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HEIG-VD
EPFL

WEBINAR ON HIGH TEMPERATURE HEAT PUMPS

7 NOVEMBER 2024

Guidelines for HTHP Integration

Cordin Arpagaus, OST

Content

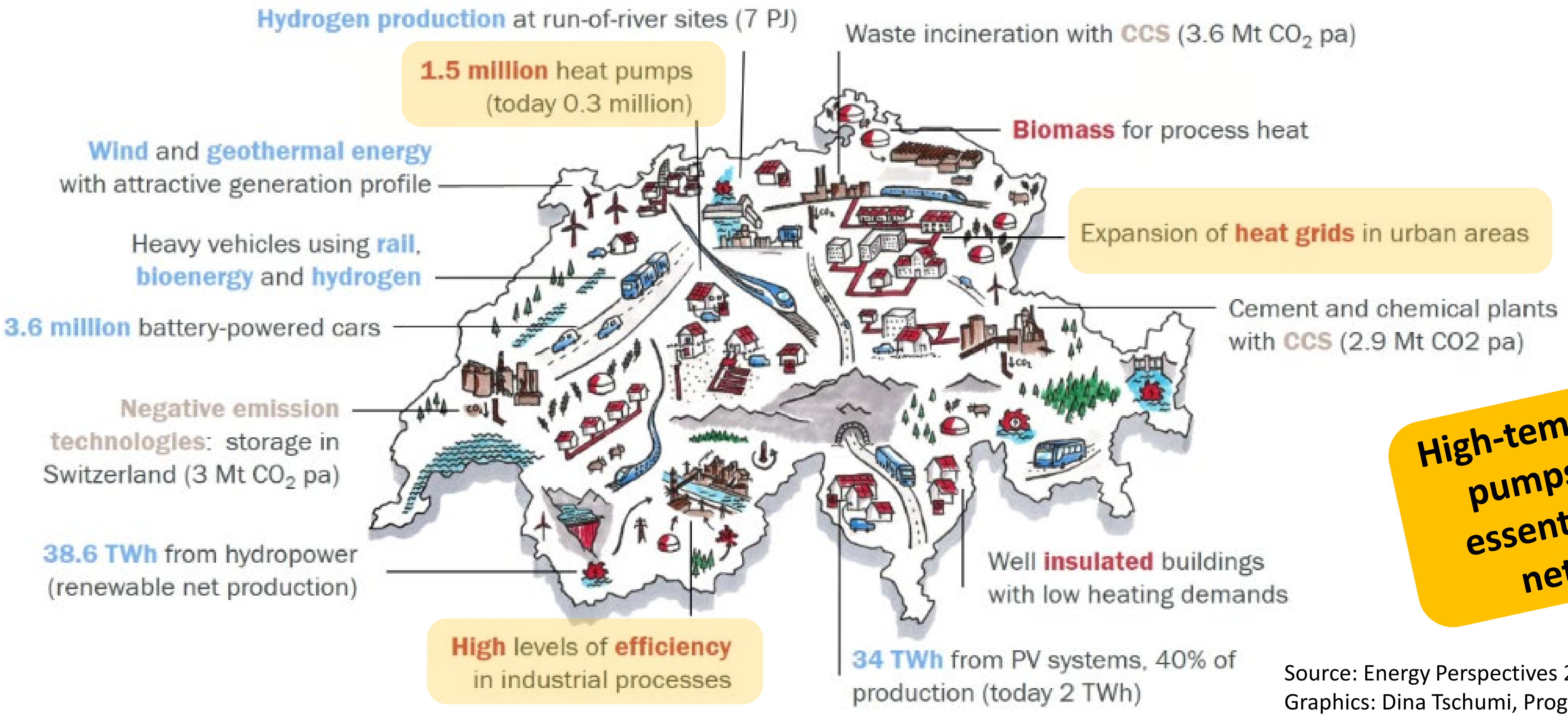
Guidelines for the implementation of HTHPs in industrial processes

AI-created picture about "guidelines for the implementation of heat pumps in industrial processes" (Adobe Firefly, 21 July 2024)

- Swiss market context
- Current HTHP technologies and demonstration cases
- Possible integration concepts
- Applying Pinch Analysis
- Preliminary assessment checklist
- Technical, financial, and socio-economic aspects

Swiss Market Context

Objectives for a climate-neutral Switzerland by 2050



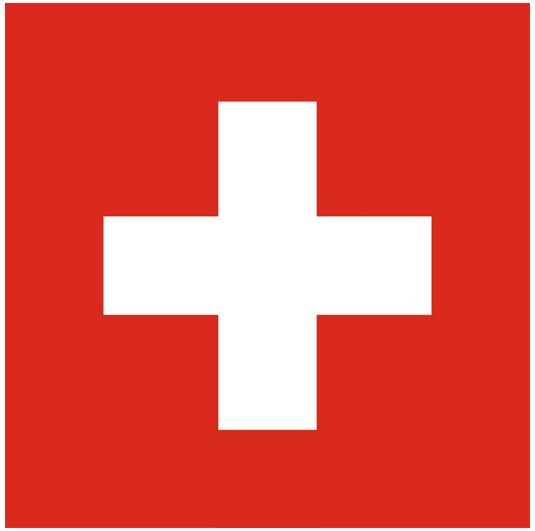
High-temperature heat pumps (HTHP) are essential to achieve net-zero goals

Source: Energy Perspectives 2050+ (EP 2050+)
Graphics: Dina Tschumi, Prognos AG

Swiss Market Context

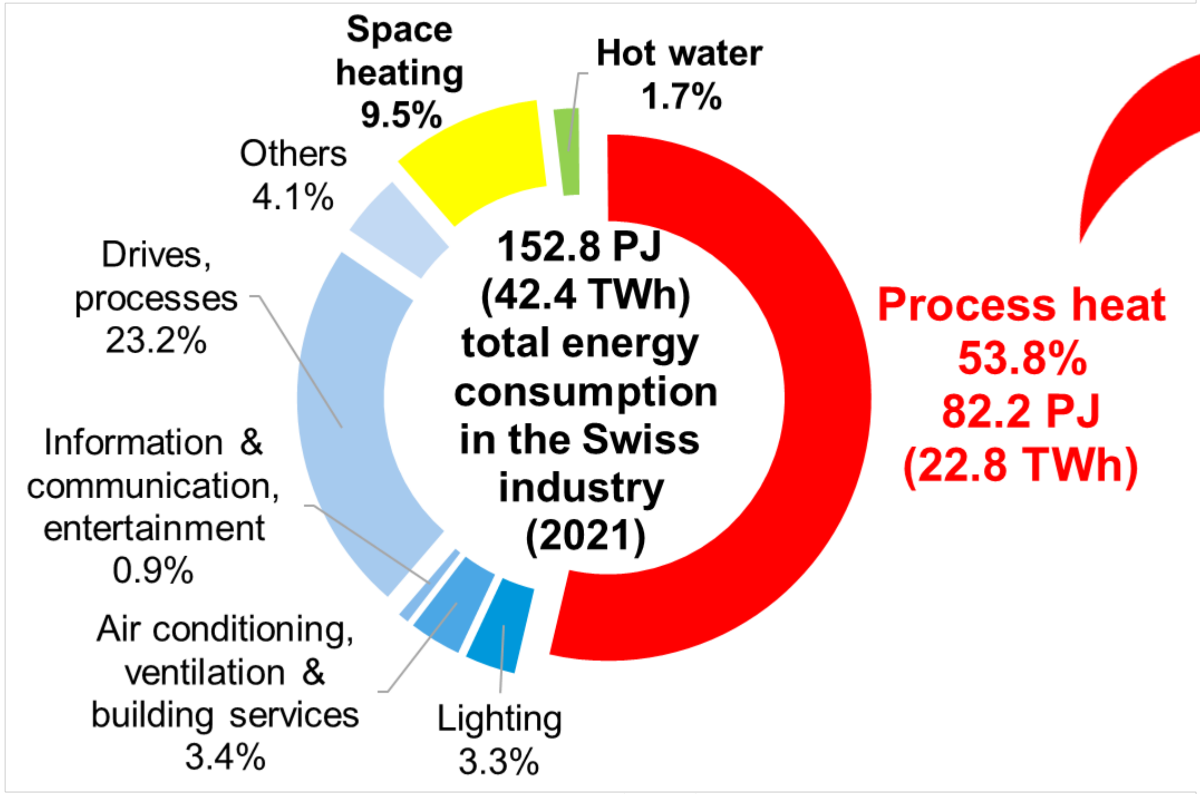
Characteristics of Industrial Landscape in Switzerland

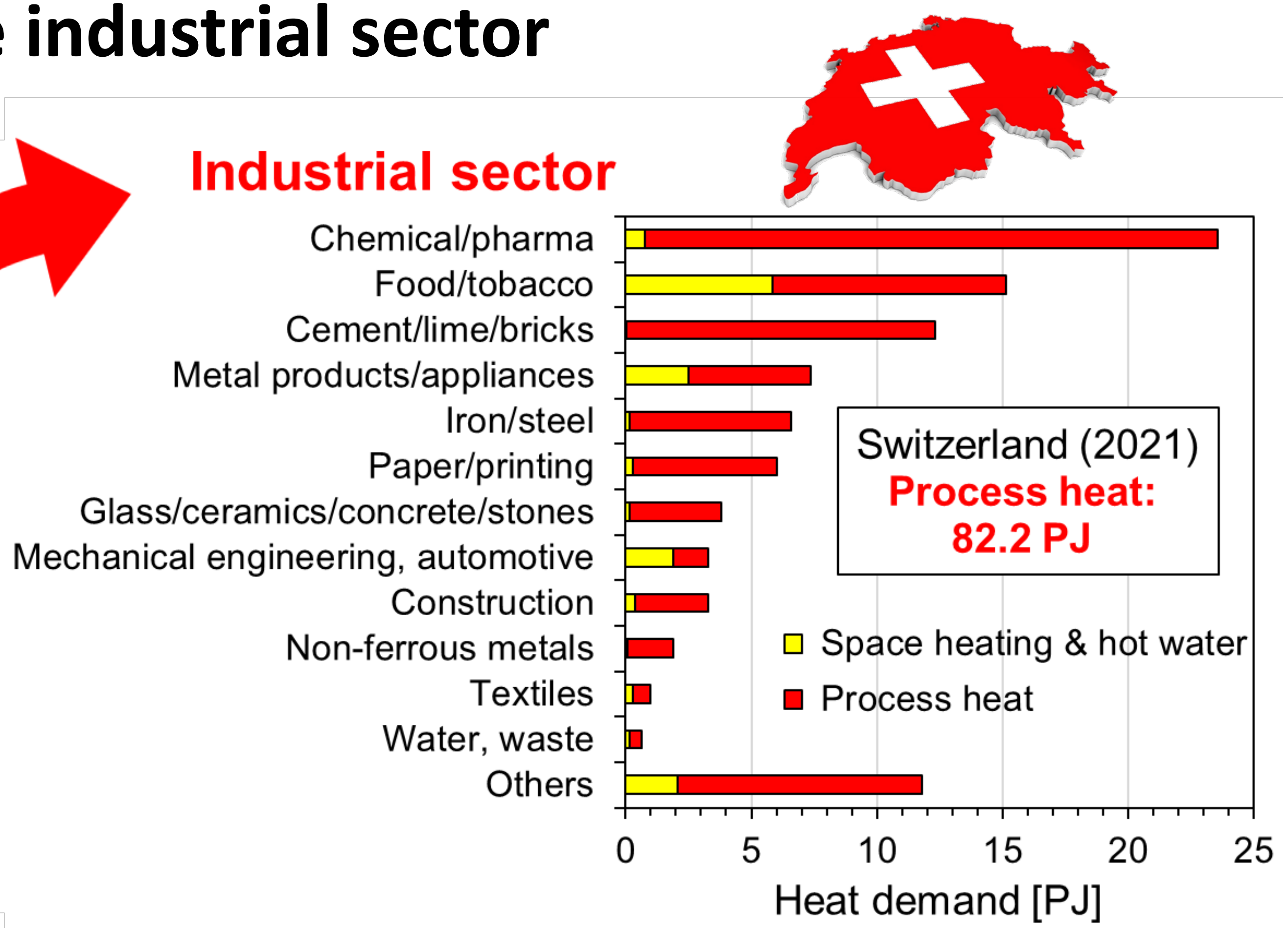
- **Proximity of industries to residential areas:** industries are often located closer to residential areas, impacts on regulations, environmental impacts, safety and comfort
- **Specific industry mix:** food and pharmaceutical/biotech sites with specific thermal energy needs
- **Multi-layered regulatory framework:** complex, municipality, canton, and national levels
- **Subsidy landscape:** supports adopting renewable energy technologies, including heat pumps, more energy-efficient and environmentally friendly
- **CO_2 taxes on all fossil thermal fuels** (e.g., fuel oil, natural gas): incentivize carbon emissions reductions, CO_2 levy is at CHF 120 per ton of CO_2



Swiss Market Context

Process heat demand (> 80 °C) in the Swiss industry (2021) representing 54% of all energy needs and showing the potential for HP and HTHP integration in the industrial sector





Sources: Data adapted from SFOE (2021)

Swiss Market Context

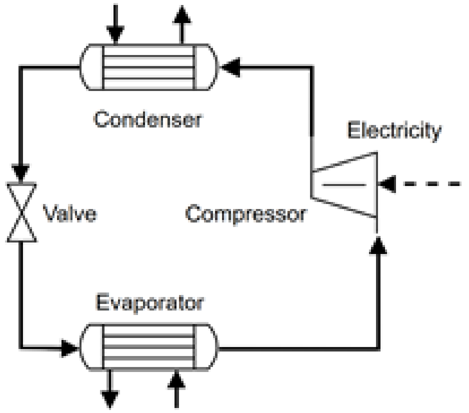
Potential energy savings through industrial HTHPs in Switzerland (top-down estimate)

	Energy consumption	Data source / Estimations
Swiss industry	42’601 GWh	**152.8 PJ as of 2021**
Process heat demand	22’919 GWh	**53.8% (>80 °C)**
Process heat and steam demand below 150 °C	6’876 GWh	**30%** (estimate based on Heat Roadmap Europe)
Energy savings potential through the use of HTHPs (= addressable process heat share)	**2’750 GWh (6.5% of the process heat demand)**	**40%** (moderate estimate of conversion rate to HPs and HTHPs based on technical analysis within SCCER EIP)

Sources: Data adapted from SFOE (2021)

Types of HTHP Technologies

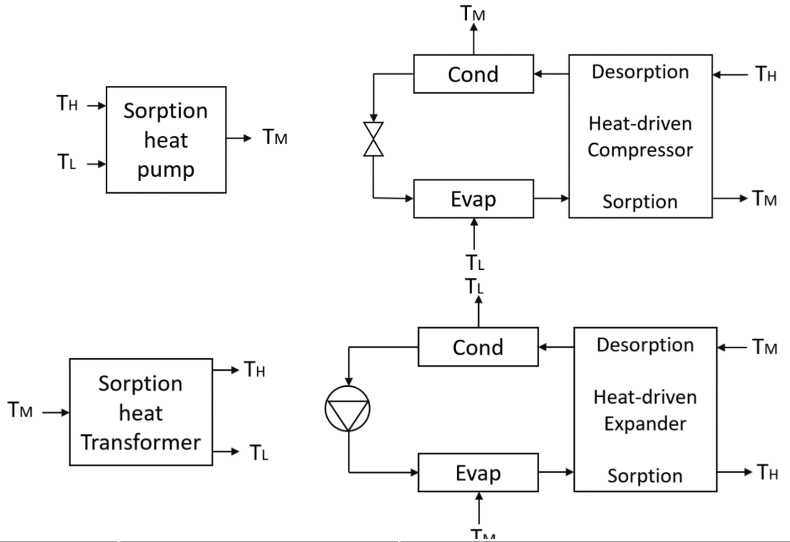
Electrically-driven HTHPs



T_cond in °C						
180	1.4	1.5	1.6	1.7	1.9	2.1
170	1.5	1.6	1.7	1.8	2.0	2.2
160	1.5	1.7	1.8	2.0	2.2	2.4
150	1.6	1.8	1.9	2.1	2.4	2.6
140	1.7	1.9	2.1	2.3	2.6	3.0
130	1.8	2.0	2.2	2.5	2.9	3.4
120	2.0	2.2	2.5	2.8	3.3	3.9
110	2.1	2.4	2.7	3.2	3.8	4.8
100	2.3	2.7	3.1	3.7	4.7	6.2
90	2.6	3.0	3.6	4.5	6.1	9.1
	20	30	40	50	60	70
	T_evap in °C					
					η_Lorenz =	50%

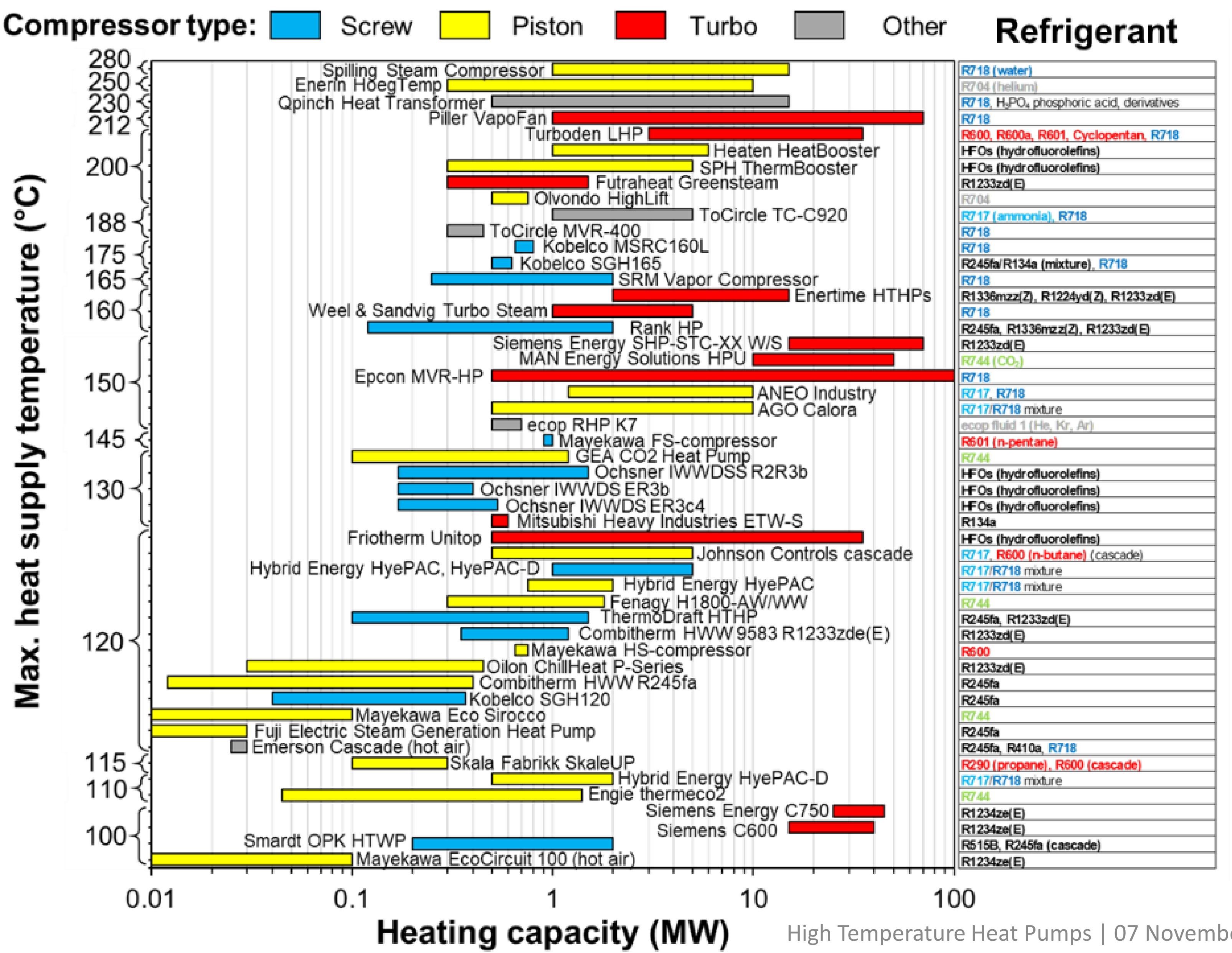
- Single-stage cycle
- Economizer cycle
- Twin or multi cycles
- Cascade cycle
- Condenser outlet split ejector cycle
- Transcritical cycle
- Joule cycle (or reverse Brayton cycle)
- Stirling cycle
- Mechanical vapor recompression (MVR)
- Steam compression systems

Thermally-driven HTHPs



Technology	COP definition	Maximum COP	Typical COPs
Sorption heat pump	$COP = \frac{\dot{Q}_{process}}{\dot{Q}_{high}}$	$COP = \left(1 - \frac{T_L}{T_H}\right) / \left(\frac{T_M}{T_M - T_L}\right)$	1.3 to 2.2
Sorption heat transformer	$COP = \frac{\dot{Q}_{process}}{\dot{Q}_{waste}}$	$COP = \left(1 - \frac{T_L}{T_M}\right) / \left(\frac{T_H}{T_H - T_L}\right)$	0.2 to 0.5
Vapor compression heat pump	$COP = \frac{\dot{Q}_{process}}{\dot{W}_{el}}$	$COP = \frac{T_H}{T_H - T_L}$	2 to 5

Market Overview of HTHPs

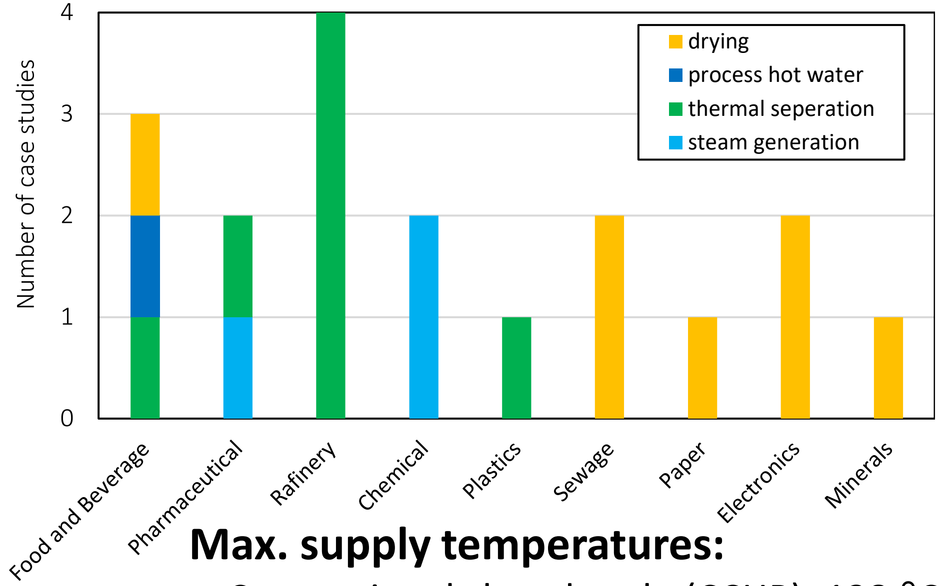


Refrigerant
R718 (water)
R717 (NH_3, ammonia)
R744 (CO_2)
R704 (helium)
R290 (propane)
R600 (n-butane)
R600a (iso-butane)
R601 (n-pentane)
HFC (R245fa, R134a, R410a)
HFO (R515B, R1234ze(E), R1224yd(Z), R1233zd(E), R1336mzz(Z))

Based on data from IEA HPT Annex 58 (2023) https://heatpumpingtechnologies.org/annex58/task1 and Arpagaus et al. (2022): China Heat Pump Conference (YouTube Video Recording)

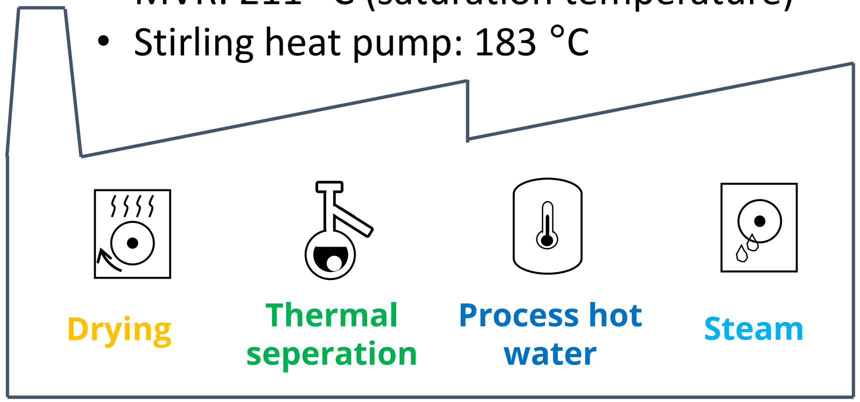
Overview of Demonstration Cases

Case Studies by industries and application processes



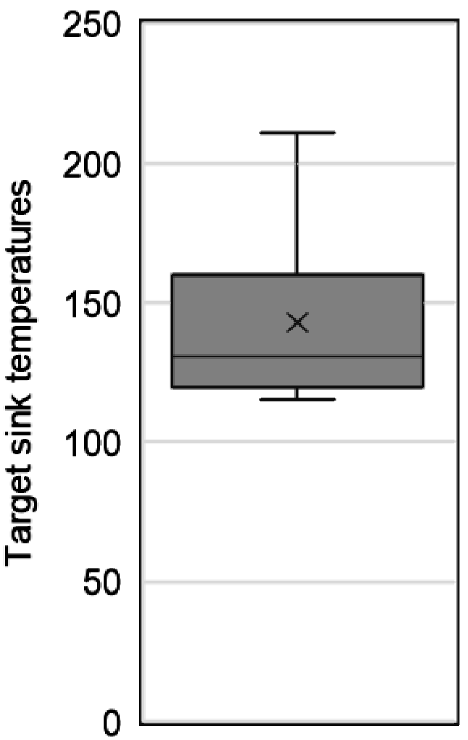
Max. supply temperatures:

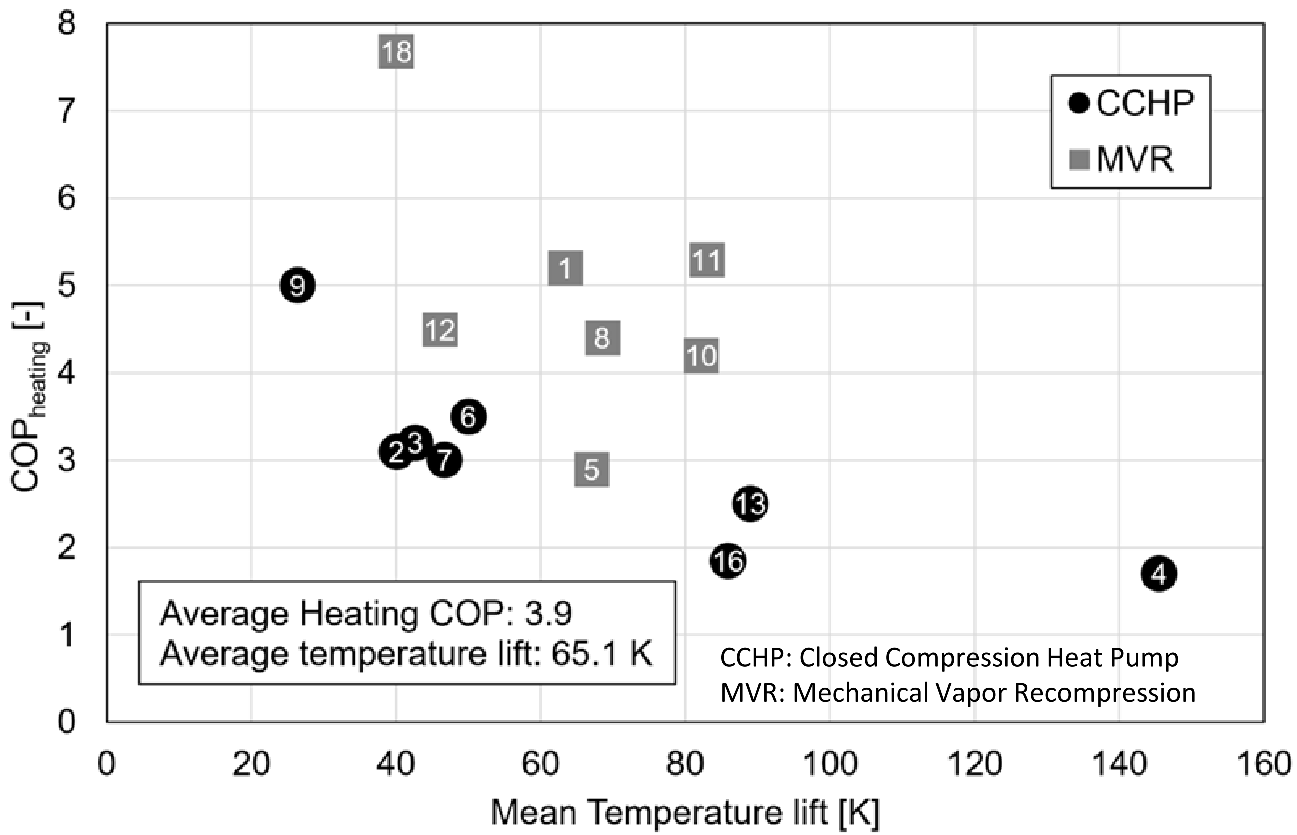
- Conventional closed-cycle (CCHP): 138 °C
- MVR: 211 °C (saturation temperature)
- Stirling heat pump: 183 °C



No.	Supplier	Industry	Process	Heat source			Heat sink			HP Type	Refrigerant	Compressor	Capacity	COP_H	Op. hours	Ref.
				Unit Operation	T_{out} [°C]	T_{in} [°C]	Unit Operation	T_{out} [°C]	T_{in} [°C]				[kW]		[h/a]	
1	n. a.	beverage	alcoholic distillation	product cooling	75	78.3	distillation	140	n. a.	MVR	n. a.	n. a.	350	5.2	n. a.	[1]
2	**Mayekawa**	electronic	coil drying	electro-painting cooling	25	30	drying	120	20	CCHP	R744	piston	89	3.1	n. a.	[1]
3	**AMT/AIT**	food	starch drying	waste heat	72	76	drying	138	96	CCHP	R-1336mzz(Z)	screw	374	3.2	4,000	[2]
4	**Olvondo**	pharma-ceutical	recooling	recooling heat	34	36	steam generation	183	178	Stirling HP	R704	piston	2,250	1.7	6,100	[2]
5	**Kobelco**	sewage	sludge drying	exhaust drying air	93	93	steam generation	160	160	MVR	R718	twin-screw, roots blower	675	2.9	n. a.	[2]
6	**Kobelco**	refinery	bioethanol distillation	process cooling	60	65	distillation	115	110	CCHP + Flash Tank	R245fa	twin-screw	1,850	3.5	n. a.	[2]
7	**MHI**	electronic	coil drying	waste heat	50	55	drying	130	70	CCHP	R134a	centrifugal	627	3.0	n. a.	[2]
8	**Piller**	plastics	thermal seperation	exhaust vapour	60	60	steam generation	131	126	MVR	R718	turbo (8 blowers)	10,000	4.4	8,000	[2]
9	**AMT/AIT**	minerals	brick drying	exhaust drying air	80	84	drying	121	96	CCHP	R-1336mzz(Z)	piston (8 compr.)	296	5	4,000	[2]
10	**Spilling**	pulp and paper	pulp drying	exhaust vapour	105	133	steam generation	201	n. a.	MVR	R718	piston (4 LT-, 2 HT-cylinders)	11,200	4.2	7,500	[2]
11	**Spilling**	chemical	chemical	exhaust vapour	105	152	steam generation	211	n. a.	MVR	R718	piston (4 LT-, 2 HT-cylinders)	12,000	5.3	7,500	[2]
12	**Rotrex, Epcon**	sewage	sludge drying	surplus steam	100	n. a.	steam generation	146	n. a.	MVR	R718	turbo (2 stages)	500	4.5	n. a.	[2]
13	**SkaleUP**	dairy	process hot water	(re)cooling	12, 0	20, 5	process hot water	115	95	CCHP	LT-C: R290, HT-C: R600	piston	300	2.5, 2.3	6,500	[2]
14	**QPinch**	chemical	steam production	exhaust vapour	120 - 145		steam generation	140 - 185		heat trans-former	H_2PO_4	heat-driven	2,900	0.45	2,500	[2]
15	**Huayuan Taimeng**	refinery	ethyl-benzene	waste heat	95	120	steam generation	152	n. a.	heat trans-former	LiBr-H_2O	heat-driven	7,553	0.48	n. a.	[2]
16	**Shanghai Nuotong**	beverage	alcoholic distillation	air	n. a.	18.9	steam generation	120	90	CCHP + Flash Tank + MVR	LT-C:R410a, HT-C:R245fa	screw	180	1.85	n. a.	[2]
17	**Huayuan Taimeng**	refinery	alkyl-benzene	waste heat	86	127	steam generation	150	n. a.	heat trans-former	LiBr-H_2O	heat-driven	5,100	0.48	n. a.	[2]
18	**Shandong Zhangqiu Blower**	refinery	ethanol distillation	exhaust vapour	76	n. a.	steam generation	116	n. a.	MVR	R718	centrifugal	n. a.	7.68	7,000	[2]

Indicative COP values





1	n. a.	distillation	78.3	140	MVR
2	Mayekawa	drying	30	120	CCHP
3	AMT/AIT	drying	76	138	CCHP
4	Olvondo	steam generation	36	183	Stirling HP
5	Kobelco	steam generation	93	160	MVR
6	Kobelco	distillation	65	115	CCHP + Flash Tank
7	MHI	drying	55	130	CCHP
8	Piller	steam generation	60	131	MVR
9	AMT/AIT	drying	84	121	CCHP
10	Spilling	steam generation	133	201	MVR
11	Spilling	steam generation	152	211	MVR
12	Rotrex, Epcon	steam generation	100	146	MVR
13	SkaleUP	process hot water	20, 5	115	CCHP
16	Shanghai Nuotong	steam generation	18.9	120	CCHP + Flash Tank + MVR
18	Shandong Zhangqiu Blower	steam generation	76	116	MVR

- **Target sink temperatures between 115 °C and 240 °C**

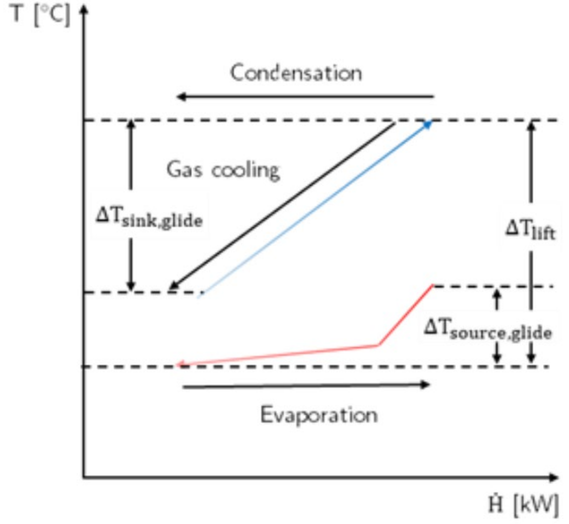
$$\Delta T_{mean} = \frac{\Delta T_{sink}}{\ln\left(\frac{T_{sink,out}}{T_{sink,in}}\right)} - \frac{\Delta T_{source}}{\ln\left(\frac{T_{source,in}}{T_{source,out}}\right)}$$

Source: IEA HPT Annex 58 (2023)

Selection of HTHP Technology

Three main application types

- **large temperature glide**



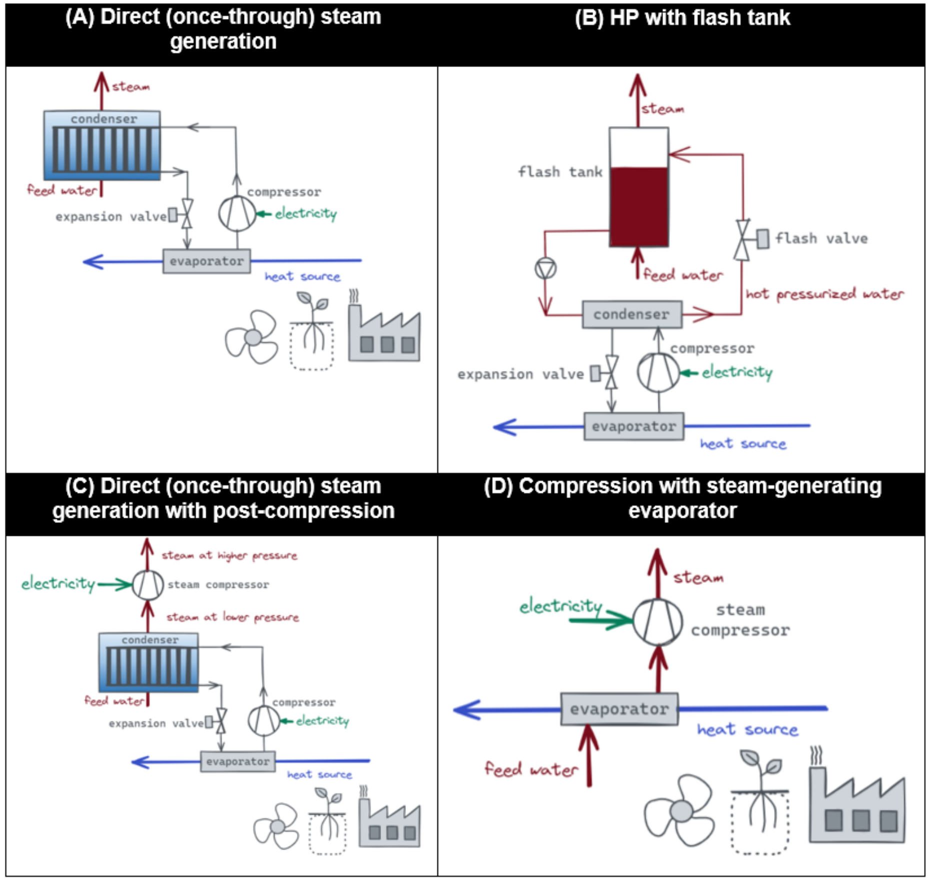
e.g. drying processes

- **Single-stage or cascaded transcritical cycle** (CO_2, HC or HFO)
- **Stirling cycle**
- **Reversed Brayton cycle**

- **hot water**

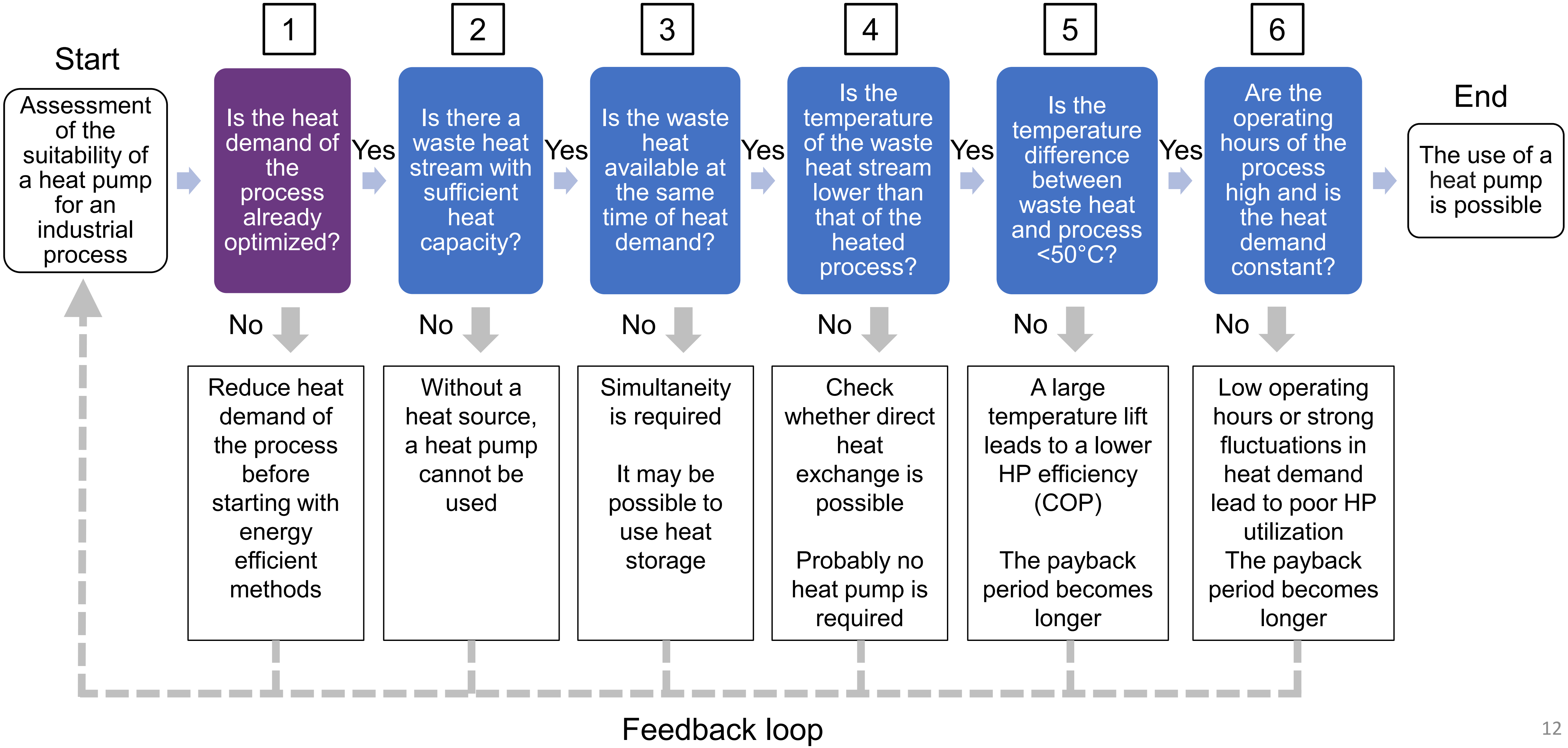
(A) **Single-stage, multi-stage, and cascade HP cycle** (using HC or HFO)
(B) **Transcritical single-stage cycle** (using CO_2)
(C) **Hybrid absorption compression HP** (using ammonia/water)

- **steam generation**



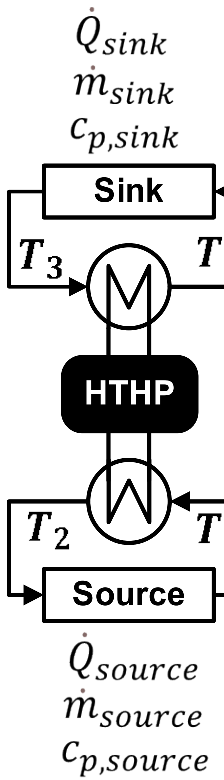
Source: IEA HPT Annex 58 Task 1 and Task 2 reports and final webinar

Preliminary Feasibility Checklist



Source: Arpagaus (2019): Book «Hochtemperatur Wärmepumpen»

Inputs for preliminary assessment



Technical parameters	Unit	Heat source	Heat sink
Medium (water, steam, air, oil, waste, etc.)			
Flow temperature	°C/bar(g)	T_1	T_3
Return temperature	°C	T_2	T_4
Heat source/sink capacity (cooling/heating demand)	kW	$\dot{Q}_{source}$	$\dot{Q}_{sink}$
Mass flow	kg/s	$\dot{m}_{source}$	$\dot{m}_{sink}$
Heat capacity	kJ/kg K	$c_{p,source}$	$c_{p,sink}$
Operating hours (time availability)	h/year		
Economic parameters			
Electricity costs	CHF/kWh		
Costs of natural gas or oil	CHF/kWh		
Heat price at sink temperature (e.g., gas price for burner)	CHF/kWh		
Heat price at source temperature (mostly free waste heat)	CHF/kWh		

Additional inputs:

Application	Specification	Examples or unit
Type of industry		Diary / Pharma / Chemical
Type of application		Drying / Humidification / UHT
Current source for applied heat		Electric, gas, or oil burner
Heat pump location on site		Existing space / New build
Distance to heat source/sink		Meters
Electrical voltage level		400/600 V
Electrical power consumption		kW (see specifications of HPs)
Internet access (fixed IP)		Yes/No
Other information		

Economic evaluation – cost model

Inputs

$\dot{Q}_h$	Heating capacity	kW
ΔT_{lift}	Temperature lift	K
$c_{inv,HP}$	Specific investment costs of HP	EUR/kW
$f_{inv,HP}$	Cost factor for planning & HP integration	-
t	Annual operating time	h/a
$f_{maintain}$	Maintenance factor (on capital costs)	-
η_{fuel}	Efficiency of gas boiler	-
i	Interest rate (discount rate)	-
c_{fuel}	Fuel price (gas, oil)	EUR/kWh
c_{el}	Electricity price	EUR/kWh
$c_{CO2\ tax}$	CO_2 tax	EUR/tCO_2
$f_{CO2,el}$	CO_2 emissions factor electricity	kgCO_2/kWh
$f_{CO2,fuel}$	CO_2 emissions factor fuel	kgCO_2/kWh

Outputs

$C_{inv,HP}$	Investment costs of HP	EUR
$\dot{m}_{CO2,reduction}$	Annual CO_2 emissions reduction	tCO_2/a
$E_{savings}$	Annual energy savings	kWh/a
C_{fuel}	Annual fuel cost savings	EUR/a
C_{el}	Annual electricity costs	EUR/a
$C_{maintain}$	Annual HP maintenance costs	EUR/a
C_{CO2}	Annual CO_2 tax compensation	EUR/a
$C_{savings}$	Annual cost savings	EUR/a
PP	Payback period	a
DPP	Discounted payback period	a

$$c_{inv,HP} = 3'157 \cdot \dot{Q}_h^{-0.322}$$

$$C_{inv,HP} = c_{inv,HP} \cdot \dot{Q}_h \cdot f_{inv,HP}$$

$$C_{maintain} = C_{inv,HP} \cdot f_{maintain}$$

$$C_{savings} = C_{CO2} + C_{fuel} - C_{el} - C_{maintain}$$

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

$$C_{el} = (\dot{Q}_h \cdot t \cdot c_{el})/COP$$

$$C_{fuel} = (\dot{Q}_h \cdot t \cdot c_{fuel})/\eta_{fuel}$$

$$C_{CO2} = \dot{m}_{CO2,reduction} \cdot c_{CO2\ tax}$$

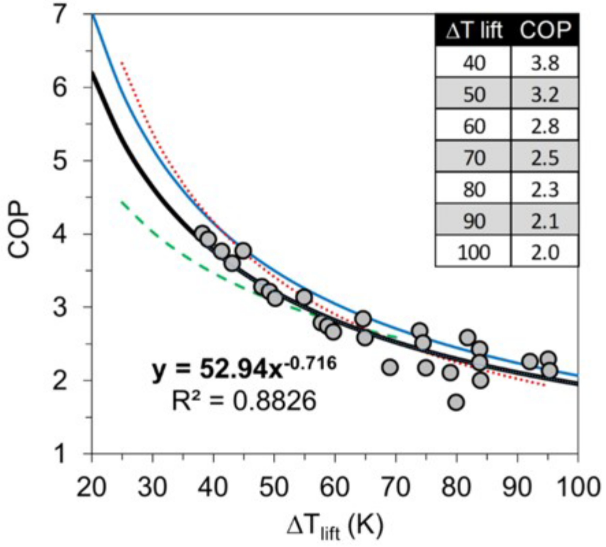
$$\dot{m}_{CO2,reduction} = \dot{Q}_h \cdot t \cdot \left(\frac{f_{CO2,fuel}}{\eta_{fuel}} - \frac{f_{CO2,el}}{COP}\right)$$

$$PP = C_{inv}/C_{savings}$$

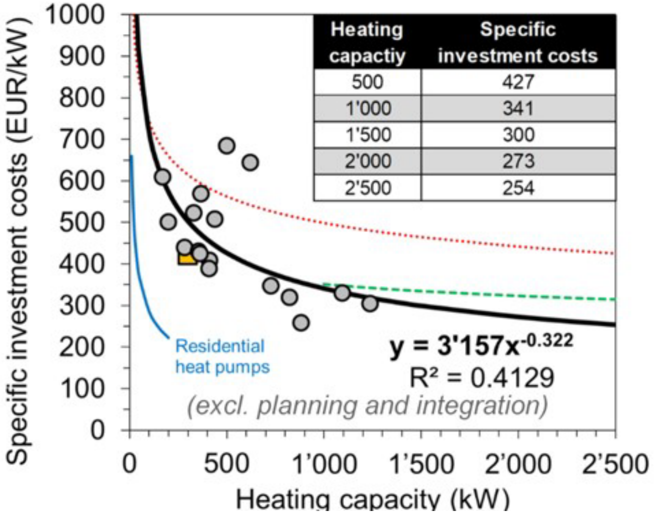
$i \rightarrow$

$$DPP = -ln\left(1 - (C_{inv} \cdot i/C_{savings})\right)/ln(1+i)$$

Discounted payback period assuming all cash inflows are equal and discrete (Bhandari, 2009)



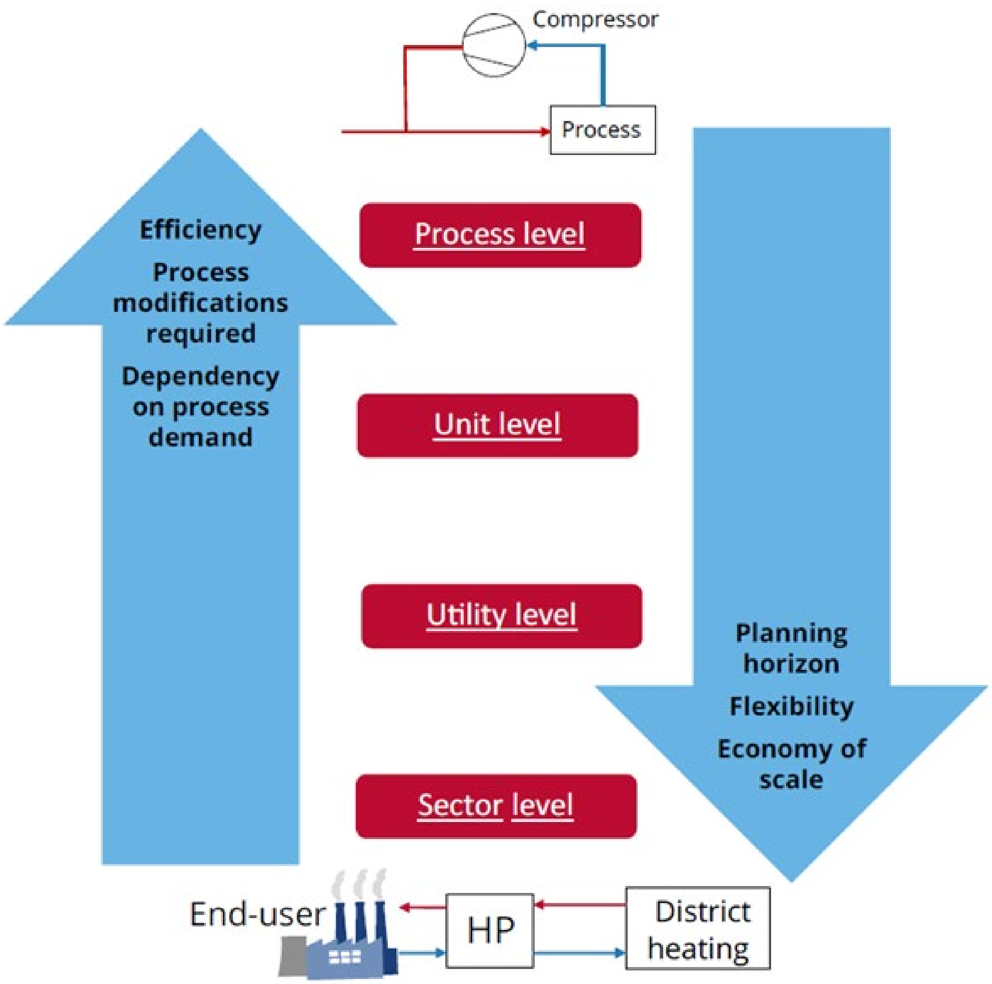
ΔT lift	COP
40	3.8
50	3.2
60	2.8
70	2.5
80	2.3
90	2.1
100	2.0



Heating capactiy	Specific investment costs
500	427
1'000	341
1'500	300
2'000	273
2'500	254

Possible Integration Levels

Different integration levels for heat pumps and their effects



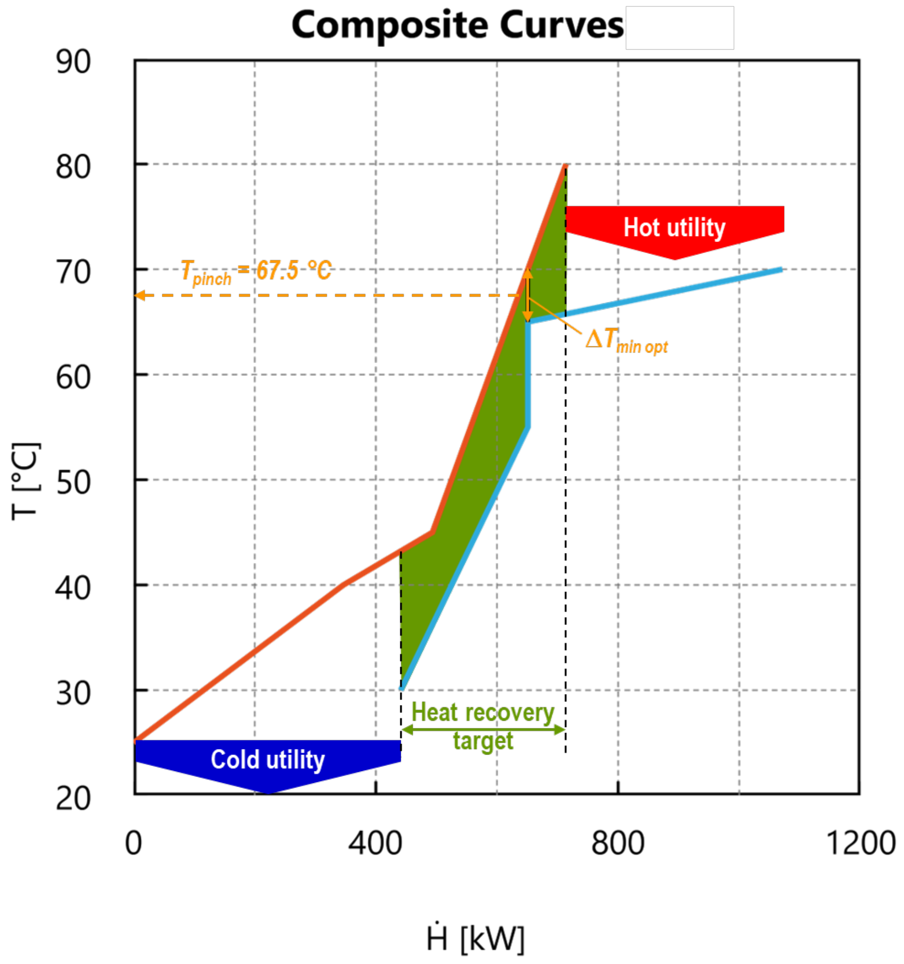
Source: IEA HPT Annex 58

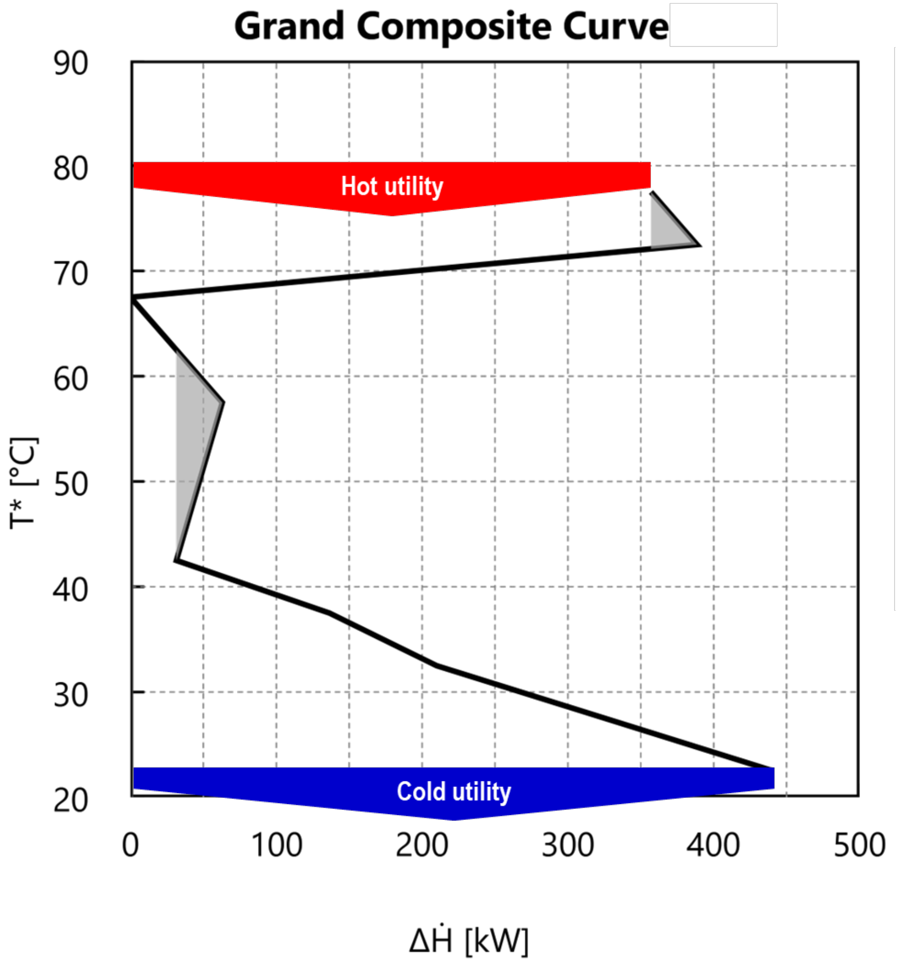
- **<u>Process stream level:</u>** heat of an exhaust stream (e.g., vapor from an evaporation process) is upgraded and fed back as heating steam (typically with MVR)
- **<u>Unit (or process) level:</u>** heat of one or several hot streams or waste heat sources of a process unit supplies the HP
- **<u>Utility level (site level):</u>** Waste heat is upgraded and distributed via the existing utility network
- **<u>Sector level (district, area level):</u>** heat source(s) and sink(s) do not belong to industrial site

Composite Curves (hot and cold)

Example process of Pinch

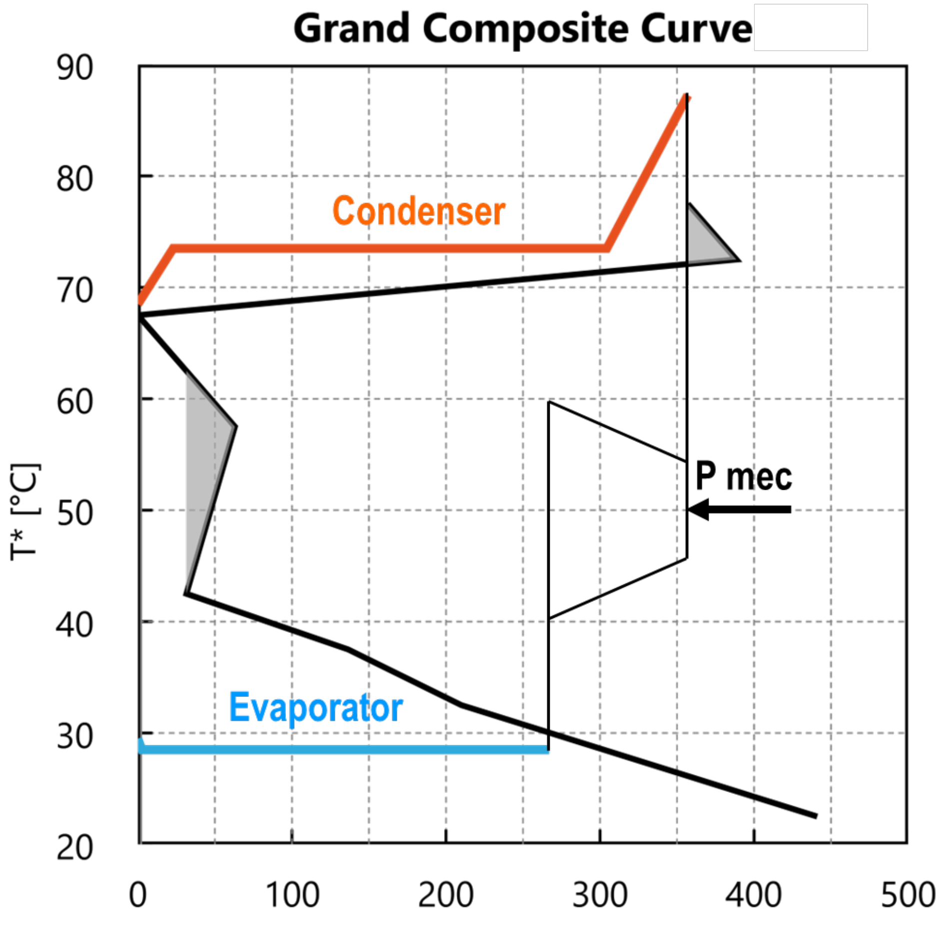
Example Process							
		T in	T out	$\dot{m}$	c_p	$\Delta\dot{H}$
Stream (heat transfer requirement)	Type	[°C]	[°C]	[kg/s]	[kJ/(kg K)]	[kW]
WasteWaterCooling	Hot (heat source)	45.0	25.0	5.50	4.20	462
ProcessWaterHeating	Cold (heat sink)	30.0	55.0	2.00	4.20	210
AirCompressorCooling	Hot (heat source)	80.0	40.0	1.50	4.20	252
TemperatureHolding	Cold (heat sink)	65.0	70.0	20.00	4.20	420





Composite Curves (hot and cold)

Optimal integration of a vapor compression HP by interpreting the GCC



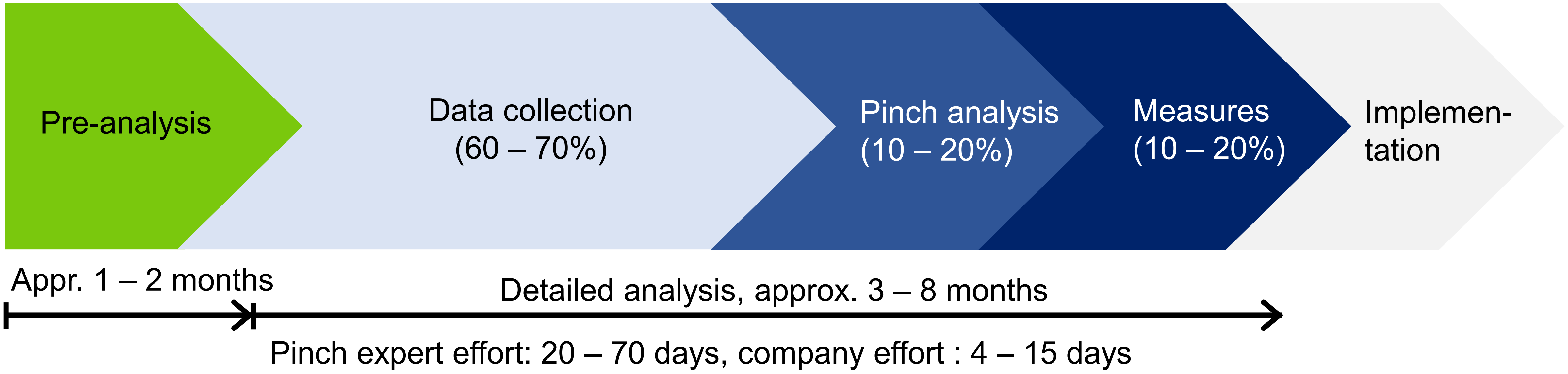
ΔḢ [kW]

<u>Golden rules:</u>

(1) Do not cool hot streams above the pinch temperature using cold utility
(2) Do not heat cold streams below the pinch temperature with hot utility
(3) Avoid heat transfer across the pinch point from hot to cold streams

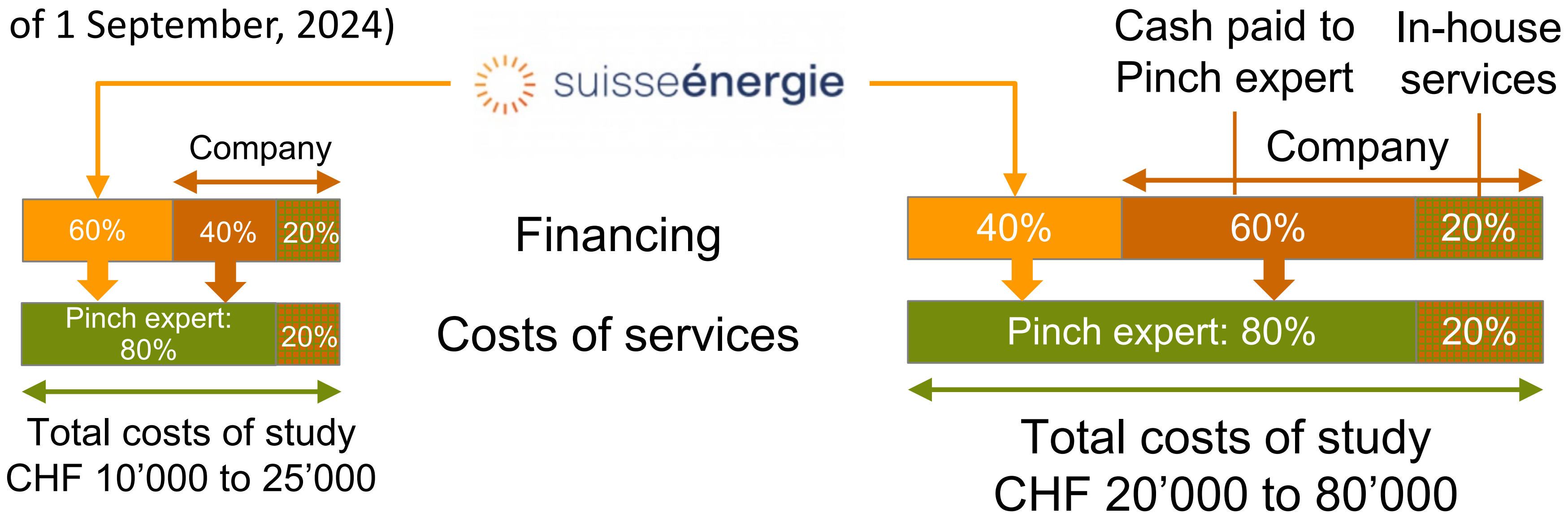
Applying Pinch Analysis

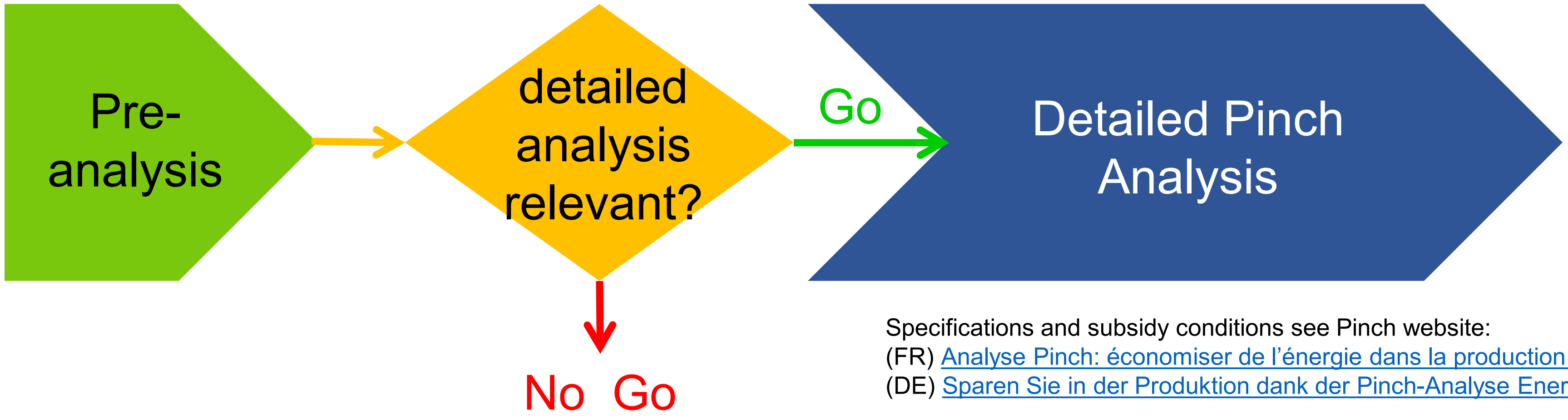
Main steps of a Pinch analysis and typical effort and duration



Typical costs and SFOE subsidies for the two-phase approach

(conditions as of 1 September, 2024)





Specifications and subsidy conditions see Pinch website:
(FR) Analyse Pinch: économiser de l'énergie dans la production (suisseenergie.ch)
(DE) Sparen Sie in der Produktion dank der Pinch-Analyse Energie

Applying Pinch Analysis

Workflow for targeting and optimizing an industrial site's heat recovery and upgrading via HP(s), including several processes

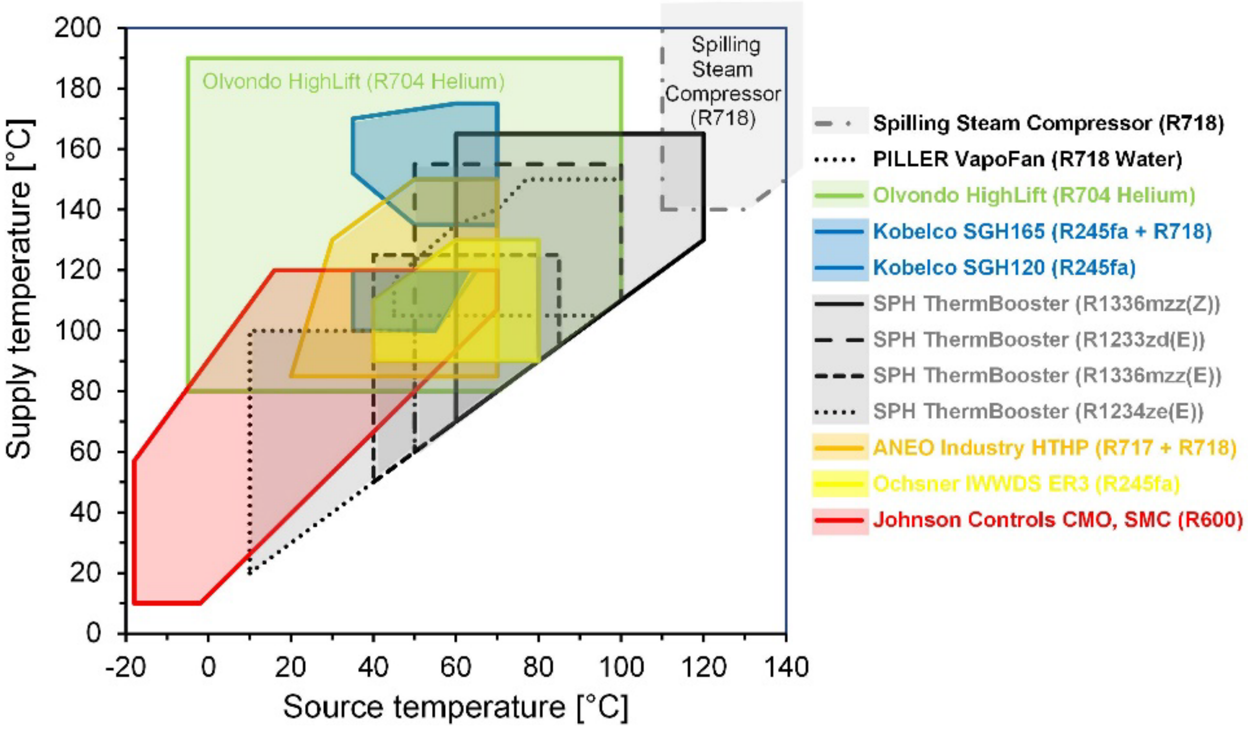
Stage A:
Heat integration potential of individual processes

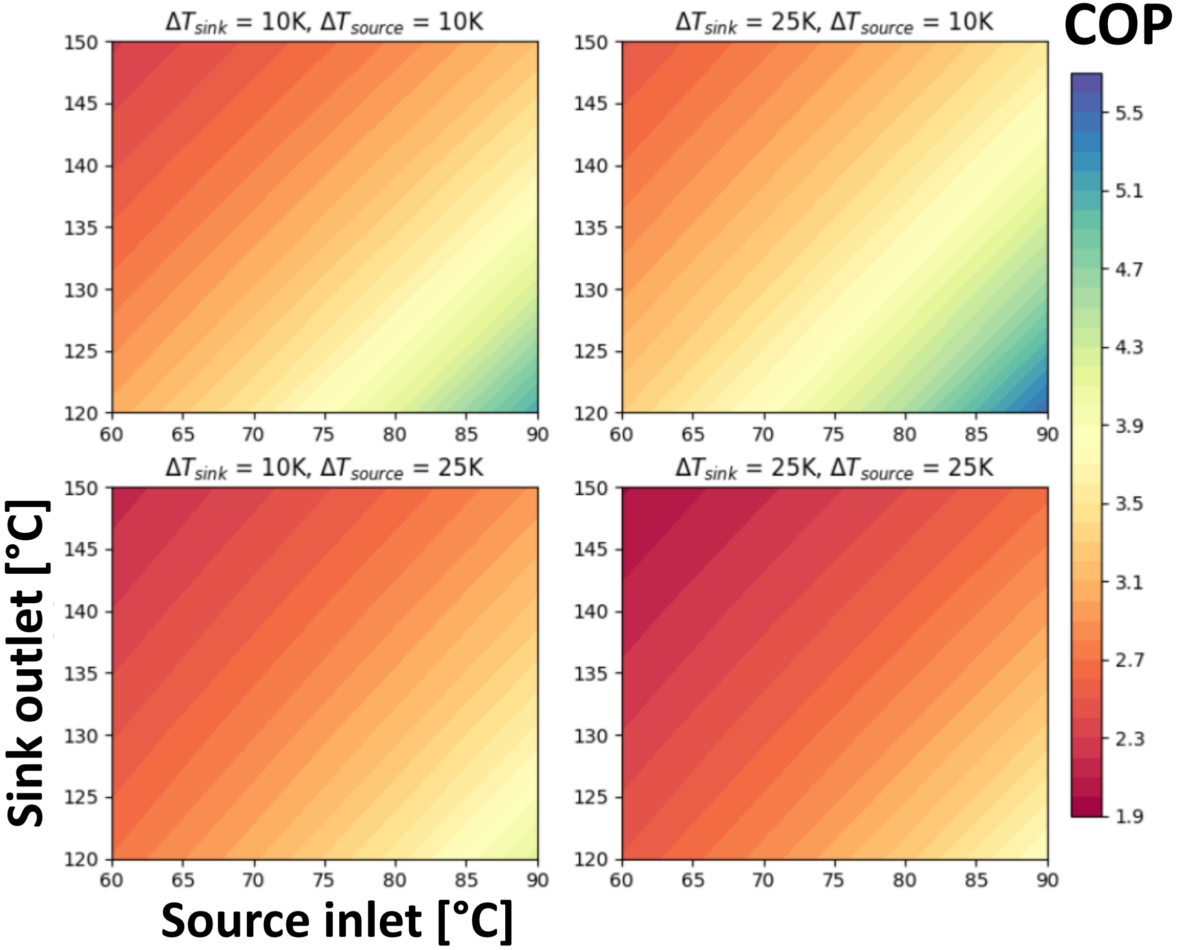
Stage B:
Inter-process heat integration potential

1. Represent CCs, heat recovery target, and Pinch temperature
2. Check for any obviously misplaced HEX
3. Analyze the GCC and check the relevance of integrating a HP at process level
4. Extract GCC segments for later inter-process heat integration analysis
5. Represent RCCs and analyze the maximum potential heat recovery and HP integration

Technical Aspects

Heat Pump Operation and Performance

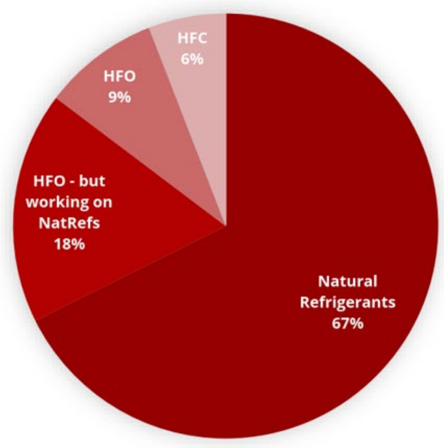




Technical Aspects

- **Infrastructure Requirements:** location for the installations, power supply, distribution network and thermal storage, automation system
- **Safety Aspects:** refrigerant, redundancy strategy, relevant standards:
  - **Chemical Risk Reduction Ordinance** (ORRChem)
  - Protection against **major accidents** (Major Accidents Ordinance, MAO)
  - Ordinance on **Air Pollution Control** (OAPC)
  - Directives on potentially **explosive atmospheres** (ATEX)
  - **Pressure Equipment** Directive (PED) or
  - Swiss National **Accident Insurance** Fund (SUVA)
- **Maintenance**
- **Technology Lock-in**

Refrigerants used in current HTHPs



Source: IEA HPT Annex 58

Frequently used natural refrigerants:

- CO_2 (R744)
- Steam (R718)
- Ammonia/Water (R717/R718)
- Hydrocarbons (R600, R600a, R601, R601a)

Frequently used HFOs:

- R-1233zd(E)
- R-1234ze(E)
- R1336mzz(Z)

→ **For every HFO HTHP, there is a NatRef alternative**

Financial Aspects

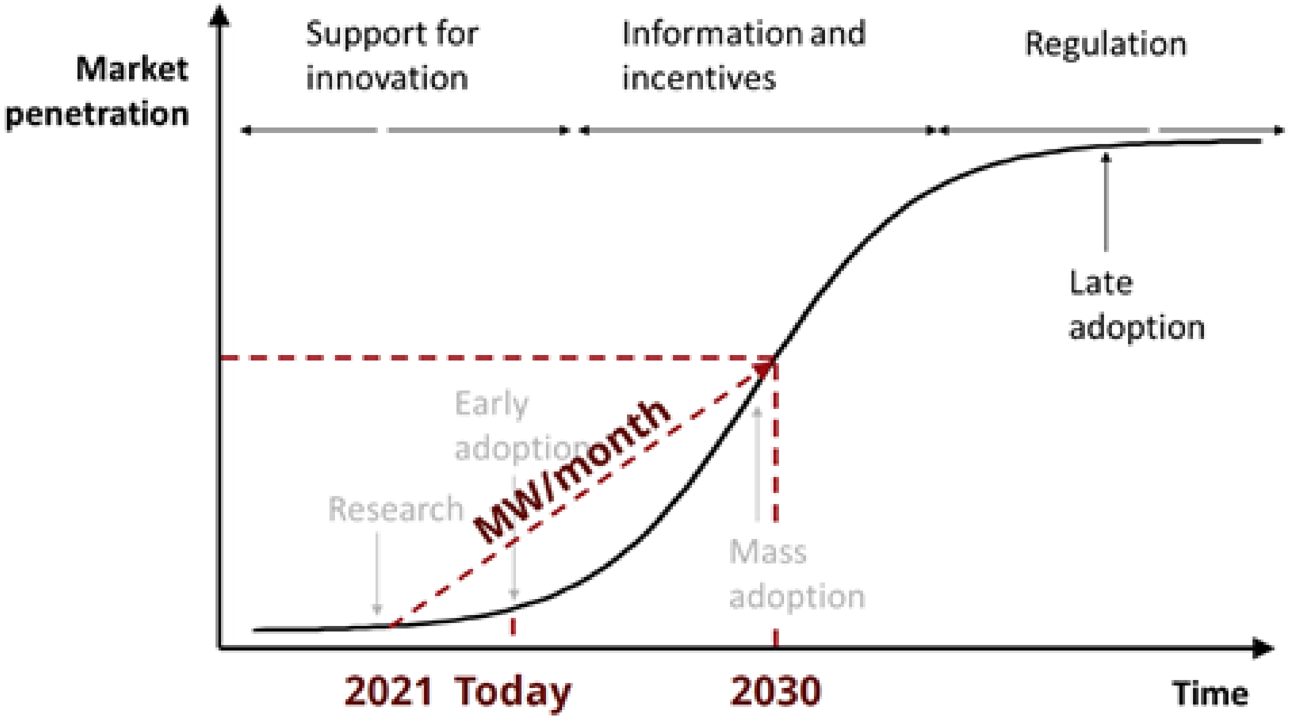
Funding programs for industrial heat pumps in Switzerland

Funding program	Pinch Analyses	Heat Pumps for Process Heat	Klimaprämie (Climate bonus)	Pilot and Demonstration
Program Manager	EnergieSchweiz (SuissEnergie)	EnergieSchweiz	EnergieZukunft Schweiz	SFOE (Swiss Federal Office of Energy)
Financing	SFOE	SFOE	KliK Foundation	SFOE
Amount	• Pre-analyses: max. 60% of total costs • Pinch analyses: • Max. 40% of total costs	• Max. 40% of additional costs compared to conventional technology (e.g., oil or gas boiler)	• 0.18 CHF/kWh heat • About 360 CHF/kW heat at 2’000 h annual operation	• Up to 40% (60%) of non-amortizable supplementary costs
Criteria	• Using PinCH Software • Trained experts • Publication of findings (summary, final report)	• Industrial process heat • Payback >4 years • Funding request before construction starts • Companies with a CO_2 tax exemption are examined individually	• Replacement of oil/gas boiler with heat pump • Order not yet placed • CO_2 savings to be transferred to Energie Zukunft Schweiz	• Application potential • Innovative content • Pilot: TRL 4 to 7 • Demonstration: TRL 7 to 9 • Publication of findings (final report)
Infos	• Website, Flyer	• Website, Flyer	• Website, Flyer	• Website

[1] https://www.energieschweiz.ch/beratung/pinch/ (DE) and https://www.suisseenergie.ch/conseil/pinch/ (FR)
[2] https://pubdb.bfe.admin.ch/de/publication/download/8357 (DE) and https://pubdb.bfe.admin.ch/fr/publication/download/8357
[3] https://www.energieschweiz.ch/prozesse-anlagentechnik/industrielle-waermepumpe/ (DE) and https://www.suisseenergie.ch/processus-technique-dinstallations/pompes-industrie/ (FR)
[4] https://pubdb.bfe.admin.ch/de/publication/download/10753 (DE) and https://pubdb.bfe.admin.ch/fr/publication/download/10753 (FR)
[5] https://www.klimapraemie.ch (DE) and https://www.primeclimat.ch (FR)
[6] https://energiezukunftschweiz.ch/wAssets/docs/foerderprogramme/klimapraemie/klimapraemie-factsheet-grosse-anlagen_2022.pdf (DE) and https://energiezukunftschweiz.ch/wAssets/docs/foerderprogramme/klimapraemie/klimapraemie-factsheet-grosse-anlagen-fr.pdf
[7] https://energiezukunftschweiz.ch/wAssets/docs/foerderprogramme/klimapraemie/klimapraemie-detaillierte-foerderkriterien_wp_de.pdf (DE) and https://energiezukunftschweiz.ch/wAssets/docs/foerderprogramme/klimapraemie/klimapraemie-detaillierte-foerderkriterien_wp_fr.pdf
[8] https://www.bfe.admin.ch/bfe/en/home/research-and-cleantech/pilot-and-demonstration-programme.html

Socio-Economic Aspects

S-curve of the HTHP technology adoption



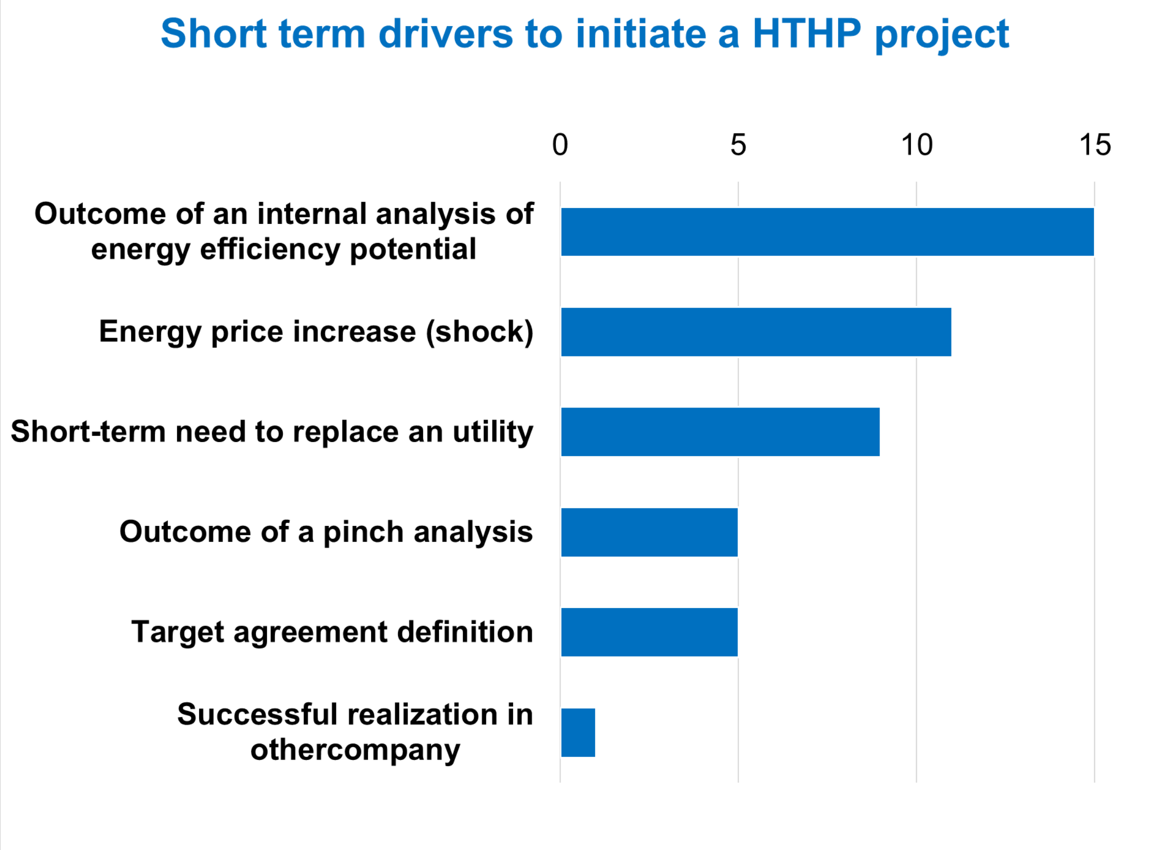
Source: Zühlsdorf (2024)

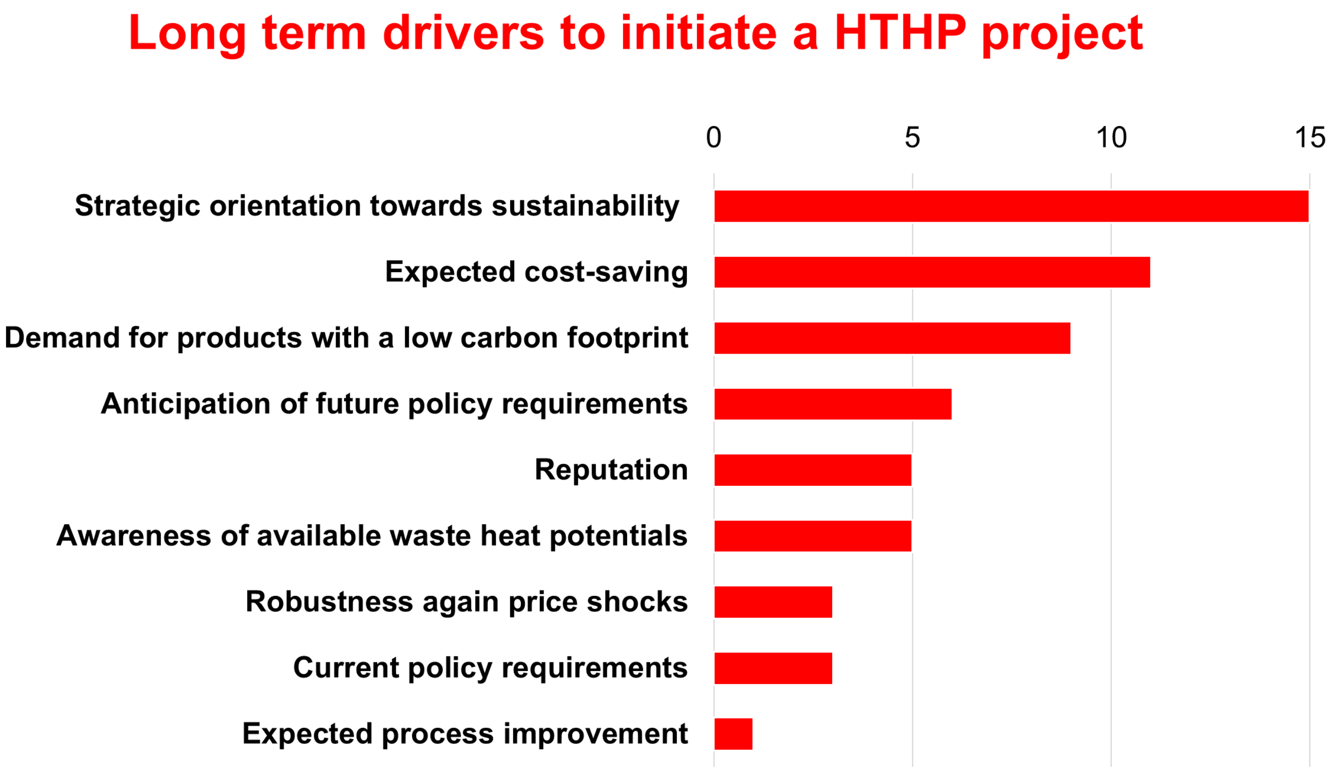
Favorable market conditions:

- Support for innovation and research
- More information
- Economic incentives
- Technology awareness
- Commitment to sustainability and decarbonization
- Involvement of various stakeholders

Socio-Economic Aspects

Drivers for HTHP adoption





Source: Survey among participants from industry, manufacturers, research, and government institutions at the Workshop on HTHPs held in Ittigen, Switzerland, in March 2023

Development Perspectives

Heating capacity	Tempe- rature	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
200 kW to 10 MW	< 120 °C	Prototypes available		Demonstrators available		Commercial roll-out		Established as preferred technology				
	120 °C - 160 °C		Prototypes available		Demonstrators available		Commercial roll-out		Established as preferred technology			
	> 160 °C			Prototypes available		Demonstrators available		Commercial roll-out		Established as preferred technology		
>10 MW	< 120 °C		Technology transfer & commercial project sales		Demonstrators available	Established as preferred technology						
	> 120 °C			Technology transfer & commercial project sales			Demonstrators available		Established as preferred technology			

Source: IEA HPT Annex 58 Task 1 Report (2023): Development perspectives for HTHPs towards 2030

Summary

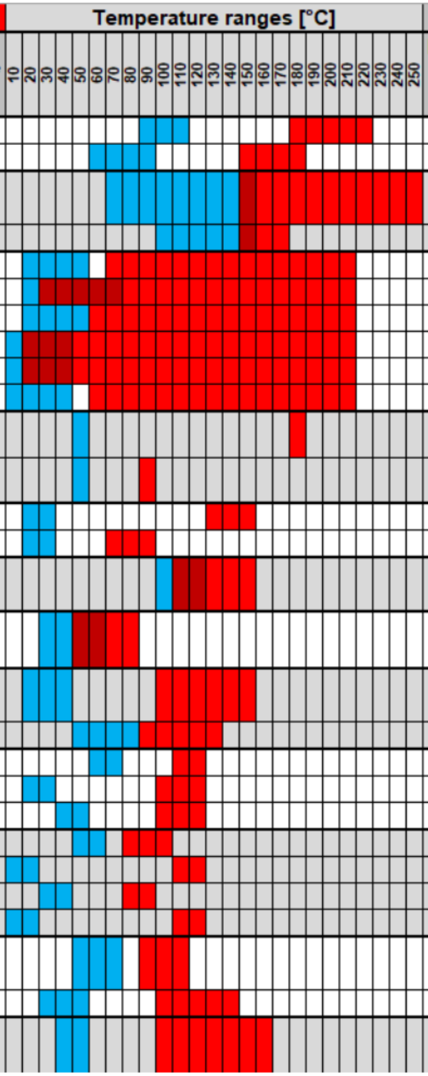
- HTHPs provide in energy savings and decarbonization
- Key target audience for the integration guidelines are engineers, managers, technicians, and planners
- There are different integration levels (process, unit, utility, sector)
- Use the feasibility checklist and preliminary assessment for integration
- Apply Pinch Analysis, which is relevant for integration
- Consider key principles and practical applications
- Consider costs, funding, and subsidies
- Have a future outlook and follow market trends

Backup Slides

Overview of Demonstration Cases

Overview of integration concepts and HP concepts

	Process	Unit Operation	Production Pattern	Source Medium	Source T_{in} [°C]	Source T_{out} [°C]	Source ΔT_{Glide} [K]	Sink Medium	Sink T_{in} [°C]	Sink T_{out} [°C]	Sink ΔT_{Glide} [K]	Mean ΔT_{Lift} [K]	Integration Level	Heat Pump Concept	Heat Pump Application
1.	Baking ovens	Baking	Continuous	Humid air	110	90	20	Air	180	220	40	100	Unit	Transcritical cascaded	Heating along large temperature glides
					90	65	25		150	180	30	88			
2.	Molded fiber dryers	Drying	Continuous	Humid air	150	70	80	Air	150	250	100	90	Process	Reversed Brayton cycle	Heating along large temperature glides
					150	100	50	Steam	150	165	15	33		Single HP	Steam generation
3.	Spray Drying	Drying	Continuous	Humid air	50	20	30	Air	64	210	146	102	Process	Cascaded HP	Heating along large temperature glides
					70	15	55		15	210	195	70		Transcritical cascaded	
					50	23	27		64	210	146	101		Reversed Brayton cycle	
				Water	40	12	28		15	210	195	87		Cascaded HP	
					40	12	28		15	210	195	87		Transcritical cascaded	
					40	12	28		64	210	146	111		Reversed Brayton cycle	
4.	Brick Drying	Drying	Continuous	Air (Water intermediate circuit)	50	- (*)	- (*)	Air (Water intermediate circuit)	- (*)	180	- (*)	- (*)	Unit	Cascaded HP	Heating along large temperature glides
			Continuous		50	- (*)	- (*)		- (*)	90	- (*)	- (*)		Single HP	Heating along large temperature glides
5.	Painting & Drying	Drying	Non-continuous	Humid air	28	22	6	Liquid	130	150	20	115	Unit	Cascaded HP	Heating along large temperature glides
							6		70	90	20	80			
6.	Biosludge drying	Drying	Continuous	Steam	120	100	20	Steam	100	146	46	13	Process	Steam compression	Steam generation
7.	Plastic granules	Drying	Continuous	Humid air	60	30	30	Air	50	80	30	20	Process	Transcritical single stage	Heating along large temperature glides
8.	Batch Sterilization	Thermal preservation	Batch	Water	40	20	20	Water	100	150	50	95	Utility	Trancritical HP	Heating along large temperature glides
					80	52	28	Steam	80	130	50	39		Flash tank + MVR	Steam generation
9.	Distillation	Thermal separation	Continuous	Water	65	60	5	Steam	110	115	5	50	Utility	HP + flash tank	Steam generation
					27	22	5	Steam	105	115	10	86		Cascaded HP	
					45	40	5	Steam	100	115	15	65		SGHP/Flash tank + MVR	
10.	Anodizing	Utility water heating	Non-continuous	Water	60	50	10	Water	82	95	13	34	Unit	Single HP	Hot water production
		Thermal treatment			20	15	5	Steam	110	120	10	98		Cascaded HP	Steam generation
		Utility water heating			40	35	5	Water	80	85	5	45		Single HP	Hot water production
		Thermal treatment			20	15	5	Steam	110	120	10	98		Cascaded HP	Steam generation
11.	Oil and Gas Processing	Thermal separation	Continuous	Oil	70	50	20	Oil	85	105	20	35	Process	Transcritical single stage	Heating along large temperature glides
				Water-glycol	45	35	10		100	140	40	80	Supply	Cascaded HP	Hot water production
12.	Extrusion cooking	Thermal treatment	Continuous	Humid air	50	45	5	Water	100	160	60	83	Process	Transcritical single stage	Hot water production



(: depending on the exact design and application)*

Steps before Pinch Analysis

Preliminary steps before definition of heat transfer requirements

1. Review the processes with production /project manager
2. Check existing heat recovery HEX(s) (if any)
3. Focus on the processing routes of different products
4. Get a clear understanding of the processing steps
5. Challenge existing operating conditions and the real process requirements
6. Define typical production planning schedule (weekly)
7. Consider heat transfer requirements of auxiliary processes, heat recovery options, and heat soures and sinks

Technical Aspects

HTHP Specifications

- Footprint and weight of the HTHP
- Minimum working duration after start-up, continuous operation capability and duration without maintenance
- Managing high variations in demand and source or sink temperatures (to maintain efficiency and stability)
- Minimum part-load functioning (% of design capacity)
- Start-up and shutdown times and capacity ramping rates
- Noise emissions and vibration (with available mitigation measures to comply with maximum allowed noise emissions)
- Precision of the output temperature
- Refrigerant type
- Material requirements
- Integration in automation system
- Electrical requirements (maximum voltage, current and frequency; standstill power; electrical noise and harmonic filter)
- Type of oil in the machine (for example, any requirement for food-grade oil to be specified)
- Environmental working conditions (humidity, ambient temperature)