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Federal Department of the Environment,
Transport, Energy and Communications DETEC

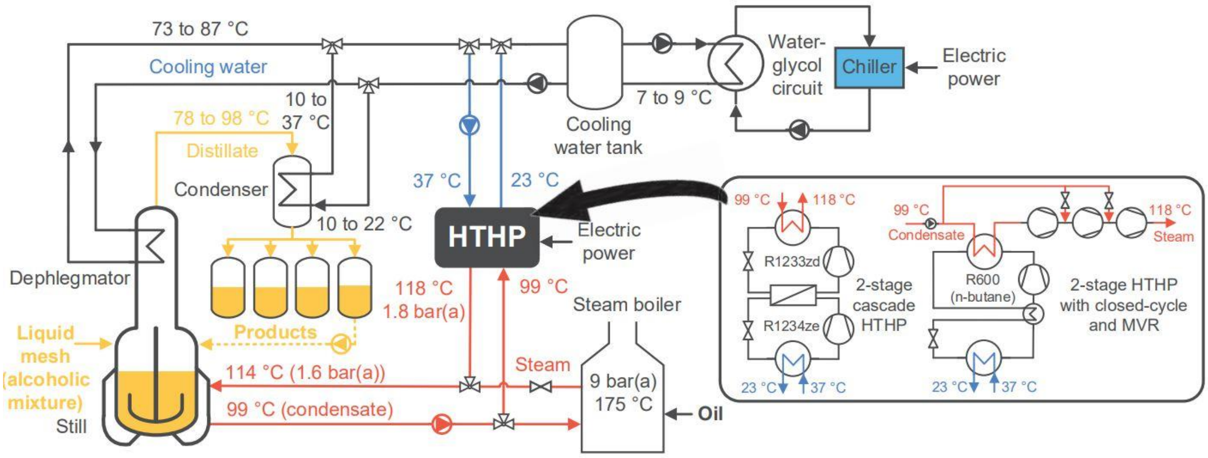
Swiss Federal Office of Energy
Energy Research and Cleantech

Final report from 24 August 2024

Annex 58 HTHP-CH – Integration of HTHPs in Swiss Industrial Processes

Appendix 4

Integration Concepts



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SFOE contract number: SI/502336-01

This is an appendix to the summary report on the project "Annex 58 HTHP-CH – Integration of HTHPs in Swiss Industrial Processes". The report and other appendices can be downloaded at https://www.aramis.admin.ch/Texte/?ProjectID=49514.

Integration Concepts for HTHPs

OST Eastern Switzerland University of Applied Sciences

ICR 2023, Workshop 19 (Commissions B1-E2) - Heat pumps
24 August 2023, Paris, France

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Integration Concepts for HTHPs
Terminology in IEA HPT Annex 58

Task 1 – Technology

- Heat pump systems (e.g., cycles, component types, configurations, etc.)
- Supplier specific technologies (e.g., omponent technologies, protected solutions, etc.)
- Irrespective of specific applications

Task 2 – Integration Concepts

- **Blueprint solution for reference processes** (e.g. hot water production, steam production, spray drying, etc.) **or systems** (e.g., dairy, slaughterhouse, hospital, etc.)
- **Can include several HP system types, irrespective of supplier**

Task 3 – Application/Transition

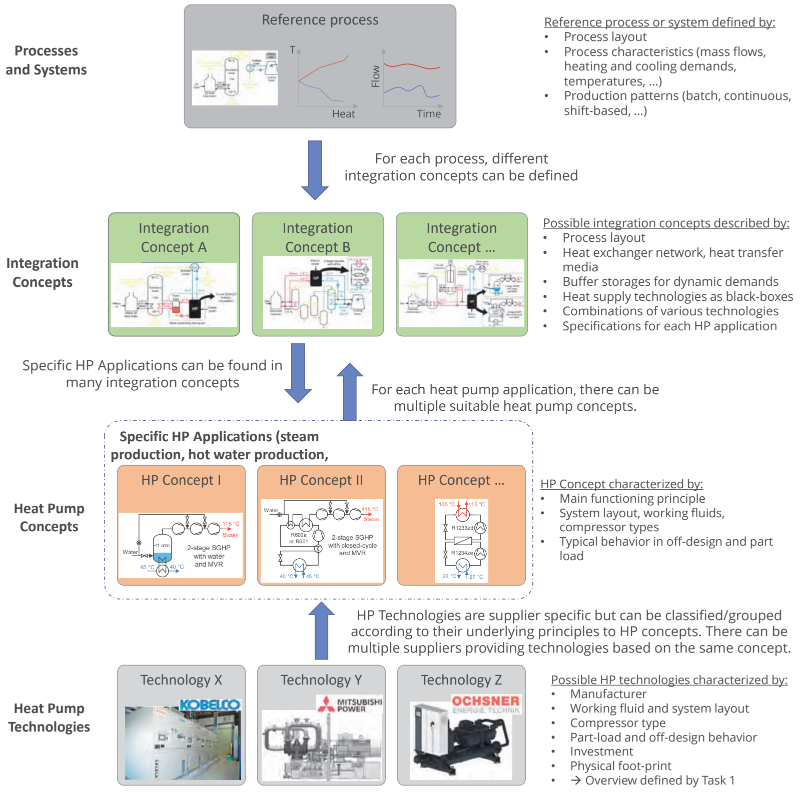
- Addressing the conversion from existing systems towards concept solutions
- Focus on case specific characteristics and challenges
- Consideration of local boundary conditions

Processes and Systems

Integration Concepts
(HP as black box, independent from HP solution)

Heat Pump Concepts

Heat Pump Technologies



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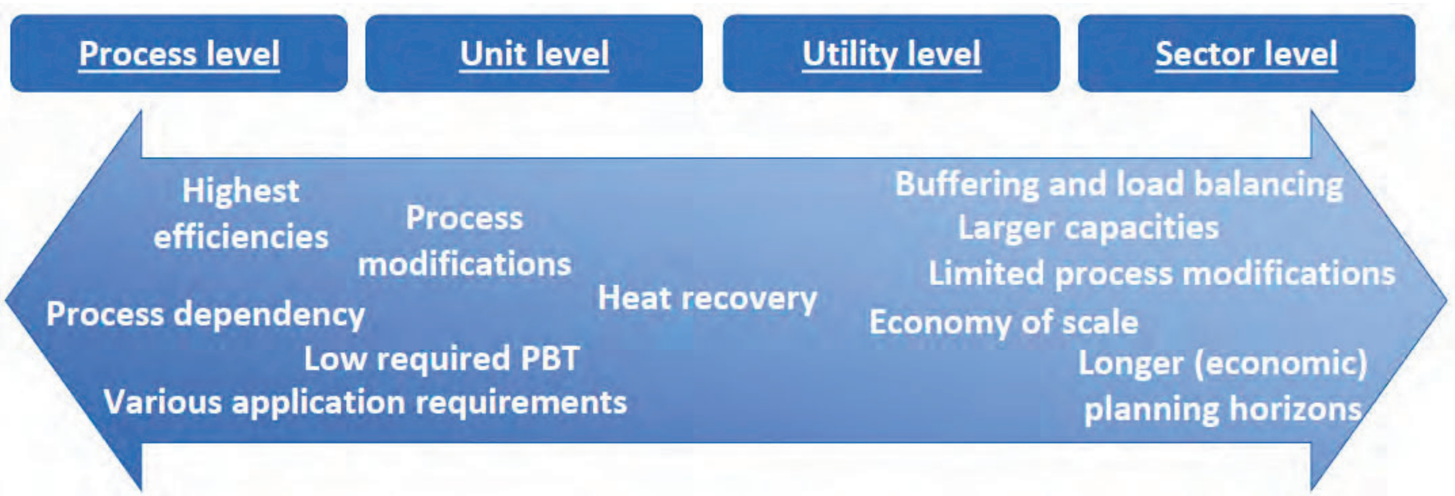
Integration levels

- (Petersen and Zühlsdorf, 2022)



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Integration Concepts for HTHPs

Literature review

- Collection of publications from journals and conference papers
- Search keywords: integration, heat pump, high-temperature
- Description: by schematic figure and literature reference
- Status/quality of integration concept: concepts, planning phase, realized
- List of examples

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Integration Concepts for HTHPs

Template for examples characterization

Process	Process description (temp, capacity, media, …)	Integration Concept	Level of integration (process, unit, utility, sector)	Combination with other heating technologies	Combination with thermal energy storage (TES)	Literature Reference
Process 1 (e.g., spray drying)		Concept A				
		Concept B				
		Concept C				
Process 2 (e.g., pasteurization)		Concept A				
		Concept B				
		Concept C				

… etc.!

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Integration Concepts for HTHPs

Examples: Distillation, drying, steam generation

Process / Example	Reference
Distillation processes bioethanol	(Arpagaus et al., 2022)
Schnapps distillation case study	(Arpagaus et al., 2023)
Whisky destillation	(Längauer et al., 2022)
Heat pump-assisted distillation	(Yang et al., 2016)
5-stage MVR-HP with water in a closed loop in two distillation columns	(Gotaas et al., 2022)
MVR-HP system with several-stage compressions	(Gotaas et al., 2022)
Spray dryer for protein-rich fish food production	(Andersen et al., 2023)
Spray drying process with HTHP, recuperator and electric heater	(Arpagaus, Bless, et al., 2023)
Integration of CO2 HTHPs and conventional heaters for spray dryers	(Bellemo and Bergamini, 2022)
Tixotherm Process for drying milk permeate powder	(Arpagaus et al., 2023)
Drying of fish food pellets at BioMar	(Petersen and Zühlsdorf, 2022)
Industrial dryer	(Holder, 2022)
Brick drying	(Wilk et al., 2023)
Starch drying	(Wilk et al., 2022, 2023, (Schlosser, 2022)
Electronic coil drying	(Schlosser, 2022)
Steam generation by ammonia bottom cycle and MVR-HP top cycle	(Gotaas et al., 2022)
Steam generation via MVR and flash tank	(Schlosser, 2022), (Schneeberger et al., 2021)
Steam generation via MVR and flash tank	(Schlosser, 2022)
Steam generation via MVR and heat exchanger	(Schlosser, 2022)
Steam production with Rotation Heat Pump	(Längauer et al., 2022)

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Integration Concepts for HTHPs

Examples: Dairy, food, paper, district heating, others

Process / Example	Reference
Cheese factory hot water generation in combination with a storage tank	(Arpagaus, 2019)
Dairy culture production from district heating with natural refrigerants	(Andersen et al., 2023)
Dairy steam generation for the CIP process	(Arpagaus et al., 2023)
Upgrading exhaust gas and process waste heat streams in the dairy industry	(Corrales Ciganda et al. 2022)
HTHP integration in a dairy TINE Bergen	(Ahrens et al., 2021) (Brække n et al., 2022)
Milk sterilization with steam	(Corrales Ciganda et al. 2022)
Brewery hot water	(Andersen et al., 2023)
Sausage cooking	(Arpagaus et al., 2023)
Pasteurizaiton	(Längauer et al., 2022)
Electrolysis	(Längauer et al., 2022)
Extrusion process	(Wilk et al., 2023)
CO_2 HTHP for wellness sauna applications	(Seitz et al., 2028)
Upgrading exhausted air waste heat in the paper industry	(Corrales Ciganda et al. 2022)
Upgrading cogeneration waste heat streams in the paper industry	(Corrales Ciganda et al. 2022)
Heat recovery and process cooling	(Kukkola, 2022)
Solarthermal and Rotation Heat Pump	(Ecop, 2023)
Upgrading district heating at DIN Forsyning	(Petersen and Zühlsdorf, 2022)
Heat from the cooling of the steelmaking process for district heating	(Barbon, 2022)
District heating and booster	(Längauer et al., 2022)

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Summary

- Heat pumps as a blackbox (different optimal HP technologies)
- Different examples
- Industries → Processes → Applications → Integration Concepts

HOT WATER

HOT AIR

STEAM

Next steps:

- Continue literature review and collect references from recent conferences: IEA HPT 2023 Chicago, IIR GL2022, ICR2023 Paris, IEA HPT Magazine, HTHP Symposium 2017, 2019, 2022, Demo Cases IEA Annex 58, etc.
- Define ways of visualization of integration concepts:
  - Simplified drawings and schematics (standardization of symbols for drawing)
  - Temperature profiles
  - Heating and cooling demand profiles (batch, continuous)
  - Pinch curves
  - …

Have confidence in HTHP technology and give it a try!

Collection of Examples (preliminary)

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Distillation processes

- Distillation processes bioethanol (Arpagaus, Bless, & Bertsch, 2022), (Arpagaus, Bless, & Bertsch, 2022) (Schlosser et al. 2022)
- Schnapps distillation case study (Arpagaus, Bless, et al., 2023)
- Whisky destillation (Längauer et al., 2022)
- Heat pump-assisted distillation (Yang et al., 2016)
- 5-stage MVR-HP with water in a closed loop in two distillation columns (Gotaas et al., 2022) (Zühlsdorf et al., 2022)
- MVR-HP system, utilizing the several-stage compressions to optimize process integration, and water steam supplied to distillation- and boiler processes (Gotaas et al., 2022) (Zühlsdorf et al., 2022)

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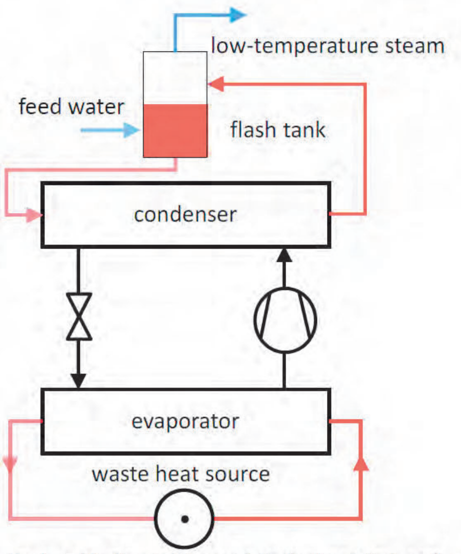
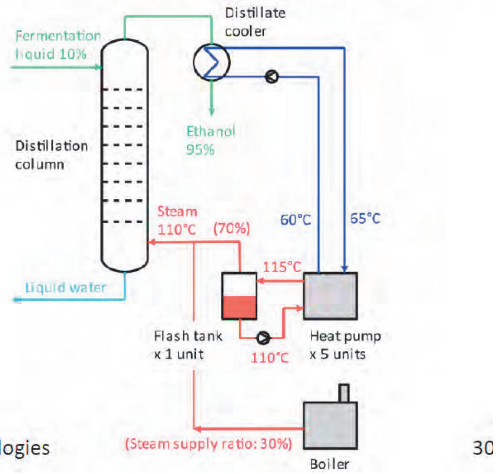
Distillation processes bioethanol (steam generation with flash tank)

- (Arpagaus, Bless, & Bertsch, 2022), (Arpagaus, Bless, & Bertsch, 2022) (Schlosser et al. 2022)



No.	Supplier	Industry	Process	Heat source			Heat sink			HP Type	Refrigerant	Compressor	Capacity	COP_H
				Unit Operation	T_{out} [°C]	T_{in} [°C]	Unit Operation	T_{out} [°C]	T_{in} [°C]				[kW]	
6	Kobelco	refinery	bioethanol distillation	process cooling	60	65	distillation	115	110	CCHP + Flash Tank	R245fa	twin-screw	1,850	3.5



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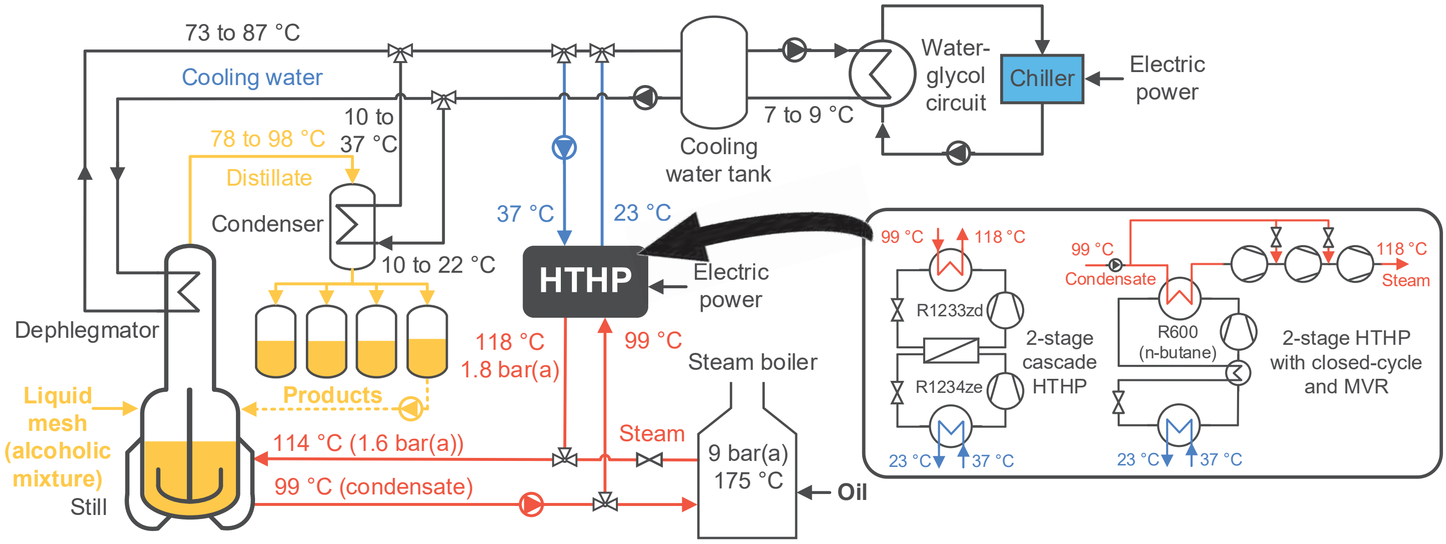
Schnapps distillation case study

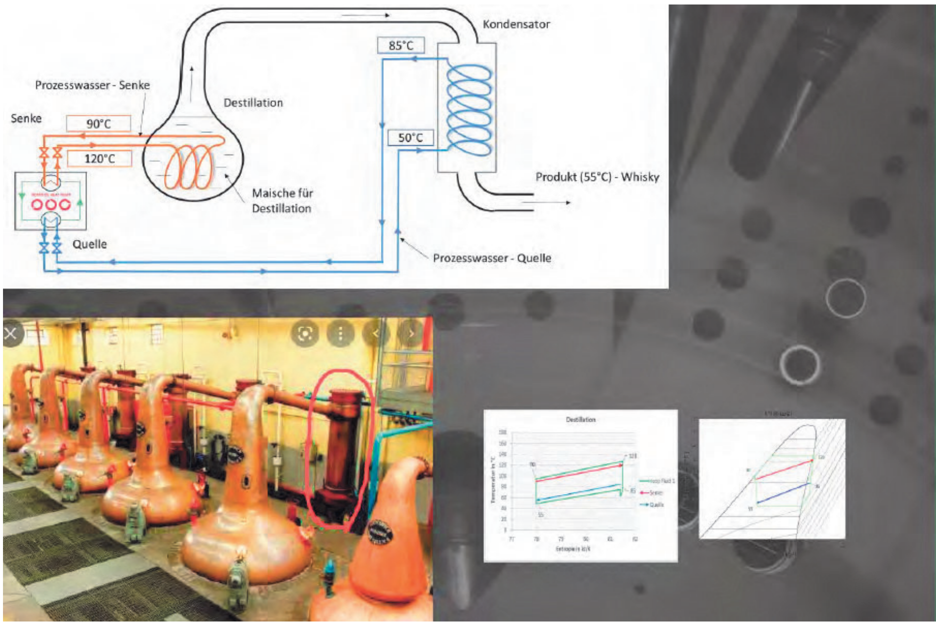
- (Arpagaus, Bless, et al., 2023)



Integration Concepts for HTHPs

Whisky distillation

- (Längauer et al., 2022)



Advantages:
- High temperatures
- flexibility

Source:
- condensation

Sink:
- destillation

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Integration Concepts for HTHPs

Heat pump-assisted distillation

- (Yang et al., 2016)

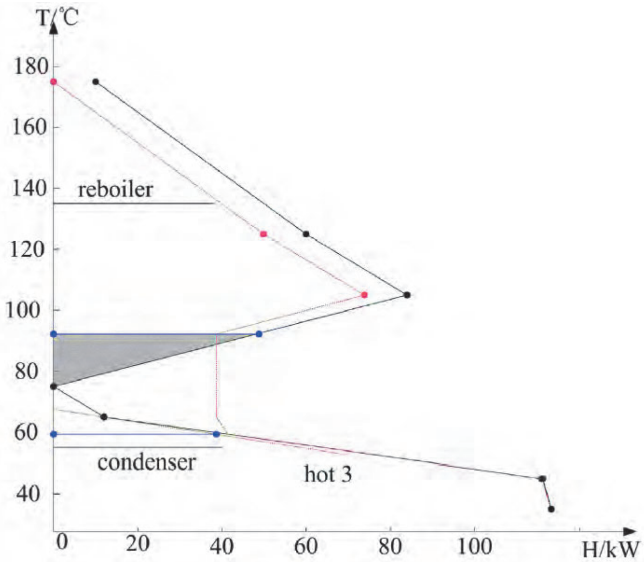

Fig. 12. Improvement of heat pump placement single-column.

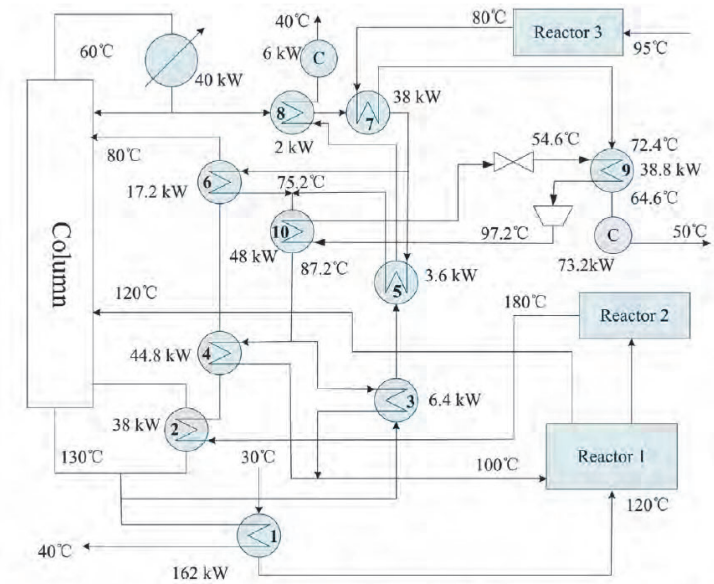

Fig. 13. Resulting flowsheet after implementing the heat integration single-column.

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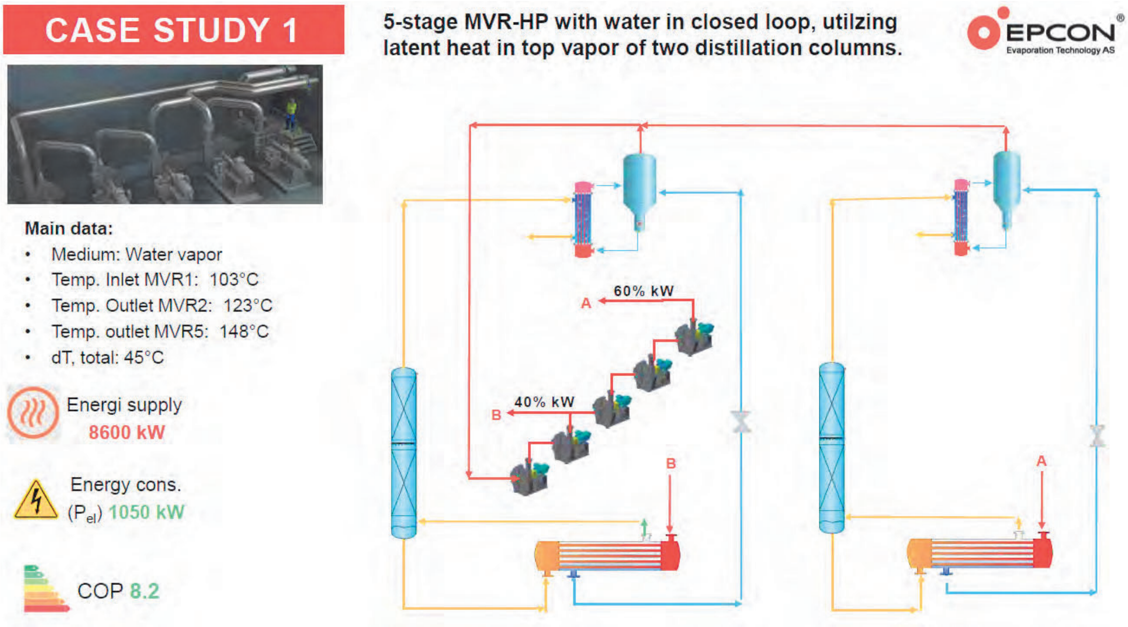
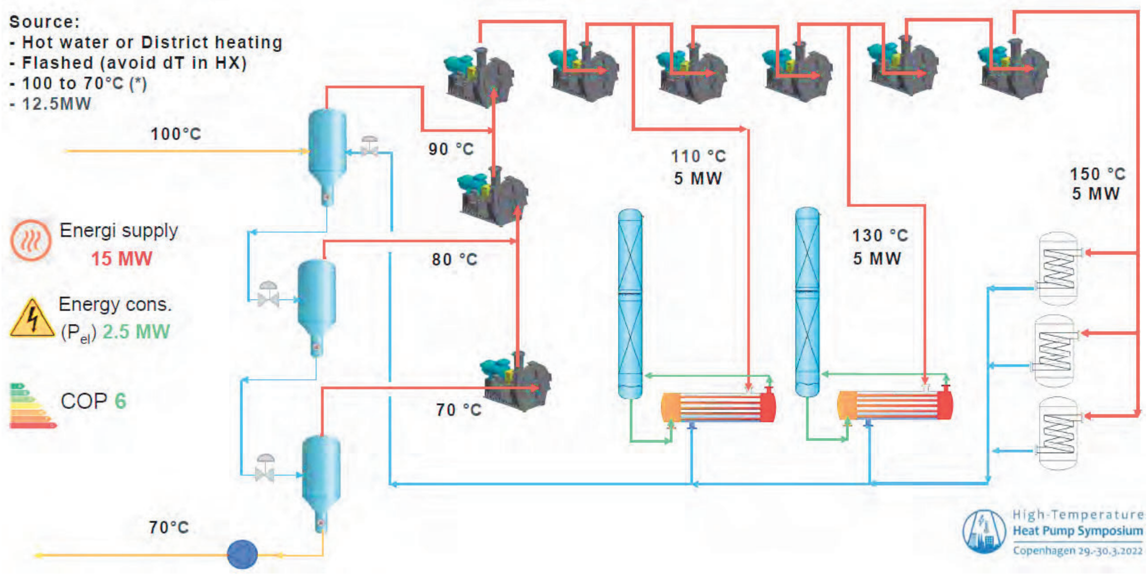
5-stage MVR-HP with water in closed loop in two distillation columns

- (Gotaas et al., 2022) (Zühlsdorf et al., 2022)



MVR-HP system, utilizing the several-stage compressions to optimize process integration, and water steam supplied to distillation- and boiler processes

- (Gotaas et al., 2022) (Zühlsdorf et al., 2022)



Spray drying

- Spray dryer for protein-rich fish food production (Andersen et al., 2023)
- Spray drying process with integration concept of a HTHP with recuperator and electric heater (Arpagaus, Bless, et al., 2023)
- Integration of high temperature CO_2 heat pumps and conventional heaters for spray dryers (Bellemo and Bergamini, 2022)

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Spray dryer for protein-rich fish food production

- (Andersen et al., 2023)

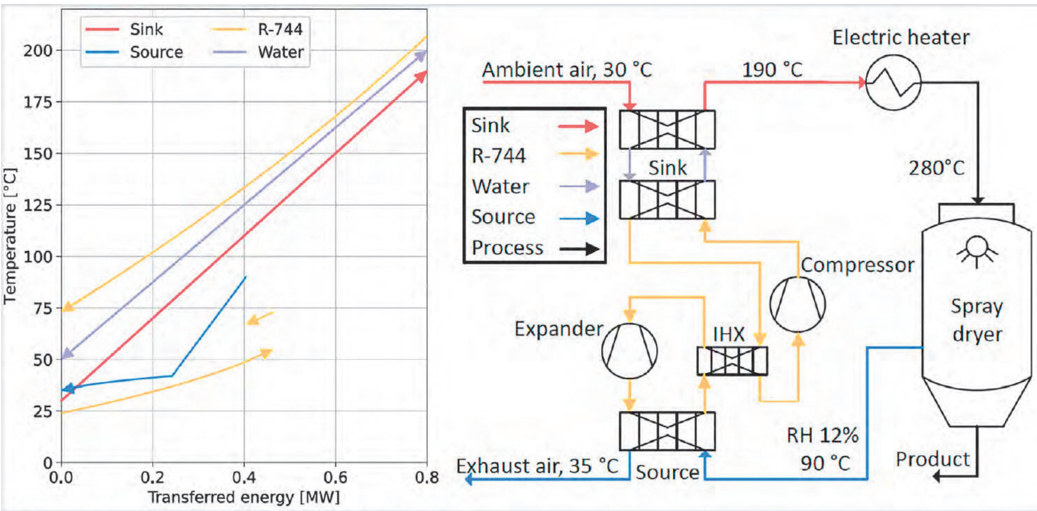

Figure 2a: Spray dryer for protein rich fish food production.

Drying of fish food at 280 °C in spray dryers using R-744 brayton heat pump

- A protein rich substance is dried in several parallel spray dryers using 15,000 kg/hr of dry air heated to 280 °C.
- Ambient air is heated from 30 °C to 190 °C in a heat exchanger connected to the heat pump by a secondary water loop before an electric heater raises the temperature to 280 °C w. a total COP of 1.77.
- The exhaust air comes out at 90 °C at 12 % relative humidity which is used as the source of the heat pump.

Heating COP	2.02
Heating capacity	0.8 MW
Sink	30 °C → 190 °C
Source	90 °C → 35 °C
Refrigerant	Carbon dioxide, R-744
Important remarks	High pressures 150 bar Compact cycle

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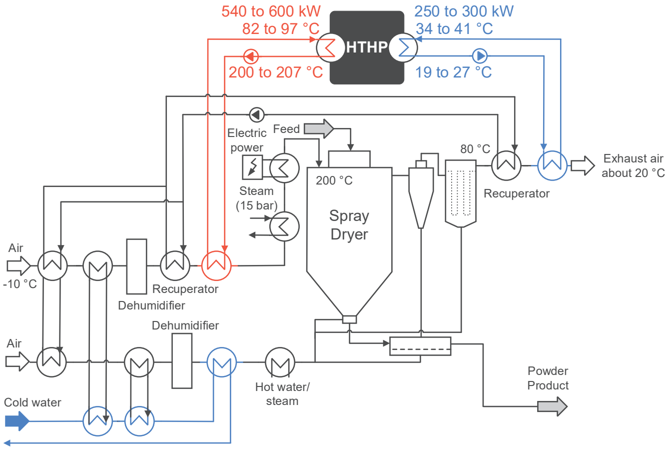
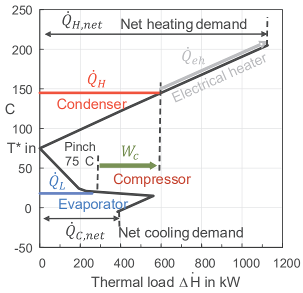
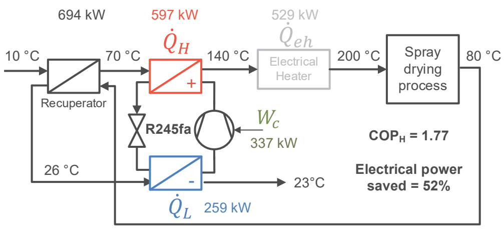
Spray drying process with integration concept of a HTHP with recuperator and electric heater

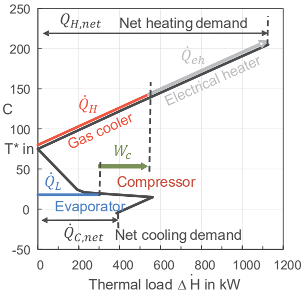
- (Arpagaus, Bless, et al., 2023)



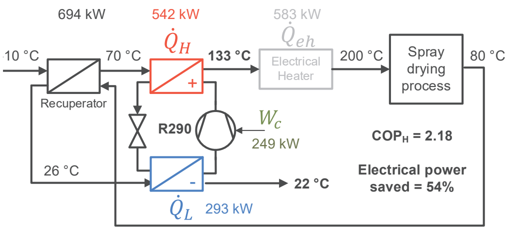


Standard R245fa heat pump with recuperator





Transcritical R290 heat pump with recuperator



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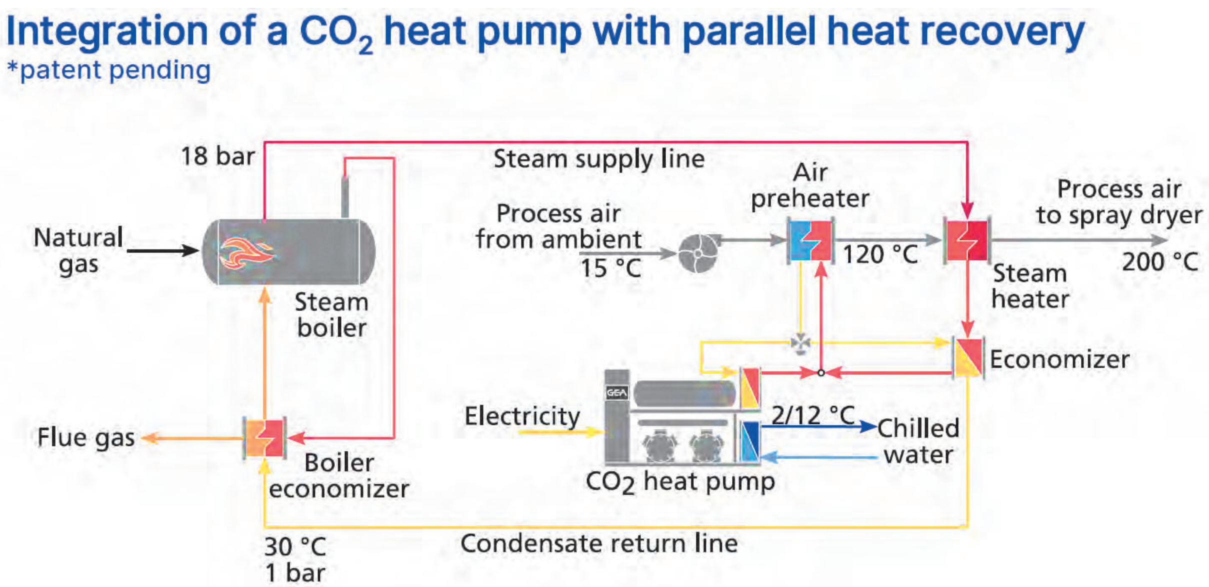
Integration of high temperature CO_2 heat pumps and conventional heaters for spray dryers

- (Bellemo and Bergamini, 2022)



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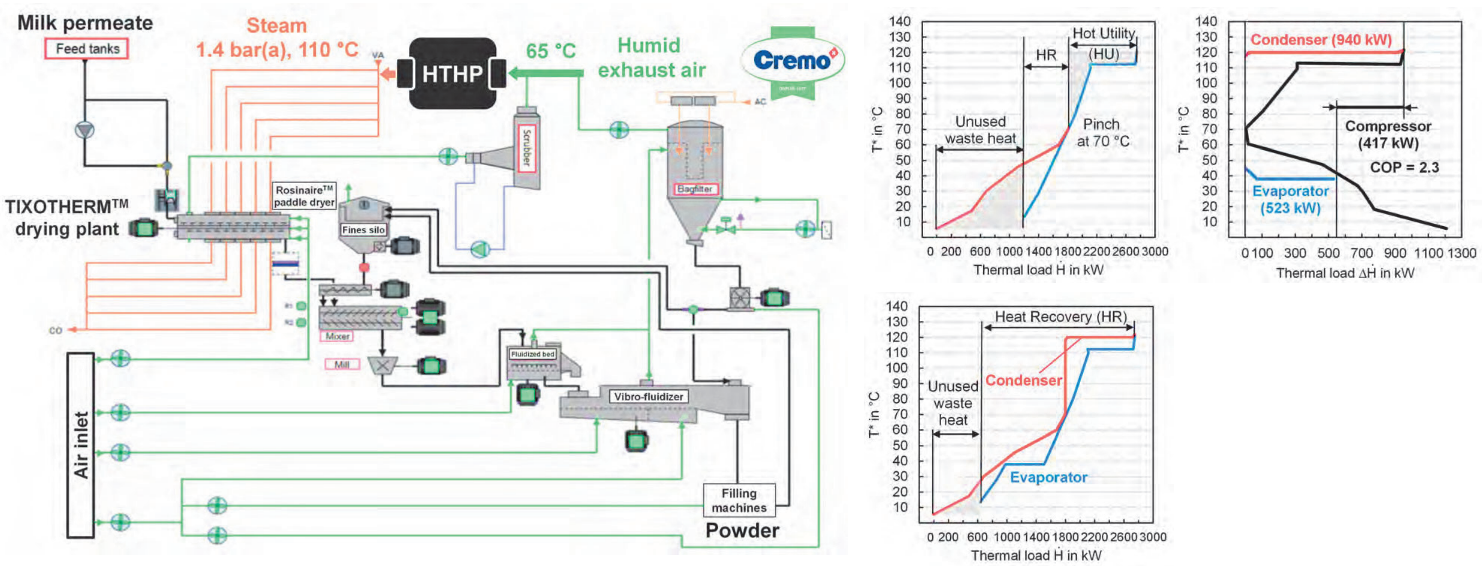
Drying processes (others)

- Tixotherm Process for drying milk permeate powder (Arpagaus, Bertsch, et al., 2023)
- Drying of fish food pellets at BioMar (Petersen and Zühlsdorf, 2022)
- Industrial dryer (Holder, 2022)
- Brick drying (Wilk et al., 2023)
- Starch drying (Wilk et al., 2022, 2023) (Schlosser, 2022)
- Electronic coil drying (Schlosser, 2022)

Tixotherm Process for drying milk permeate powder

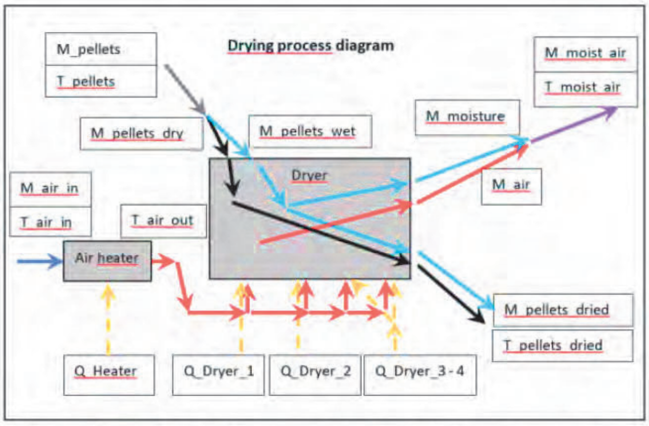
- (Arpagaus, Bertsch, et al., 2023)



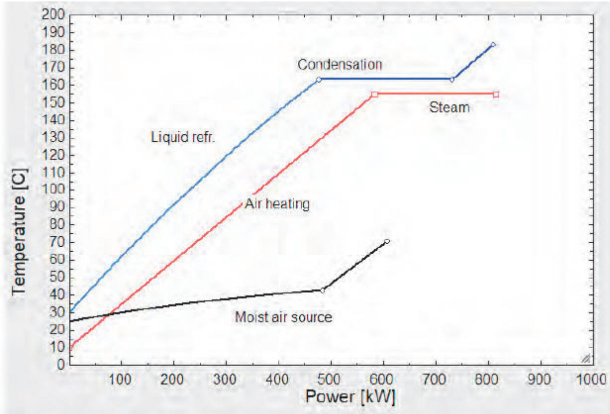
Integration Concepts for HTHPs

Drying of fish food pellets at BioMar

- (Petersen and Zühlsdorf, 2022)



Schematic of the drying process. Wet pellets enter at the top. Hot air is added from left, and additional heat is supplied at bottom. Warm, humid air exits at top right. Finished, dries pellets exit at bottom right



Energy balance showing the power used for hot air and additional heat (shown in red). The energy content in the moist air source is shown in black. The potential energy output of a heat pump using pentane as medium is shown in blue.

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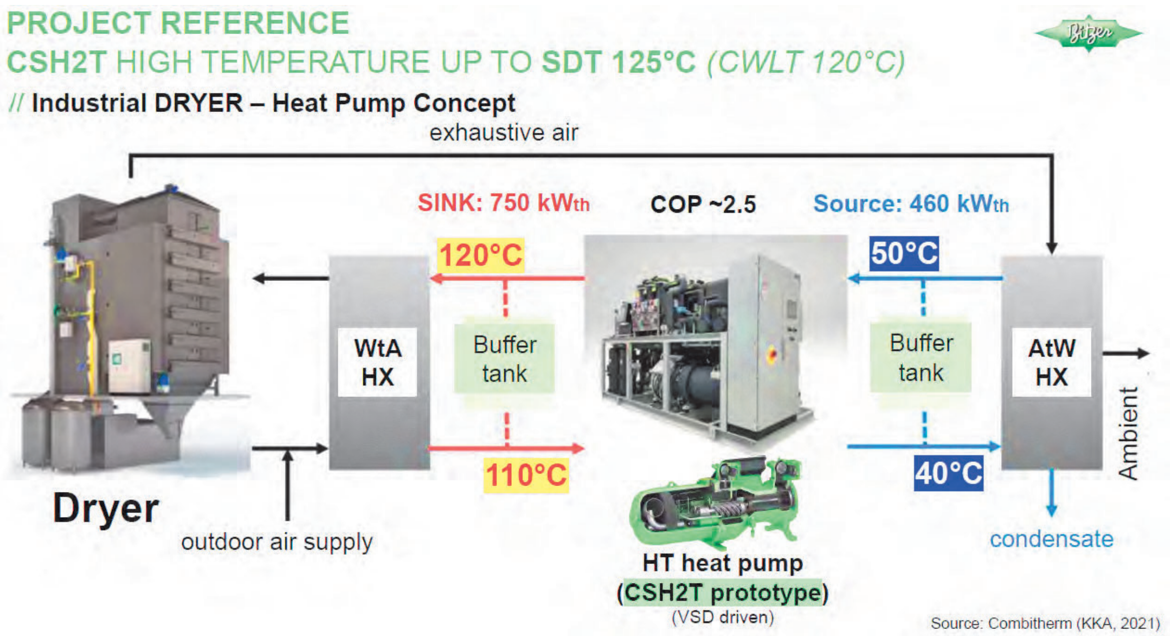
Integration Concepts for HTHPs

Industrial dryer

- (Holder, 2022)



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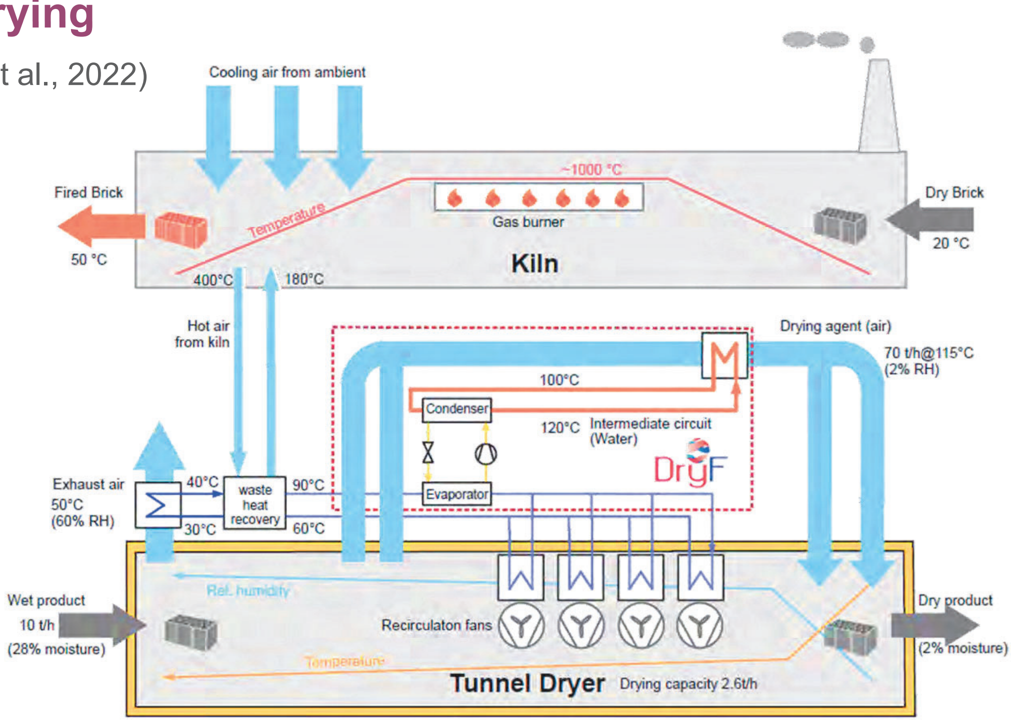
Brick drying

- (Wilk et al., 2022)



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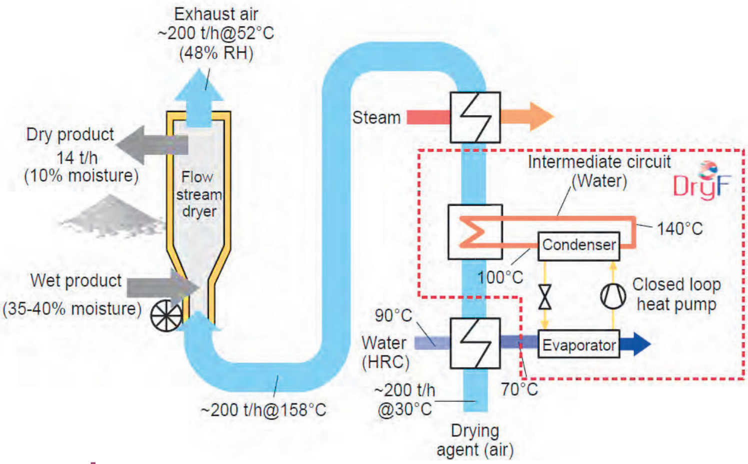
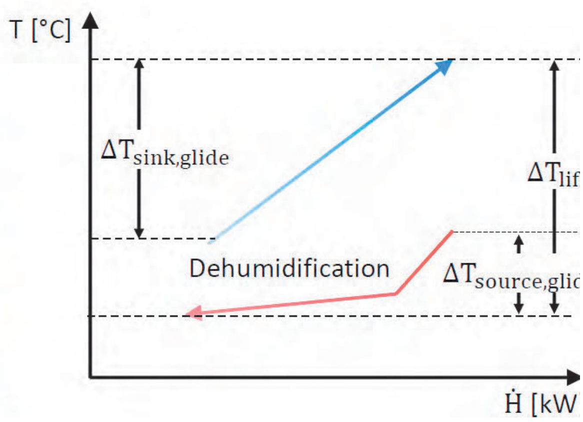
Integration Concepts for HTHPs

Starch drying

- (Wilk et al., 2022, 2023), (Schlosser, 2022)

No.	Supplier	Industry	Process	Heat source			Heat sink			HP Type	Refrigerant	Compressor	Capacity	COP_H
				Unit Operation	T_{out} [°C]	T_{in} [°C]	Unit Operation	T_{out} [°C]	T_{in} [°C]				[kW]	
3	AMT	food	starch drying	waste heat	72	76	drying	138	96	CCHP	R-1336mzz(Z)	screw	374	3.2
9	Viking	minerals	brick drying	exhaust drying air	80	84	drying	121	96	CCHP	R-1336mzz(Z)	piston (8 compr.)	296	5





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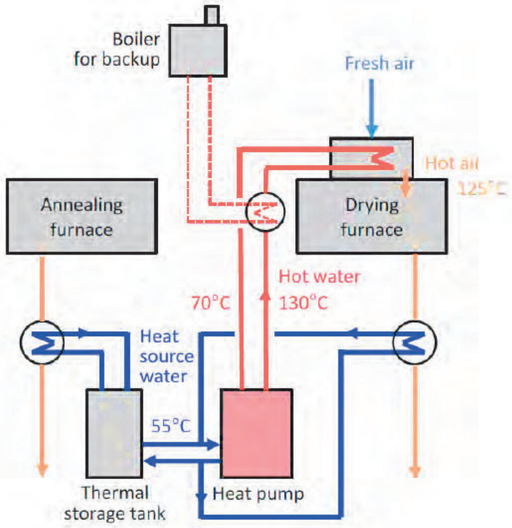
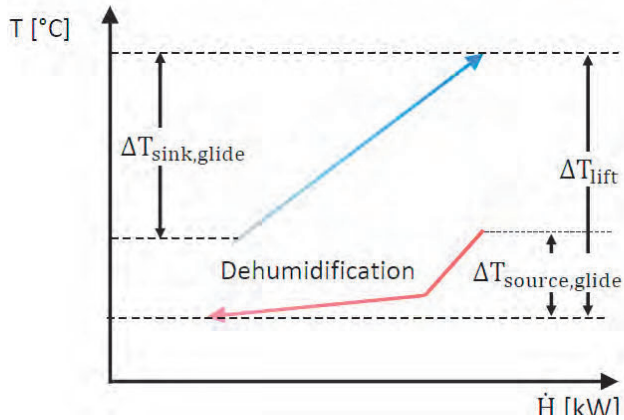
Integration Concepts for HTHPs

Electronic coil drying

- (Schlosser, 2022) in (Zühlsdorf et al., 2022)

No.	Supplier	Industry	Process	Heat source			Heat sink			HP Type	Refrigerant	Compressor	Capacity	COP_H
				Unit Operation	T_{out} [°C]	T_{in} [°C]	Unit Operation	T_{out} [°C]	T_{in} [°C]				[kW]	
2	Mayekawa	electronic	coil drying	painting cooling	25	30	drying	120	20	CCHP	R744	piston	89	3.1
7	MHI	electronic	coil drying	waste heat	50	55	drying	130	70	CCHP	R134a	centrifugal	627	3.0





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Integration Concepts for HTHPs

Steam generation

- Steam generation by ammonia bottom cycle combined with MVR-HP top cycle supplying HP steam directly (Gotaas et al., 2022)
- Steam generation via MVR and flash tank (Schlosser, 2022), (Schneeberger et al., 2021)
- Steam generation via MVR and flash tank (Schlosser, 2022)
- Steam generation via MVR and heat exchanger (Schlosser, 2022)
- Steam production with Rotation Heat Pump (Längauer et al., 2022)

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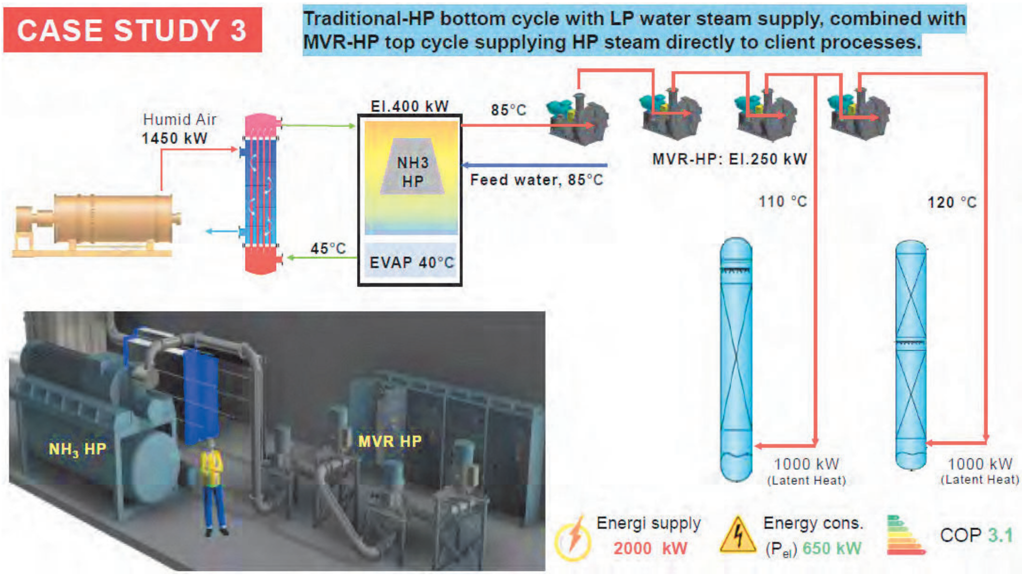
Integration Concepts for HTHPs

Steam generation by ammonia bottom cycle combined with MVR-HP top cycle supplying HP steam directly

- (Gotaas et al., 2022) in (Zühlsdorf et al., 2022)



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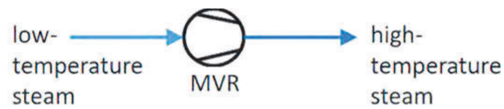
Integration Concepts for HTHPs

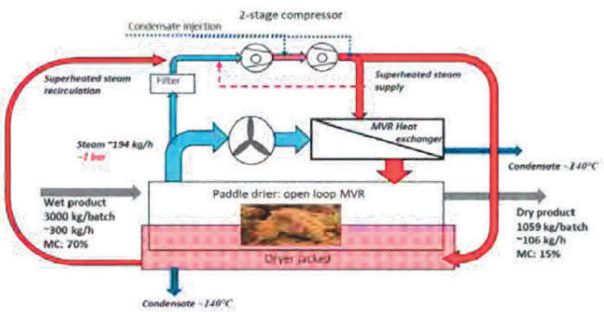
Steam generation via MVR and flash tank

- Alcoholic distillation, pulp drying, chemical (Schlosser, 2022)
- MVR sludge drying (Schneeberger et al., 2021)

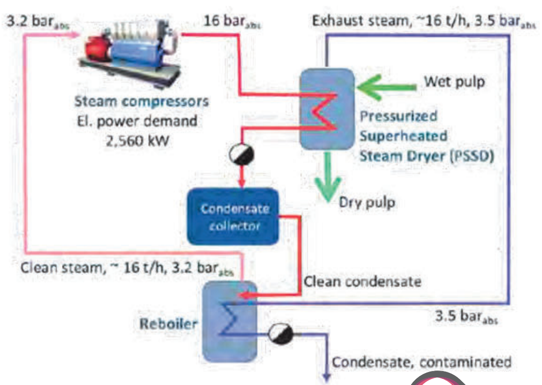
No.	Supplier	Industry	Process	Heat source			Heat sink			HP Type	Refrigerant	Compressor	Capacity	COP_H
				Unit Operation	T_{out} [°C]	T_{in} [°C]	Unit Operation	T_{out} [°C]	T_{in} [°C]				[kW]	
1	n. a.	beverage	alcoholic distillation	product cooling	75	78.3	distillation	140	n. a.	MVR	n. a.	n. a.	350	5.2
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
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
12	Rotrex, Epcon	sewage	sludge drying	surplus steam	100	n. a.	steam generation	146	n. a.	MVR	R718	turbo (2 stages)	500	4.5



MVR sludge dryer (Schneeberger et al. 2021)



Spilling piston compressors runnig 7500 h/a



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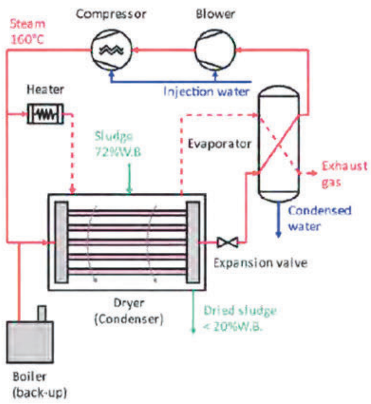
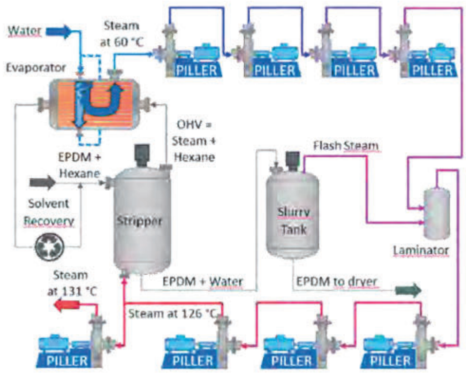
Integration Concepts for HTHPs

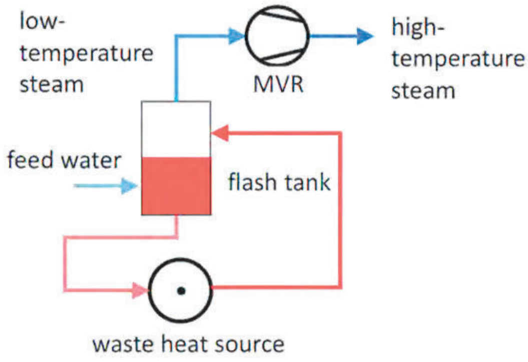
Steam generation via MVR and flash tank

- Sludge drying, thermal separation (Schlosser, 2022)

No.	Supplier	Industry	Process	Heat source			Heat sink			HP Type	Refrigerant	Compressor	Capacity	COP_H
				Unit Operation	T_{out} [°C]	T_{in} [°C]	Unit Operation	T_{out} [°C]	T_{in} [°C]				[kW]	
5	Kobelco	sewage	sludge drying	exhaust drying air	93	93	steam generation	160	160	MVR	R718	twin-screw, roots blower	675	2.9
8	Piller	plastics	thermal seperation	exhaust vapour	60	60	steam generation	131	126	MVR	R718	turbo (8 blowers)	10,000	4.4







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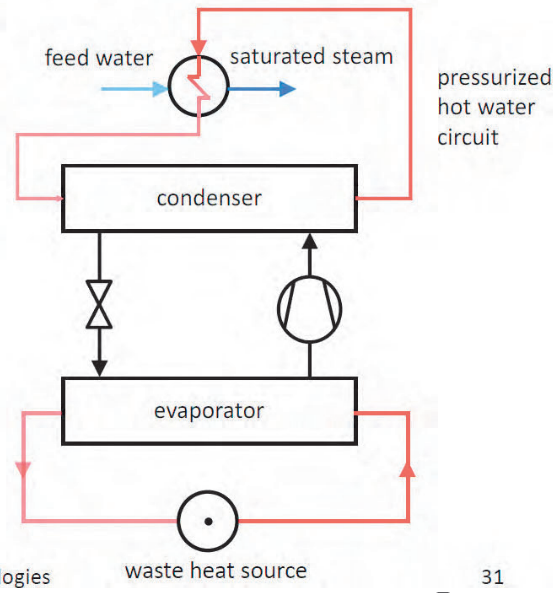
Integration Concepts for HTHPs

Steam generation via MVR and heat exchanger

- Pharma recooling (Schlosser, 2022)

No.	Supplier	Industry	Process	Heat source			Heat sink			HP Type	Refrigerant	Compressor	Capacity	COP_H
				Unit Operation	T_{out} [°C]	T_{in} [°C]	Unit Operation	T_{out} [°C]	T_{in} [°C]				[kW]	
4	Olvondo	pharma-ceutical	recooling	recooling heat	34	36	steam generation	183	178	Stirling HP	R704	piston	2,250	1.7



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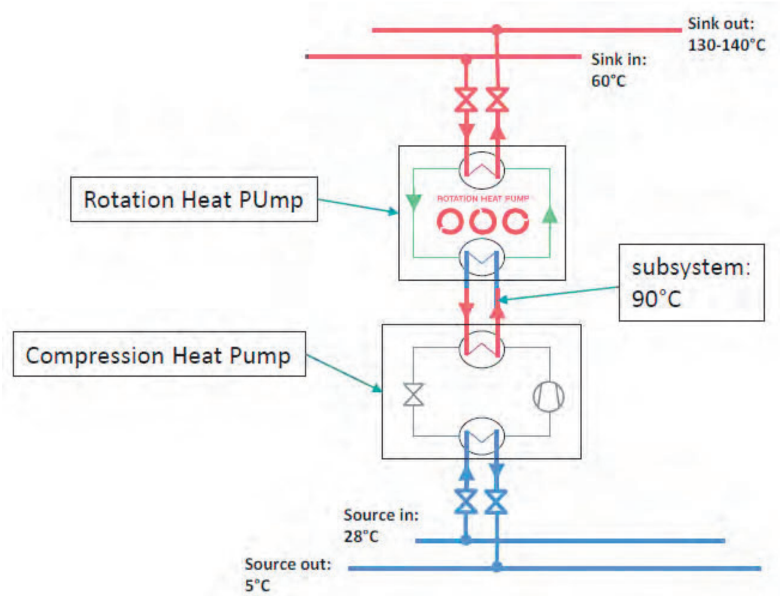
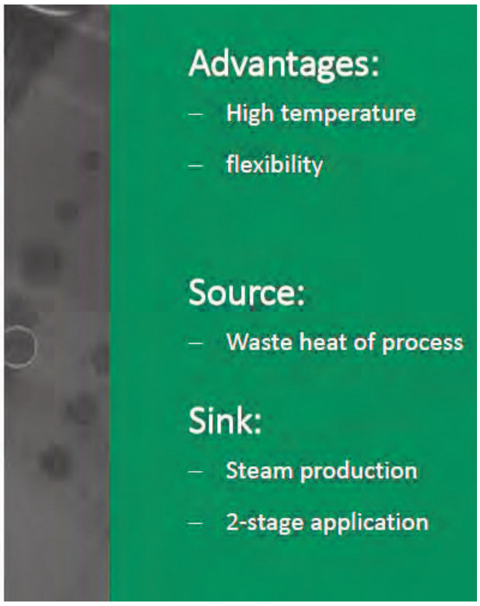
Steam production with Rotation Heat Pump

- (Längauer et al., 2022)



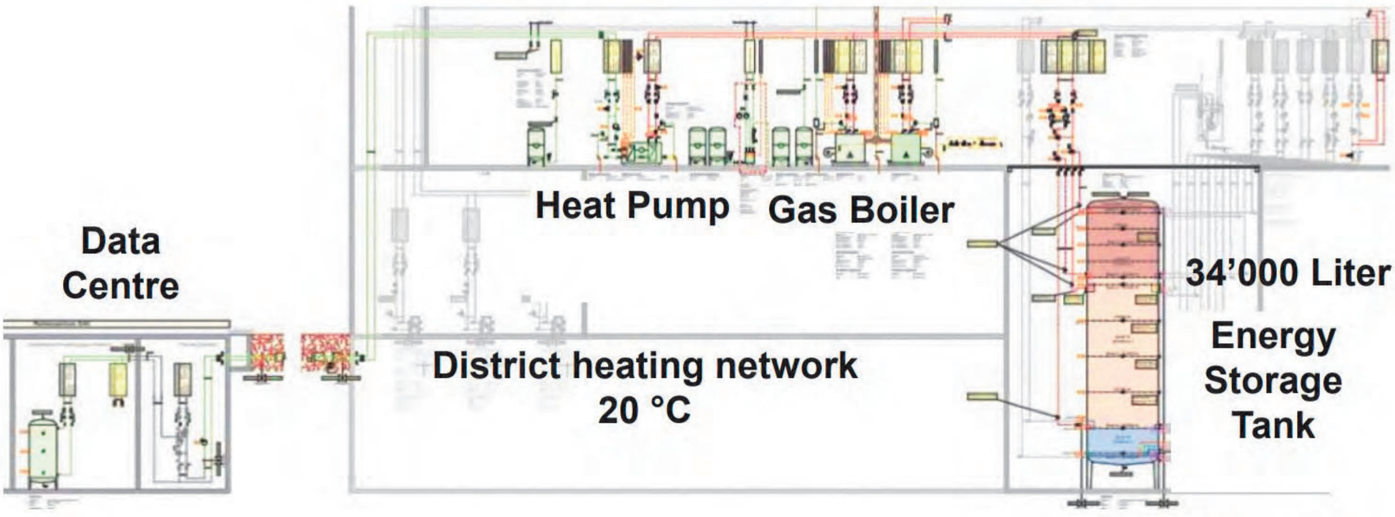


Milk industry

- Cheese factory hot water generation in combination with a storage tank (Arpagaus, 2019)
- Dairy culture production from district heating with natural refrigerants (Andersen et al., 2023)
- Dairy steam generation for the CIP process (Arpagaus et al., 2023)
- Upgrading cogeneration exhaust gas and process waste heat streams in the dairy industry (Corrales Ciganda et al. 2022)
- HTHP integration in a dairy TINE Bergen (Ahrens et al., 2021) (Brækken et al., 2022)
- Milk sterilization with steam (Corrales Ciganda et al. 2022)

Cheese factory hot water generation with a storage tank

- (Arpagaus, 2019)



Source: Amstein + Walthert

Dairy culture production from district heating with natural refrigerants

- (Andersen et al., 2023)

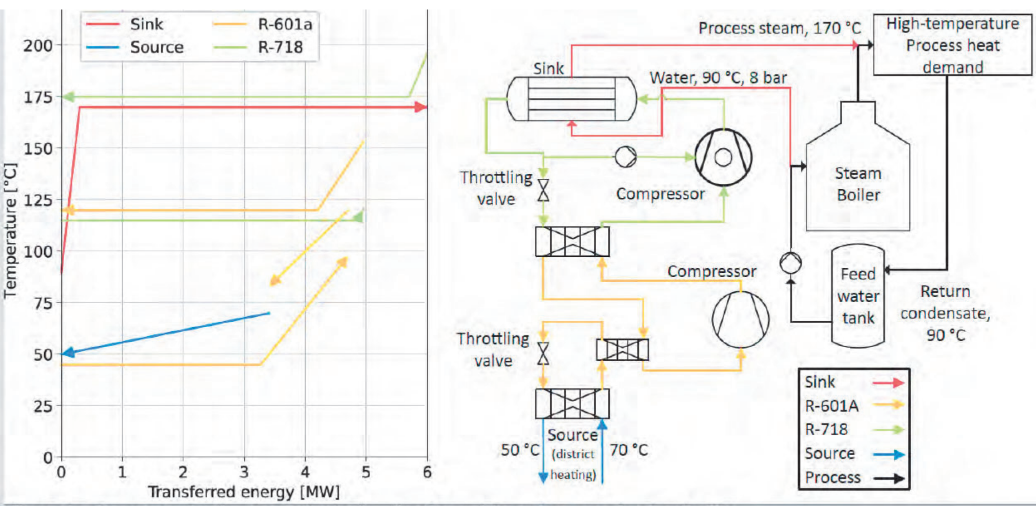


Figure 3a: Steam production from district heating for a dairy culture production facility.

Wort boiling with hot water system using R-601a from heat recovery tank

- A brewery uses 2.4 MW of hot water at 145 °C for wort boiling distributed several temporally offset batches in parallel. The remaining processes are covered by the heat recovery tank.
- Water returns from the high-temperature processes at 90 °C which is heated back up to 145 °C by the heat pump keeping the conventional gas boiler as a back-up.
- 90 °C hot water from the heat recovery tank supplies the heat pump and returns at 80 °C. The tank is supplied by a ammonia heat pump and recovered process heat.

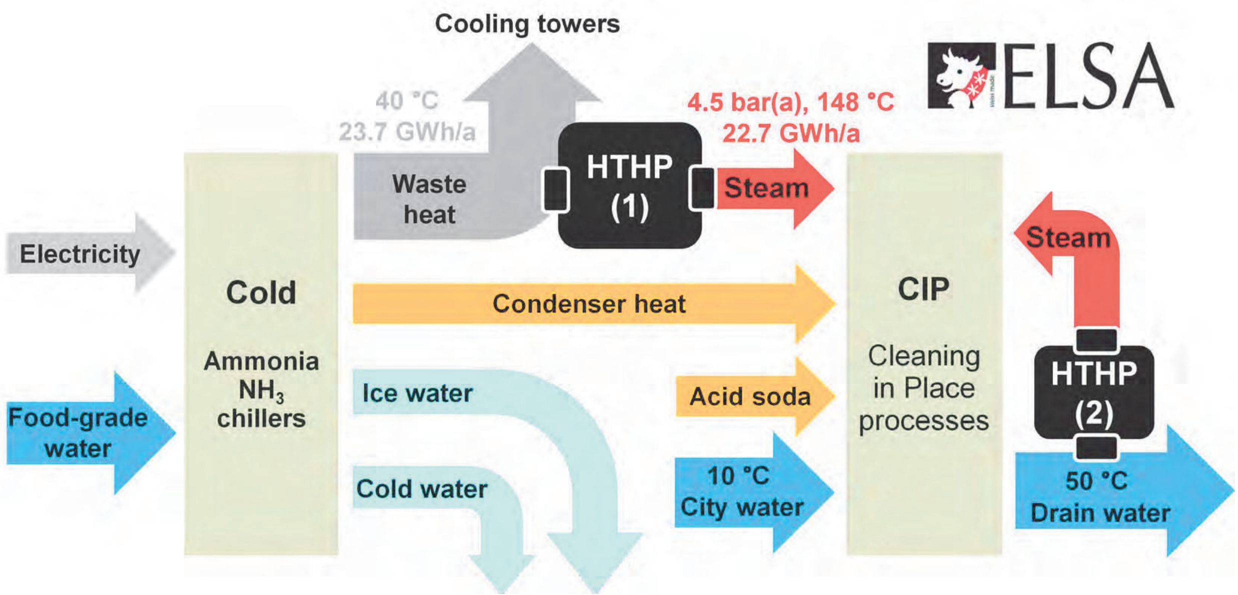
Heating COP		4.93	
Heating capacity		2.4 MW	
Sink	Source	90 °C → 145 °C	90 °C → 80 °C
Refrigerant		Isopentane, R-601a	
Important remarks		COP of 2.49 w. bottom HP ATEX required	

Figure 3b: Steam production from district heating for a dairy culture production facility.

Integration Concepts for HTHPs

Dairy steam generation for the CIP process

- (Arpagaus et al., 2023)



Integration Concepts for HTHPs

Upgrading cogeneration exhaust gas and process waste heat streams in the dairy industry

- (Corrales Ciganda et al. 2022)

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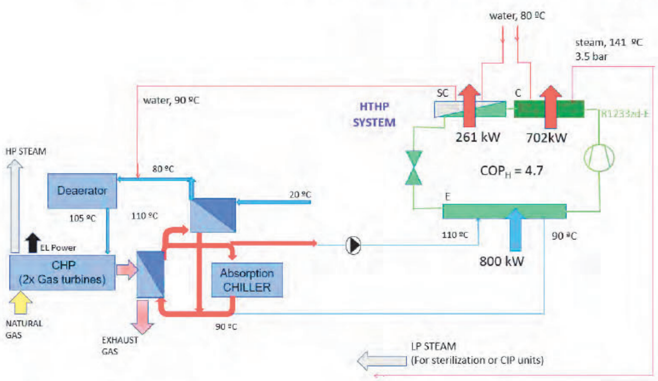
HTHP application combined with cogeneration units (I):
Exhaust gas heat from gas turbines *(Dairy plant)*



*Preliminary technoeconomic assesment**

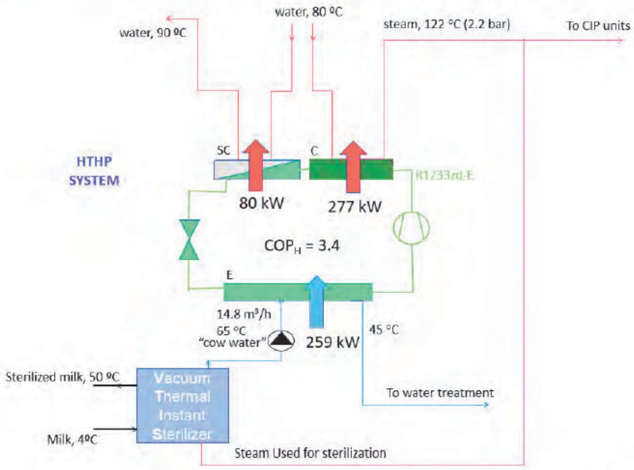
	Value
Yearly operating hours	6000
Heat Produced (MWh/year)	5778
PES (MWh/year)	4740
Investment cost (€/kW)	400
Payback period Spain (years)	2,48
Payback period Germany (years)	1,99
Payback period Italy (years)	2,36

**Energy costs assumed: Natural Gas: Spain:27.7 €/MWh ,Germany 29.2 €/MWh, Italy: 32.7 €/MWh*
Electricity: Spain:85.4 €/MWh , Germany: 65.1 €/MWh, Italy: 106.7 €/MWh

Milk sterilization with steam

- (Corrales Ciganda et al. 2022)

Potential HTHP integration in a dairy plant



*Preliminary technoeconomic assesment**

	Value
Yearly operating hours	2000
Heat Produced (MWh/year)	714
PES (MWh/year)	472
Investment cost (€/kW)	600
Payback period Spain (years)	15,33
Payback period Germany (years)	10,61
Payback period Italy (years)	15,04

**Energy costs assumed: Natural Gas: Spain:27.7 €/MWh ,Germany 29.2 €/MWh, Italy: 32.7 €/MWh Electricity: Spain:85.4 €/MWh , Germany: 65.1 €/MWh, Italy: 106.7 €/MWh*

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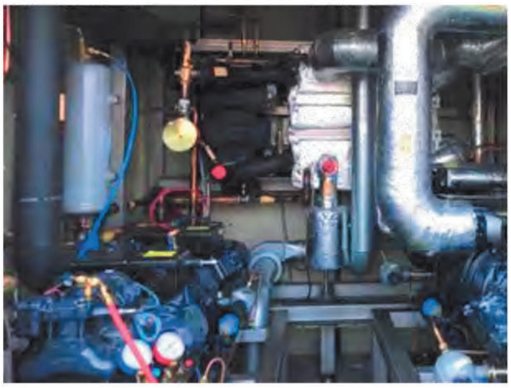
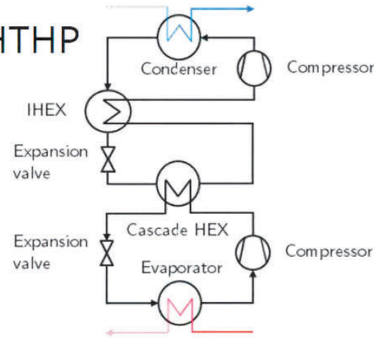
HTHP integration in a dairy TINE Bergen

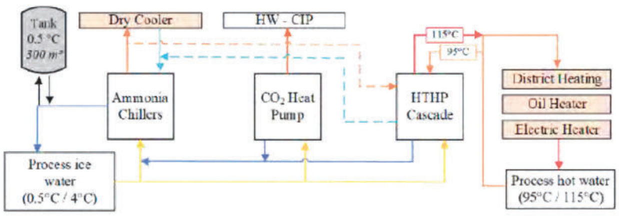
- Combined cold and heat supply (Schlosser, 2022), (Ahrens et al., 2021), (Schlemminger et al. 2022), (Brækken et al., 2022)

Demo case - hot water production with cascade HTHP

No.	Supplier	Industry	Process	Heat source			Heat sink			HP Type	Refrigerant	Compressor	Capacity	COP$_H$
				Unit Operation	T_{out} [°C]	T_{in} [°C]	Unit Operation	T_{out} [°C]	T_{in} [°C]				[kW]	
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







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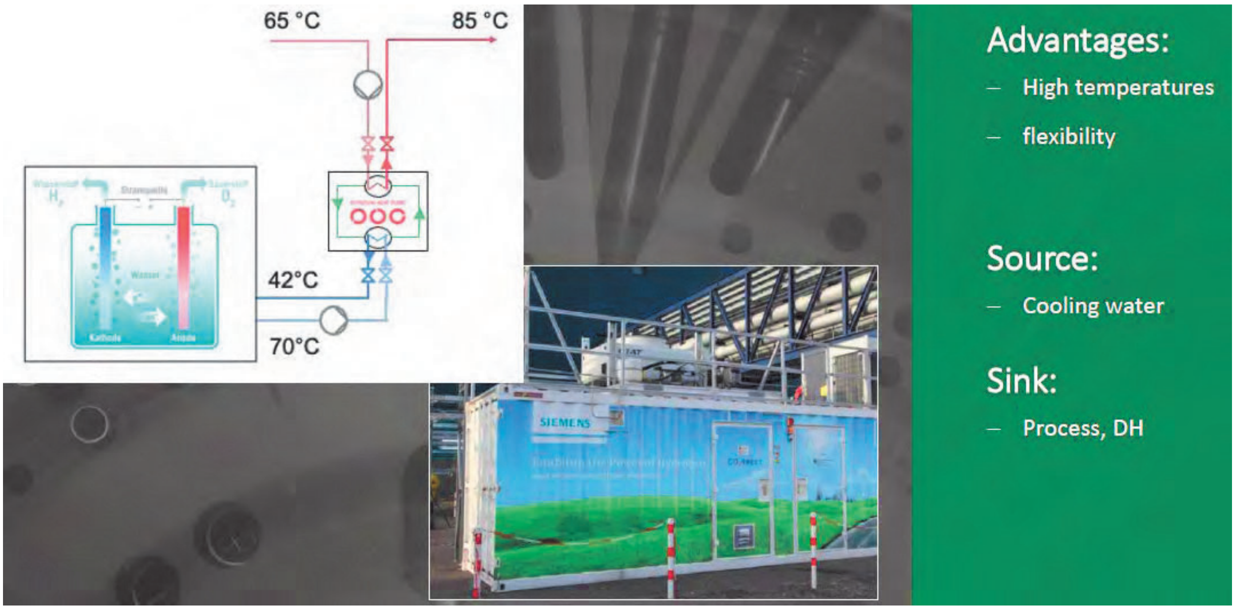
Electrolysis

- (Längauer et al., 2022)



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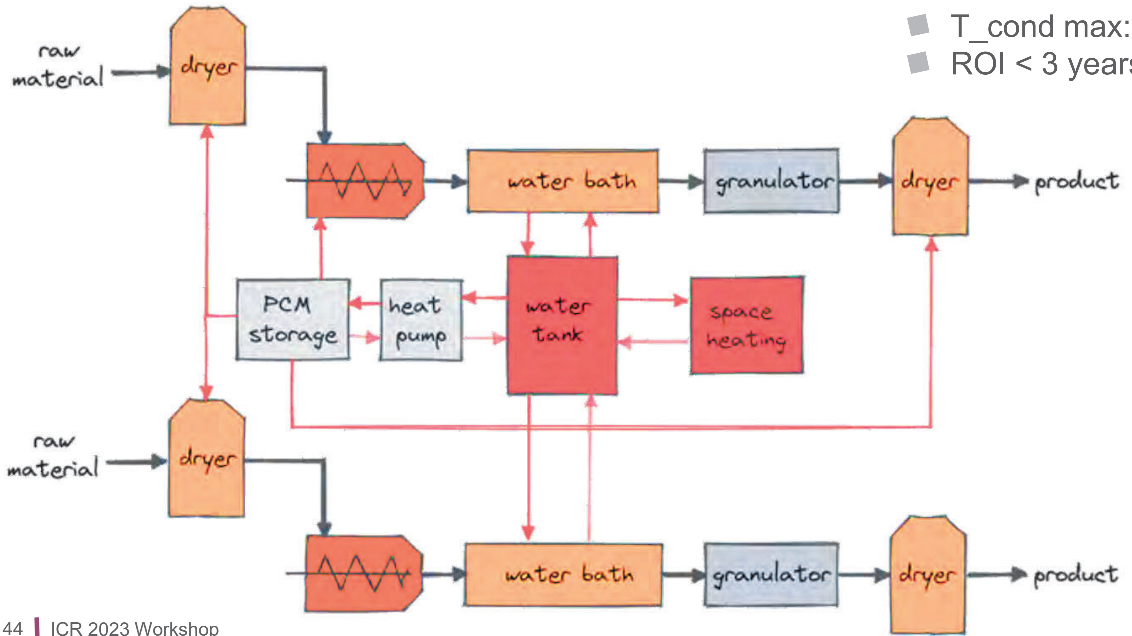
Extrusion process

- (Wilk et al., 2023) at Geba Kunststofftechnik (Austria)

- 50 kW Butane (R600) HTHP
- Source: 50-80 °C
- Sink: hot water up to ca. 130 °C
- Water bath: 48 °C
- T_cond max: 125 °C
- ROI < 3 years



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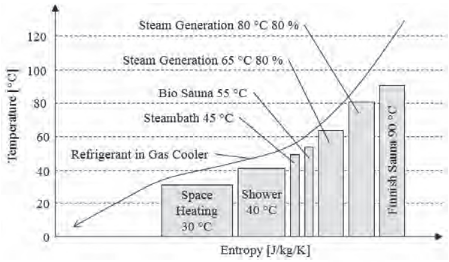
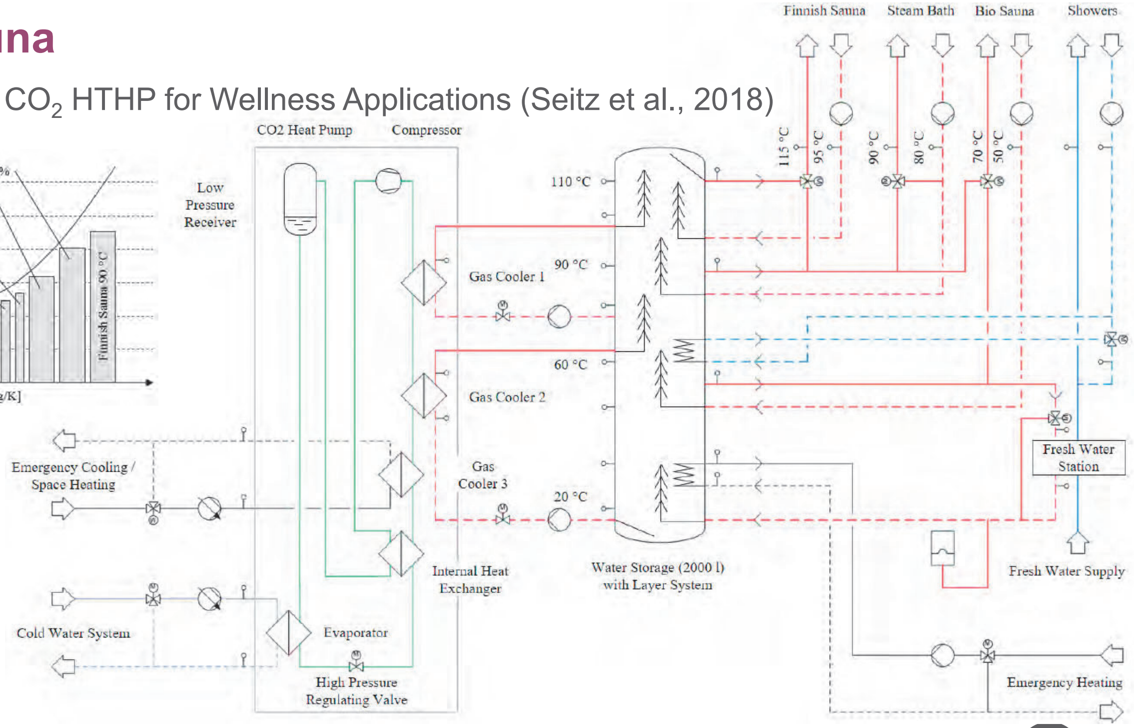
Integration Concepts for HTHPs

Wellness Sauna

- Integration of a CO_2 HTHP for Wellness Applications (Seitz et al., 2018)





Integration Concepts for HTHPs

Food & Beverage

- Brewery hot water (Andersen et al., 2023)
- Sausage cooking (Arpagaus et al., 2023)
- Pasteurizaiton (Längauer et al., 2022)

Integration Concepts for HTHPs

Brewery hot water

- (Andersen et al., 2023)

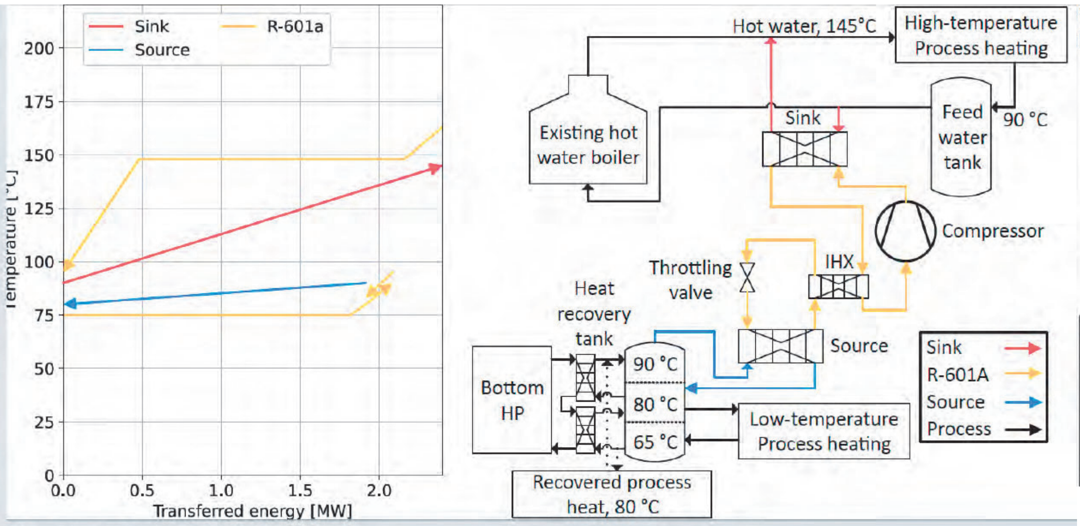


Figure 1a: Hot water system for a brewery.

Wort boiling with hot water system using R-601a from heat recovery tank

- A brewery uses 2.4 MW of hot water at 145 °C for wort boiling distributed several temporally offset batches in parallel. The remaining processes are covered by the heat recovery tank.
- Water returns from the high-temperature processes at 90 °C which is heated back up to 145 °C by the heat pump keeping the conventional gas boiler as a back-up.
- 90 °C hot water from the heat recovery tank supplies the heat pump and returns at 80 °C. The tank is supplied by a ammonia heat pump and recovered process heat.

Heating COP		4.93	
Heating capacity		2.4 MW	
Sink	Source	90 °C → 145 °C	90 °C → 80 °C
Refrigerant		Isopentane, R-601a	
Important remarks		COP of 2.49 w. bottom HP ATEX required	

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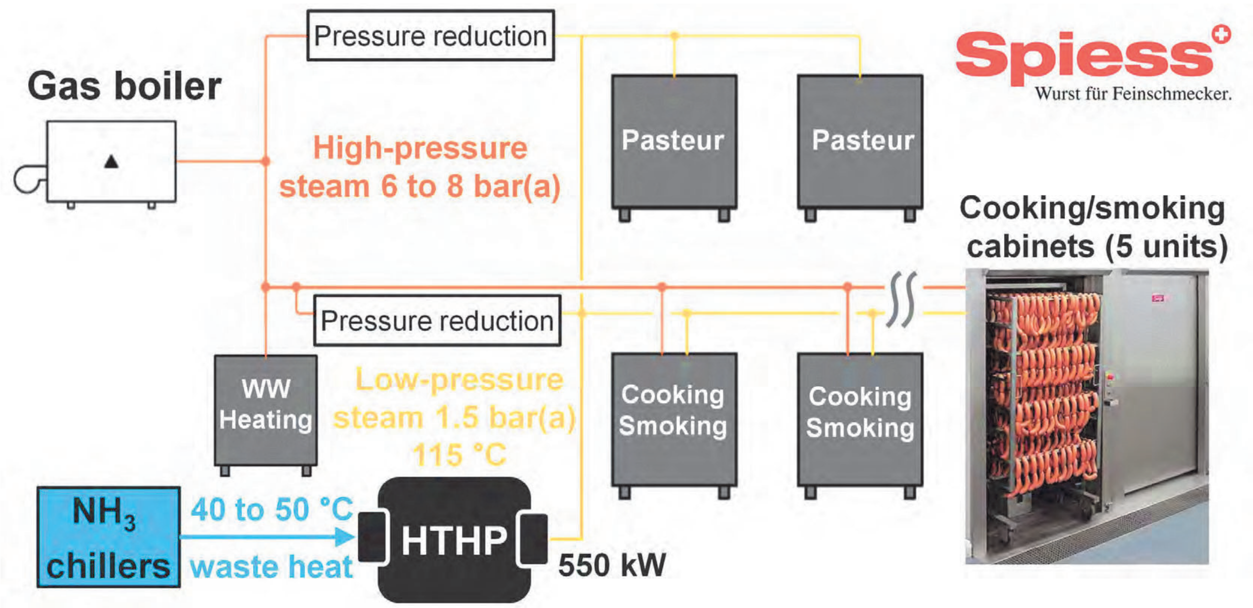
Integration Concepts for HTHPs

Sausage cooking

- (Arpagaus et al., 2023)



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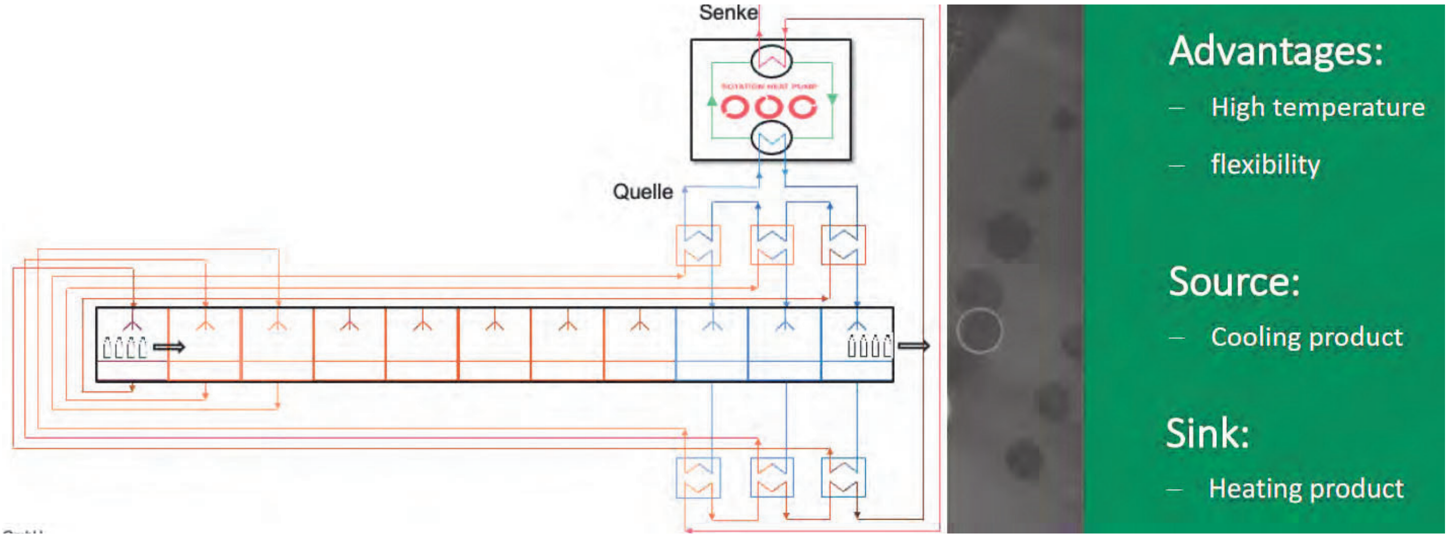
Integration Concepts for HTHPs

Pasteurization

- (Längauer et al., 2023)



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Integration Concepts for HTHPs

Paper industry

- Upgrading exhausted air waste heat in the paper industry (Corrales Ciganda et al. 2022) (Zühlsdorf et al., 2022)
- Upgrading cogeneration waste heat streams in the paper industry (Corrales Ciganda et al. 2022) (Zühlsdorf et al., 2022)

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Upgrading exhausted air waste heat in the paper industry

- (Corrales Ciganda et al. 2022), (Zühlsdorf et al., 2022)

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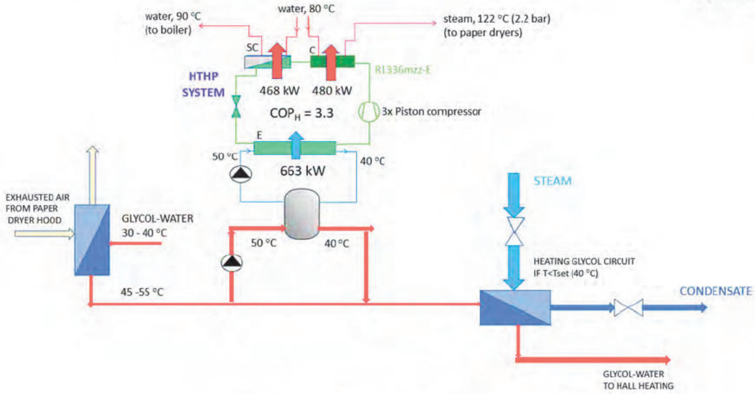
Potential HTHP integration in a paper factory



*Preliminary technoeconomic assesment**

	Value
Yearly operating hours	6000
Heat Produced (MWh/year)	5688
PES (MWh/year)	4283
Investment cost (€/kW)	600
Payback period Spain (years)	5,16
Payback period Germany (years)	3,59
Payback period Italy (years)	5,30

**Energy costs assumed: Natural Gas: Spain:27.7 €/MWh ,Germany 29.2 €/MWh, Italy: 32.7 €/MWh*
Electricity: Spain:85.4 €/MWh , Germany: 65.1 €/MWh, Italy: 106.7 €/MWh

Upgrading cogeneration waste heat streams in the paper industry

- (Corrales Ciganda et al. 2022), (Zühlsdorf et al., 2022)

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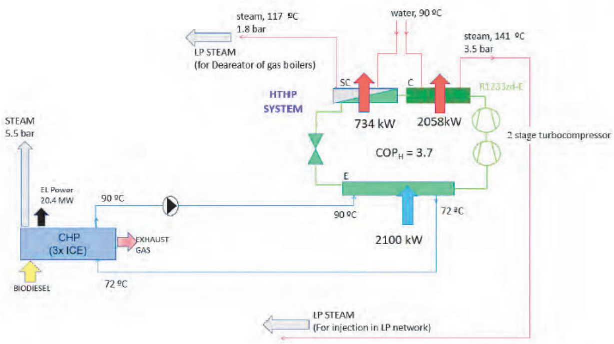
Copenhagen 29.-30.3.2022

HTHP application combined with cogeneration units (II): cooling system of biodiesel ICE *(Paper factory)*



*Preliminary technoeconomic assesment**

	Value
Yearly operating hours	6000
Heat Produced (MWh/year)	16656
PES (MWh/year)	11578
Investment cost (€/kW)	400
Payback period Spain (years)	3,09
Payback period Germany (years)	2,26
Payback period Italy (years)	3,09

**Energy costs assumed: Natural Gas: Spain:27.7 €/MWh ,Germany 29.2 €/MWh, Italy: 32.7 €/MWh*
Electricity: Spain:85.4 €/MWh , Germany: 65.1 €/MWh, Italy: 106.7 €/MWh

General processes (heating and cooling)

- Heat recovery and process cooling (Kukkola, 2022)
- Solarthermal and Rotation Heat Pump (Ecop, 2023)

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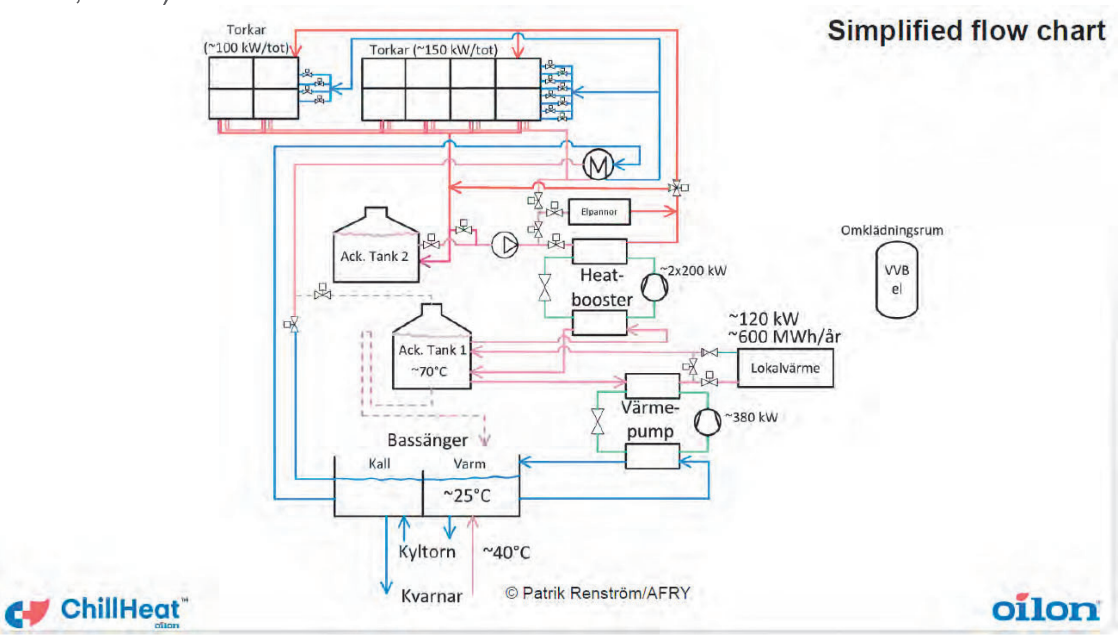
Heat recovery and process cooling

- (Kukkola, 2022)



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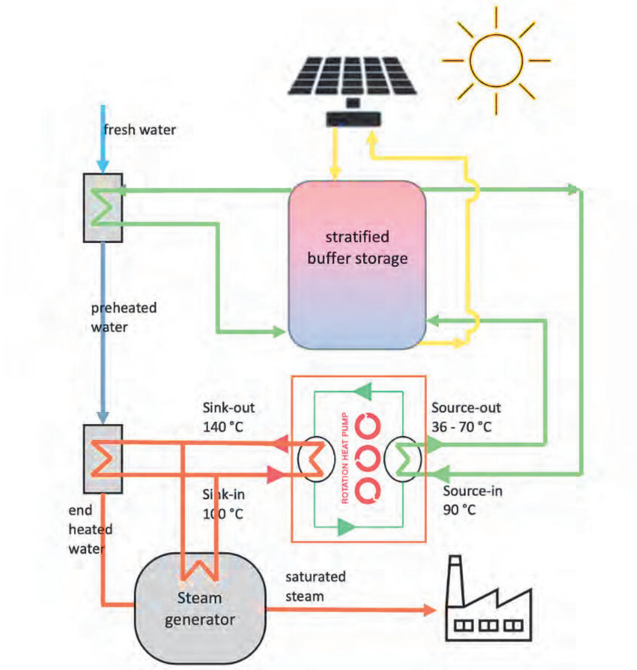
Integration Concepts for HTHPs

Solarthermal and Rotation Heat Pump

- (Ecop, 2023)



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Integration Concepts for HTHPs

District heating

- Upgrading district heating at DIN Forsyning (Petersen and Zühlsdorf, 2022)
- Heat from the cooling of the steelmaking process for district heating (Barbon, 2022)
- District heating and booster (Längauer et al., 2022)

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Integration Concepts for HTHPs

Upgrading district heating at DIN Forsyning

- (Petersen and Zühlsdorf, 2022)

Danish district heat utility (Din Forsyning, Esbjerg)

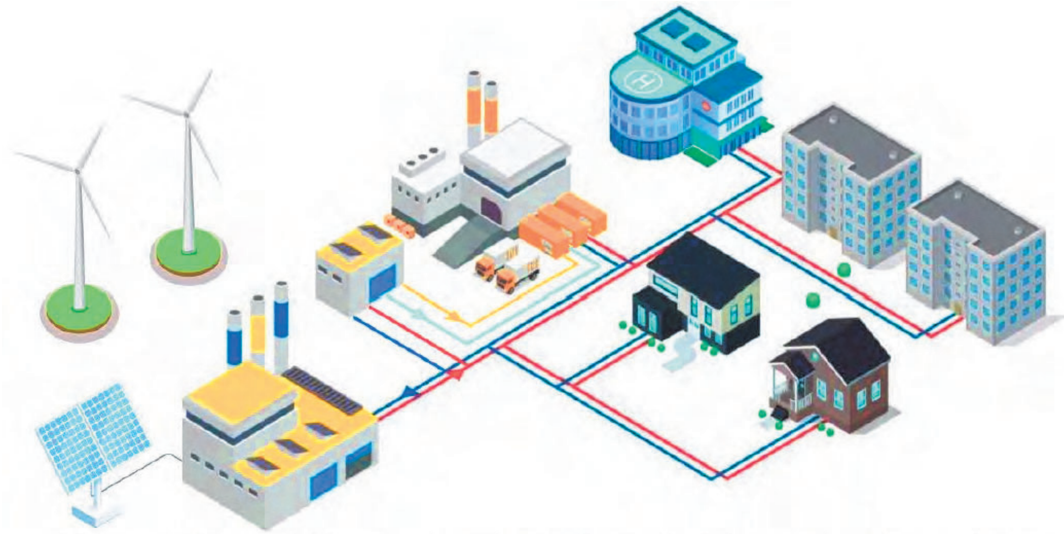
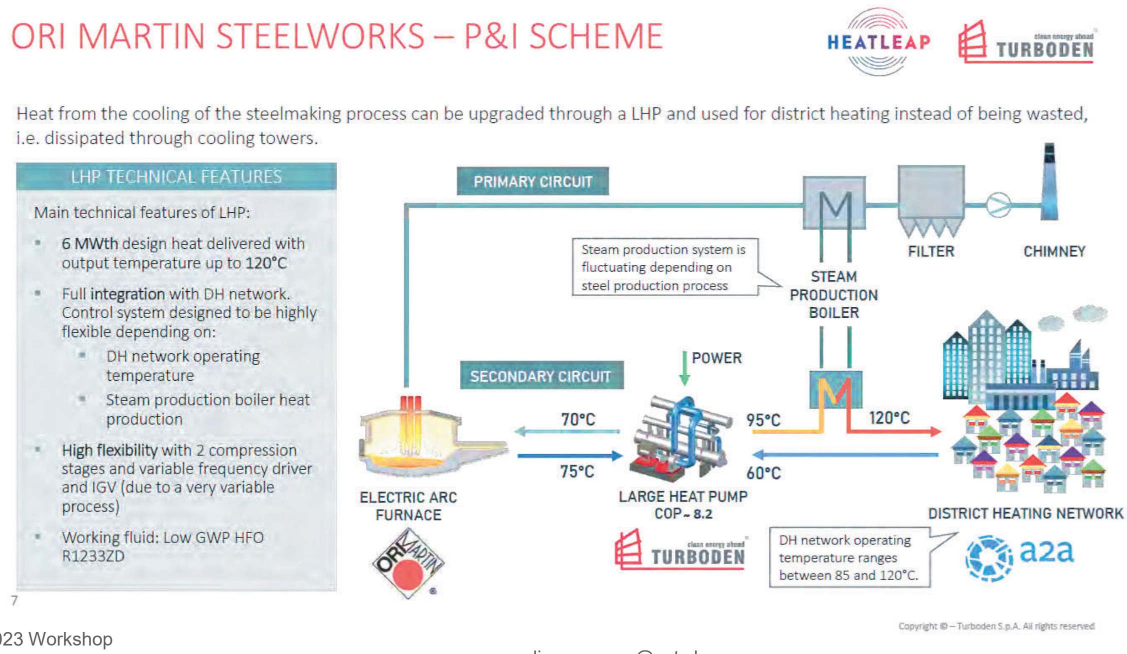


Illustration of utility company (left) supplying a variety of energy services: District heating for residential and industrial customers (red & blue), steam and cooling for industrial customers (orange and light blue). The system may also include collection of waste heat from industrial consumers (not shown).

Integration Concepts for HTHPs

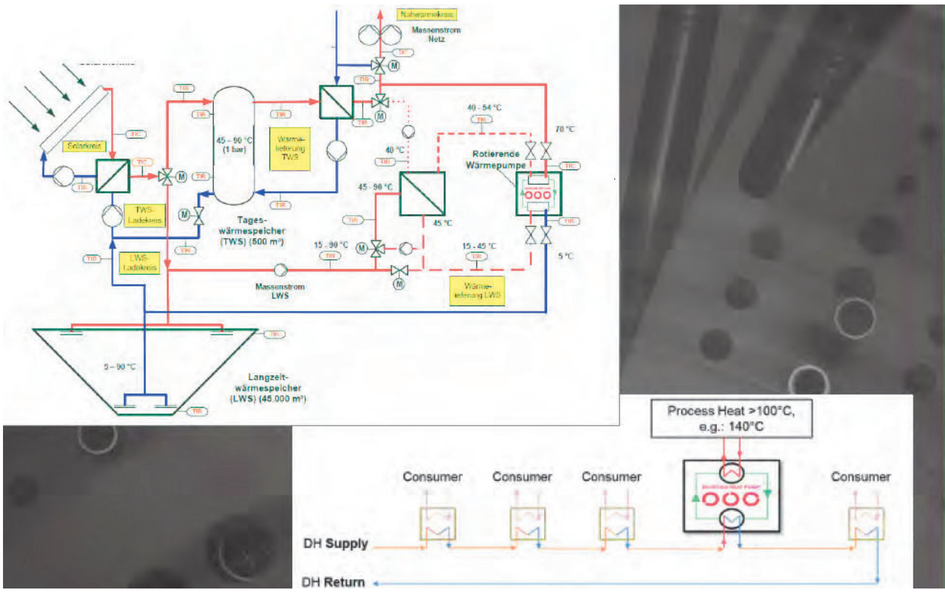
Heat from the cooling of the steelmaking process for district heating

- (Barbon, 2022)



District heating and booster

- (Längauer et al., 2022)



Advantages:
- Sensible heat transfer
- Flexibility
- High temperatures

Source:
- Storage

Sink:
- Heat supplier
- District heating
- Flue gas condensation

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