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HIGH TEMPERATURE HEAT PUMPS

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Demonstration case studies from IEA Annex 58

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Source: https://heatpumpingtechnologies.org/annex58/task1/#demonstration-cases

Introduction

- **Task 1** “Technologies – State of the art and ongoing developments for systems and components” aimed at providing an overview of high-temperature heat pump technologies for supplying heat at temperatures above 100 °C.

- Detailed information was collected about heat pump systems and **successful demonstration cases**.

- The review of heat pump systems included both **commercially available systems**, as well as **systems under development**.

- The demonstration cases are based on **systems in operation** and focusing on the **applications** and **end-user experiences**.

Food and beverage

Supplier: Skala Fabrikk AS

Installation year: 2021

Application: Ice- and process hot water production, and upgrade of LT heat from dry-cooler

Solution: Retrofitting existing boilers at dairy plant in Norway to cover ice water production

Temperature ranges (source): 4 °C → 0.5 °C (ice water), 3 °C → -1°C (water/glycol circuit)

Temperature ranges (sink): pressurized process hot water 95 → 115 °C

Refrigerant: LT cycle R290; HT cycle R600

Power: 0.3 MW (heat) + 0.15 MW (cold)

Compressor: Piston

COP: 3.4 (ice water mode); 2.5 – 3.2 (dry cooler mode)

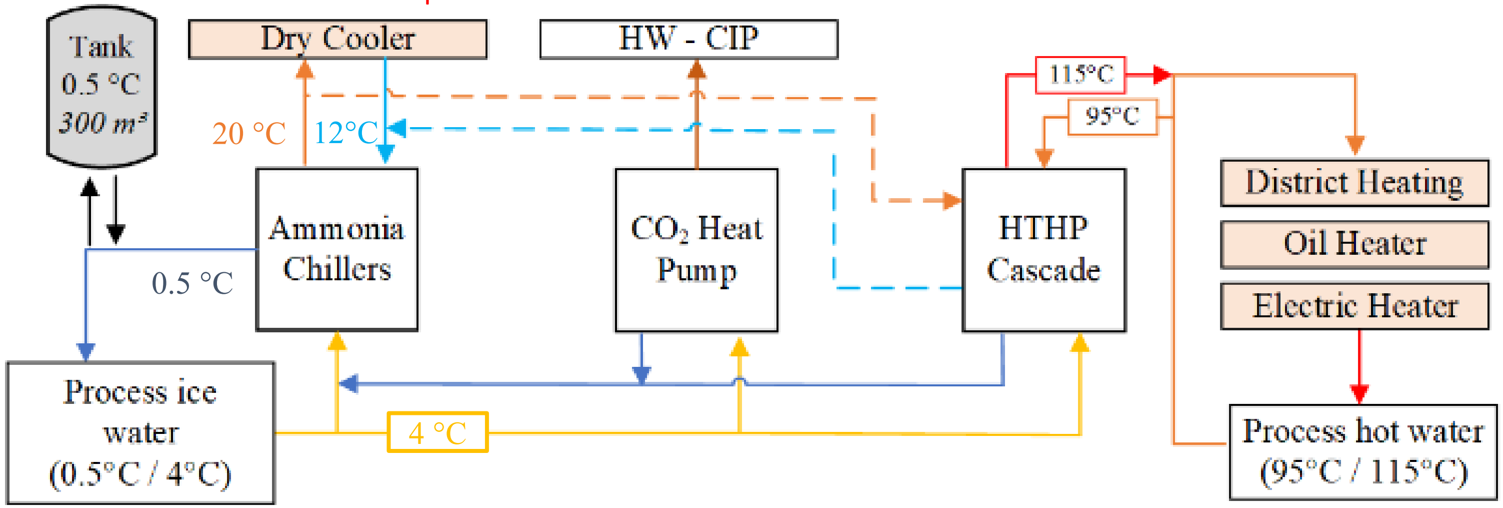
Investment cost: 500 – 700 €/kW thermal supply capacity (sink + source)

Savings: Up to 62% primary energy

Estimated annual CO_2 savings: Up to 94%

Takeaway: End-user tuned the production process (i.e. reducing the supply temperature); potential for designing new processes and plants optimized for HTHP integration

Ammonia chiller evaporator



Ammonia chiller condenser

HTHP Condenser

https://heatpumpingtechnologies.org/annex58/wp-content/uploads/sites/70/2022/07/annex58casehthp-for-simultaneous-process-cooling-and-heating-skaleup.pdf

Food and beverage

Supplier: AMT Kältetechnik and AIT

Installation year: 2020

Application: Starch production facility in Austria

Solution: DryFiciency HP in wheat starch dryer process, uses hot water to supply hot air

Temperature ranges (source): 76 °C → 72 °C (design point), 81 °C → 78 °C (operation)

Temperature ranges (sink): 96 °C → 138 °C (design point), 102 °C → 152 °C (operation)

Refrigerant: HFO-1336mzz(Z) (HFO low GWP refrigerant)

Power: 0.3 MW

Compressor: Screw compressors

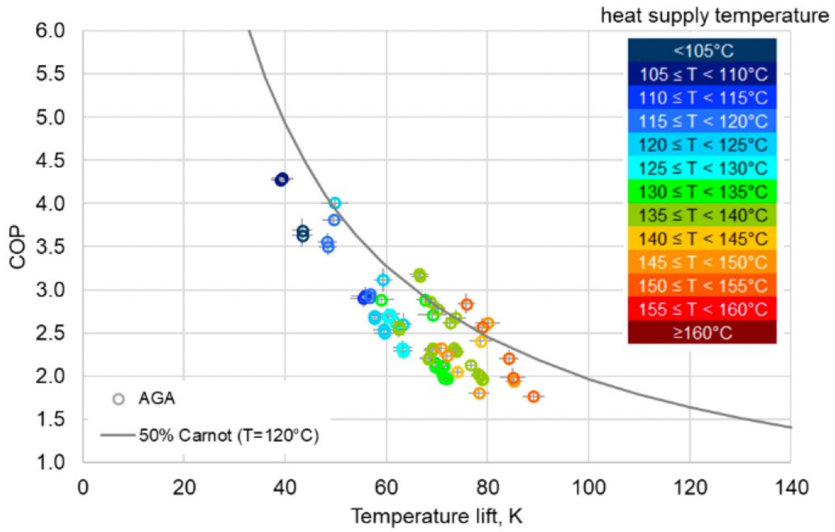
COP: 3.2 (design point); 2.8 (operation)

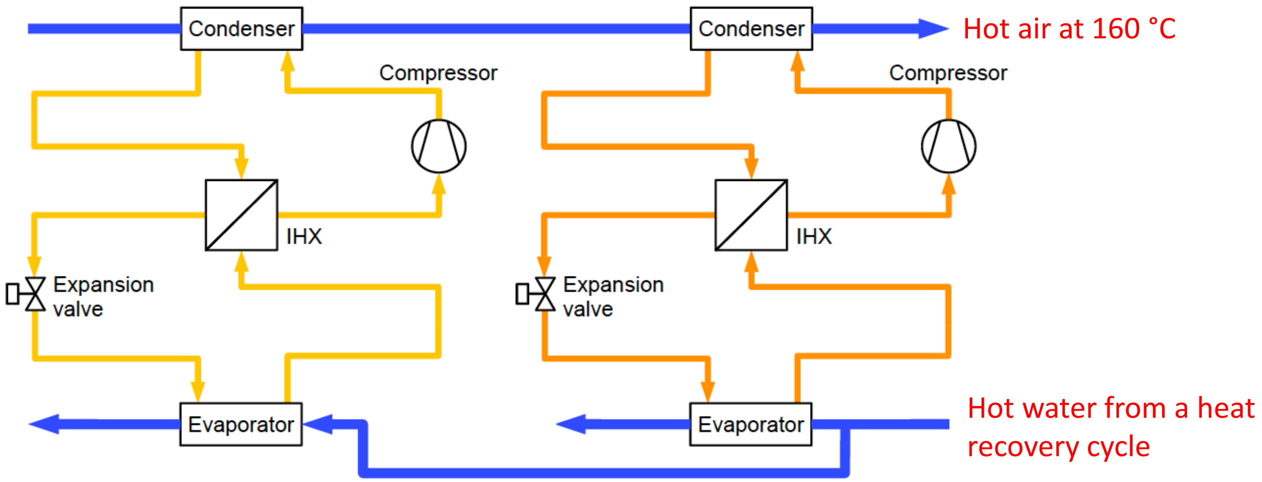
Investment cost: -

Savings: 42,900 €/a at 138 °C

Estimated annual CO_2 savings: 660 t/a at 138 °C

Challenges: Material compatibility, mechanical design, integration infrastructure, and process control





https://heatpumpingtechnologies.org/annex58/wp-content/uploads/sites/70/2022/07/hthp annex58dryfwbgfinal-1.pdf

Sewage

Supplier: Anlet and KOBELCO

Installation year: 2016

Application: Sewage sludge drying at Hodano water treatment (Japan)

Solution: Indirect dryer and a MVR system. The sludge water content is reduced from 72% W.B. (wet base) to 20% W.B.

Temperature ranges (source): 93 °C

Temperature ranges (sink): 160 °C

Refrigerant: R718 (water)

Power: 0.6 MW

Compressor: Blower + Twin-screw compressor

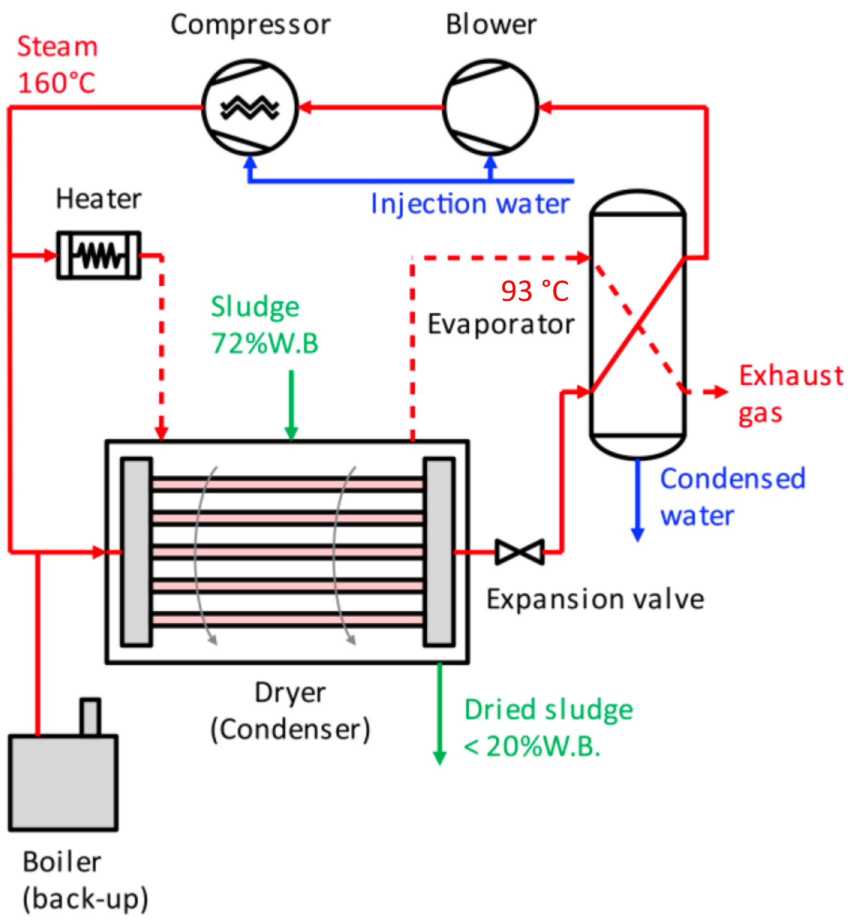
COP: 2.9

Investment cost: -

Savings: Life cycle cost (40%) and energy consumed (46%)

Estimated annual CO_2 savings: 51% reduction

Takeaway: Decisive factors for the end-user: (i) reduction of total running costs (waste disposal cost vs. electricity cost); and (ii) easy operation and maintenance



https://heatpumpingtechnologies.org/annex58/wp-content/uploads/sites/70/2022/07/casehadano-city.pdf

Sewage

Supplier: Rotrex, Epcon Evaporation Technology, Scanship

Installation year: 2020

Application: Sludge drying at Scanship, Drammen (Norway)

Solution: Open loop MVR HP on two batch dryers

Temperature ranges (source): 100 °C (steam)

Temperature ranges (sink): 125 °C → 146 °C (steam)

Refrigerant: R718 (water)

Power: 0.5 MW

Compressor: Turbo-compressor

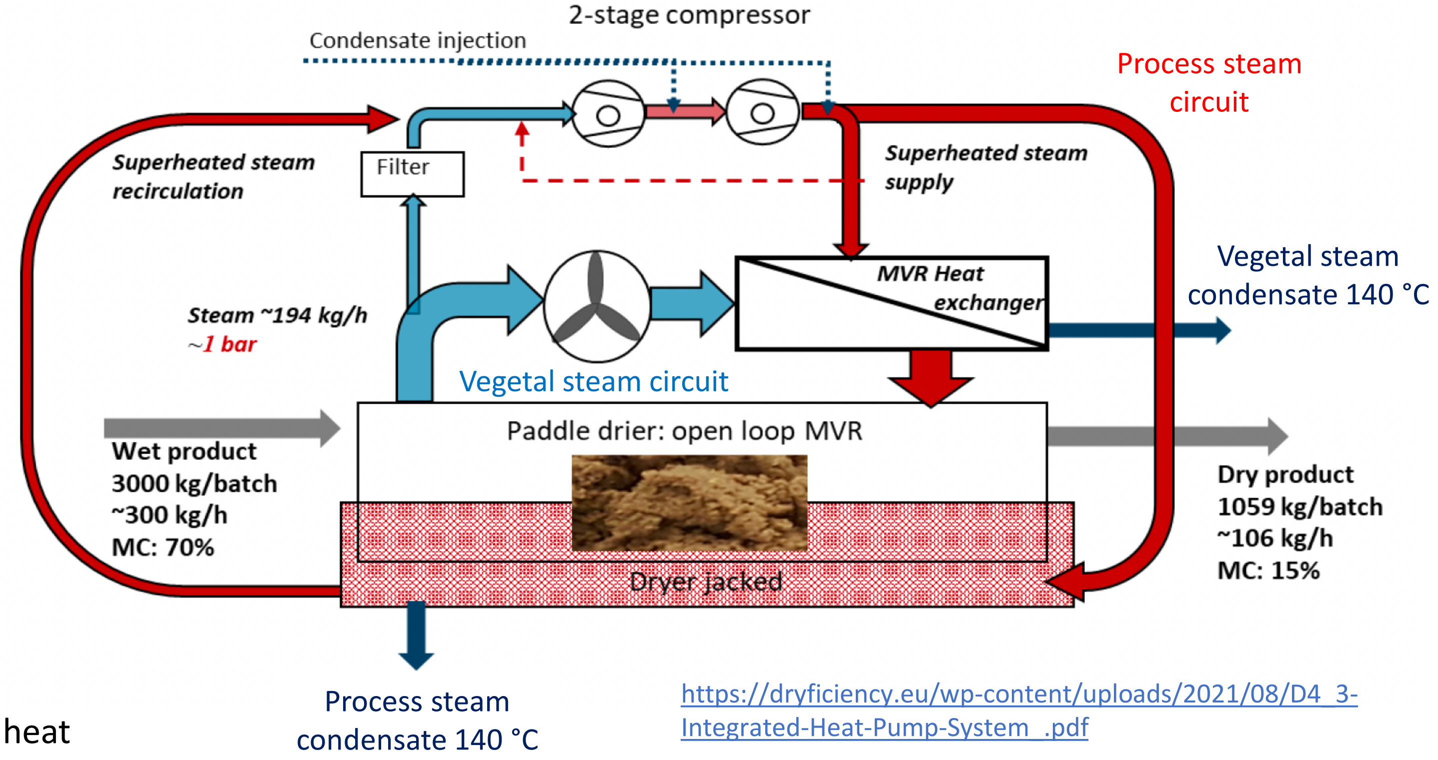
COP: 4.5 (supply at 146 °C), 8.6 (supply at 125 °C)

Investment cost: -

Savings: Energy costs (82%) and primary energy consumption (76%)

Estimated annual CO_2 savings: -

Challenges: Operational start-up to integrate the turbo-compressor heat pump with the steam dryer (i.e. maintaining superheated steam coming from the dryer)



https://dryficiency.eu/wp-content/uploads/2021/08/D4_3-Integrated-Heat-Pump-System_.pdf

Electronics

Supplier: MHI Thermal Systems

Installation year: 2012

Application: Transformer coil drying process (Japan)

Solution: HTHP replaces steam boiler. The HP uses both exhaust heat from drying process and annealing process as heat source

Temperature ranges (source): 55 °C → 50 °C (water)

Temperature ranges (sink): 70 °C → 130 °C (pressurized water)

Refrigerant: R134a

Power: 0.6 MW

Compressor: Centrifugal

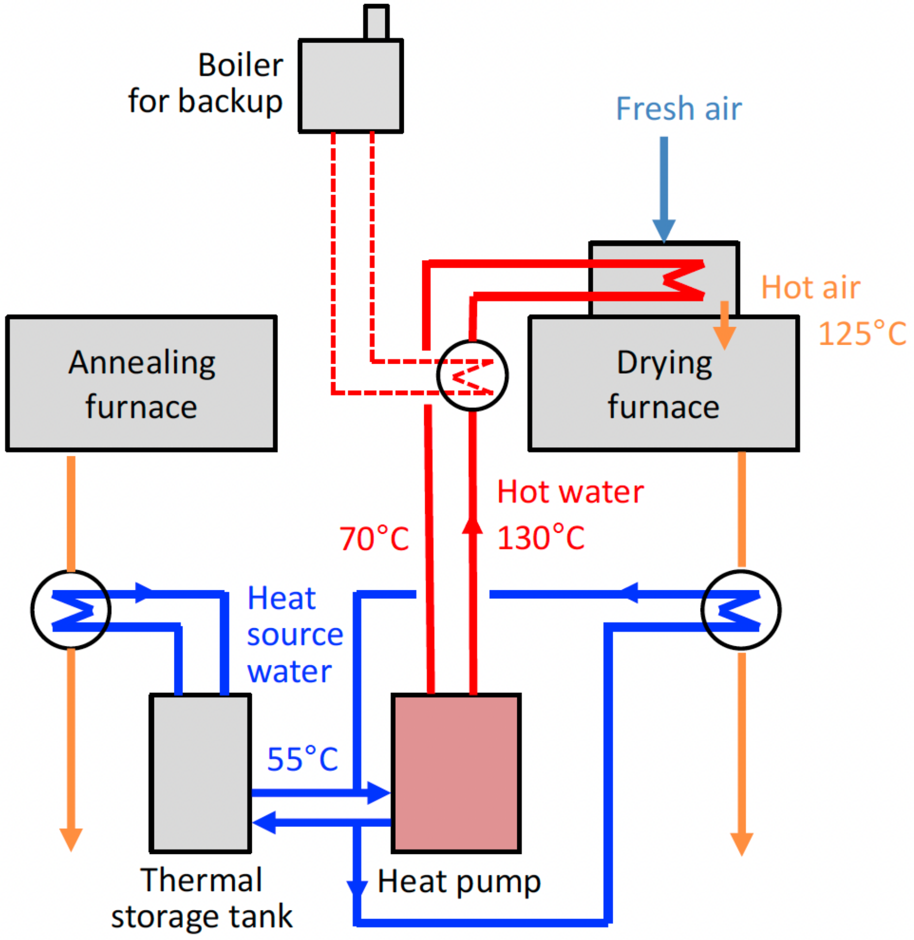
COP: 3.0

Investment cost: -

Savings: Energy cost reduced by 65%

Estimated annual CO_2 savings: Reduced by 60%

Takeaway: Preliminary detailed analysis of the heat demand and waste heat before the installation of the HP was the key to success



https://heatpumpingtechnologies.org/annex58/wp-content/uploads/sites/70/2022/07/casetakaoka-toko.pdf

Chemicals

Supplier: Piller Blowers & Compressors

Installation year: 2017

Application: Processes/Plastics/EPDM Separation

Solution: Steam generation heat pump for stripping units where solvents from the reaction process are separated from the product

Temperature ranges: 60°C (source) – 130°C (sink)

Refrigerant: R718 (water)

Power: 10 MW

Compressor: Turbo

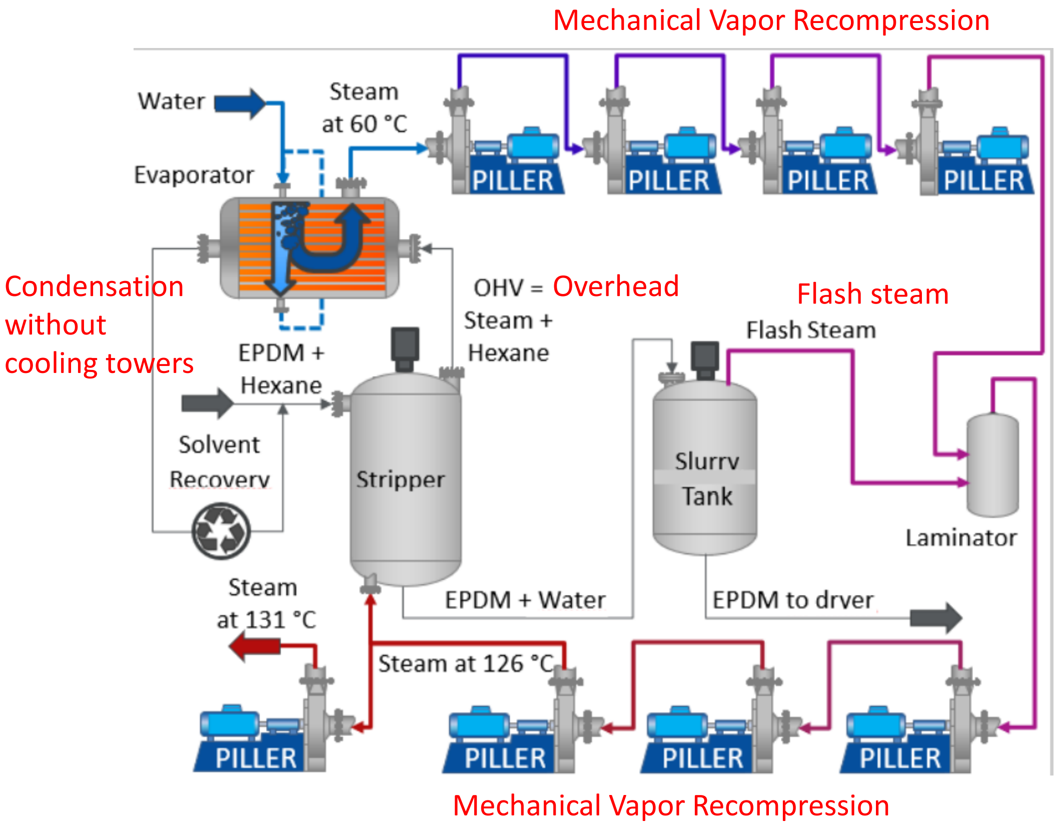
COP: 4.4

Investment cost: 6,800,000 €

Payback period: 1.7 years

Savings: 4,000,000 €/a (80 % in energy consumption)

Estimated annual CO_2 savings: 12,400 t/a (62% CO_2 emissions reduction)



Production of Ethylene Propylene Diene Monomer

https://www.piller.de/fileadmin/media/pdf-files/product-sheets/steam-regeneration-epdm.pdf
https://heatpumpingtechnologies.org/annex58/wp-content/uploads/sites/70/2022/07/hthpannex58-pillardemocases-1.pdf

Chemicals

Supplier: Spilling Technologies GmbH

Installation year: 2018

Application: Chemical/Chemicals

Solution: Upgrade excess steam from reactor cooling (5 bar) by compressing steam to 19.5 bar

Temperature ranges: 150°C (source) – 240°C (sink)

Refrigerant: R718 (water)

Power: 12 MW

Compressor: Piston (4LT-2HT), first stage 5 → 12 bar, second stage 12 → 19.5 bar, enables variation of 30% to 100 % steam flow rate

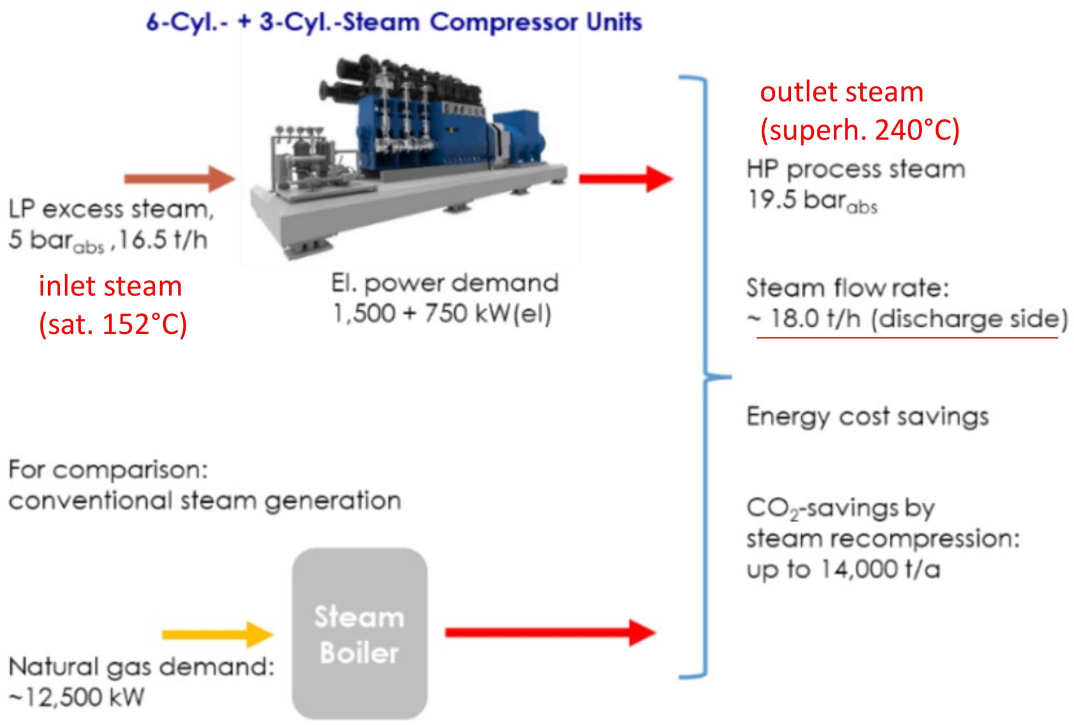
COP: 5.3 (condensing and subcooling heat to 105 °C)

Investment cost: 2,200,000 € (excl. integration)

Payback period: not disclosed

Savings: 12.5 MW of natural gas

Estimated annual CO_2 savings: 14,000 t/a (7500 h, 0.281 kg/kWhee)



Condensate is injected into the steam to avoid too high steam temperatures from the compression (increase in discharge flow)

https://heatpumpingtechnologies.org/annex58/wp-content/uploads/sites/70/2022/07/spillinghthpannex58democaseiifinal-1.pdf

Chemicals

Supplier: Qpinch

Installation year: 2020

Application: Chemical/Steam generation at Borealis

Solution: Upgrade LT heat from ethylene polymerization reactor and a LP steam to MP & HP steam. Oligomerization of H_3PO_4 to transform waste heat into chemical energy.

Temperature ranges: 80-135°C (variable source) – 160°C (sink)

Refrigerant: H_3PO_4 (phosporic acid loop)

Power: 2.9 MW (3-5% of the thermal output power as electricity)

Compressor: Heat driven

COP: 0.45 (temperature lifts 80 K, heat output 400 kW to 1.3 MW)

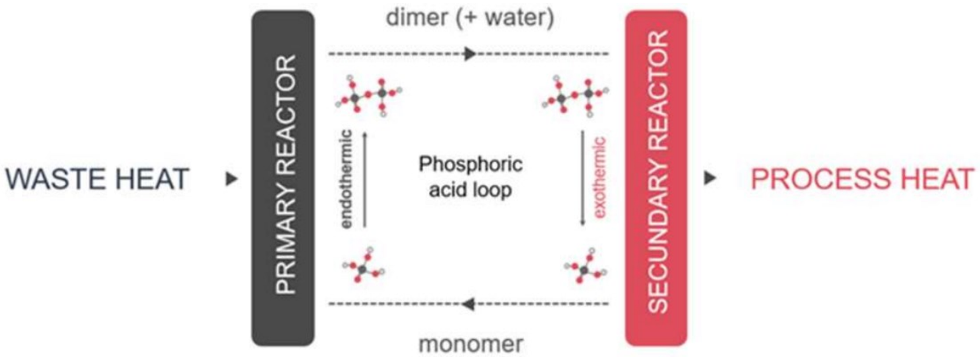
Investment cost: not disclosed

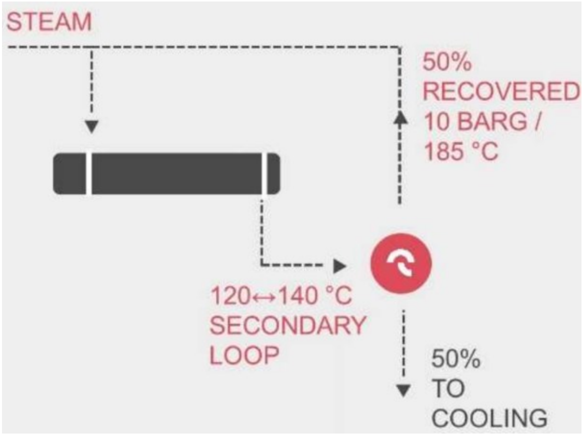
Payback period: not disclosed

Savings: 190,000 € EU ETS credits

Estimated annual CO_2 savings: 2,200 t/a

Challenges: LDPE reactor has 40 recipes with highly fluctuating residual heat temperatures and output. Footprint of 4 m x 6 m and a height of 15 m





Three different residual heat sources that are combined via an intermediate hot water loop that feeds the QHT unit

https://heatpumpingtechnologies.org/annex58/wp-content/uploads/sites/70/2022/07/caseqpinchborealis.pdf

Ceramics

Supplier: AMT Kältetechnik and AIT

Installation year: 2019

Application: Processes/Minerals/Brick drying (Wienerberger AG: 200 brick dryers)

Solution: DryFiciency HP uses hot water to supply hot air for the last zone of the dryer

Temperature ranges: 85°C (source) – 120°C to 160°C (sink)

Refrigerant: R1336mzz(Z) (HFO low GWP refrigerant)

Power: 0.2 MW – 0.3 MW

Compressor: Piston (x 8)

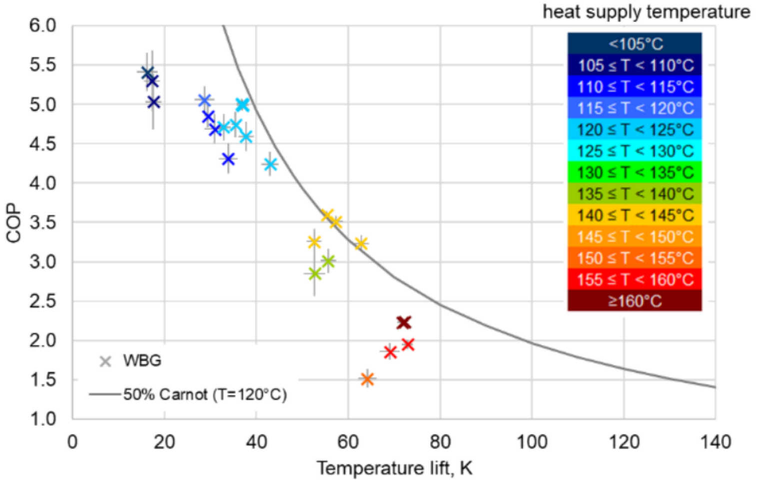
COP: 2.2 (highest T) - 5.0 (design)

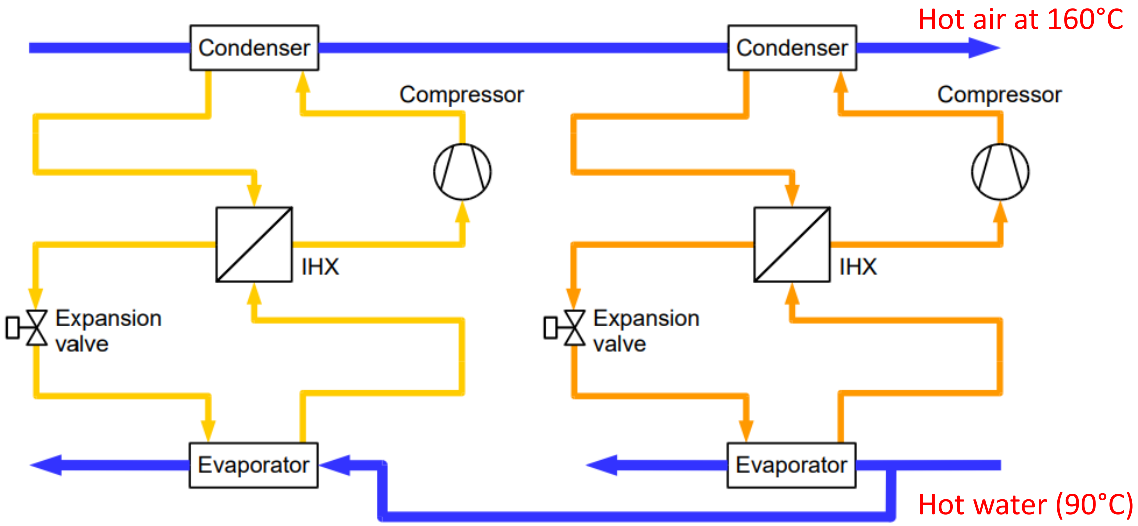
Investment cost: not disclosed

Payback period: not disclosed

Savings: 60,500 €/a at 120°C

Estimated annual CO_2 savings: 590 t/a





It uses hot air from the kiln and the moist exhaust air from the dryer as heat sources to produce hot water

https://heatpumpingtechnologies.org/annex58/wp-content/uploads/sites/70/2022/07/hthpannex58dryfwbgfinal-1.pdf

Pulp and paper

Supplier: Spilling Technologies GmbH

Installation year: 2016

Application: Processes/Pulp/Pulp drying

Solution: Steam mechanically recompressed for pulp drying in a Pressurized Superheating Steam Dryer. No external source of steam is required.

Temperature ranges: 130°C (source) – 240°C (sink)

Refrigerant: R718 (water)

Power: 11.2 MW

Compressor: Piston (4LT: 3.2 → 8 bar and 2HT: 8 → 16 bar)

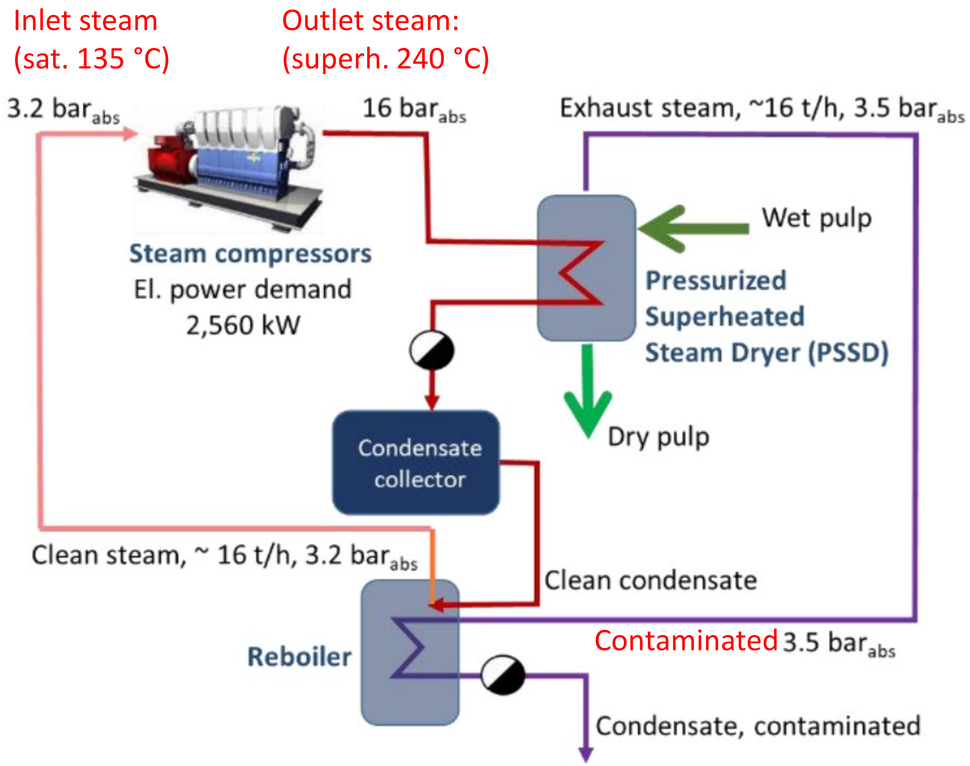
COP: > 4.2 (condensing and subcooling heat to 105 °C)

Investment cost: 2,500,000 € (excl. integration)

Payback period: not disclosed

Savings: not disclosed

Estimated annual CO_2 savings: 14,000 t/year (6,000 h, 0.013 kg/kWh$_{ee}$)



https://heatpumpingtechnologies.org/annex58/wp-content/uploads/sites/70/2022/07/spillinghthpannex58democaseifinal-1.pdf

Biorefinery

Supplier: Kobelco

Installation year: 2013

Application: Processes/Biorefinery/Distillation

Solution: Ethanol concentration (95%) from beet syrup, wheat and rice. Distillation is 60% of steam consumption. Dehydration with zeolite membrane to 99.5%

Temperature ranges: 60°C (source) – 120°C (sink)

Refrigerant: R245fa

Power: 1.9 MW (4 x 0.37 MW + 1 x 0.37 MW)

Compressor: Twin screw

COP: > 3.5

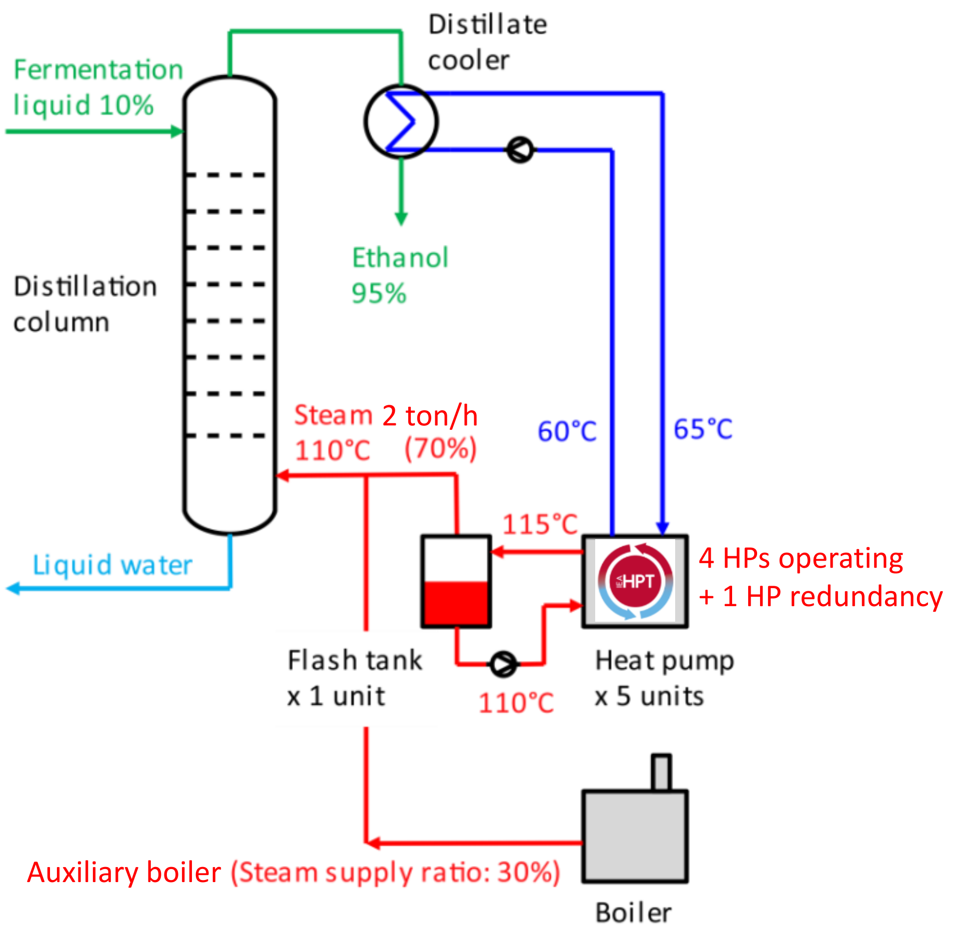
Investment cost: not disclosed

Payback period: 3 years

Savings: Energy consumption reduced by 54%

Estimated annual CO2 savings: Emissions reduced by 43%

Challenges: End-user was concerned about the reliability



https://heatpumpingtechnologies.org/annex58/wp-content/uploads/sites/70/2022/07/casehokkaido-bioethanol.pdf
https://www.jeh-center.org/asset/00032/monodukurinidenki/vol4_hokkaidobaioetanoru.pdf.pdf

Pharmaceutics

Supplier: Olvondo Technology AS

Installation year: 2017

Application: Pharma/Recooling (Pharma)

Solution: Steam generation at AstraZeneca (R&D facility in Gothenburg)

Temperature ranges: 35°C (source) – 180°C (sink)

Refrigerant: R704 (Helium)

Power: 1.5 MW (3 x 500 kW)

Compressor: Piston

COP: 1.7

Investment cost: 1,800,000 €, 3 x HPs (excl. integration, incl. monitoring & control & He solution)

Payback period: 3 years

Savings: 9.4 GWh/y

Estimated annual CO_2 savings: 600 t/a

Challenges: Raising the TRL of the heat pump from level 7 to level 9.

10 bar steam-generating heat pump using rejected heat from air conditioning chillers.

Proven concept for a Stirling engine operated as an industrial-scale heat pump.

https://klimat2030.se/astrazeneca-i-goteborg-leder-fossilfri-utveckling/
https://heatpumpingtechnologies.org/annex58/wp-content/uploads/sites/70/2022/07/caseastrazenecaolvondo.pdf

Summary demonstration case studies

Industrial sector	Food and beverage	Food and beverage	Sewage	Sewage	Electronics	Chemicals	Chemicals	Chemicals	Ceramics	Pulp and paper	Biorefinery	Pharmaceutics
Supplier	Skala Fabrikk AS	AMT Kältetechnik and AIT	Anlet and KOBELCO	Rotrex, Epcon Evaporation Technology, Scanship	MHI Thermal Systems	Piller Blowers & Compressors	Spilling Technologies GmbH	Qpinch	AMT Kältetechnik and AIT	Spilling Technologies GmbH	Kobelco	Olvondo Technology AS
Installation year	2021	2020	2016	2020	2012	2017	2018	2020	2019	2016	2013	2017
Application	Ice- and process hot water production, and upgrade of LT heat from dry-cooler	Starch production facility in Austria	Sewage sludge drying at Hodano water treatment (Japan)	Sludge drying at Scanship, Drammen (Norway)	Transformer coil drying process (Japan)	Processes/Plastics/EPDM Separation	Chemical/Chemicals	Chemical/Steam generation at Borealis	Processes/Minerals/Brick drying (Wienerberger AG: 200 brick dryers)	Processes/Pulp/Pulp drying	Processes/Biorefinery/Distillation	Pharma/Recooling (Pharma)
Solution	Retrofitting existing boilers at dairy plant in Norway to cover ice water production	DryFiciency HP in wheat starch dryer process, uses hot water to supply hot air	Indirect dryer and a MVR system. The sludge water content is reduced from 72% W.B. (wet base) to 20% W.B.	Open loop MVR HP on two batch dryers	HTHP replaces steam boiler. The HP uses both exhaust heat from drying process and annealing process as heat source	Steam generation heat pump for stripping units where solvents from the reaction process are separated from the product	Upgrade excess steam from reactor cooling (5 bar) by compressing steam to 19.5 bar	Upgrade LT heat from ethylene polymerization reactor and a LP steam to MP & HP steam. Oligomerization of H3PO4 to transform waste heat into chemical energy.	DryFiciency HP uses hot water to supply hot air for the last zone of the dryer	Steam mechanically recompressed for pulp drying in a Pressurized Superheating Steam Dryer. No external source of steam is required.	Ethanol concentration (95%) from beet syrup, wheat and rice. Distillation is 60% of steam consumption. Dehydration with zeolite membrane to 99.5%	Steam generation at AstraZeneca (R&D facility in Gothenburg)
Temperature ranges (source)	4 °C à 0.5 °C (ice water), 3 °C à -1°C (water/glycol circuit)	76 °C à 72 °C (design point), 81 °C à 78 °C (operation)	93 °C	100 °C (steam)	55 °C à 50 °C (water)	60 °C	150 °C	80-135 °C (variable source)	85°C	130 °C	60 °C	35 °C
Temperature ranges (sink)	pressurized process hot water 95 à 115 °C	96 to 138 °C (design point), 102 to 152 °C (operation)	160 °C	125 to 146 °C (steam)	70 to 130 °C (pressurized water)	130°C	240 °C	160 °C	120 to 160°C (sink)	240 °C	120 °C	180 °C
Refrigerant	LT cycle R290; HT cycle R600	HFO-1336mzz(Z) (HFO low GWP refrigerant)	R718 (water)	R718 (water)	R134a	R718 (water)	R718 (water)	H3PO4 (phosporic acid loop)	R1336mzz(Z) (HFO low GWP refrigerant)	R718 (water)	R245fa	R704 (Helium)
Heating capacity	0.3 MW (heat) + 0.15 MW (cold)	0.3 MW	0.6 MW	0.5 MW	0.6 MW	10 MW	12 MW	2.9 MW (3-5% of the thermal output power as electricity)	0.2 – 0.3 MW	11.2 MW	1.9 MW (4 x 0.37 MW + 1 x 0.37 MW)	1.5 MW (3 x 500 kW)
Compressor	Piston	Screw compressors	Blower + Twin-screw compressor	Turbo-compressor	Centrifugal	Turbo	Piston (4LT-2HT), first stage 5 à 12 bar, second stage 12 à 19.5 bar, enables variation of 30% to 100 % steam flow rate	Heat driven	Piston (x 8)	Piston (4LT: 3.2 à 8 bar and 2HT: 8 à 16 bar)	Twin screw	Piston
COP	3.4 (ice water mode); 2.5 – 3.2 (dry cooler mode)	3.2 (design point); 2.8 (operation)	2.9	4.5 (supply at 146 °C), 8.6 (supply at 125 °C)	3	4.4	5.3 (condensing and subcooling heat to 105 °C)	0.45 (temperature lifts 80 K, heat output 400 kW to 1.3 MW)	2.2 (highest T) - 5.0 (design)	> 4.2 (condensing and subcooling heat to 105 °C)	> 3.5	1.7
Investment cost	500 – 700 €/kW thermal supply capacity (sink + source)	not disclosed	not disclosed	not disclosed	not disclosed	6.8 Mio. EUR (payback 1.7 years)	2.2 Mio. EUR (excl. integration) Payback period: not disclosed	not disclosed	not disclosed	2.5 Mio. EUR (excl. integration)	not disclosed payback 3 years	1.8 Mio. EUR 3 x HPs (excl. integration, incl. monitoring & control & He solution) Payback 3 years
Savings	Up to 62% primary energy	42'900 EUR/a at 138 °C	Life cycle cost (40%) and energy consumed (46%)	Savings: Energy costs (82%) and primary energy consumption (76%)	Energy cost reduced by 65%	4 Mio. EUR/a (80 % in energy consumption)	12.5 MW of natural gas	190'000 EUR EU ETS credits	60'500 EUR/a at 120 °C	Savings: not disclosed	Energy consumption reduced by 54%	9.4 GWh/y
Estimated annual CO_2 savings	Up to 94%	660 t/a at 138 °C	51% reduction	not available	Reduced by 60%	12,400 t/a (62% CO_2 emissions reduction)	14,000 t/a (7500 h, 0.281 kg/kWhee)	2'200 t/a	590 t/a	14'000 t/year (6,000 h, 0.013 kg/kWh_{ee})	Emissions reduced by 43%	600 t/a
Takeaway / Challenges	End-user tuned the production process (i.e. reducing the supply temperature); potential for designing new processes and plants optimized for HTHP integration	Material compatibility, mechanical design, integration infrastructure, and process control	Decisive factors for the end-user: (i) reduction of total running costs (waste disposal cost vs. electricity cost); and (ii) easy operation and maintenance	Operational start-up to integrate the turbo-compressor heat pump with the steam dryer (i.e. maintaining superheated steam coming from the dryer)	Preliminary detailed analysis of the heat demand and waste heat before the installation of the HP was the key to success	not available	not available	LDPE reactor has 40 recipes with highly fluctuating residual heat temperatures and output. Footprint of 4 m x 6 m and a height of 15 m	not available	not available	End-user was concerned about the reliability	Raising the TRL of the heat pump from level 7 to level 9.