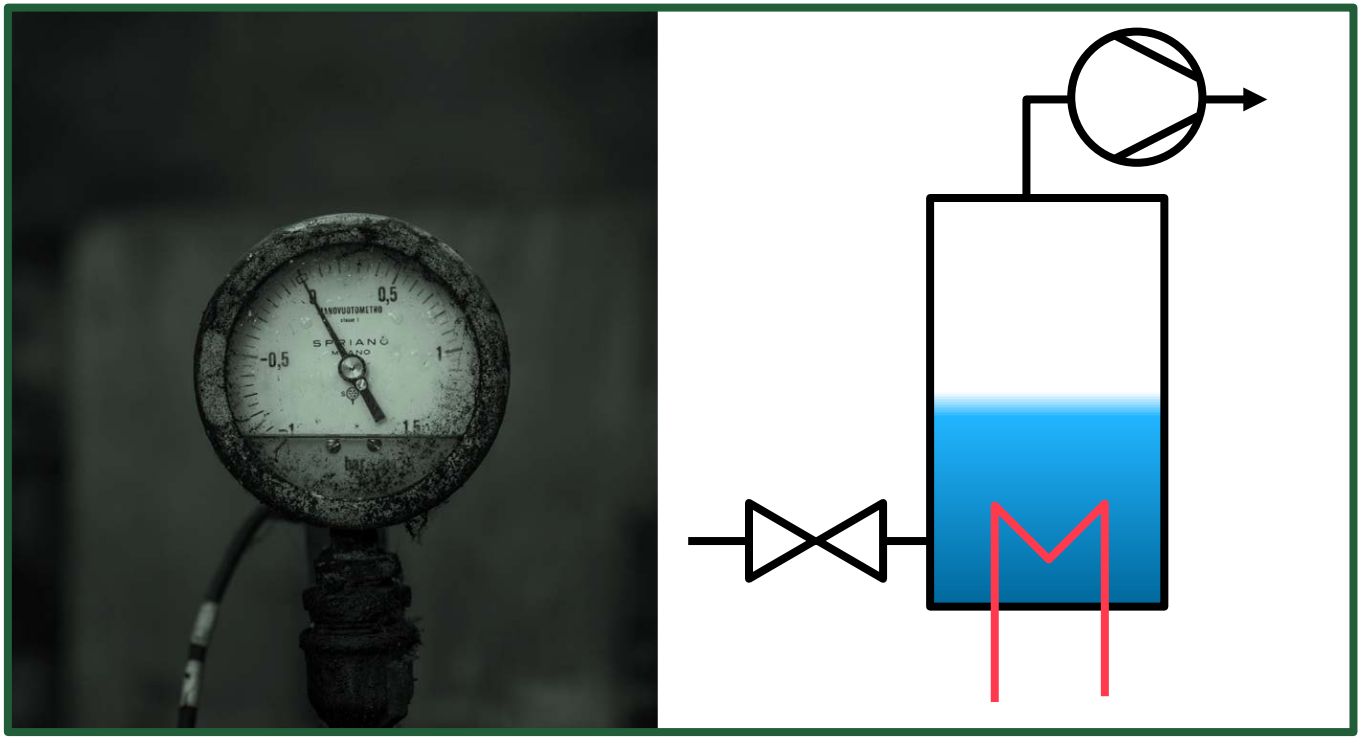
WP2- Future Focus

- Steam generation
- PROCESS: **HIGH TEMPERATURE HEAT PUMP**
  - COP ~ 1 (with heat source of 18°C)



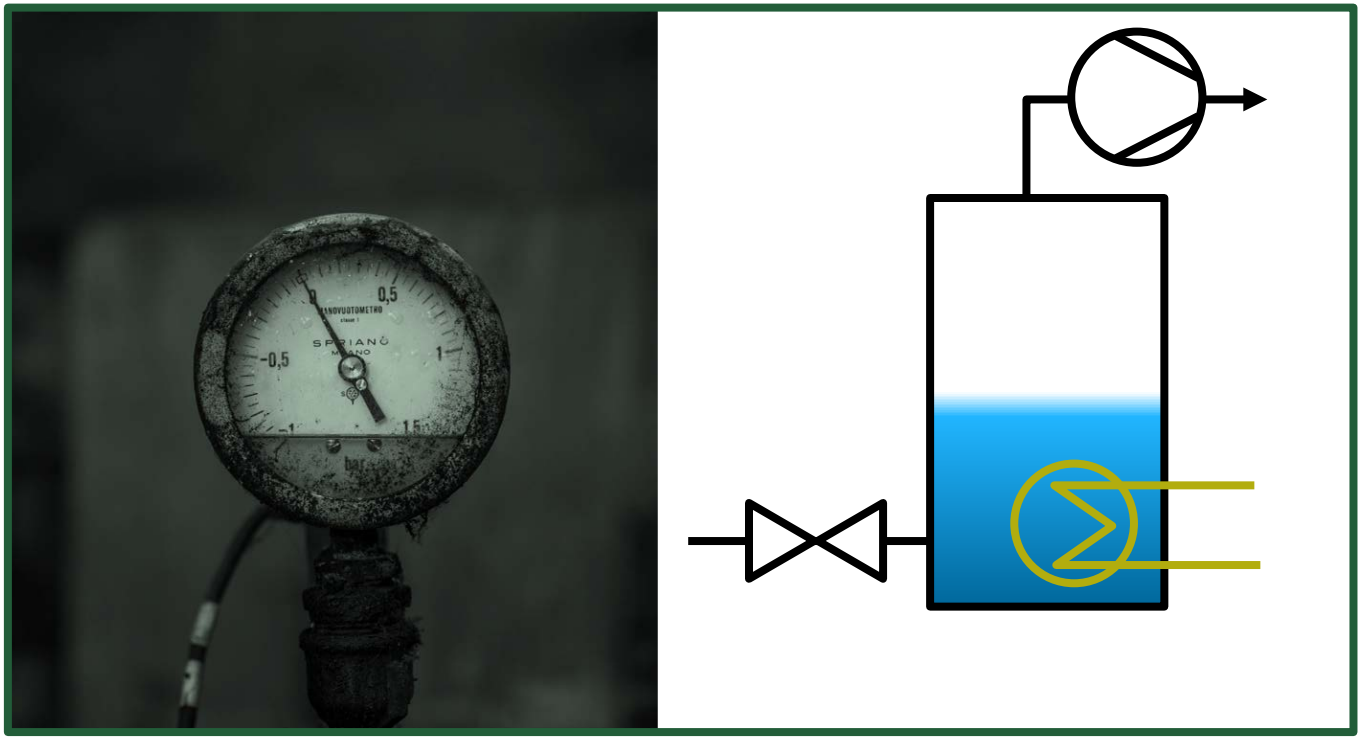
WP2- Future Focus

- Steam generation
- PROCESS: **STANDARD HEAT PUMP**
  - Low pressure



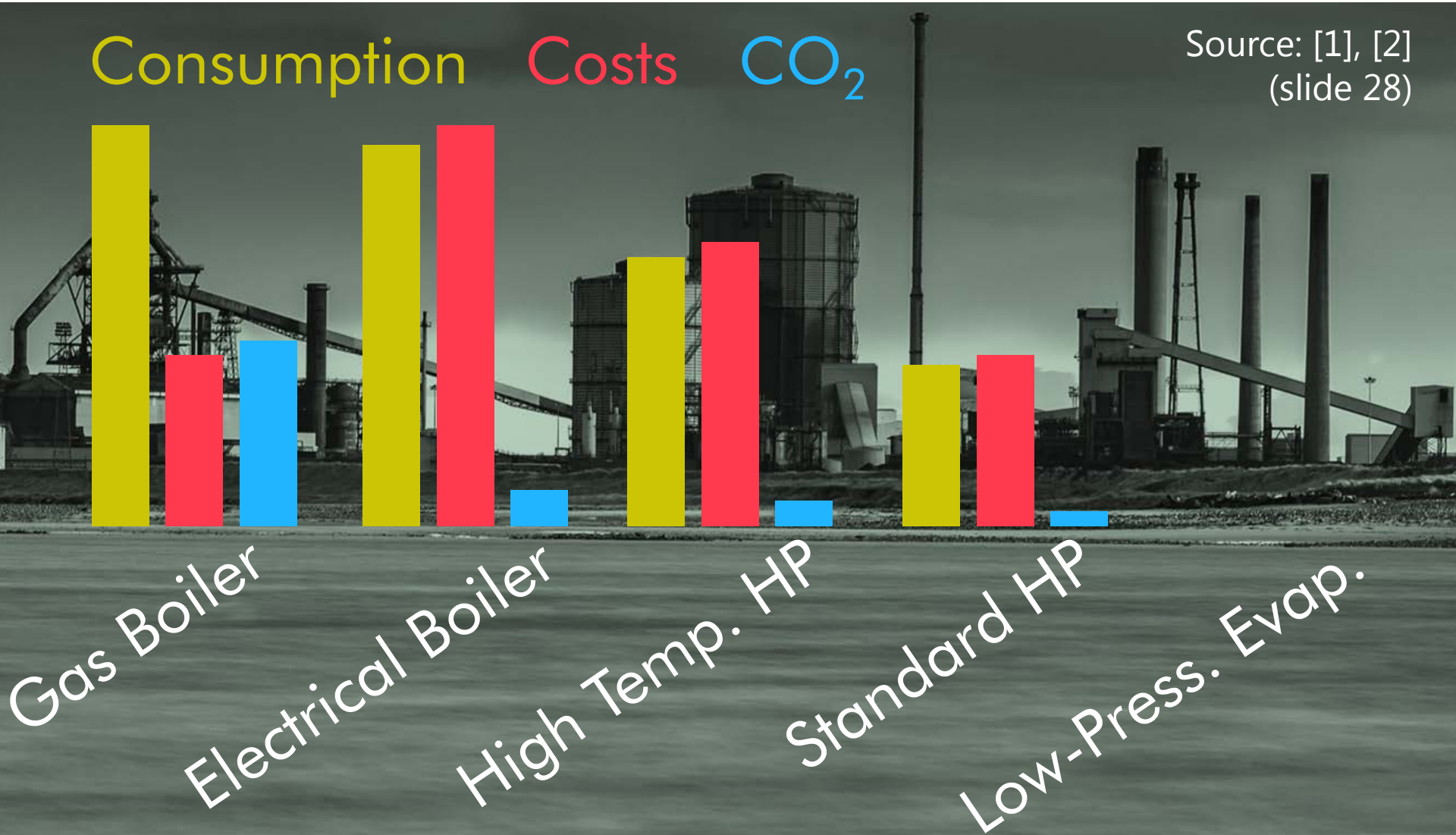
WP2- Future Focus

- Steam generation
- PROCESS: **LOW-PRESSURE EVAPORATION**
  - Low pressure
  - Using waste heat as heat source



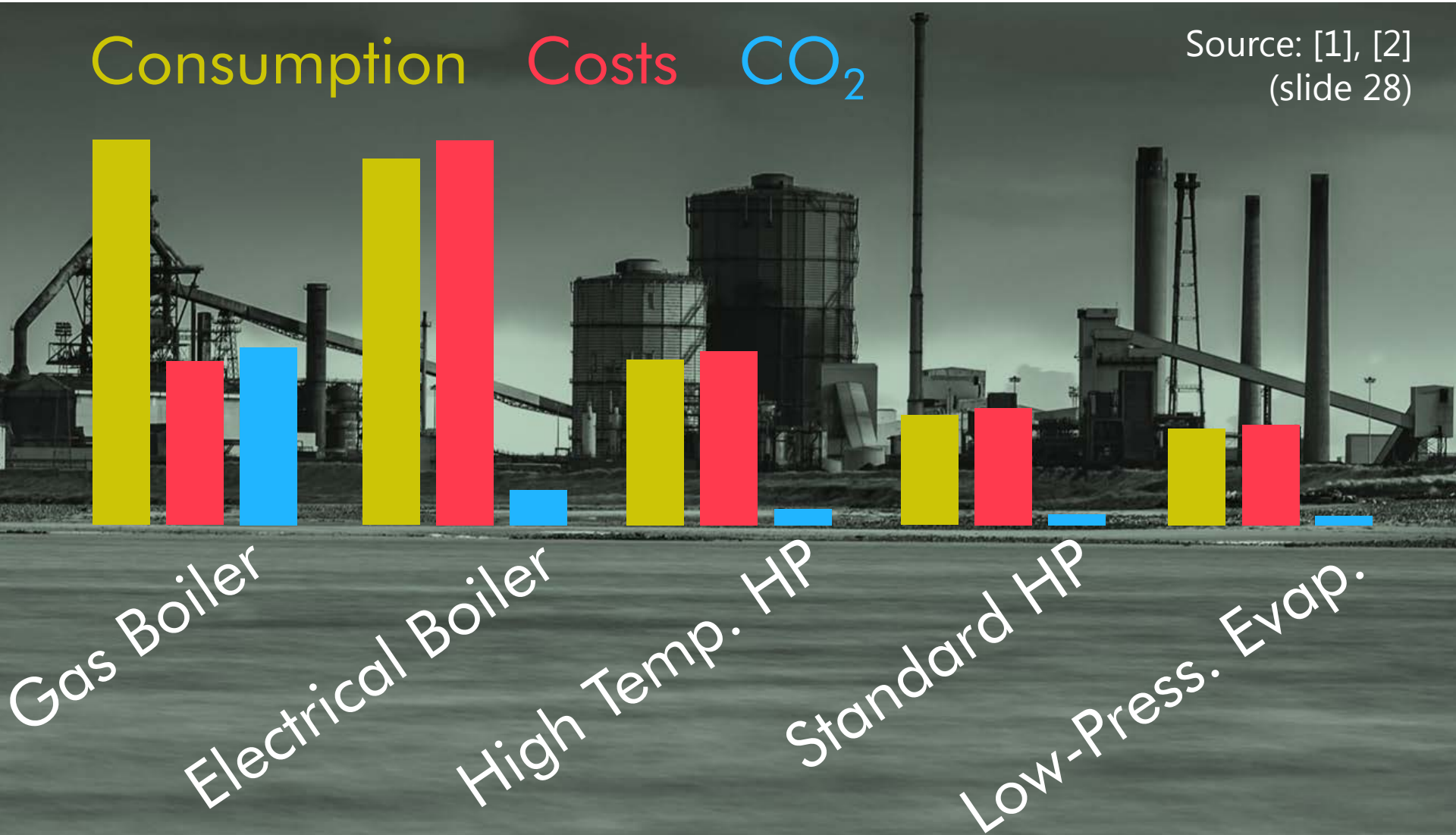
WP2- Future Focus

- Steam generation: RESULTS



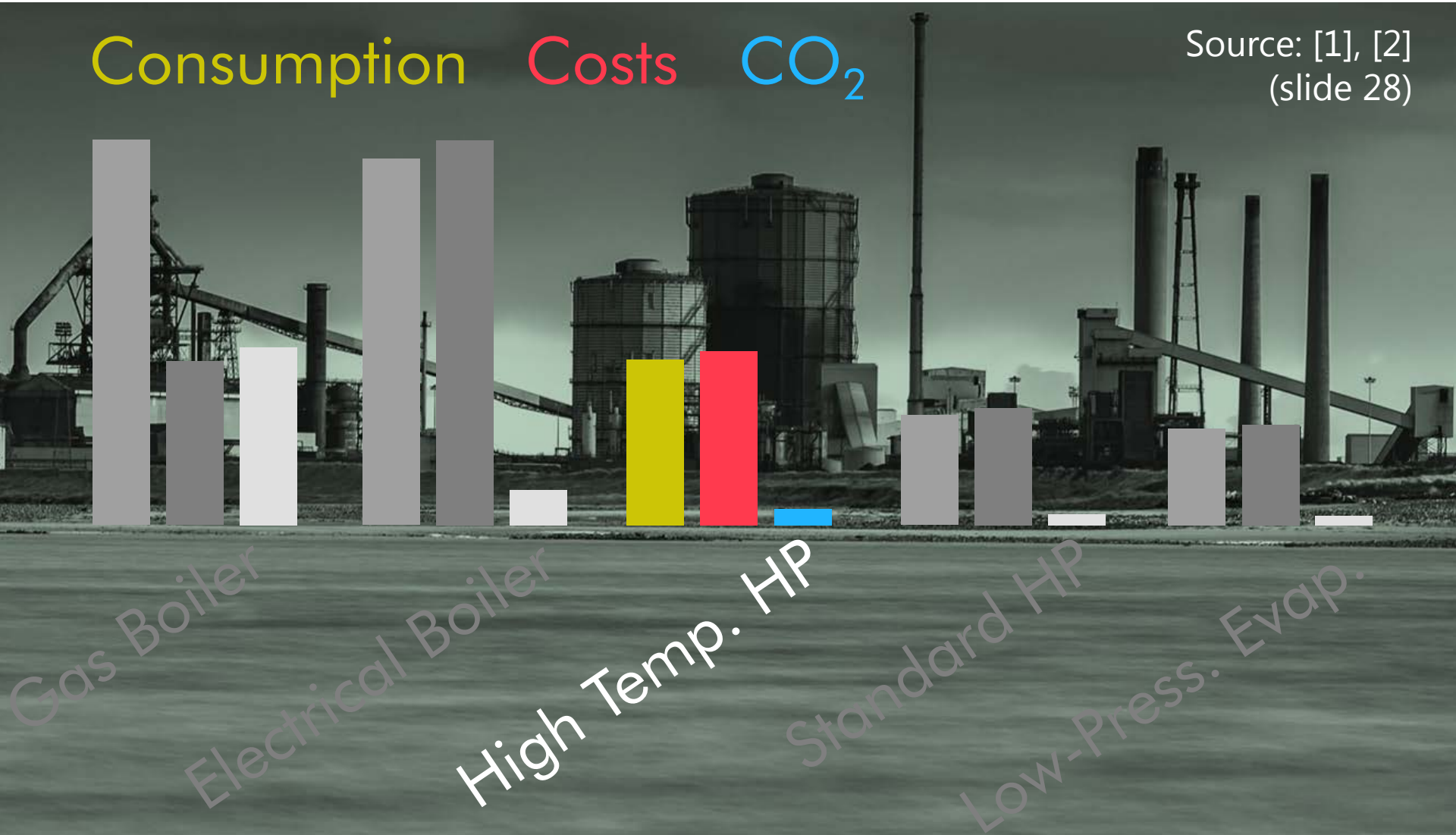
WP2- Future Focus

- Steam generation: RESULTS + **55°C WASTE HEAT**



WP2- Future Focus

- HIGH-TEMPERATURE HEAT PUMP



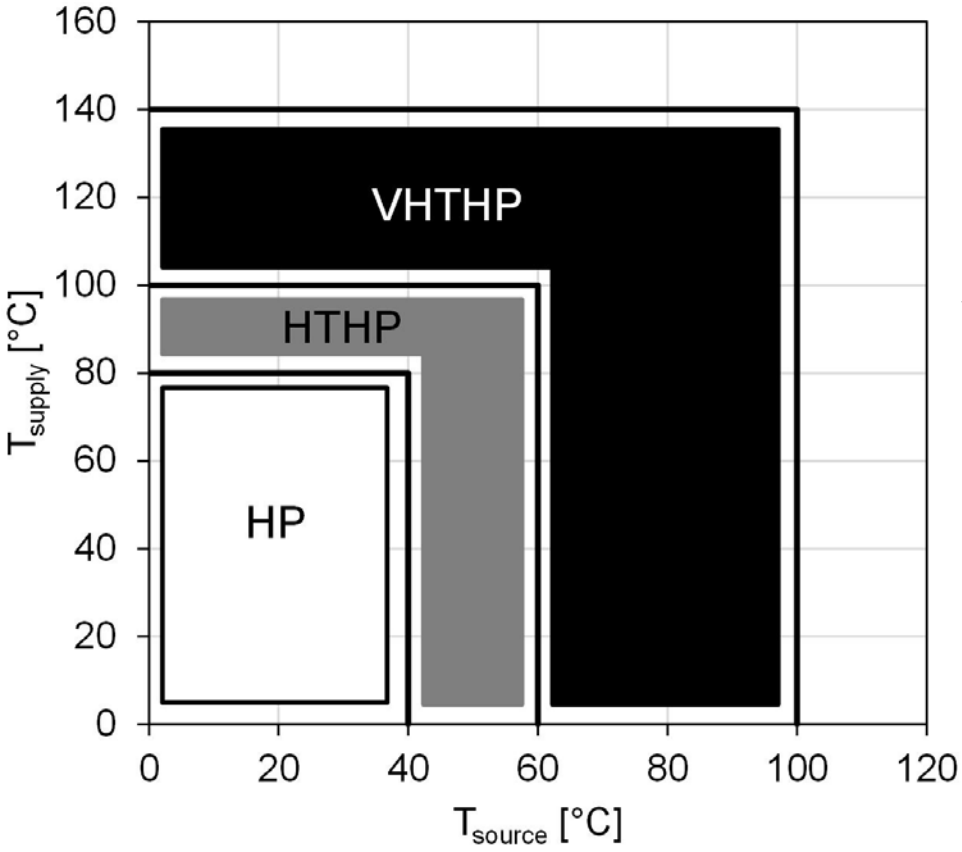
WP2- Future Focus

- HIGH TEMPERATURE HEAT PUMP

- Literature Review (Market Overview, Research Status, Refrigerants)
- Demonstrator (System Design, Experimental set-up)
- Future tasks (Review Paper, Conferences, Prototype Experiments)

WP2- Future Focus

- Development of temperature levels

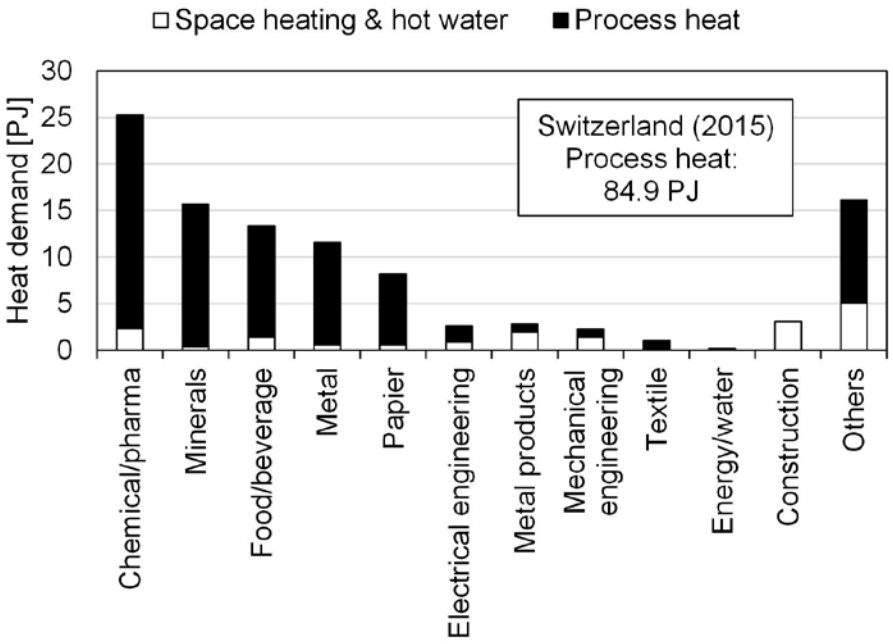


VHTHP: very high temperature heat pump
HTHP: high temperature heat pump
HP: conventional heat pump

(Bobelin et al., 2012; IEA, 2014a; Jakobs and Laue, 2015; Peureux et al., 2012, 2014)

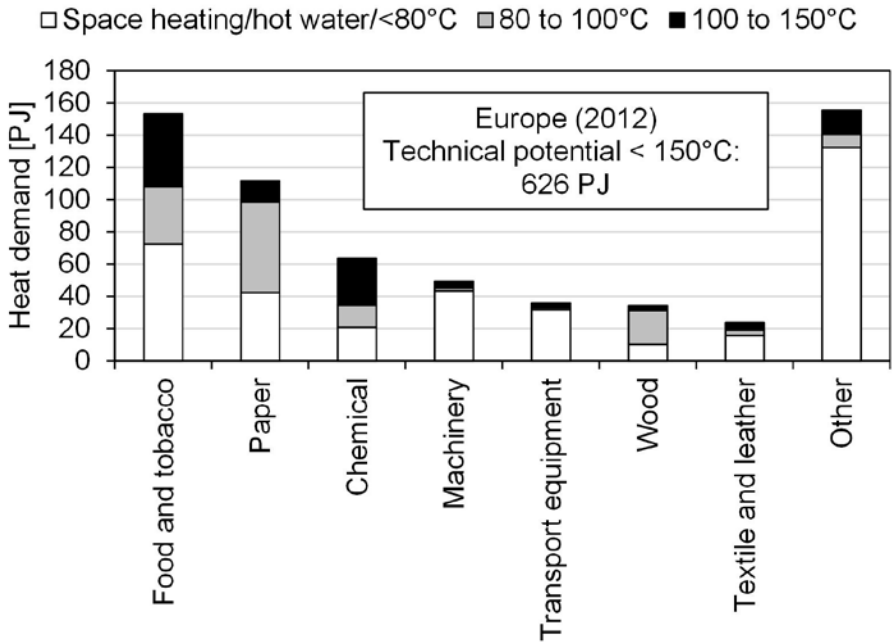
WP2- Future Focus

- Theoretical potential for HTHPs in Switzerland



(BFE, 2016; Pulfer and Spirig, 2014)

- Technical potential of process heat in Europe accessible with industrial heat pumps



(based on Eurostat data from 2012 of 33 countries, Nellissen and Wolf, 2015)

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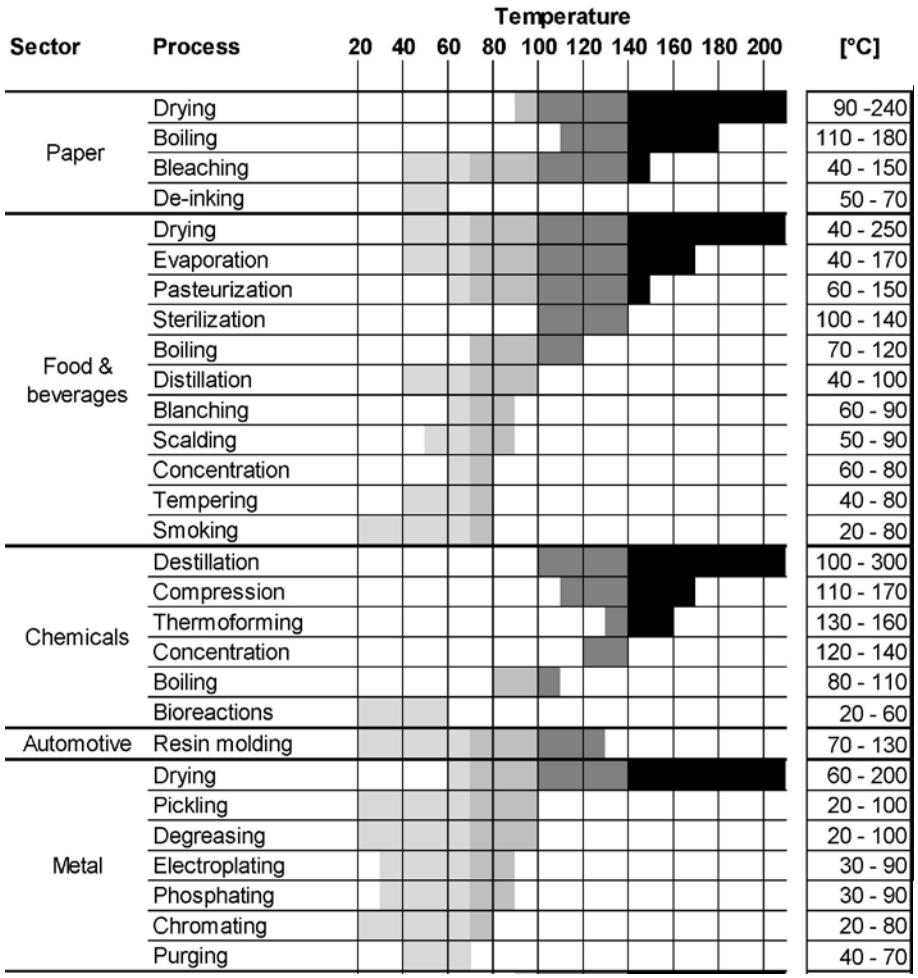
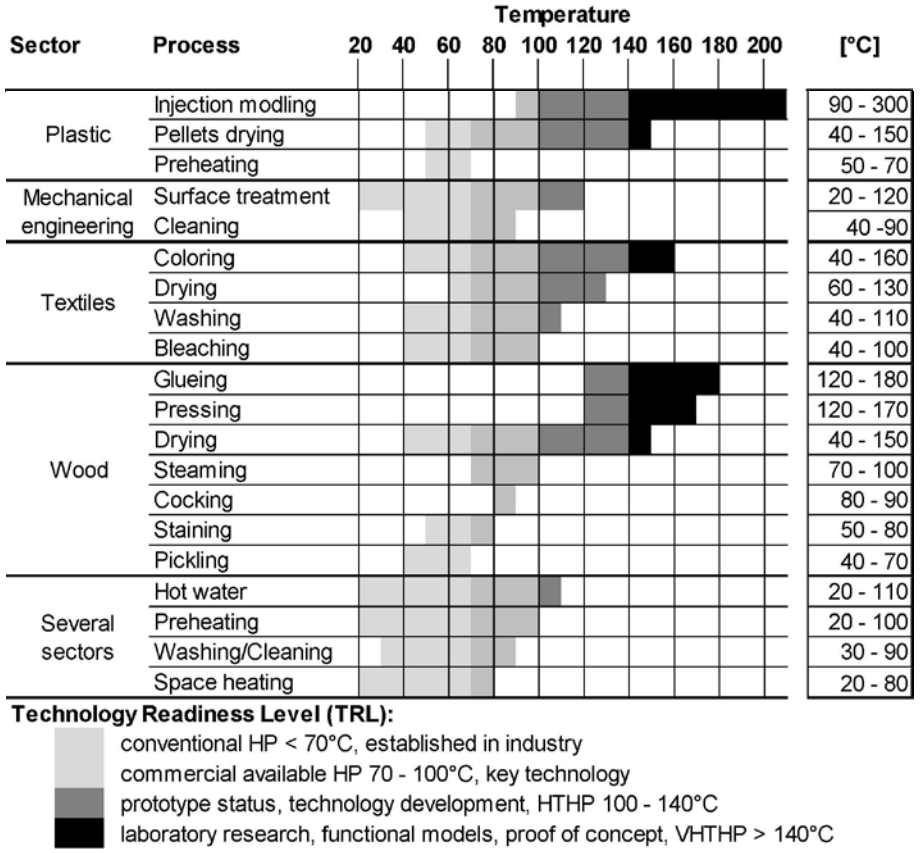
SCCER EIP EFFICIENCY OF INDUSTRIAL PROCESSES

- Overview of processes in different industrial sectors

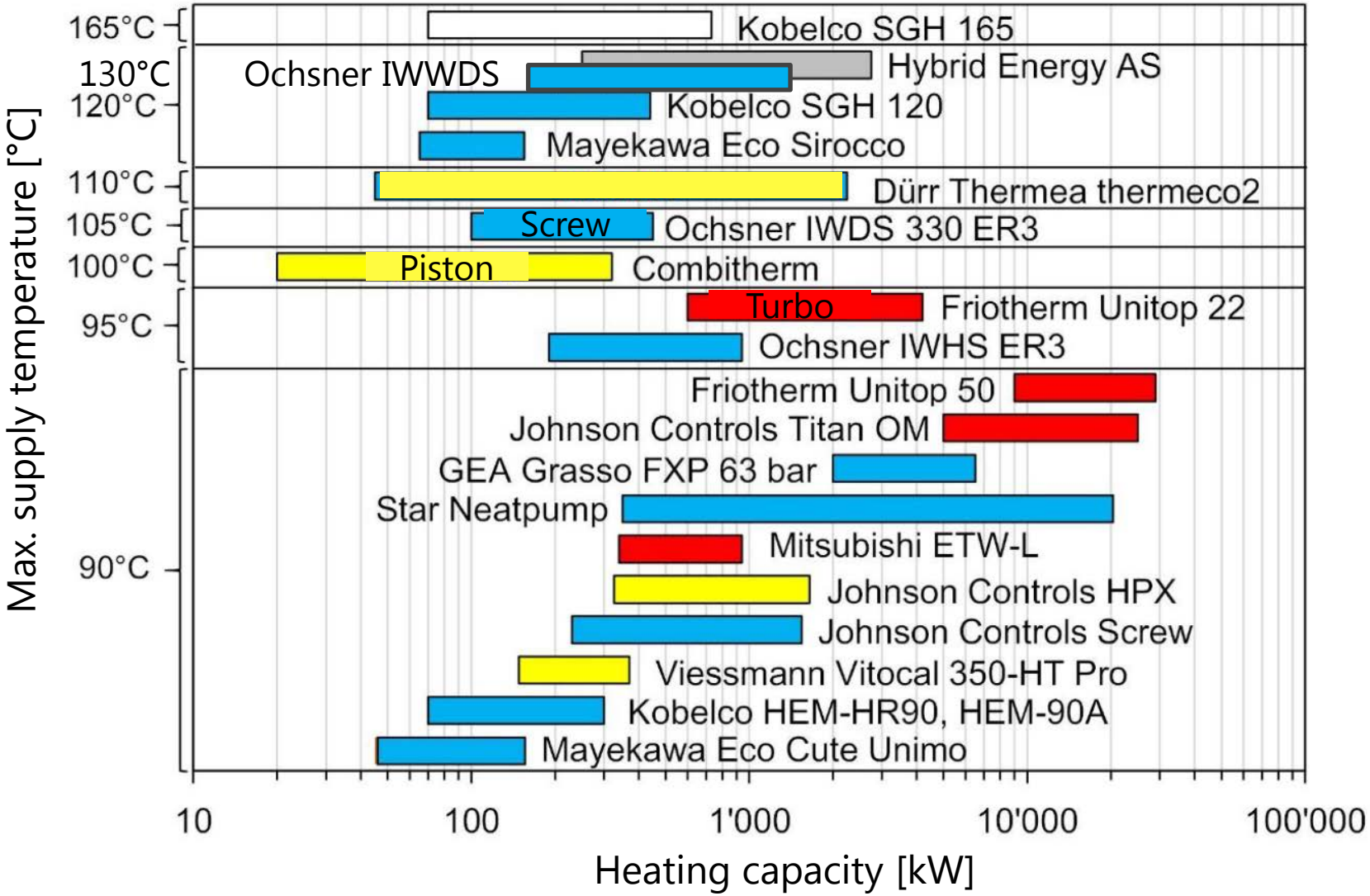




(Brunner et al., 2007; Hartl et al., 2015; IEA, 2014b; Kalogirou, 2003; Lambauer et al., 2012; Lauterbach et al., 2012; Noack, 2016; Ochsner, 2015; Rieberer et al., 2015; Watanabe, 2013; Weiss, 2007, 2005; Wolf et al., 2014)

WP2- Future Focus

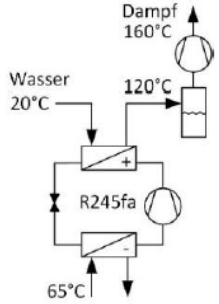
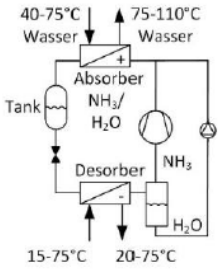
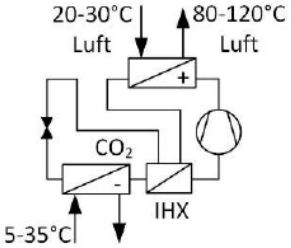
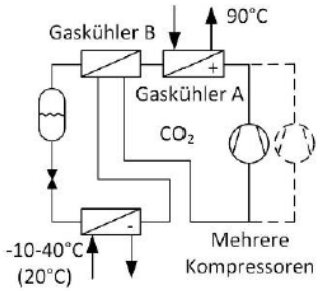
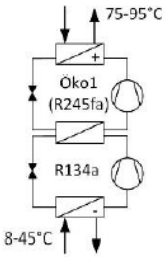
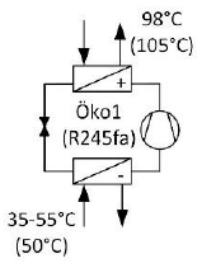
- Market overview of HTHPs with supply temperatures >90°C



WP2- Future Focus

SCCER EIP EFFICIENCY OF INDUSTRIAL PROCESSES

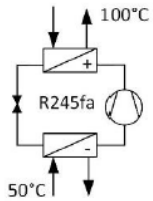
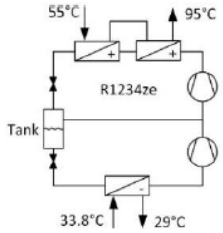
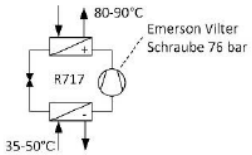
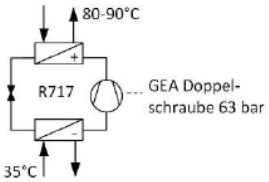
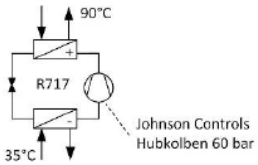
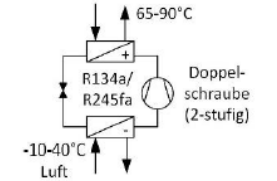
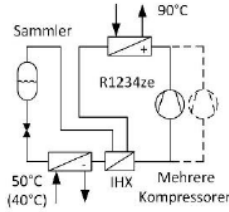
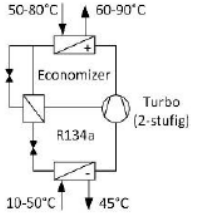
- Commercial HTHPs

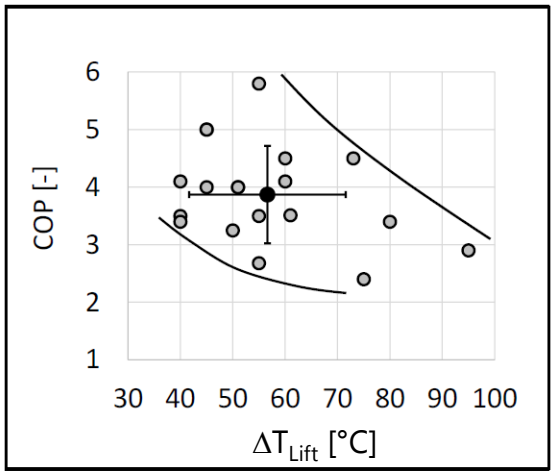
Kobelco SGH 120 / 165  (IEA, 2014a; Kaida et al., 2015; Kuromaki, 2012; Watanabe, 2013)	 T_Q/T_S (ΔT) / COP 65/120 (55) / 3.5	Hybrid Heat Pump[20]  (Jensen et al., 2015a, 2015b)	 T_Q/T_S (ΔT) / COP 20/95 (75) / 2.4 40/100 (60) / 4.5
Mayekawa transkritische CO_2 Wärmepumpe Eco Sirocco  (IEA, 2014a; Mayekawa, 2010; Watanabe, 2013)	 T_Q/T_S (ΔT) / COP 20/100 Luft (80) / 3.4 25/120 H_2O (95) / 2.9	Thermeco$_2$ HHR1000[21] mit 6 Hubkolbenverdichter, bis 1100 kW  (Dürr thermea GmbH, 2016; IEA, 2014a; Thermea, 2012)	 T_Q/T_S (ΔT) / COP 20/80 (60) / 3.9-4.3
Ochsner IWHS 400 ER3 Schraube, 380 kW  (Ochsner, 2015)	 T_Q/T_S (ΔT) / COP 45/90 (45) / 4.0	Ochsner IWDS 330 ER3 Schraube, 312 kW  (Zauner, 2016)	 T_Q/T_S (ΔT) / COP 50/105 (55) / 2.68

WP2- Future Focus

SCCER EIP EFFICIENCY OF INDUSTRIAL PROCESSES

- Commercial HTHPs

Combitherm[22]  (Blesl et al., 2014; Wolf et al., 2014)	 T_Q/T_S (ΔT) / COP 50/100 (50) / 3.1-3.4	Friotherm Unitop 22/22 3'300 kW, 2-stufiger Turbo  (Friotherm AG, 2005; Wojtan, 2016)	 (ΔT in °C) / COP 34/95 (61) / 3.51
Star Refrigeration Neatpump[23] NP601 380 kW bis 2.6 MW, Vilter VSSH Schraube 76 bar  (EMERSON, 2012)	 T_Q/T_S (ΔT) / COP 50/90 (40) / 3-4 35/80 (45) / 5 39/90 (51) / 4	GEA Grasso FX P Heat Pump[24] Doppelschraube 63 bar  (Dietrich and Fredrich, 2012)	 T_Q/T_S (ΔT) / COP 35/80 (45) / 5.0
Johnson Controls SABROE HeatPAC™-HPX[25] Hubkolben 60 bar  (Johnson Controls, 2017)	 T_Q/T_S (ΔT) / COP 39/90 (51) / 4.0	Kobelco HEM-HR90 Doppelschraube (2-stufig)  (Kuromaki, 2012; Oue and Okada, 2013)	 T_Q/T_S (ΔT) / COP 17/90 (73) / 4.5 35/90 (55) / 5.8
Viessmann Vitocal 350-HT Pro[26]  (Viessmann, 2016)	 T_Q/T_S (ΔT) / COP 50/90 (40) / 3.4	Mitsubishi ETW-L[27]  (IEA, 2014a; Watanabe, 2013).	 T_Q/T_S (ΔT) / COP 50/90 (40) / 4.1



COP vs. temperature lift
for various industrial HTWPs
COP = 3.9 ± 0.8
ΔT_{Lift} = 57 ± 15 K

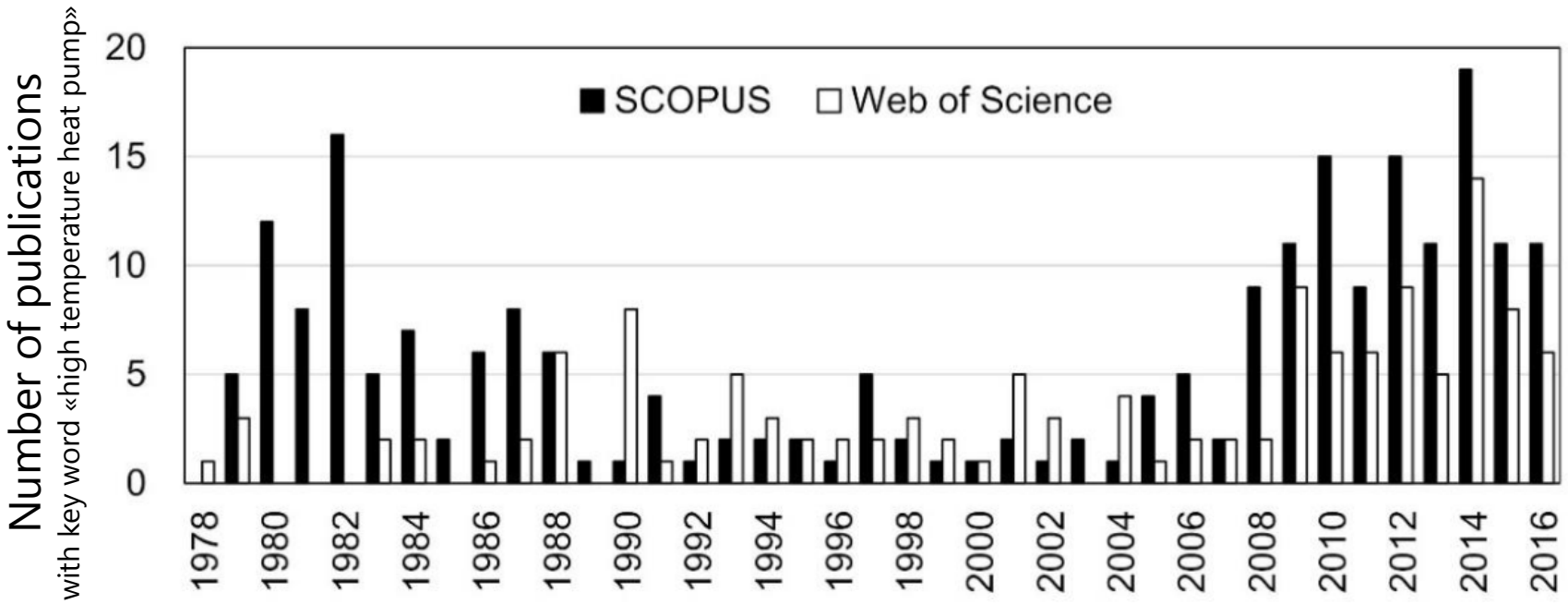
WP2- Future Focus

- Market overview – Conclusions

- **>20 HTHP models** with supply temperature >90°C identified from 12 manufacturers, Benchmark: Kobelco SGH120 and Mayekawa Eco Sirocco with 120°C
- **Heat source:** water, brine, waste heat or waste water (17 to 65°C)
- **COP:** 2.4 to 5.8 at a temperature lift of 40 to 95 K
- **Heating capacity:** from about 20 kW to 20 MW
- **Refrigerants:** R245fa, R717 (NH3), R744 (CO2), R134a, R1234ze(E)
- **Compressors:** 1- and 2-shaft screws, 2-stage turbochargers, reciprocating compressors (parallel)
- **Cycles:** usually 1-stage, optimization by IHX, parallel compressors, economizer, intermediate injection, 2-stage cascade (R134a/R245fa) or with a flash economizer

WP2- Future Focus

- Research activity on HTHPs



Number of publications with search key word «high temperature heat pump» in data bases SCOPUS (www.scopus.com) and Web of Science (www.webofknowledge.com).

WP2- Future Focus

SCCER EIP EFFICIENCY OF INDUSTRIAL PROCESSES

- Experimental research projects of HTHPs

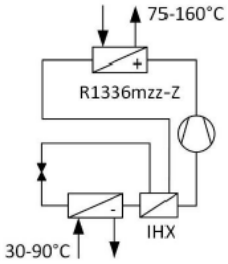
Organisation, Projektpartner	Kreislauf	Kompressor	Kältemittel	Quellen- und Senkentemperatur [°C]	Heizleistung [kW]	Referenz
				20 40 60 80 100 120 140 160		
Austrian Institute of Technology (AIT), Wien, Chemours, Bitzer	IHX	Hubkolben	R1336mzz-Z		12	(Helminger et al., 2016)
Austrian Institute of Technology (AIT), Wien, Chemours, Bitzer	1-stufig	Hubkolben	R1336mzz-Z		12	(Fleckl et al., 2015a, 2015b)
PACO, University Lyon, EDF Electricité de France	Flash Tank	Doppelschraube	H_2O (Wasser)		300	(Chamoun et al., 2014, 2013, 2012a, 2012b)
Institut für Luft- und Kältetechnik (ILK), Dresden	1-stufig	n.v.	HT 125		12	(Noack, 2016)
Friedrich-Alexander Universität Erlangen-Nürnberg, Siemens	IHX	Hubkolben	LG6		10	(Reißner, 2015; Reißner et al., 2013a, 2013b)
Alter ECO, EDF Electricité de France	IHX und Unterkühler	Doppel Scroll	ECO3 (R245fa)		50-200	(Bobelin et al., 2012; IEA, 2014a)
Tokyo Electric Power Company, Japan	1-stufig	Schraube	R601		150-400	(Yamazaki and Kubo, 1985)
Austrian Institute of Technology (AIT), Wien, Edtmayer, Ochsner	Economizer	Schraube	ÖKO1 (R245fa)		250-400	(Wilk et al., 2016b)
Kyushu University, Fukuoka, Japan	1-stufig	Doppelrotations-kompressor (2-stufig)	R1234ze(Z)		1.8	(Fukuda et al., 2014)
Johnson Controls, EDF Electricité de France	Economizer und IHX	Doppelschraube Zentrifugal Turbo	R245fa		300-500 900-1'200	(IEA, 2014a)

WP2- Future Focus

SCCER EIP EFFICIENCY OF INDUSTRIAL PROCESSES

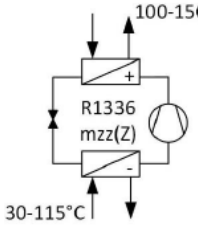
- Heat pump cycles and COPs

(Helminger et al., 2016)
12 kW, mit IHX, Hubkolben



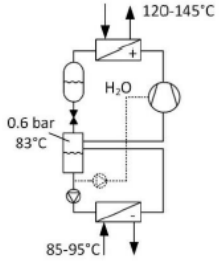
	COP
ΔT=35°C	4.7-5.8
ΔT=70°C	2.6-3.4

(Fleckl et al., 2015a, 2015b)
12 kW, Hubkolben



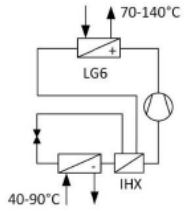
	COP
ΔT=35°C	4.2-5.8
ΔT=70°C	2.1-2.5

PACO(Chamoun et al., 2014, 2013, 2012a, 2012b)
300 kW, mit Flash Tank, Doppelschraube



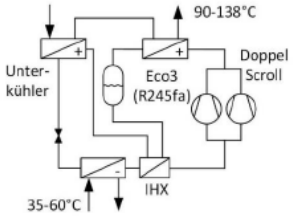
	COP
ΔT=27°C (94/121)	5.5
ΔT=55°C (75/130)	3.6

(Reißner, 2015; Reißner et al., 2013a, 2013b) 12 kW, mit IHX, Hubkolben



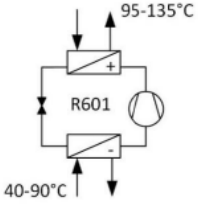
	COP
ΔT=30°C	3.6-6.0
ΔT=60°C	2.5-3.2

Alter ECO *(Bobelin et al., 2012; IEA, 2014a)* 50-200 kW, mit IHX und Unterkühler, Doppel Scroll



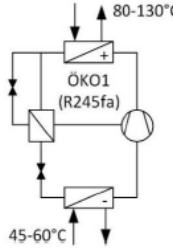
	COP
ΔT=35°C	6-7
ΔT=70°C	2-3

(Yamazaki and Kubo, 1985)
150-400 kW, Schraube



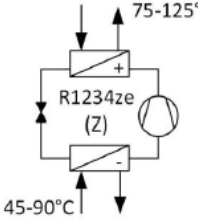
	COP
ΔT=40°C	6.4-7.0
ΔT=70°C	2.6-3.0

(Wilk et al., 2016b)
250-400 kW, mit Economizer, Schraube



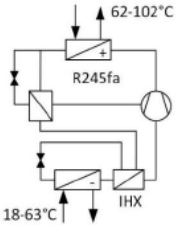
	COP
ΔT=35°C	3.6-3.9
ΔT=70°C	2.1-2.3

(Fukuda et al., 2014)
1.8 kW, Doppelrotations-kompressor (2-stufig)



	COP
ΔT=30°C	5.4-6.6

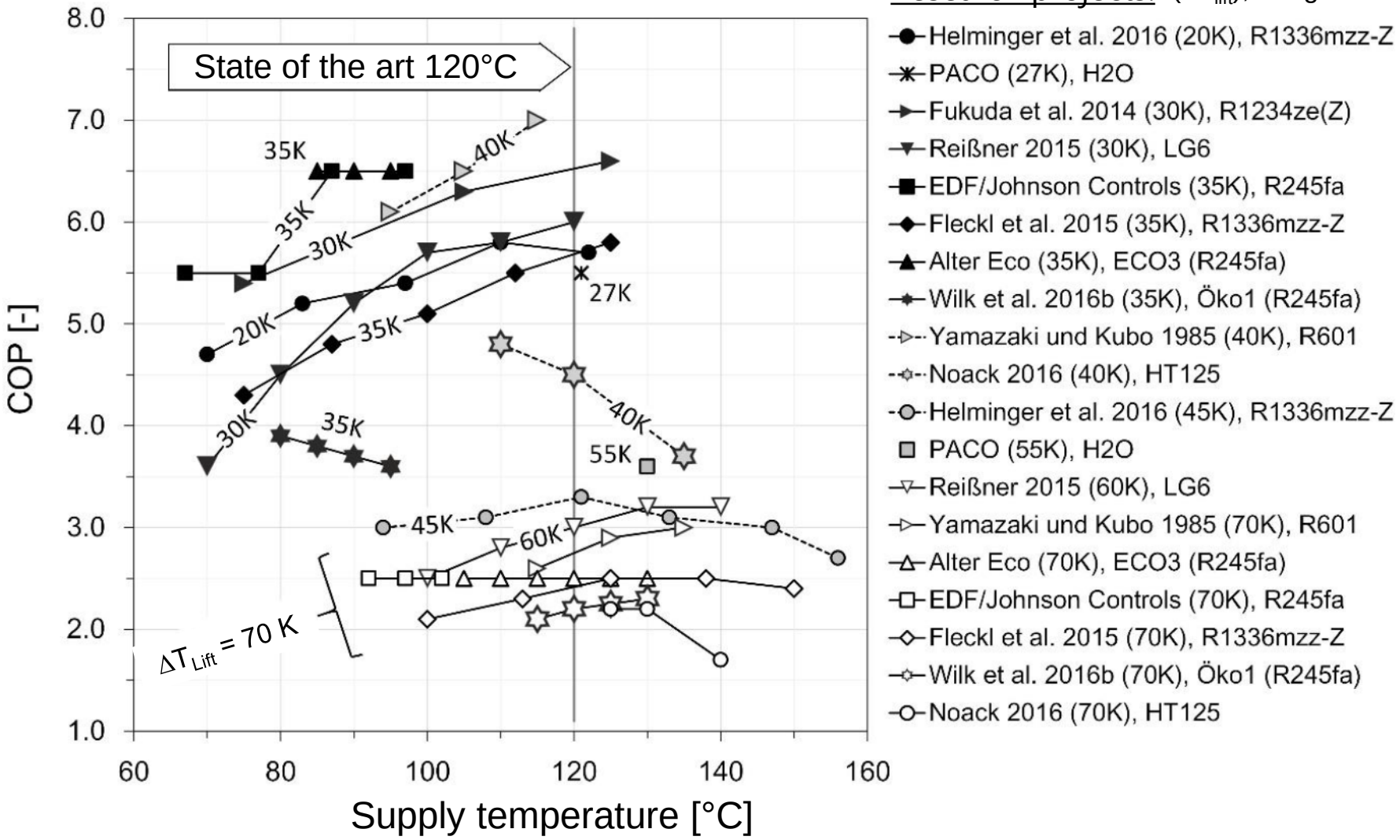
EDF/Johnson Controls (IEA, 2014a) mit Economizer und IHX, 300-500 kW, Doppelschraube, 900-1'200 kW, Zentrifugal



	COP
ΔT=35°C	5-7
ΔT=70°C	2-3

WP2- Future Focus

- COP vs. supply temperature at different temperature lifts



WP2- Future Focus

- Conclusions – Research status

- **Sink temperature up to 160°C** at AIT (Vienna), 1-stage with IHX and R1336mzz(Z)
- **10 research projects** reached > 100°C
- **Heating capacity:** laboratory scale 12 kW, larger prototypes >100 kW
- **COPs** (at 120°C supply temperature): 5.7 to 6.5 (30 K temperature lift), 2.2 to 2.8 (70 K)
- **Cycles:** all 1-stage, partly with IHX and/or economizer with intermediate injection
- **Refrigerants:** R1336mzz(Z), R718 (H2O), R245fa, R1234ze (Z), R601, LG6 (Siemens), ÖKO1 (contains R245fa, Ochsner), ECO3 (R245fa, Alter ECO), HT125 (ILK, Dresden)
- **Compressors:** reciprocating pistons in laboratory systems

WP2- Future Focus

- Refrigerants – selection criteria

Criteria	Required properties
Thermal suitability	High critical temperature, low critical pressure
Environmental	ODP = 0, low GWP, short atmospheric life
Safety	Non-toxic, non-combustible (safety group A1)
Efficiency	High COP, low pressure ratio, minimal overheat to prevent fluid compression, high volumetric capacity
Availability	Available in the market, low price
Other factors	Good solubility in oil, thermal stability of the refrigerant-oil mixture, lubricating properties at high temperatures, material compatibility with steel and copper

	T_krit	p_krit	ODP	GWP	SG	M
	[°C]	[bar]	[-]	[-]		[g/mol]
n-pentane	196.6	33.7	0	20	A3	72.2
R365mfc	186.9	32.7	0	804	A2	148.1
R123	183.7	37.0	0.02	77	B1	152.9
R1233zd(E)	166.5	36.2	0.0003	6	A1	130.5
Novec649	168.7	18.7	0	1	A1	316.0
R245fa	154.0	36.5	0	858	B1	134.0
R1234ze(Z)	150.1	35.3	0	<1	A2	114.0
R600	152.0	38.0	0	20	A3	58.1
Water	373.9	220.6	0	0	A1	18.0
R1336mzz-Z	171.3	29.0	0	9	A1	164.1

WP2- Future Focus

- Concept for HTHP laboratory prototype

HFO refrigerants

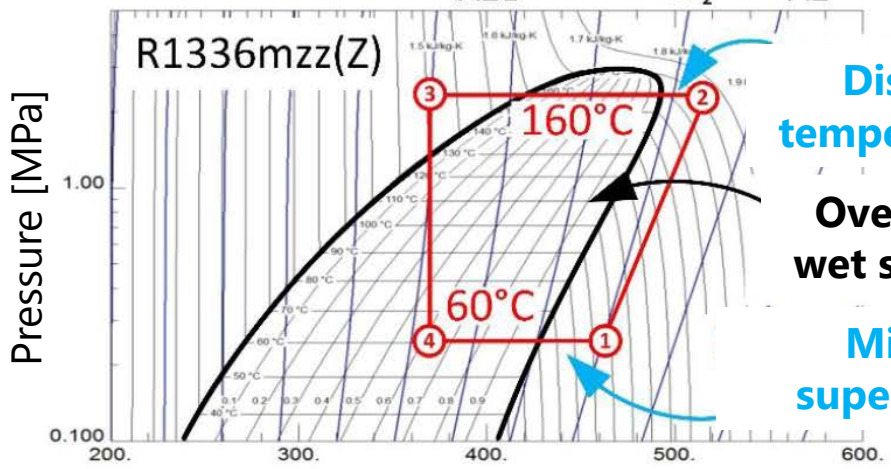
R1336mzz(Z) 171.3°C 29.0 bar A1

R1233zd(E) 166.5°C 36.2 bar A1

R1234ze(Z) 150.1°C 35.3 bar A2L

R1234ze(E) 109.4°C 36.4 bar A2L

R1234yf 94.7°C 33.8 bar A2



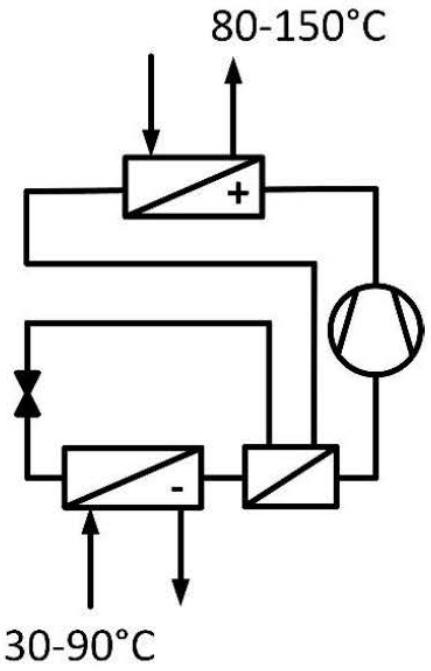
Discharge gas temperature control

Overhanging wet steam area

Minimal superheating

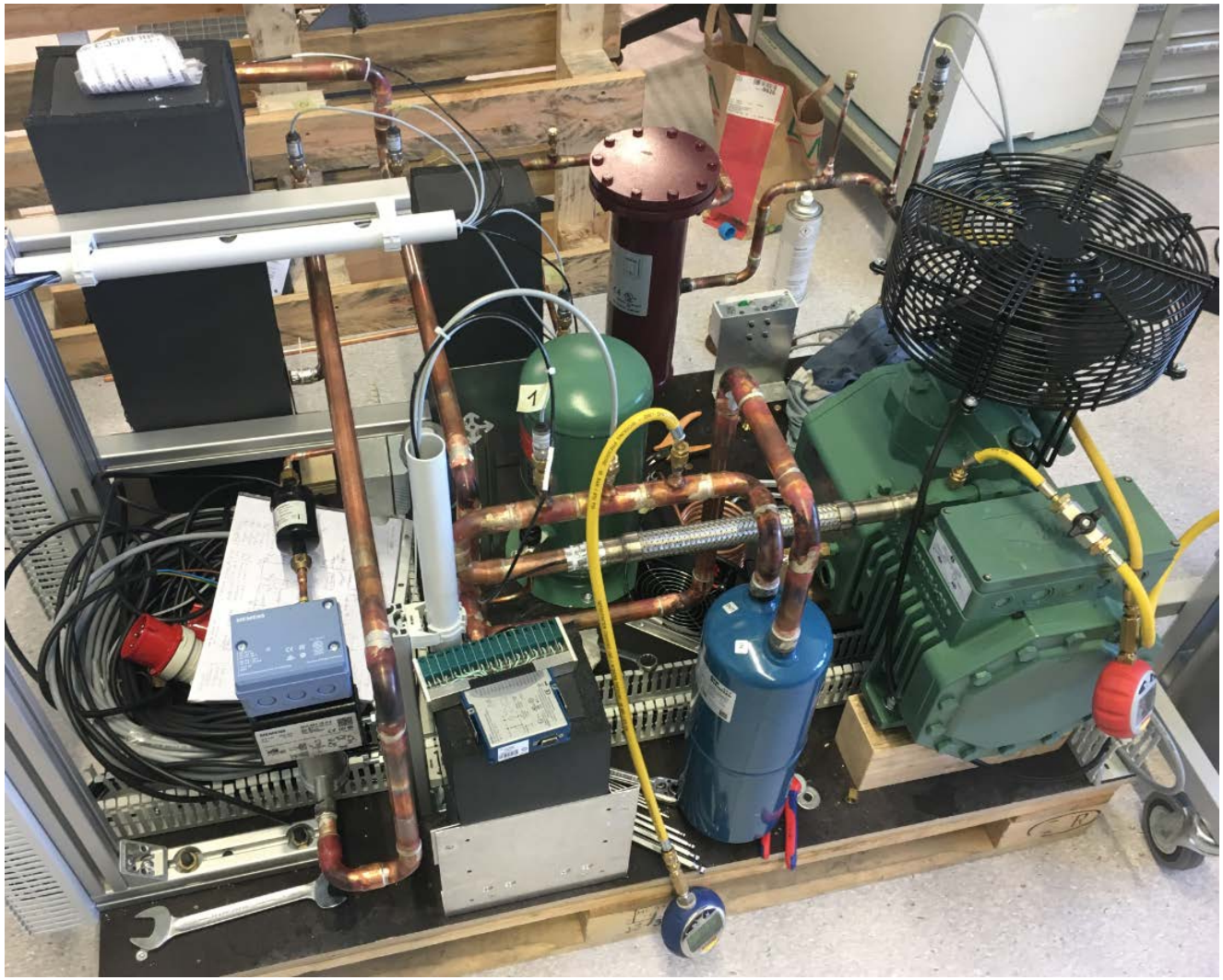
Cycle

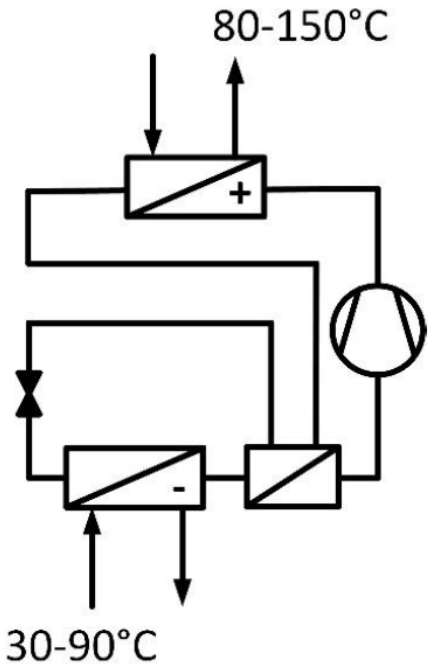
1-stage with IHX



WP2- Future Focus

- Experimental test setup – HTHP laboratory prototype (Aug 25, 2017)





WP2- Future Focus

- Next steps (Sept 2017-2018)

- Review paper on High Temperature Heat Pumps
- Experimental HTHP test setup (instrumentation and testing)
- Conference Papers (HTHP Design, Simulation, Experimental Results)

WP2- Future Focus

SCCER EIP EFFICIENCY OF INDUSTRIAL PROCESSES

Discussion (10 min)

Sources:
[1]: E. Federal Department of Economic Affairs, Research, Natural gas price, (http://gaspreise.preisueberwacher.ch/web/index.asp?z=5&codekategorie=Typ%20VI) (Apr 2016).
[2]: F. E. C. ElCom, Comparison of electricity prices, (May 2016) https://www.strompreis.elcom.admin.ch/Map/ShowSwissMap.aspx