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Book of presentations of the International Workshop on High Temperature Heat Pumps

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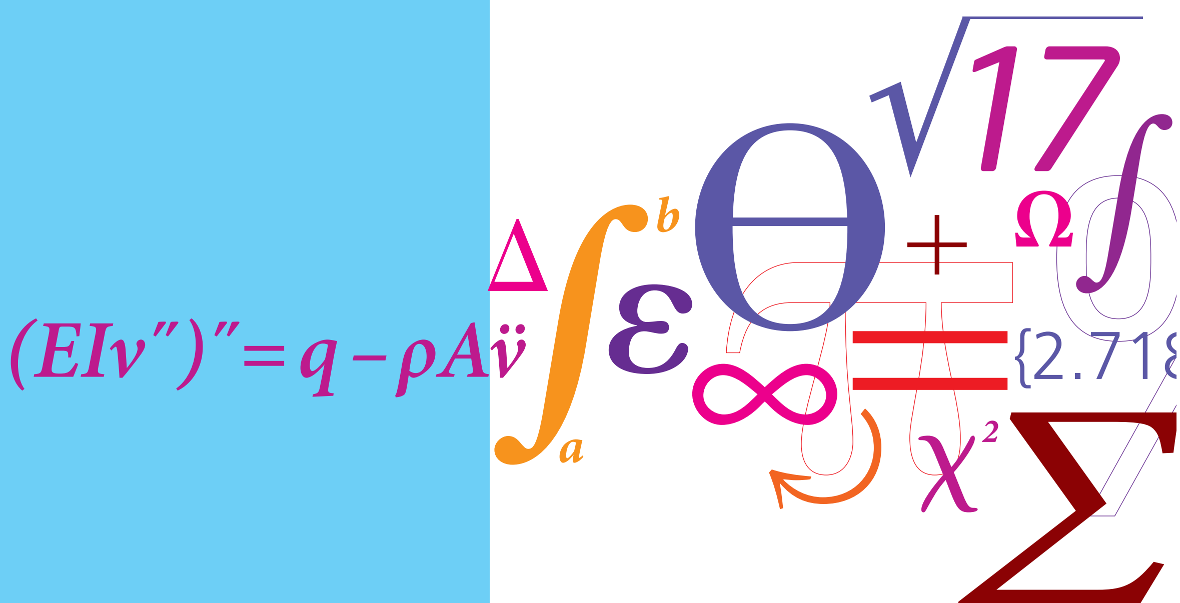
DTU

International Workshop on High Temperature Heat Pumps



11. September 2017
Copenhagen, Denmark

DANISH TECHNOLOGICAL INSTITUTE

SINTEF

DTU Mechanical Engineering
Department of Mechanical Engineering

Introduction

Modern society moves towards an electrified energy system based on wind, solar and other renewable sources. Utilizing these sources efficiently by heat pumps is highly attractive and a significant potential for improving the energy system by extensive adaptation of heat pumping technology in all fields exists. However, challenges are present for heat pump technology. In particular for high temperature applications like industrial processes and to some extent district heating, heat pumps are not yet commercially available. In some countries the expansion already occurs, but other places the development is much more limited. Some obstacles relate to regulations and boundary conditions which may not be favorable for heat pumps and electrification. But, the level of the technology will probably also improve with regards to temperature limits, efficiency, capacity, and economy, and hence inherently become an attractive alternative to fossil fuels.

The focus on developments for the future is apparent in both industrial and scientific research and development activities at all levels. DTU Technical University of Denmark, Danish Technological Institute and Norwegian SINTEF are all involved in these activities in collaboration with national and international partners.

Based on these common interests and the many exciting activities we decided to invite for a workshop for a broad audience ranging from manufacturers, system suppliers, industrial users, consultants, research institutes, and academia. The meeting attracted more than 60 participants attending the 18 talks and a final panel discussion on the 11. September 2017 in Copenhagen.

The talks were divided in four sessions focusing on

- Market Potential - Developments – Challenges
- Research and Development Projects
- Heat pump developments - Market ready products
- Case studies including realized projects

Altogether the presentations showed significant activity in both the Nordic countries, in Europe, and worldwide. Heat pumps are installed and investigated in various branches and both the foreseen industrial progress and the longer term perspectives indicated by academic research target the challenges and will soon make high temperature heat pumping far more attractive.

The concluding panel discussion involved Andrew J. Marina – Researcher at ECN (Energy Research Centre of the Netherlands), Kim Andre Lovas – Consultant, TINE SA Oslo, Morten Deding – Heat Pump Product Director Johnson Controls, Palle Lemminger – Manager, Innoterm A/S, and Petter Nekså – Chief Scientist, SINTEF. The panelists presented their suggestions on measures that will enhance the utilization of high temperature heat pumps in industry.

The following common conclusions were drawn from the discussion:

- Heat pumps are required for combating climate change
- Avoid wasting excess energy from industry by use of heat recovery
- Technical innovations for achieving lower specific investment costs should be achieved
- Equalize boundary conditions for heat pumps and other technologies
- Broader collaboration and interaction between technology developers and end-users will be beneficial
- Calculation tools may be useful for communicating the potentials to potential users
- Demonstration projects involving all parties including end-users, consultants, manufacturers as well as R&D can constitute a good opportunity to realize the before-mentioned suggestions

As organizers we are grateful to all participants and in particular the speakers for interesting and well-prepared presentations. In the following we present the collection of slides presented at the meeting.

Brian Elmegaard, Technical University of Denmark
Benjamin Zühlsdorf, Technical University of Denmark
Lars Reinholdt, Danish Technological Institute
Michael Bantle, SINTEF

Impressions of the workshop

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1 Overview – Market Potential – Developments – Challenges

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IEA HPT TCP Annex 35 + 48:

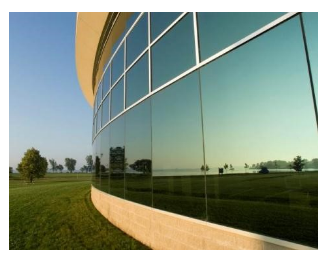
Heat Pump Application in Commercial and Industrial Processes

IZW e.V.
Information centre on
heat pumps and refrigeration

Dr.-Ing. Rainer M. Jakobs

IEA HEAT PUMPING TECHNOLOGIES

Research, Development, Demonstration and Promotion of Heat Pumping Technology



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- The IEA Technology Collaboration Programme on Heat Pumping Technologies, HPT TCP, and the Heat Pump Centre, the central information activity of the programme.
  http://heatpumpingtechnologies.org
- The goal is to accelerate the implementation of heat pumps and related heat pumping technologies.
  Including air conditioning and refrigeration.
- HPT TCP is member of IEA International Energy Agency (IEA), the programme was founded in 1978.
  HPT TCP has been active since almost 40 years.
- There are today 16 member countries:
  Austria, Belgium, Canada, Denmark, Finland, France, Italy, Germany, Japan, the Netherlands, Norway, South Korea, Sweden, Switzerland, United Kingdom and the United States.

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- Annexes = Projects
  One of the main activities within the programme is to run collaborative research, development, demonstration and deployment projects. They are called Annexes and they are conducted on a combination of cost sharing and task-sharing basis by the participating countries.
- One person/organization is appointed to manage the Annex, to be the Operating Agent of the Annex.
- **http://heatpumpingtechnologies.org/ongoing-annexes/**

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Agenda IEA HPT TCP Annex 35 + 48

- **Background**
- **Market overview, barriers for applications**
- **Technology**
- **Case Studies**
- **Summary and outlook**

- **Report: Download http://www.izw-online.de/annex35/index.php**

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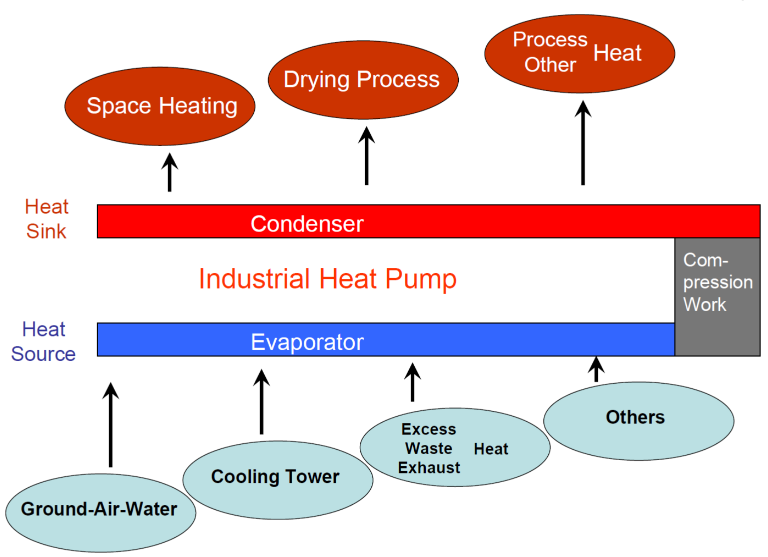
Heat Source and Heat Sink in Industrial Heat Pumps



Background

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IEA HPP - IETS Annex 35/13: Application of Industrial Heat Pumps

- As a joint venture of the IEA Implementing Agreements Industrial Energy-related Technologies and Systems (IETS) and Heat Pump Programme (HPP)
- 9 IEA countries A CDN D DK F JAP Korea NL S
  15 participating organizations
- Operating agent: IZW e.V. Germany
- Start date: 01st May 2010 End date: 30th April 2014
- Report: 31st October 2014 689 pages
  39 R&D projects 115 applications
  85 publications of the participants

IEA HPP Annex 48: Industrial Heat Pumps, Second Phase

- IEA countries A CH DK F JAP UK
- Operating agent: IZW e.V. Germany
- Start date: 01st April 2016 End date: 31st March 2019

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Results - Final Report HPP Annex 35

Task	Members		Sum.	Intro.	OA	A	CDN	DK	F	D	Jap	Korea	NL	S	Total pages
	Cover and Content	Pages			**2**										**2**
	Executive Summary	Pages			**10**										**10**
	Basics of IHP	Pages			17										**17**
1	**HP Energy situation, energy use, market overview, barriers for application**	Pages	1-5	6-9		10-24	25-31	32-37	38-50	51-63	64-70	71-77	78-93	94-100	100
2	**Modeling calculation + economic models**	Pages		1-29		30-34			35-57				58-76		76
3	**R & D Projects**	Pages	7	12		13--25	26-55	56-75	76-89	90-106	107-148	149-159	160-178		178
4	**Case studies**	Pages	9	14		15-47	48-80	81-94	95	96-148	149-185	186-197	198-214		214
	Appendix	Pages									16		34		46
5	**Communication, awareness of potential**	Pages		1-4		5-16							8		34
	Publication	Pages			17-26										
	Annex Meetings	Pages			27-27										
	Workshops	Pages			28-34										
	Policy Paper	Pages			1-12										12
													Total pages:		**689**

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Task 1:

Heat Pump Energy situation, energy use, market overview, barriers for application

A, **CDN**, DK, **F**, **D**, Japan, Korea, NL, S

Market overview 9

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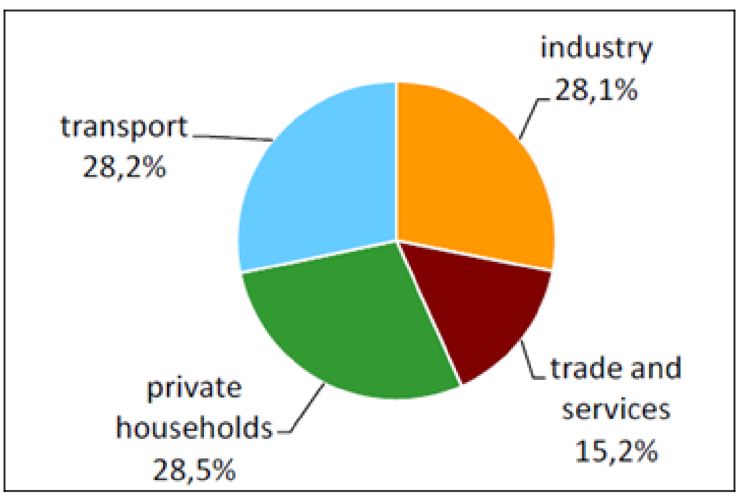
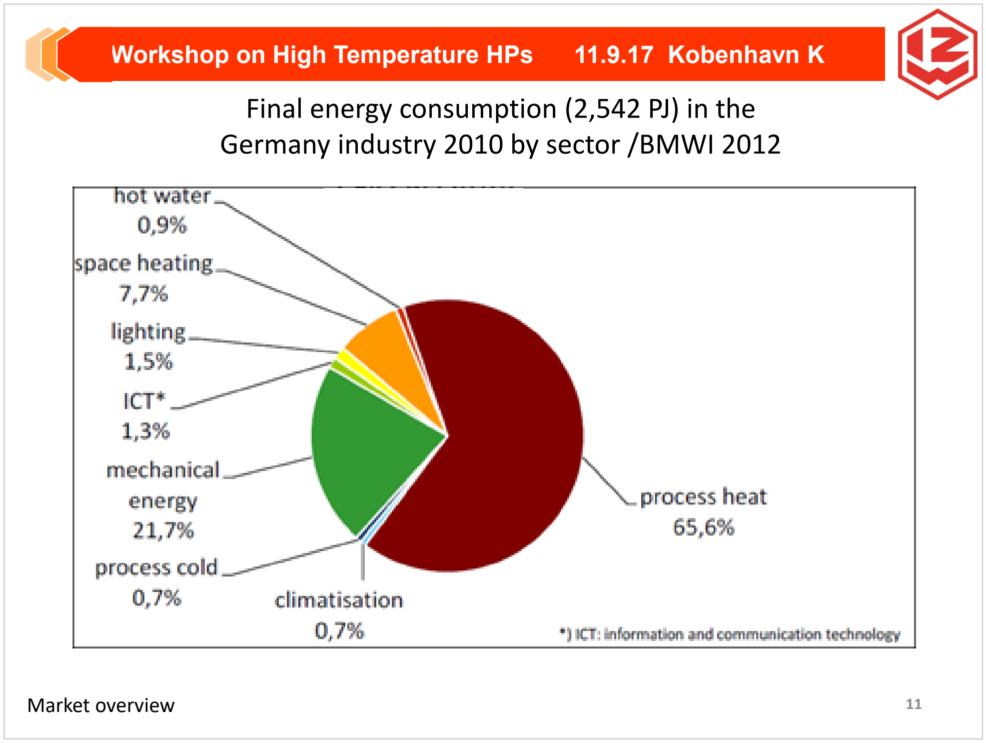
Final energy consumption (9,060 PJ) in Germany 2010 by sector /BMWI 2012



Market overview 10


Workshop on High Temperature HPs 11.9.17 Kobenhavn K
Final energy consumption (2,542 PJ) in the Germany industry 2010 by sector /BMWI 2012
hot water 0,9%
space heating 7,7%
lighting 1,5%
ICT* 1,3%
mechanical energy 21,7%
process cold 0,7%
climatisation 0,7%
process heat 65,6%
*) ICT: information and communication technology
Market overview
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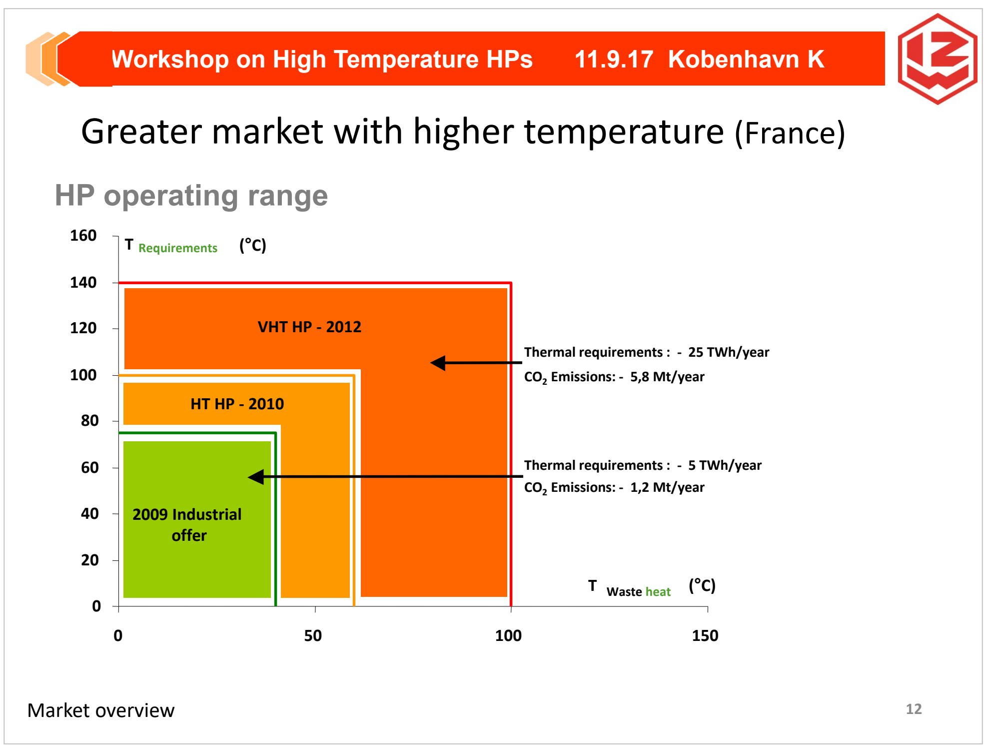
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Greater market with higher temperature (France)
HP operating range
T Requirements (°C)
160
140
120
100
80
60
40
20
0
VHT HP - 2012
HT HP - 2010
2009 Industrial offer
Thermal requirements : - 25 TWh/year
CO2 Emissions: - 5,8 Mt/year
Thermal requirements : - 5 TWh/year
CO2 Emissions: - 1,2 Mt/year
T Waste heat (°C)
0
50
100
150
Market overview
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Barriers and Solutions

Challenging Heat & Electricity Prices

→ Focus on Countries with favorable Price Ratios:
- Sweden
- Finland
- Bulgaria
- Netherlands
- France
- etc.

→ Focus on Rural Areas without Gas Networks

Country	Electricity/Gas Price Ratio: Households	Electricity/Gas Price Ratio: Small Enterprises	Electricity/Gas Price Ratio: Large Enterprises	Indicator
Sweden	1,2	1,3	1,0	↑
Finland		1,8	1,2	↑
Bulgaria	1,9	2,6	2,0	↑
Netherlands	1,5	2,6	2,6	↑
France	1,4	2,7	2,5	↑
Slovenia	2,5	2,1		↑
Portugal	2,1	2,5	2,4	↑
Estonia	2,5	2,6	2,2	↑
Austria	2,8	2,7	2,0	↑
Poland	2,4	2,8	2,4	→
Lithuania	1,7	3,4		→
Croatia	2,6	2,6		→
Hungary	3,1	2,4	2,8	→
Latvia	2,2	3,5	2,7	→
Luxembourg	3,2	2,3		→
Slovakia	1,7	3,5	3,2	→
Denmark	4,2	1,9	2,7	→
Czech Republic	2,2	3,7	2,9	→
Spain	2,9	3,5	2,5	→
Greece	2,3	4,0		→
Italy	2,2	3,9	3,7	→
Romania	4,2	3,0	2,8	→
Belgium	2,8	4,0	3,2	→
Germany	3,0	4,0	3,5	→
Ireland	4,1	3,9		↓
United Kingdom	2,8	4,2	5,1	↓
EU-28	2,4	3,3	3,0	→

Market overview

Source: IER Stuttgart Stefan Wolf Chillventa CONGRESS 10.10.2016

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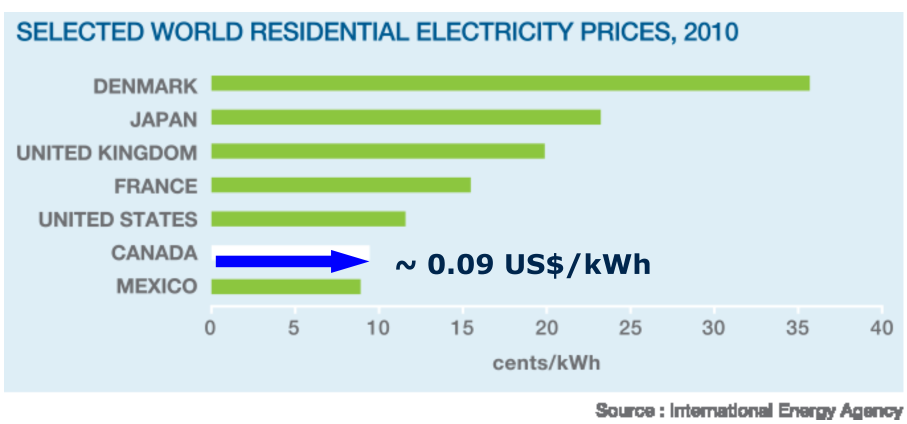
Average electricity pricing (2010)



Source: Natural Resources Canada

Market overview

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Heat Pump Energy situation, energy use, market overview, barriers for application
The country reports show that the industrial energy consumption in the participating countries varies between 17 to 58 % with great differences of the manufacturing sectors.
The barriers can be solved, as shown in the results of the Annex:
• short payback periods are possible (less than 2 years),
• high reduction of CO2-emissionen (up to more than 50%),
• temperatures higher than 100 °C are possible,
• supply temperatures lower than 100 °C are standard.
Market overview
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Task 3:
R & D Projects
A, CDN, DK, F, D, Japan, Korea, NL
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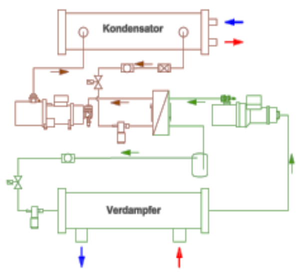
High-temperature HPs of Austrian manufacturers: E.g.

Intro
IHP Austria
AHP in Industry
Conclusion

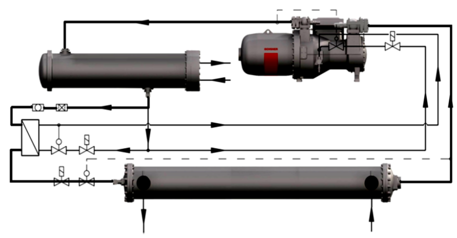
Company **Ochsner** offers HPs

- with **new refrigerant** ("Öko 1"): non-flammable, not toxic
- for **heat sink temperatures** up to **95°C** (temp. difference 5 to 10 K)
- Two different types:
  - IHWSS for a temperature lift from 10 to 95°C
  - IHWS for a temperature lift from 40 to 95°C

High-temperature heat pump (Ochsner, 2013)



IWHSS "two-stage" – Cascade cycle (Ochsner, 2013)



IWHS "single-stage" – economizer cycle (Ochsner, 2013)

Technology

Source: Rene Rieberer [TU Graz] HPP Annex 35 Workshop – May 12th, 2014, Montreal

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High-Temperature Heat Pumps for Industrial Applications in Japan

Closed-cycle mechanical heat pump

- Transcritical CO_2 cycle
- Single-stage compression reverse Rankine cycle
- Two-stage compression reverse Rankine cycle
- **Cascade reverse Rankine cycle**

Open-cycle hybrid vapor recompression heat pumps

- Hybrid means "mechanical and thermal"

Technology

Choyu WATANABE et al ; IEA HPP Workshop, HPC2014 in Montreal, Canada

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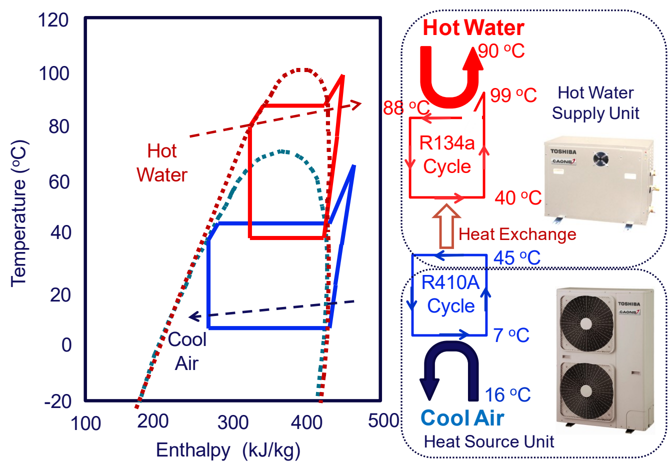
Cascade Reverse Rankine Cycle Heat Pump using R410A *



Specifications of the Heat Pump

Rated Heating Power (kW)	14.0
Rated COP*	3.5
Leaving Temperature Range (°C)	50 to 90
Ambient air temperature range (°C)	-15 to 43

*: Atmospheric Air Temperature: 25°C Dry Bulb, 21°C Wet Bulb, Entering Water Temperature: 60°C, Leaving Water Temperature: 65°C

*: Takayama, T., Suzuki, H., Iba, I., Hongou, I., Sakuraba, I., Miyaoka, Y. and Nakayama, H. (2012). "Development of High Temperature Water Circulation Type Heat Pump for Industries (Air-to-Water Heat Pump with a Maximum Output Water Temperature of 90 oC)", Proc. of the 2012 JSRAE Annual Conference, F122 (in Japanese)

Technology

Choyu WATANABE et al ; IEA HPP Workshop, HPC2014 in Montreal, Canada

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Refrigerants

name	components	ratio [m %]	ODP *	GWP *	NBP * [° C]	T_{crit} [° C]	p_{crit} [bar]	Savety classification
R410A	R32/R125 [a]	50/50 [a]	0 [b]	1730 [b]	-51.6 [a]	72.6 [b]	49.0 [b]	A1 [g]
R134a	$C_2H_2F_4$ [a]	-	0 [a]	1300 [a]	-26.1 [a]	101.0 [a]	40.6 [a]	A1 [g]
R245fa	$C_3H_3F_5$ [a]	-	0 [c]	950 [c]	15.3 [a]	154.0 [c]	36.4 [c]	B1 [e]
R717	NH_3 [g]	-	0 [g]	0 [g]	-33.0 [g]	133.0 [g]	114.2 [a]	B2 [g]
R744	CO_2 [g]	-	0 [g]	1 [g]	-57.0 [g]	31.0 [g]	73.8 [a]	A1 [g]
SES36	R365mfc/PFPE [f]	65/35 [f]	0 [f]	3126 [f]	35.6 [f]	177.6 [f]	28.5 [f]	unknown
DR-2	unknown	-	0 [d]	9,4 [d]	33.4 [d]	171.3 [d]	29.0 [d]	A1 (expected) [d]

*) ODP: Ozone Depletion Potential GWP: Global Warming Potential NBP: Normal Boiling Point

Quellen:
a) IFA, b) Solvay Fluor GmbH 2010, c) Honeywell International Inc. 2010, d) Kontomaris 1/10/2011, e) Klein 2009, f) Riva et al. 2006, g) Bitzer Kühlmaschinenbau GmbH 2010

S. Wolf; IER – University of Stuttgart Annex 35 meeting 17.03.2013 16

Technology

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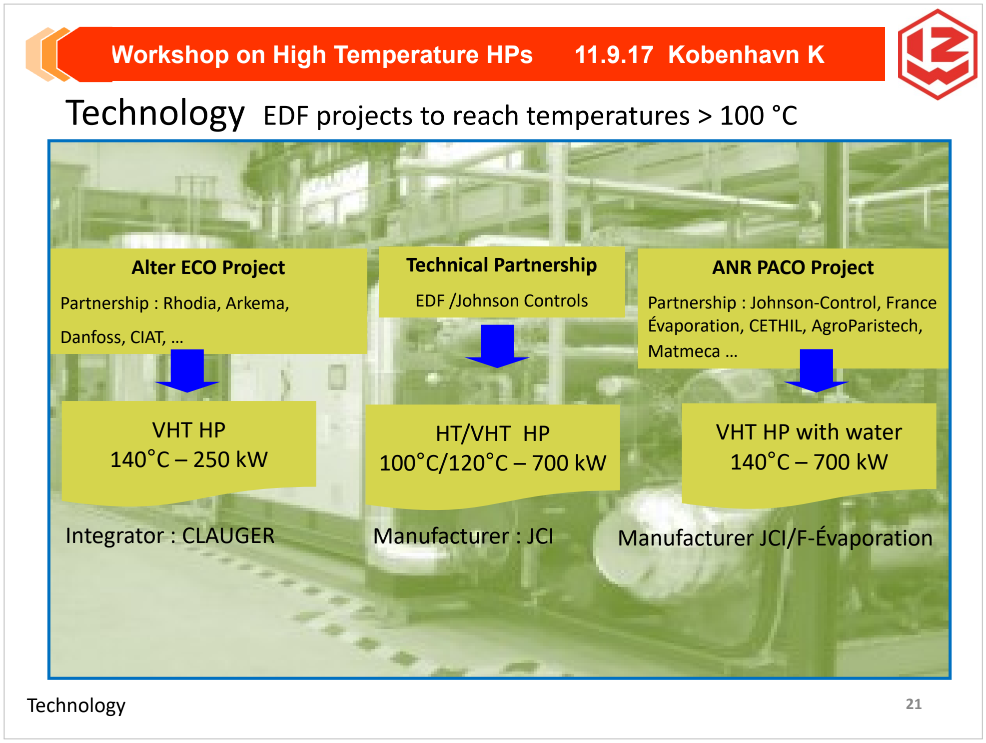
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Technology EDF projects to reach temperatures > 100 °C
Alter ECO Project
Partnership : Rhodia, Arkema, Danfoss, CIAT, …
VHT HP
140°C – 250 kW
Integrator : CLAUGER
Technical Partnership
EDF /Johnson Controls
HT/VHT HP
100°C/120°C – 700 kW
Manufacturer : JCI
ANR PACO Project
Partnership : Johnson-Control, France Évaporation, CETHIL, AgroParistech, Matmeca …
VHT HP with water
140°C – 700 kW
Manufacturer JCI/F-Évaporation
Technology
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Task 4: Case studies
A, CDN, DK, F, D, Japan, Korea, NL
Case studies
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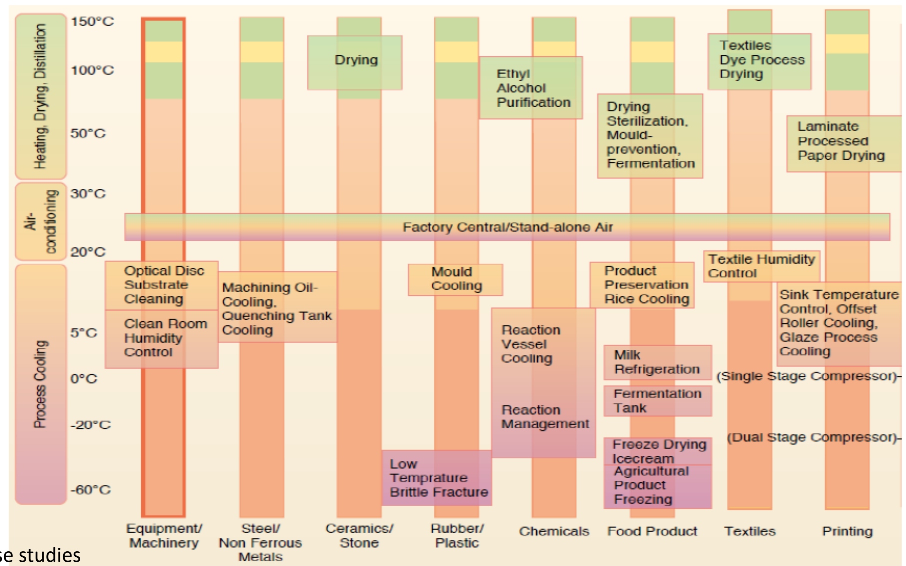
Case Studies

Source: NT Japan Annex 35



Case studies

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Application, Industry	Member Country	Year	System	Refrigerant	Cooling Heating Drying Waste heat	Heating Capacity	Supply tempe-rature	Pay back period	Reduction CO_2	Reduction energy/cost	Report page
Food: meat, sausage	A	eld	Mech Compr	R-134a	W	257 kW	55 °C		75%		420
Ice rink	A	2013	Mech Compr	R-717	W	413 kW	60 °C		75%		422
Food: brewery	A	2012	Mech Compr	R-717	W	370 kW	63-77 °C	5.7 a		64,000 €/a 18.3 %	426
Fish farm	CDN	eld	Mech Compr	R-22	H	109	10–12 °C	1.3 a			460
Wood drying low temp	CDN	eld	Mech Compr		D	5.6 kW	n. a.			21.5%	463
Wood drying high temp	CDN	eld	Mech Compr		D	2 x 65 kW	Up to 100 °C			50%	471
Washing metal items	DK	2011	Mech Compr	R-134a	H	25 kW	60 °C	2.5 a	20 t/a	50%	493
Food: Slaughter-house	D	2011	Mech Compr	R-744	C&H	800 kW	90 °C		510 t/a		500
Food: Dairy	D	2011	Mech Compr	R-717	W	3.45 MW	58 °C		30-40%		506

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Case studies

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Application, Industry	Member Country	Year	System	Refrigerant	Cooling Heating Drying Waste heat	Heating Capacity	Supply tempe-rature	Pay back period	Reduction CO_2	Reduction energy/cost	Report page
Food: Dairy	D	2011	Mech Compr	R-717	W	3.45 MW	58 °C		30-40%		506
Coating Powder	D	2012	Mech Compr		D	240 kW	45 °C	5 a			531
Food: Malt production	D	2010	Mech Compr	R-717	D	3,250 kW	35 °C				546
Food: Brewery	D	2012	Mech Compr	R-134a	H	77 kW	55 °C	< 6 a			547
Food: Noodle production	Jap	2008	Mech Compr	R-744 trans.	C & H	C 56 kW H 72 kW	5 °C 90 °C	8.2 a	31%	25%	557
Transformer casing (painting)	Jap	2009	Mech Compr	R-744 trans.	D	110 kW	80–120 °C		13%	12%	565
Automotive (painting)	Jap	2009	Mech Compr	R-407E	D	566 kW	n. a.	3 – 4 a	47%	63%	569
Automotive – Washing process	Jap	2009	Mech Compr	R-134a	C & H	8 x 45.3 kW 6 x 22,3 kW	65 °C		86%	73%	575
Greenhouse	Jap	2010	Mech Compr	R-410A		6 x 18 kW	20 °C		63%	50%	580
Food: Drying of french fries	NL	2012	Mech Compr	R-717	D	880 kW	70 °C	4 a		70%	NL-06
Greenhouse Tomatoes	NL	2003	Mech Compr	R-134a	C&H	3 x 1.25 MW	42-50 °C	> 10 a	40-60 %	29%	NL-27

Case studies 25

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Intro
IHP Austria
AHP in Industry
Conclusion

Some applications in Austria

Compression heat pump in in a brewery:

- NH_3 Compression HP (COFELY)
- 370 kW heating capacity
- Waste heat from:
  - + air compressor
  - + chillers
- Heat upgrade from ca. **40 to 77 °C**
- Space and process water heating
- ROI: 5,7a

Source: klima:aktiv

Company:

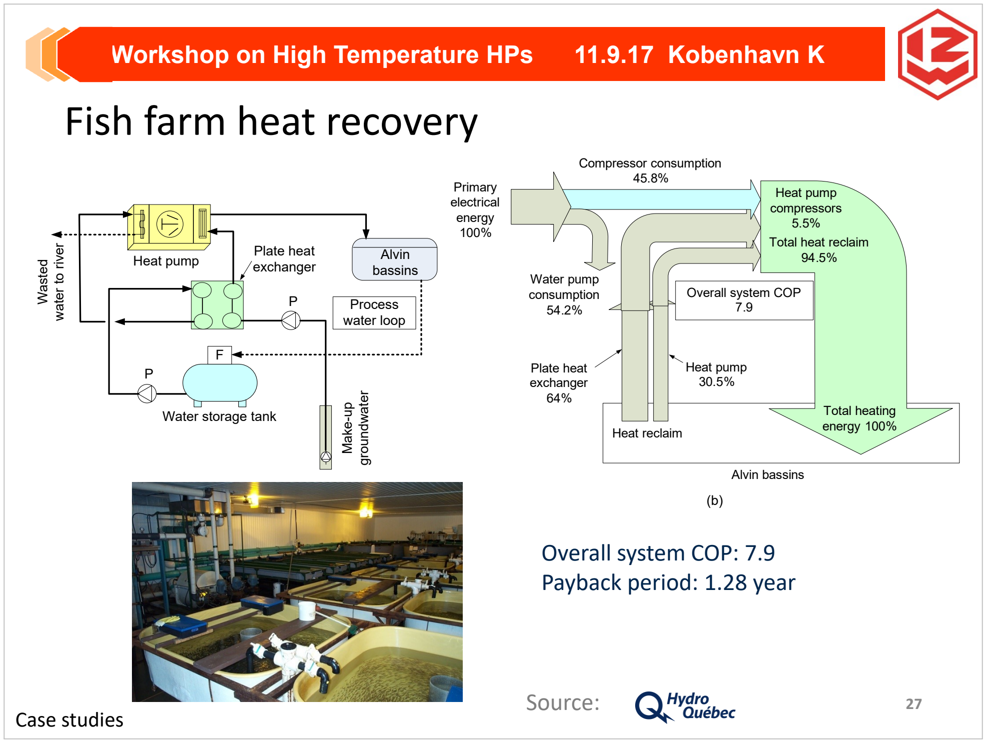
MOHREN SEIT 1834

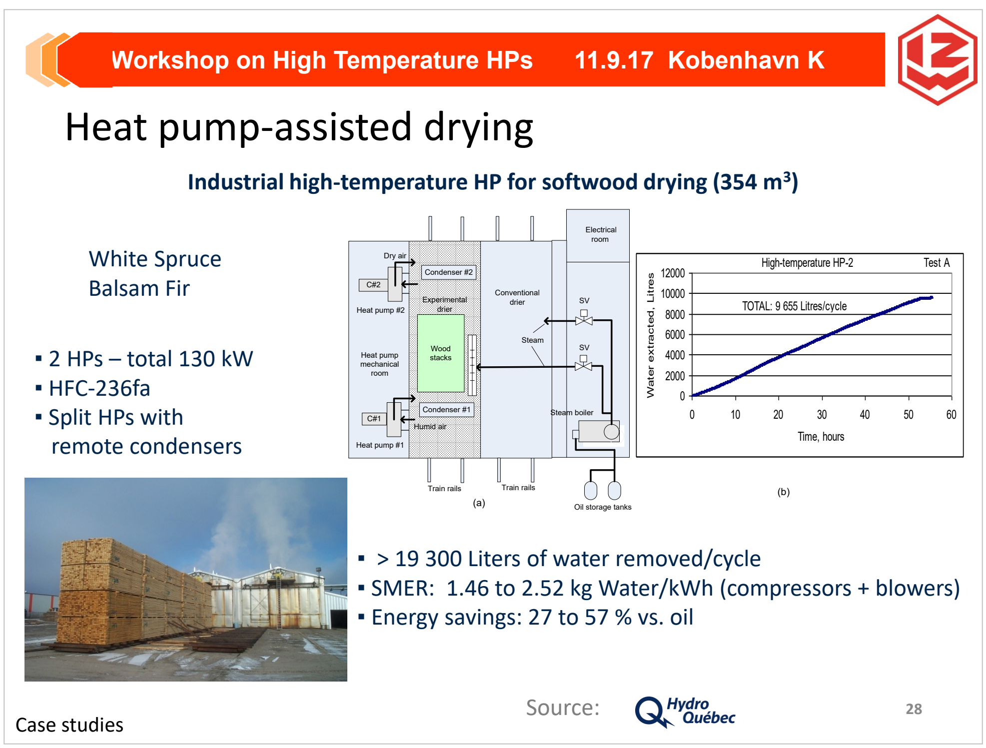
*www.**mohrenbrauerei**.at*

HP @ Mohrenbrauerei (Source: klima:aktiv, 2012)

Case studies

Source: Rene Rieberer [TU Graz] HPP Annex 35 Workshop – May 12th, 2014, Montreal 26


Workshop on High Temperature HPs 11.9.17 Kobenhavn K
Fish farm heat recovery
Wasted water to river
Heat pump
Plate heat exchanger
Alvin bassins
Process water loop
P
F
P
Water storage tank
Make-up groundwater
Primary electrical energy 100%
Compressor consumption 45.8%
Heat pump compressors 5.5%
Total heat reclaim 94.5%
Water pump consumption 54.2%
Overall system COP 7.9
Plate heat exchanger 64%
Heat pump 30.5%
Total heating energy 100%
Heat reclaim
Alvin bassins
(b)
Overall system COP: 7.9
Payback period: 1.28 year
Source: Hydro Québec
27
Case studies


Workshop on High Temperature HPs 11.9.17 Kobenhavn K
Heat pump-assisted drying
Industrial high-temperature HP for softwood drying (354 m3)
White Spruce
Balsam Fir
▪ 2 HPs – total 130 kW
▪ HFC-236fa
▪ Split HPs with remote condensers
Electrical room
Dry air
Condenser #2
C#2
Experimental drier
Heat pump #2
Conventional drier
Heat pump mechanical room
Wood stacks
Steam
SV
Condenser #1
C#1
Humid air
Heat pump #1
Steam boiler
Train rails
(a)
Oil storage tanks
High-temperature HP-2
Test A
TOTAL: 9 655 Litres/cycle
Water extracted, Litres
Time, hours
(b)
▪ > 19 300 Liters of water removed/cycle
▪ SMER: 1.46 to 2.52 kg Water/kWh (compressors + blowers)
▪ Energy savings: 27 to 57 % vs. oil
Source: Hydro Québec
28
Case studies

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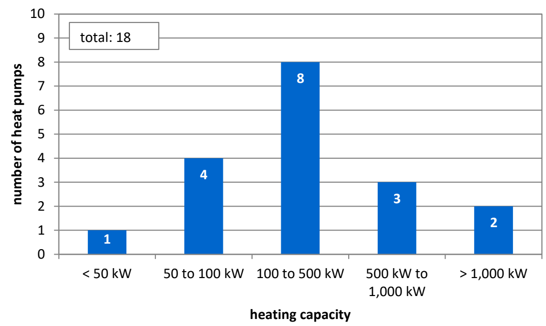
Selected applications of industrial heat pumps in Germany - Size

Collection of 18 heat pump applications in the German industry:

- 13 use waste heat to provide space heating
- 5 use waste heat to provide process heat



Case studies Source: IER University Stuttgart 29

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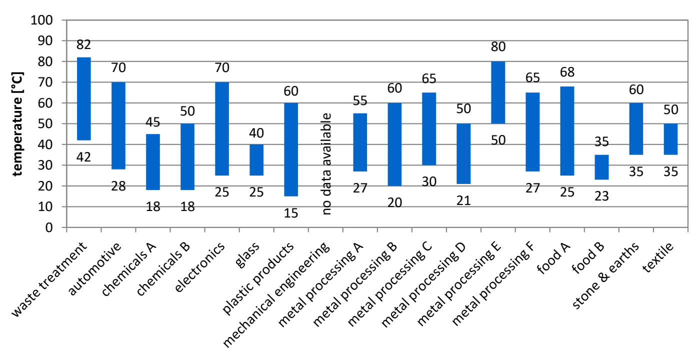
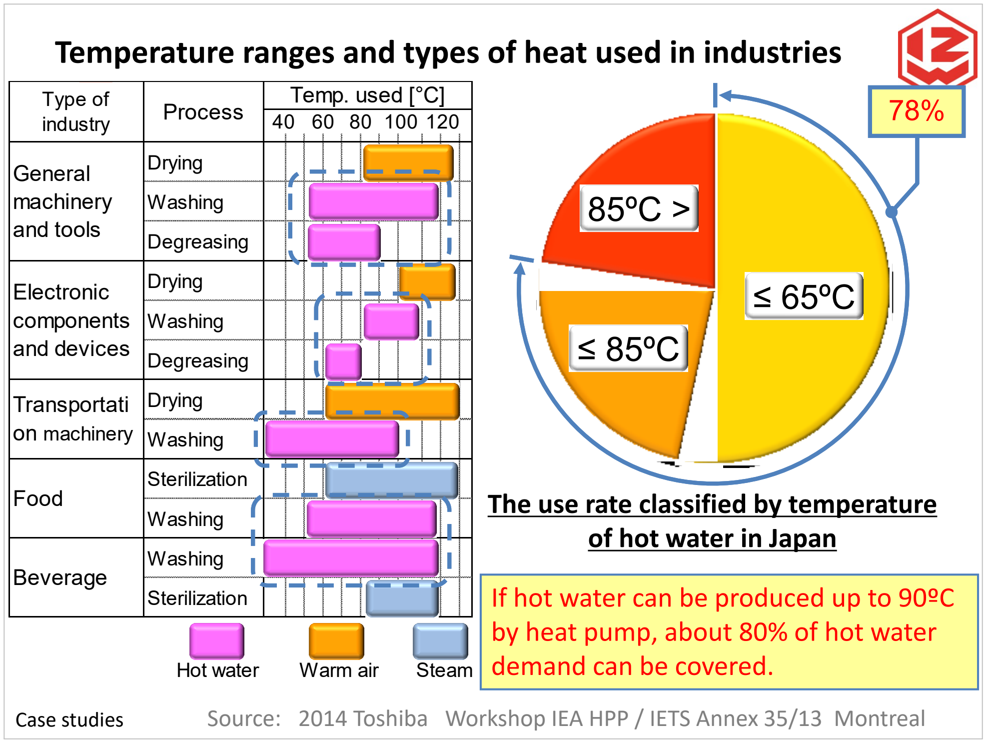
Selected applications of industrial heat pumps in Germany - Temperatures

Collection of 18 heat pump applications in the German industry:

- 13 use waste heat to provide space heating
- 5 use waste heat to provide process heat



Case studies Source: IER University Stuttgart 30



Temperature Applied for IHP

Source: NT Japan
Annex 48

Industry	Industrial process	Temp. [°C]
Food production	Freezing foods	-60 ~ -30
	Cooling of chicken	-20 ~ 5
	Cooling of noodle	1 ~ 3
	Sterilization and cooling of milk	3 ~ 5, 70 ~ 75
	Ham production	2 ~ 80
	Retort pouch	3 ~ 5, 70 ~ 75
	Fermentation of Japanese sake	14 ~ 15
	Fermentation and temperature control of wine	16 ~ 20
	Seaweed drying	20 ~ 30
	Temperature control of yeasts and bread	22 ~ 30
	Fermentation of miso and shoyu	27 ~ 28, 38 ~ 40
	Rice koji drying	35
agriculture	Low temperature storage	1 ~ 6
	Pre-cooling	3 ~ 5
	Cooling & washing for milking process	0 ~ 4, 40 ~ 60
	Mushroom cultivation	13 ~ 20
	Temperature control for slop culture	15 ~ 25
	Greenhouse cultivation	18 ~ 32
	Dehumidifier cultivation	20 ~ 23
	Heating for stock breading	20 ~ 30
	Egg incubation	36 ~ 38

Industry	Industrial process	Temp. [°C]
forestry	Lumber dehumidifier	40 ~ 60
Wholesale trade	Freezing exhibit case	-20 ~ -10
	Cooling vehicle	-10 ~ 0
	Hot water sully for cooking room	60 ~ 80
services	Heating for indoor pool water	~ 35
	Heating for hot spring	~ 60
	Hot water supply for bathhouse	50 ~ 65
Textile industry	Dry cleaning	20 ~ 30
	Cloth drying	60 ~ 80
	Dyeing heating	90
	Towel dyeing	~ 100
Lumber & wood	Drying of furniture and musical instr.	38 ~ 60
Pulp, paper	Drying of paper and pulp	80 ~ 130
Chemical ind. and petroleum refinery	Concentration of medicine	20 ~ 60
	Dehumidifying of incense stick	25 ~ 30
	Separation and synthesis of petro.	60 ~ 120
	Petroleum refinery	60 ~ 180
	Distillation of chemicals	80 ~ 170
Waste manag.	Dehydration of dirty mud	~ 60

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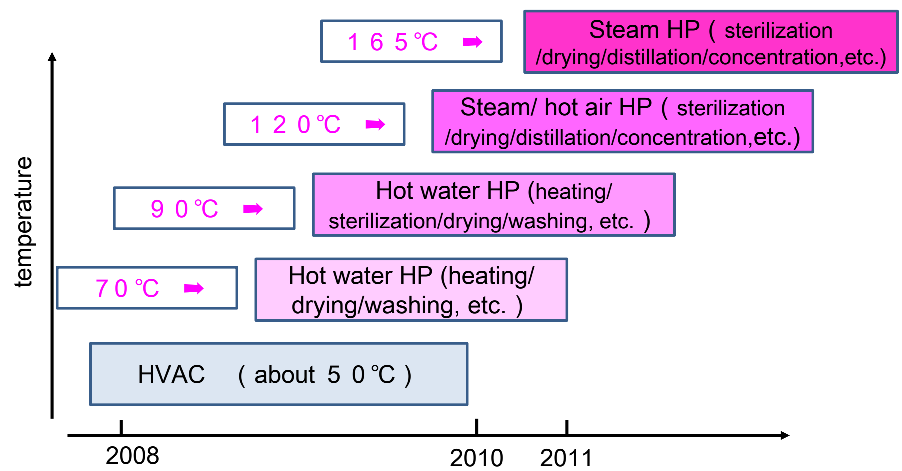
Application for High Temperature Use of IHP



Source: NT Japan
Annex 48

Source : Guide of IHP application, JEHC, 2017

Case studies 33

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Problems of Practical Heat Usage in Factory

- **A large amount of low temperature heat is wasted.**

Processes in a factory generate exhausted heat in different forms. All input energy in a factory is finally wasted as low level of heat.

- **Low effective use of steam boiler system**

Practical steam supply system has nearly 50% of heat loss generated in processes of boiler, piping and drain.

- **Constant temperature of heat supply**

Heat in a factory is used for heating, drying, washing, etc. at different heat levels. However, heat of constant temperature is supplied for those purposes.

- **Separate heat supply for heating and cooling**

It is required for both heating and cooling in production processes. Different technologies are separately adopted for heating and cooling.

Source: NT Japan
Annex 48

Source : Guide of IHP application, JEHC, 2017

Case studies 34

Selection of Best Practices

Source: NT Japan Annex 48

No	2	21	43	83	94
Industry	Food	Machinery	Chemicals	Food	Machinery
Process applied	Heating/ cooling	Heating/ cooling	Distillation/ concentration	Distillation/ concentration	Heating
Location	Hyogo	Aichi	Hokkaido	Kochi	Mie
Year of installation	2010	2010	–	2015	2013
User (company)	Kosmos Food, co. Ltd	Aishin A W, Ltd	Hokkaido Bioethno, Ltd	Muroto Deep Sea Water, Ltd	Fuji Electric co.Ltd.
HP manufacturer	MAYEKAWA MFG. Ltd	General HP Industries, Ltd.	KOBE STEEL, Ltd	Sasakura Engineering Ltd	Fuji Electric co.Ltd.
HP system	Water-source hot water supply HP	Water-source HP chiller	Water-source steam supply HP	Mechanical vapor recompression	Water-source steam supply HP
Refrigerant	CO_2	R134a	R245fa	steam	R245fa
Compressor type	reciprocate	scroll	screw	roots	reciprocate
Heating/cooling capacity (kW)	828	66	9,250	–	30
Supply temperature (℃)	90	65	120	70	120
Heat source/ heat sink	Simultaneous heating/cooling	Simultaneous heating/cooling	Exhausted heat of cooling tower	Exhausted steam	Exhausted cooling water of cogeneration
Savings energy (%)	–	84	40	79	46
Savings CO_2 emissions (%)	87	80	43	79	40
Savings energy cost (%)	80	79	54	78	55
Evaluation	c, d, f, g	d, e. f, g	a, b, d, g	c, d, e, f, g	a, d, g

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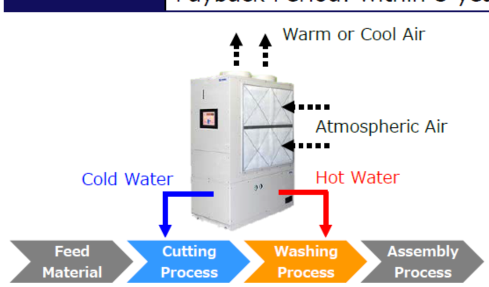
Best Practice 2 Outline

Source: NT Japan Annex 48

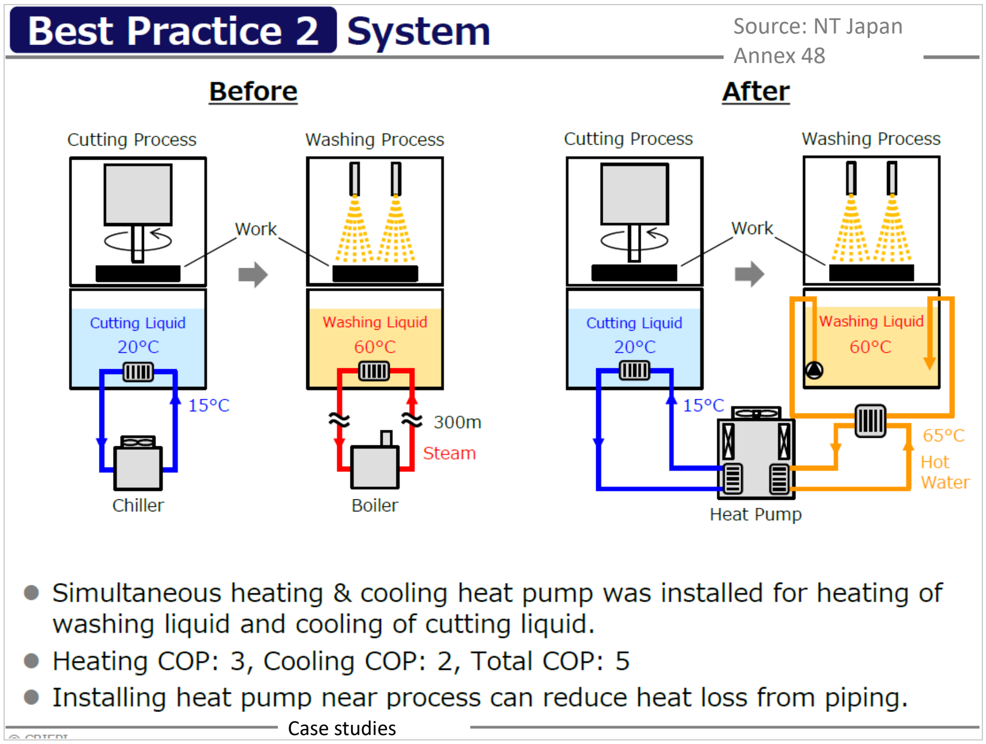
ID	#21	Annex	35	Installed Year	2010
Industry	Machinery (Automobile Parts Production)				
Processes	Cutting, Washing				
Application	Simultaneous Hot Water (65°C) and Cold Water (15°C) Supply				
Purposes	Reduction of Boiler Steam				
System	Water-to-Water and Air-to-Water Heat Pumps (6+8=14 units) Refrigerant: R134a Heating Capacity: 22kW/unit (6 units), 43kW/unit (8 units)				
Effects	CO_2 Reduction: 80%, Energy Cost Reduction: 79% Payback Period: within 5 years (estimated)				

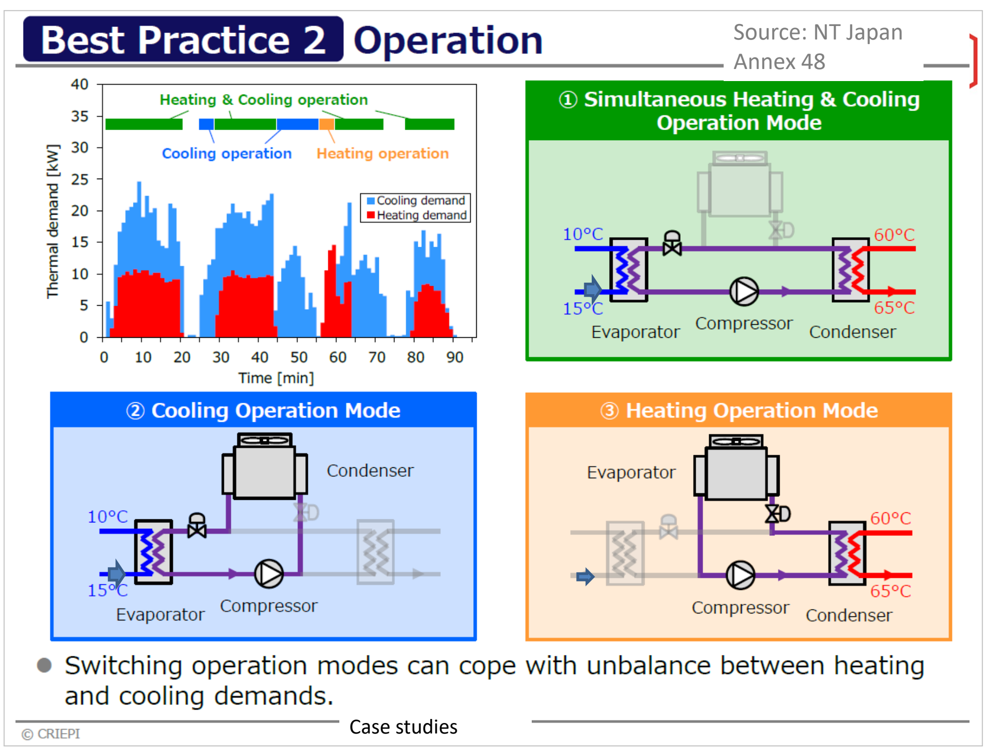


Process and Application

External Appearance of Installed Heat Pumps

Case studies


Best Practice 2 System
Source: NT Japan
Annex 48
Before
After
Cutting Process
Washing Process
Work
Cutting Liquid
20°C
Washing Liquid
60°C
15°C
300m
Steam
Chiller
Boiler
65°C
Hot Water
Heat Pump
● Simultaneous heating & cooling heat pump was installed for heating of washing liquid and cooling of cutting liquid.
● Heating COP: 3, Cooling COP: 2, Total COP: 5
● Installing heat pump near process can reduce heat loss from piping.
Case studies


Best Practice 2 Operation
Source: NT Japan
Annex 48
Heating & Cooling operation
Cooling operation
Heating operation
Cooling demand
Heating demand
Thermal demand [kW]
Time [min]
① Simultaneous Heating & Cooling Operation Mode
② Cooling Operation Mode
③ Heating Operation Mode
10°C
15°C
60°C
65°C
Evaporator
Compressor
Condenser
● Switching operation modes can cope with unbalance between heating and cooling demands.
Case studies
© CRIEPI

Best Practice 2 Effects

Source: NT Japan
Annex 48

- CO_2 Emission
  - 80% reduced
  - 1,094 tons/year reduced
- Primary Energy Consumption
  - 84% reduced
  - 437 kL/year reduction (Fuel oil equivalent)
- Energy Cost
  - 79% reduced
  - 26 million JPY/year
- Payback Period
  - 3.5 years

Case studies

Best Practice 1 Outline

Source: NT Japan
Annex 48

ID	#2	Annex	35	Installed Year	2010
Industry	Food (Freeze-Dried Foods Production)				
Processes	Food Processing, Sterilization, Washing, Building Air-Conditioning				
Application	Simultaneous Hot Water (90°C) and Cold Water (10°C) Supply				
Purposes	Renewal of Facilities, Energy Saving, Energy Cost Reduction				
System	Water-to-Water Heat Pumps (3 units) Refrigerant: CO_2 (Trans-critical Cycle), Heating Capacity: 80kW/unit				
Effects	CO_2 Reduction: 87%, Energy Cost Reduction: 80% Payback Period: within 5 years (estimated)				

Freeze-Dried Foods (ex. Instant Soups)

External Appearance of Installed Heat Pumps

Case studies

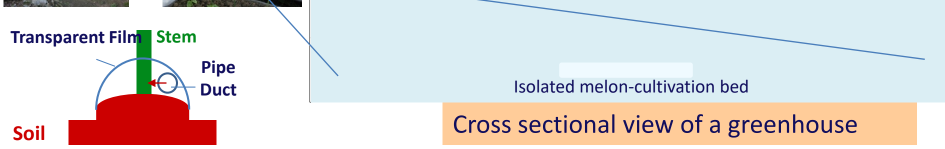
Applying Heat Pump Technology to Agricultural Production *

Industry	Fruit Cultivation
Process	Green House Air-conditioning
Application	Space Heating in Winter and Space Cooling in Summer
Purpose	Reduction of Fuel Heavy Oil in Winter and Air-conditioning in Summer
System overview	Air-to-Air Inverter-controlled Greenhouse Heat Pumps using R410A (7 Units) with Heating Capacity 18 kW (20 °C) and Cooling Capacity 16 kW (27 °C) , Twin Type 6 Sets and Single Type 1 Set
Effect	Primary energy consumption was reduced by 49%.

Twin Type

Outdoor Unit 2 Indoor Units

Type	Twin	Single
Number of Indoor Units	2	1
Cooling (Standard) COP	5.48	3.86
Heating (Standard) COP	5.50	4.90
Heating (Cold climate) COP	3.77	3.20



Cross sectional view of a greenhouse

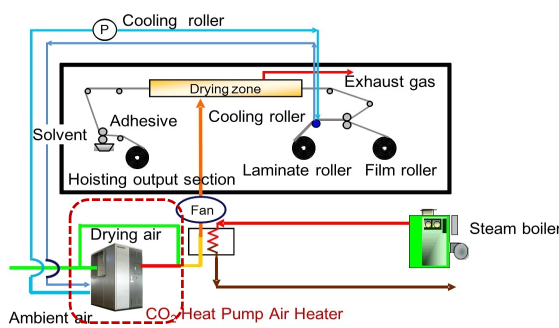
*: JEHC (Sep. 2011). Electro-Heat Hand Book, Japan Electro-Heat Center (JEHC), Ohmsha, Tokyo, ISBN 978-4-274-21037-2.

Case studies Choyu WATANABE et al ; IEA HPP Workshop, HPC2014 in Montreal, Canada 41

CO_2 Heat Pump Air Heater for Drying Process *

Industry	Laminate Printing
Process	Drying, Cooling
Application	Hot Air Supply to Drying Zone and Cool Water Supply to Cooling Roller
Purpose	Reduction of Steam (Fuel Gas)
System Overview	Water-source Heat Pump Using CO_2 Refrigerant (1 Unit) for Hot Air Supply with Heating Capacity 110 kW, Operating Range of Hot Air Leaving Temperature 80 to120 °C and That of Heat Source Water Entering Temperature 5 to 32 °C, COP
Effect	Primary energy consumption was reduced by 46%.

Reciprocating-type compressor
Heating air: from 20 to 100 °C Heating Capacity: 110 kW **Heating COP: 3.4**
Cooling water: from 30 to 25 °C Cooling Capacity: 81 kW, **Cooling COP: 2.5**
Total COP: 5.9



*: Kando, M. (2012). "Case Studies of High Temperature Heat Pump to the Industrial Field from System Study to Operation", Proc. of the 2012 JSRAE Annual Conference, F112.

Case studies Choyu WATANABE et al ; IEA HPP Workshop, HPC2014 in Montreal, Canada 42

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Summary

- Heat pumps can provide high temperatures up to 100 °C at large heating capacities (several MW).
- Industrial heat pump systems reach payback times between 2 and 7 years
- Heat pumps become especially economical feasible, when both hot and cold side are used
- Heat pumps are ready for the industry!

Barriers and threats:

- Insufficient knowledge about industrial processes among HVAC planners
- Rising electricity prices (e.g. in Germany), while gas and oil prices remain stable or decrease

Summary 43

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Outlook

- Main Goal of the new HPT-Annex 48 is to overcome difficulties and barriers for the market introduction of industrial heat pumps.
- Collected cases studies of industrial branches with a large potential, should be analyzed
- Development of a web based information platform for heat pumps in industrial and commercial application
- Creating information material for IHP (training) courses
- The IHP potential for more efficient use of energy and reduction of greenhouse gas emission should be prepared for policy makers

Outlook 44

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Many thanks for your kind attention

Herzlichen Dank für Ihre freundliche Aufmerksamkeit

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EUROPEAN HEAT PUMP SUMMIT
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24 - 25 October 2017 // Nuremberg

https://www.hp-summit.de/

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Your energy. Our passion.

High Temperature Heat Pumps in Dutch Industry

Market Potential and Challenges in Implementation

Andrew Marina

International Workshop on High Temperature Heat Pumps - Copenhagen

11th September, 2017

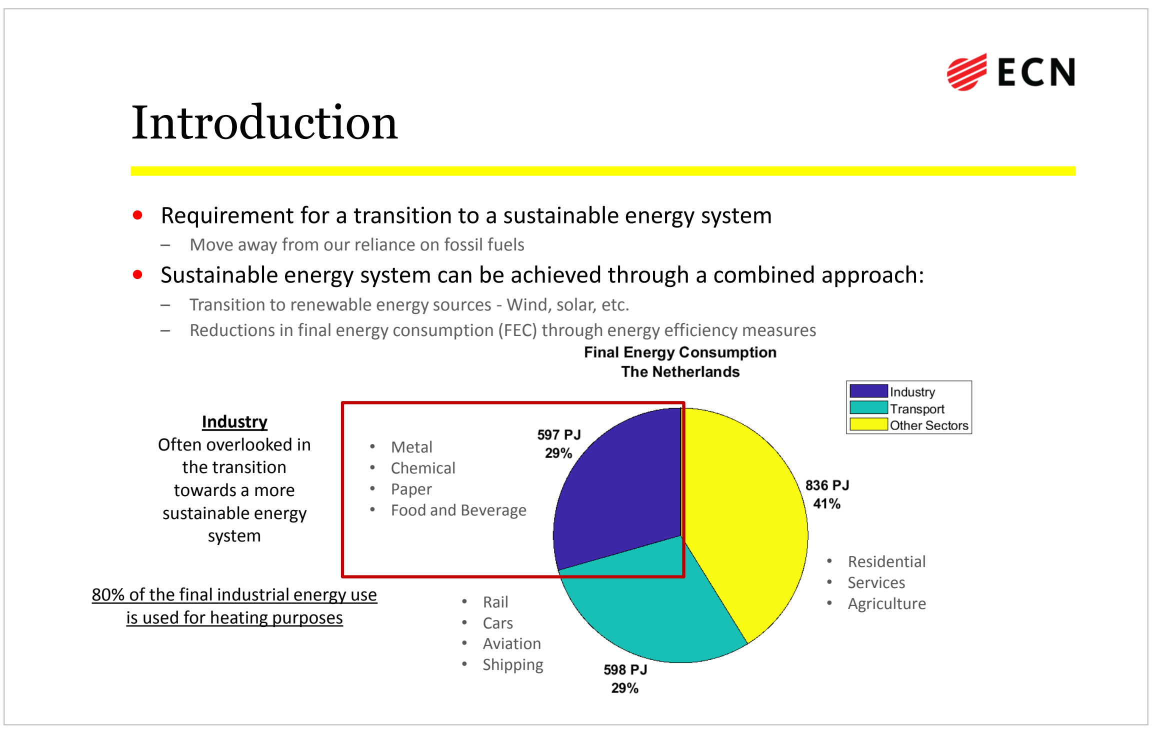
www.ecn.nl

ECN

Presentation Outline

- Industrial Energy use in the Netherlands
- Requirement for active heat recovery technologies (heat pumps) in industrial processes
- Results of industrial heat pump market study
- Challenges in implementing heat pumps in practice


Industrial Energy Usage & Case for Heat Pumps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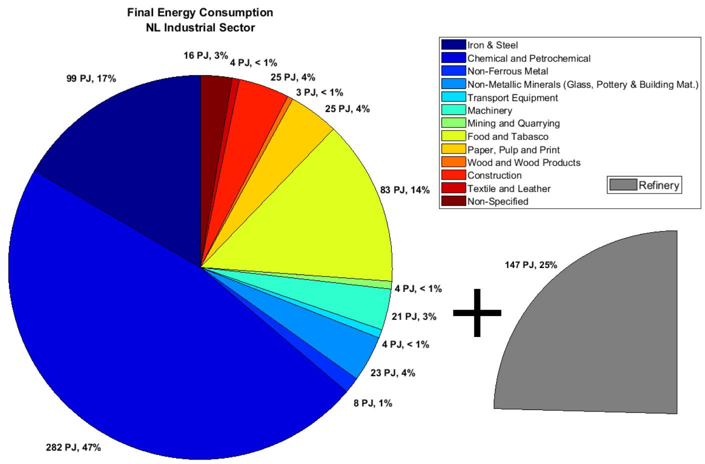
Introduction
Requirement for a transition to a sustainable energy system
Move away from our reliance on fossil fuels
Sustainable energy system can be achieved through a combined approach:
Transition to renewable energy sources - Wind, solar, etc.
Reductions in final energy consumption (FEC) through energy efficiency measures
Final Energy Consumption
The Netherlands
Industry
Transport
Other Sectors
Industry
Often overlooked in the transition towards a more sustainable energy system
80% of the final industrial energy use is used for heating purposes
Metal
Chemical
Paper
Food and Beverage
597 PJ
29%
836 PJ
41%
598 PJ
29%
Rail
Cars
Aviation
Shipping
Residential
Services
Agriculture

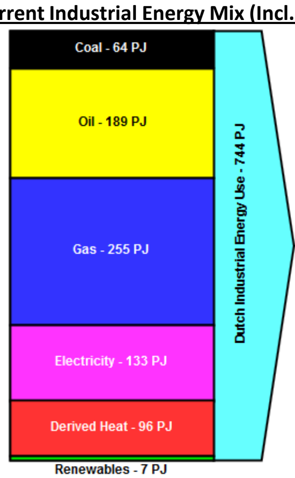
Dutch Industry

- Final energy consumption
  - 597 PJ
- Energy use dominated by selected sectors
  - Chemical and petrochemical
  - Iron and steel
  - Food and beverage
- Refinery sector is the additional piece of the pie
  - Similar processes to the chemical sector
- Total combined energy consumption
  - 744 PJ

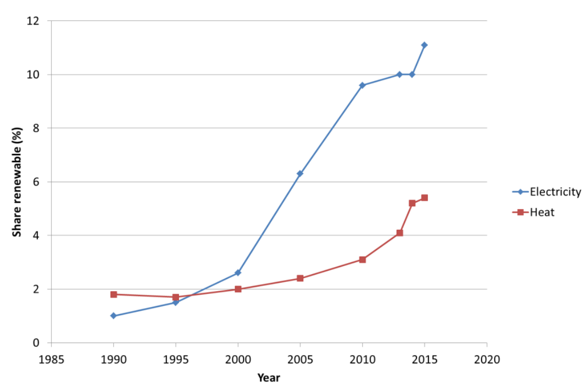


Transitioning to Sustainable Energy Sources

Current Industrial Energy Mix (Incl. Refinery)



Excluding feedstock

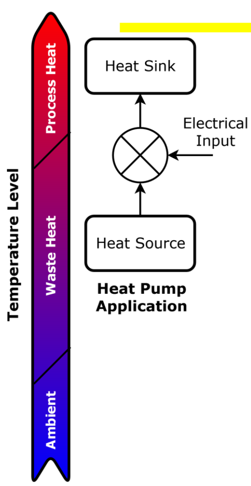


- Share of renewables in electricity system growing at greater rate than heating system
- Increasing shares of renewable electricity enable alternate heating technologies

Utilising Waste Heat in Industry

- Heat is the primary driver for a number of industrial processes
  - Low temperature after use in the process → heat is discarded to ambient
- Waste heat is an untapped energy source
  - Recovery can lead to large reductions in primary energy consumption
- Technologies for waste heat recovery – Active or Passive:
  - Passive: Heat is reused directly in the process
  - Active: Heat is converted to a higher temperature or another form of energy (electricity, cold)
- Limits to the amount of passive heat recovery
  - Industrial processes designed for passive reuse of waste heat
  - Elaborate heat exchanger networks
- Integration of active technologies is essential to fully exploit the potential for waste heat in industry

Heat Pumps in Industrial Processes

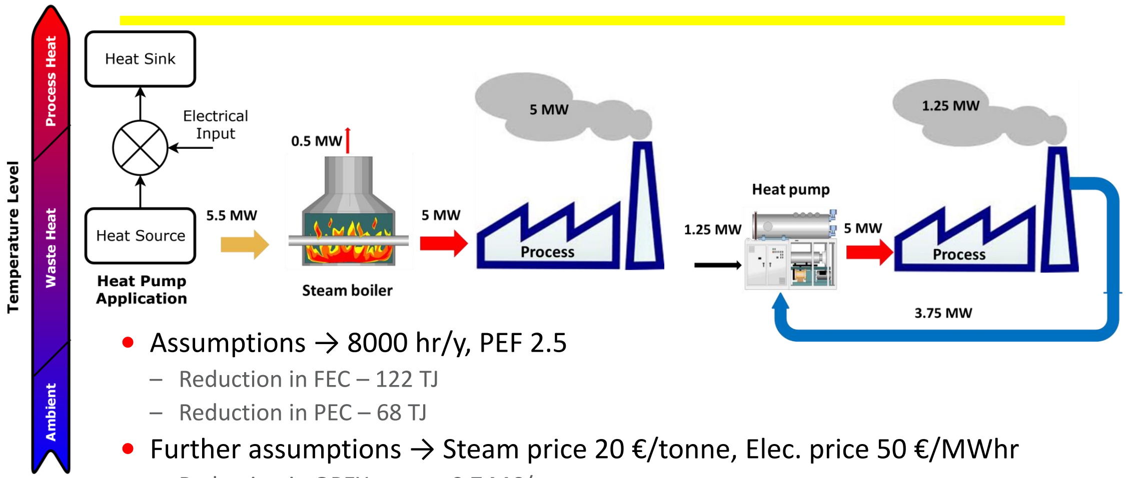


- Heat pump is an active technology able to upgrade the temperature of a waste heat source with electrical energy input
  - Performance limited by thermodynamic laws:

$$COP_{THEORETICAL} = \frac{T_{SINK}(K)}{T_{SINK}(K) - T_{SOURCE}(K)} = \frac{\dot{Q}_{SINK}}{\dot{W}_{IN}}$$

- Growing drivers for the implementation for heat pumps
  - Take advantage of renewable electricity and waste heat
  - Electrical input a factor of 2 – 5 lower than process heat output
  - Falling CAPEX
  - Increases in technology development
  - Ability to operate a high temperatures
  - Low payback times

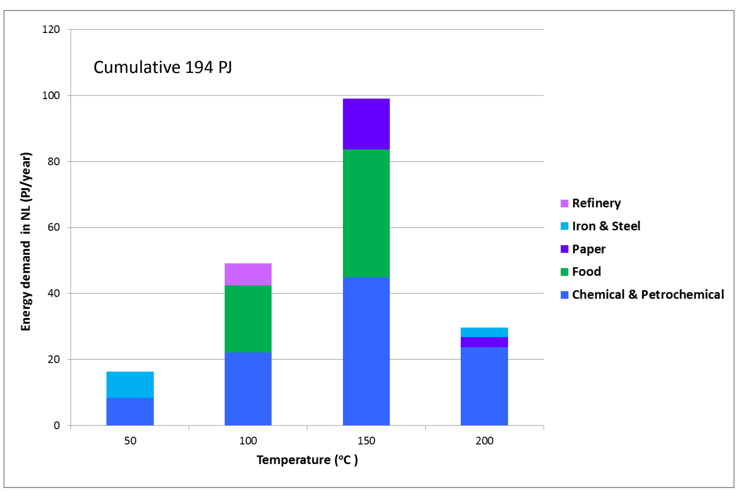
Heat Pump in Industrial Process



- Assumptions → 8000 hr/y, PEF 2.5
  - Reduction in FEC – 122 TJ
  - Reduction in PEC – 68 TJ
- Further assumptions → Steam price 20 €/tonne, Elec. price 50 €/MWhr
  - Reduction in OPEX costs – 0.7 M€/y

Process Heat Demand

Dutch Industry



- Heat pumps well suited to deliver process heat temperature below 200°C
  - Paper and pulp industry (25 PJ)
  - Food and beverage industry (83 PJ)
  - Chemical industry (282 PJ)
  - Refinery industry (147 PJ)
- Focus on these sectors within market studies
  - 72% of the industrial energy usage
  - Heat <200°C accounts for approximately 194 PJ
  - 36% of energy consumption in these sectors, 26% of total industrial consumption

Determining the Heat Pump Market
Methodology

ECN

- Bottom up approach for determining the heat pump market
- Focus on sectors which have high heating requirements at T < 200°C
- Collate generalized information from processes within these industries
  - Partial process heat and waste heat information
    - Temperature levels
    - Heat quantities
    - Media contained
  - Focus on heat streams suitable for heat pump utilization
  - Determine typical production rates and operating hours for processes
- Couple with production statistics from PRODCOM or industry bodies
- Verification utilizing top down approach
  - Energy usage statistics - EUROSTAT

Case Study – Heat Pump Assisted Distillation Column

ECN

- Production of Styrene through the dehydrogenation of ethylbenzene
  - Energy usage of approx. 11 PJ in NL

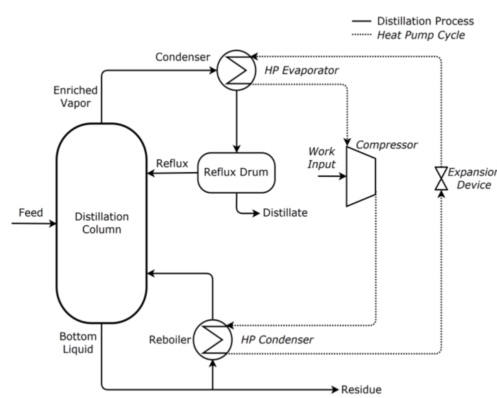
Reboiler Temperature	102°C
Condenser Temperature	45°C
Pinch Temperature	90°C
Reboiler Duty	2.2 GJ/tonne
Condenser Duty	1.7 GJ/tonne
Typical Plant Capacity	200 kT/a
Columns in NL	5

- Calculation of the thermal performance through
  - Estimation based on Carnot limitations

$$COP_{THEORETICAL} = 0.5\frac{T_{SINK}(K)}{T_{SINK}(K) - T_{SOURCE}(K)} = \frac{\dot{Q}_{SINK}}{\dot{W}_{IN}}$$

COP	Reduction in FEC (PJ)	Reduction in PEC (PJ)
3.3	1.62	**0.56**

  - Total in database - 57 distillation columns in chemical industry covering manufacture of 19 chemical products



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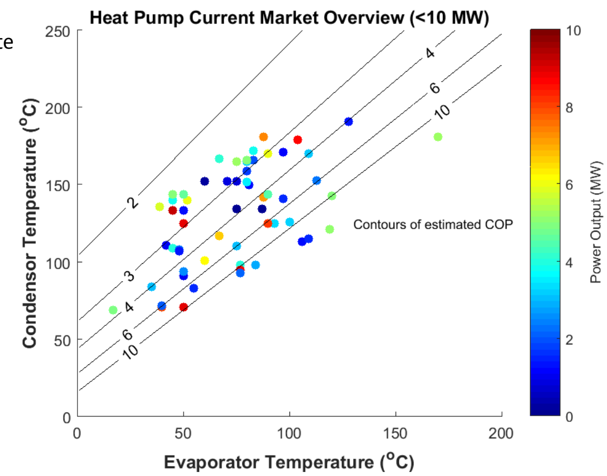
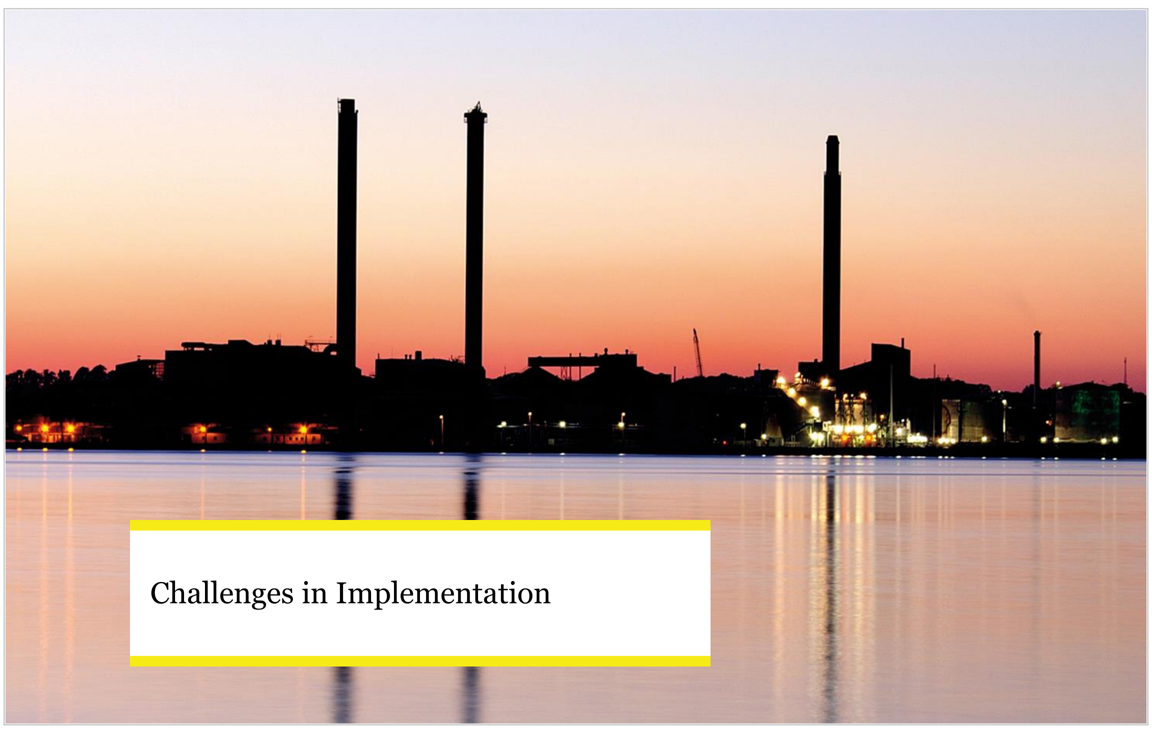
NL Heat Pump Market Overview

- Overview of the NL industrial heat pump market can be achieved through use waste heat and process heat signatures and quantities
- Key parameters:
  - HP evaporator (source) temperature
  - HP condenser (sink) temperature
  - HP thermal output power
- Key figures:
  - Total cumulative potential:
    2.4 GW
  - Number of individual applications:
    108
  - Total possible heat pump installations:
    340
  - Average condenser power:
    7.0 MW
  - Reduction in FEC/PEC:
    45 PJ / 15 PJ





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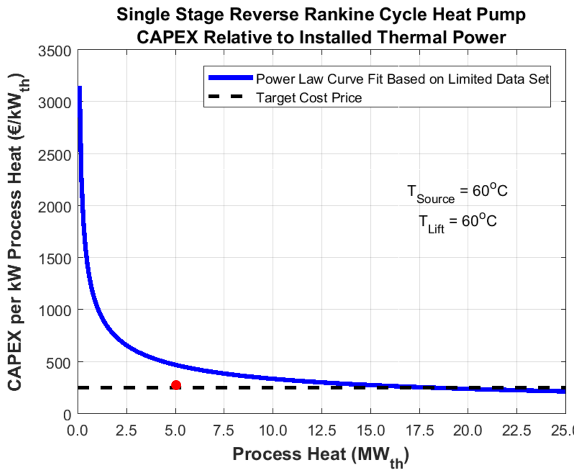
Challenging Economics

- Low cost of energy as well as process utility equipment makes economics for heat pumps challenging
  - Cost target of <200 €/kW_{th} for heat pumps to be competitive
- Previous example:
  - 5 MW_{th}
  - Cost saving 0.7 M€/year
  - Payback time of 3 years → CAPEX = 210 €/kW_{th}
- Differing temperature conditions and thermal powers lead to differing business cases
  - Average condenser power of 7 MW
  - Higher frequency of occurrences of lower power machines → More challenging economics
- What about integration costs?
  - Limited electrical infrastructure on-site
  - No standard method for integration



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Other Challenges

- Perceived risks as emerging technology
- Coupling to existing heat integrated plants
- Conservative energy efficiency targets
  - Limited subsidies for energy efficiency compared to renewable energy
  - Focus on process equipment or process techniques
- Energy is not the core business
  - But… changing due to customer demands
- Competing technological options
  - Government intervention

Summary

- Large industrial sector in the Netherlands
  - Energy use dominated by chemical, iron and steel, food and beverage and refinery sectors
- Growing driver for heat pumps in industry
  - Take advantage of renewable electricity generation and waste heat from processes
  - Suitable for delivering process heat temperatures up to 200°C
- Utilized a bottom up approach to determine the industrial heat pump market in NL
  - Potential 2.4 GW installed capacity over 340 installations
- Industrial heat pumps face a number of challenges preventing implementation
  - High capital costs combined with low energy prices
  - Perceived technology risk and conservative energy efficiency targets

Contact

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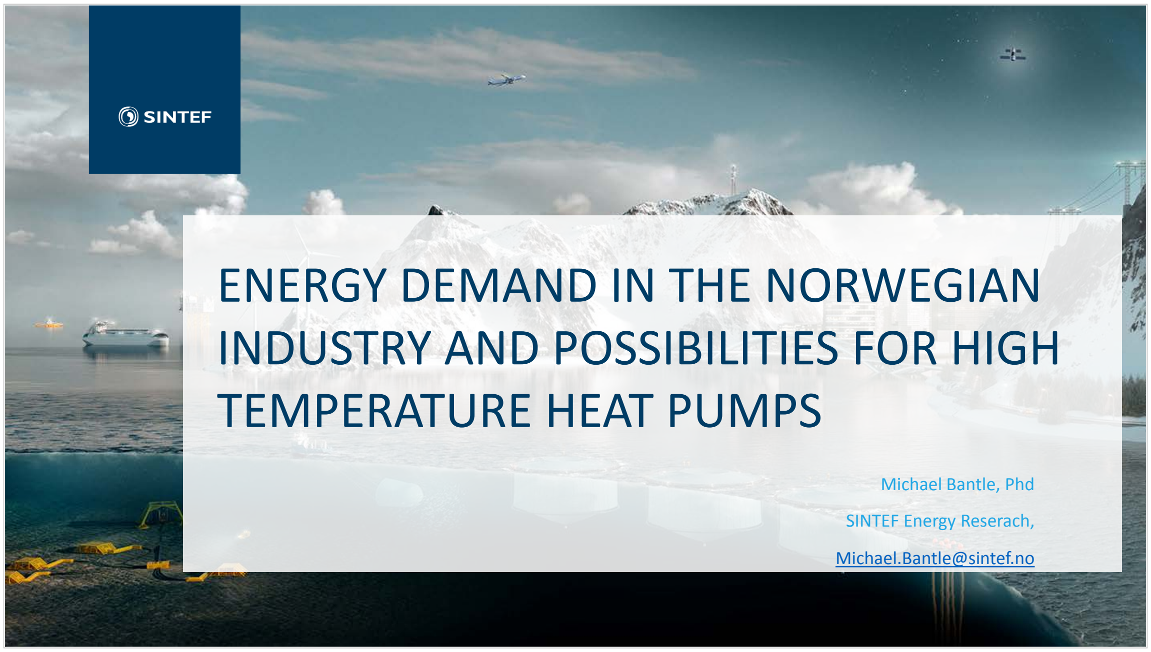
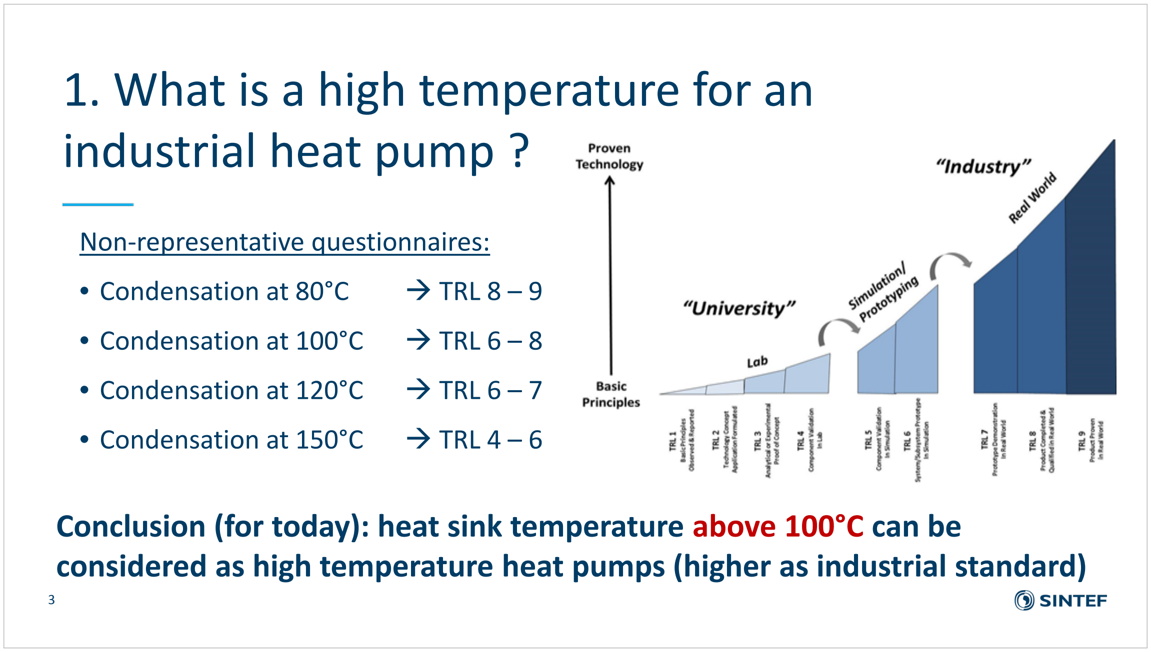
1755 ZG, Petten,
The Netherlands

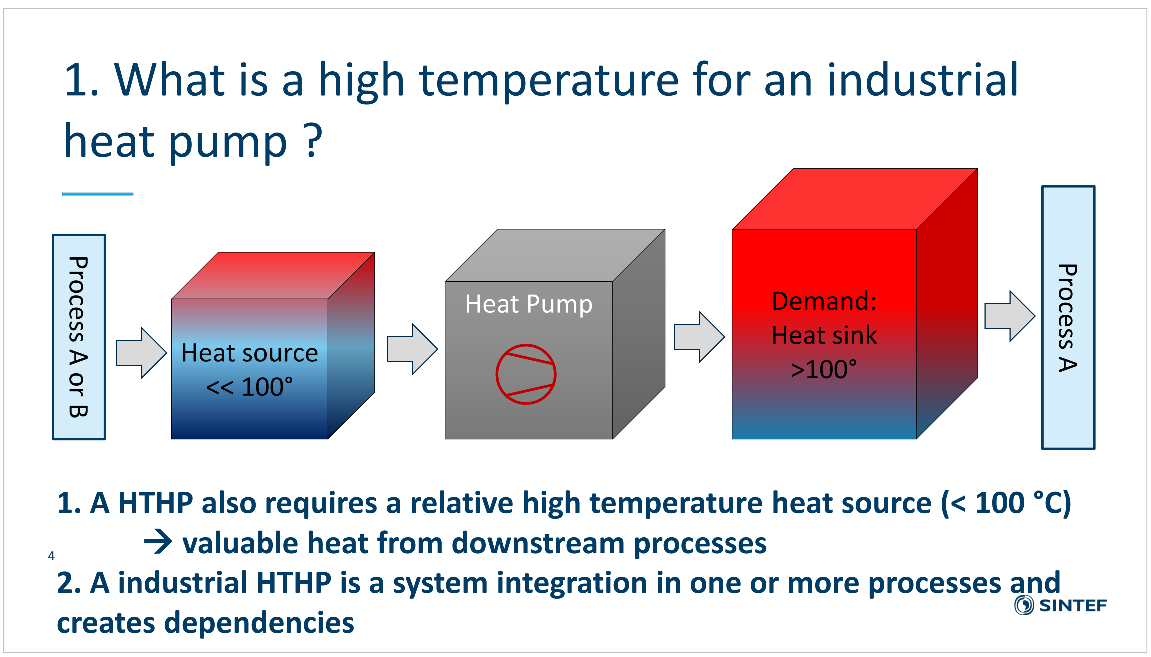


Outline

1. What is high temperature for a heat pump?
2. Energy demand in Norway
3. Excess heat inventory in Norway
4. Processes suited for HTHP
5. Return of Investment
6. Conclusions

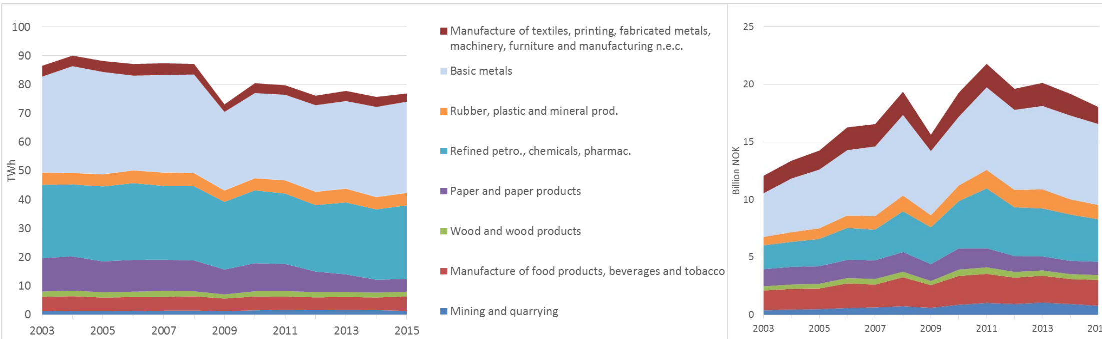
2 SINTEF


1. What is a high temperature for an industrial heat pump ?
Non-representative questionnaires:
• Condensation at 80°C → TRL 8 – 9
• Condensation at 100°C → TRL 6 – 8
• Condensation at 120°C → TRL 6 – 7
• Condensation at 150°C → TRL 4 – 6
Proven Technology
Basic Principles
"University"
Lab
Simulation/ Prototyping
"Industry"
Real World
Conclusion (for today): heat sink temperature above 100°C can be considered as high temperature heat pumps (higher as industrial standard)
3
SINTEF


1. What is a high temperature for an industrial heat pump ?
Process A or B
Heat source
<< 100°
Heat Pump
Demand:
Heat sink
>100°
Process A
1. A HTHP also requires a relative high temperature heat source (< 100 °C)
→ valuable heat from downstream processes
4
2. A industrial HTHP is a system integration in one or more processes and creates dependencies
SINTEF

2. Energy Demand in Norway

Overall **energy use and cost** for Norwegian industry



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SINTEF

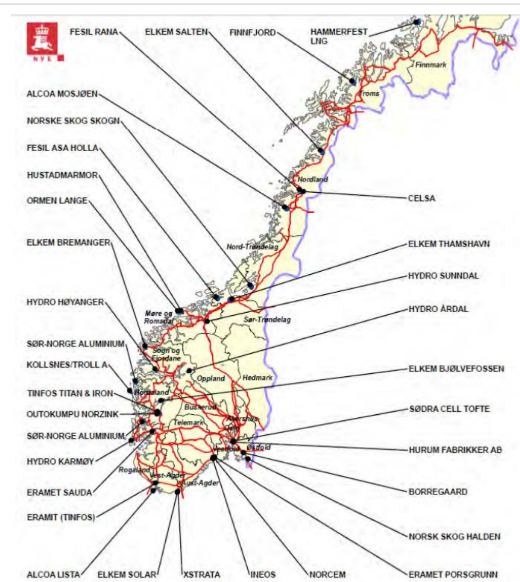
2. Energy Demand in Norway

Industry locations well distributed all over Norway

Industry often located in places without high external heat demand

Location and name of the largest energy-intensive industries in Norway per 2012

(Ref: Energiintensiv industri - En beskrivelse og økonomisk analyse av energiintensiv industri i Norge. NVE - Norges vassdrags- og energidirektorat; 2013)



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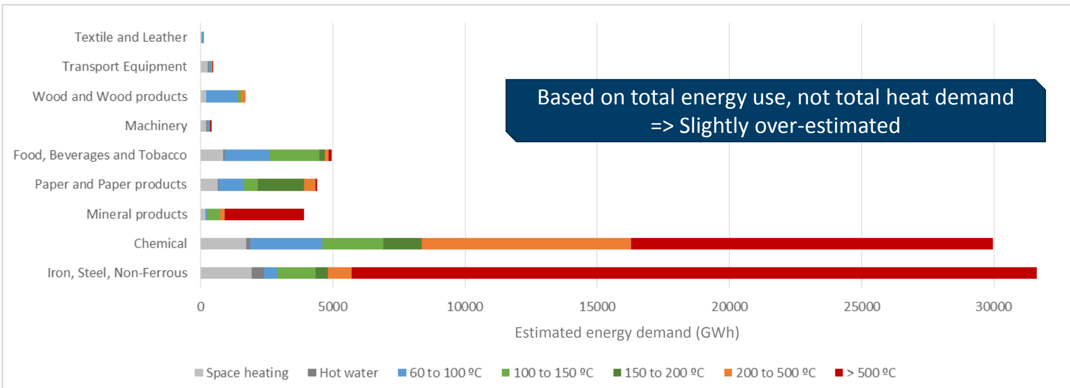
2. Energy Demand in Norway



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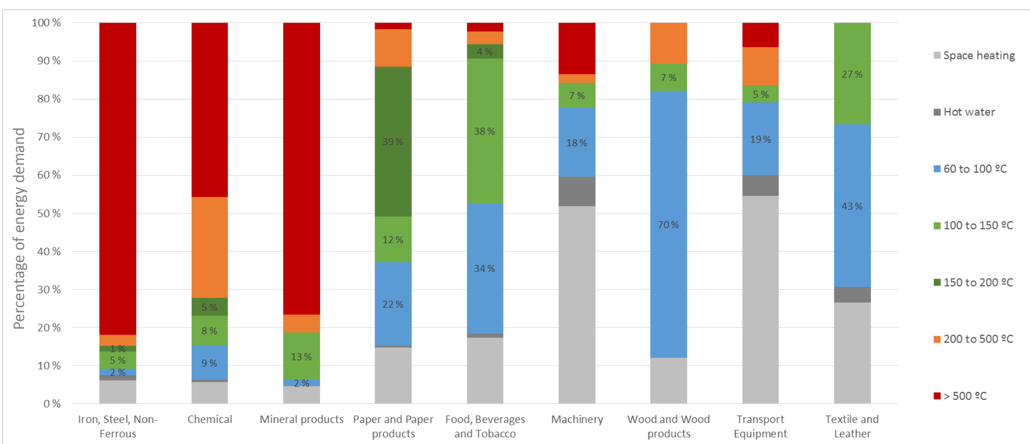
2. Energy Demand in Norway



8

***Estimates** based on Lauterbach et al. The potential of solar heat for industrial processes in Germany. Renewable and Sustainable Energy Reviews. 2012;16(7):5121-5130*

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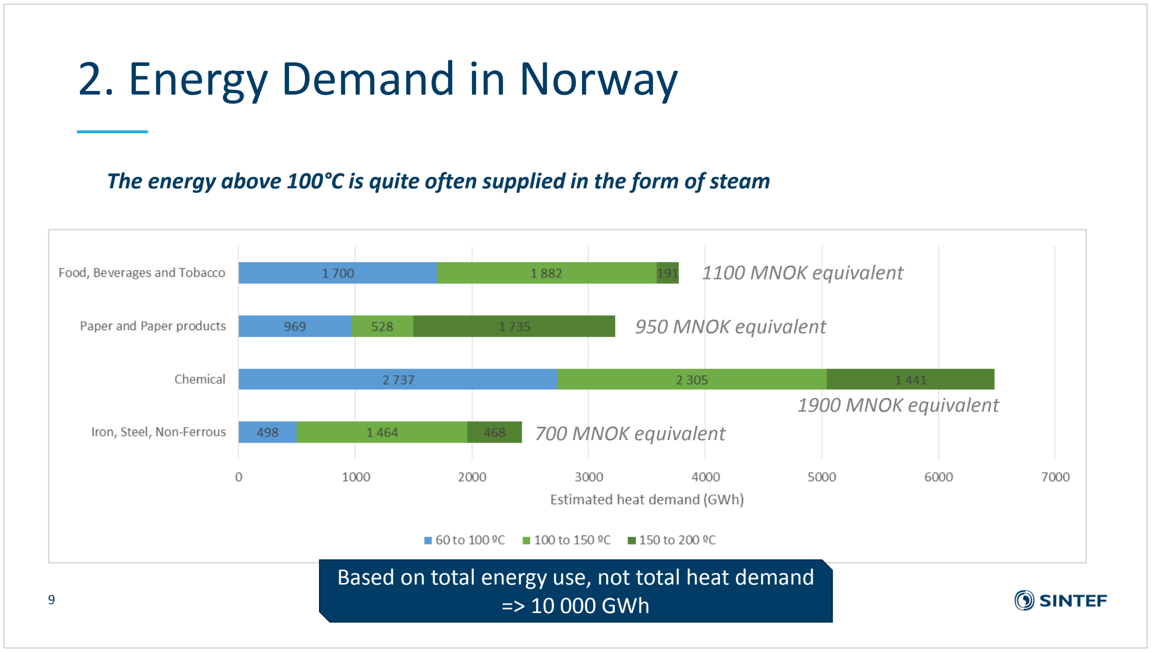
2. Energy Demand in Norway
The energy above 100°C is quite often supplied in the form of steam
Food, Beverages and Tobacco
1 700
1 882
191
1100 MNOK equivalent
Paper and Paper products
969
528
1 735
950 MNOK equivalent
Chemical
2 737
2 305
1 441
1900 MNOK equivalent
Iron, Steel, Non-Ferrous
498
1 464
468
700 MNOK equivalent
0 1000 2000 3000 4000 5000 6000 7000
Estimated heat demand (GWh)
60 to 100 ºC
100 to 150 ºC
150 to 200 ºC
Based on total energy use, not total heat demand
=> 10 000 GWh
9
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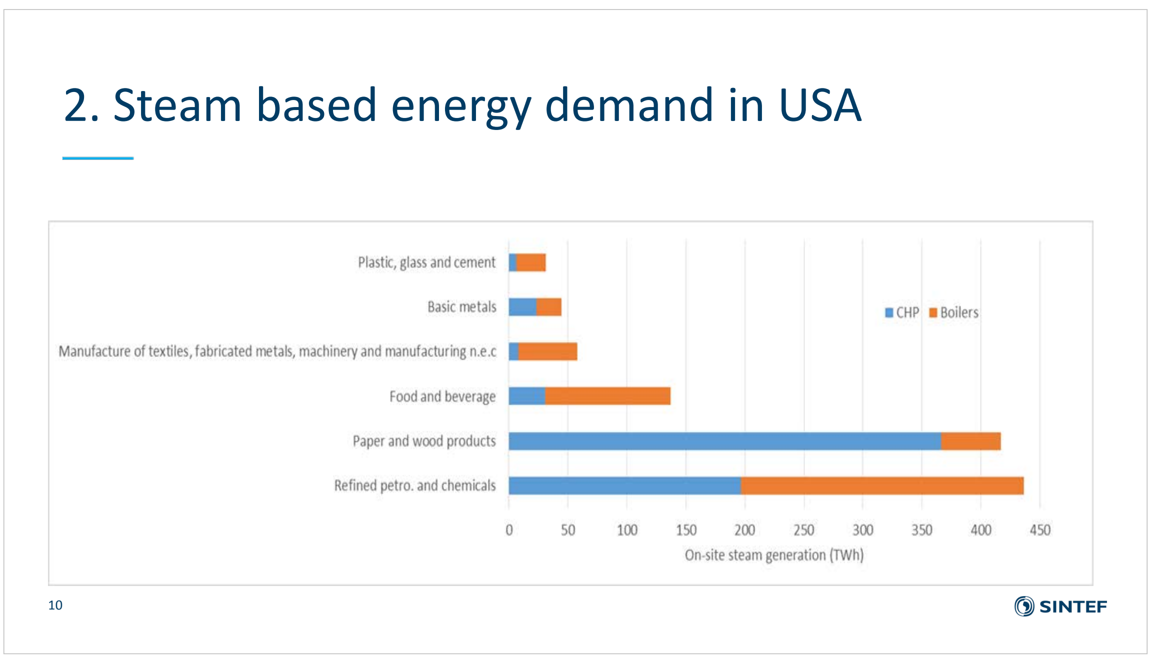
2. Steam based energy demand in USA
Plastic, glass and cement
Basic metals
Manufacture of textiles, fabricated metals, machinery and manufacturing n.e.c
Food and beverage
Paper and wood products
Refined petro. and chemicals
CHP
Boilers
0 50 100 150 200 250 300 350 400 450
On-site steam generation (TWh)
10
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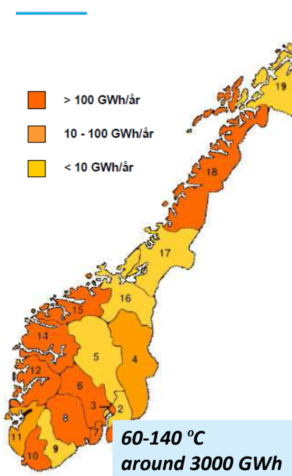
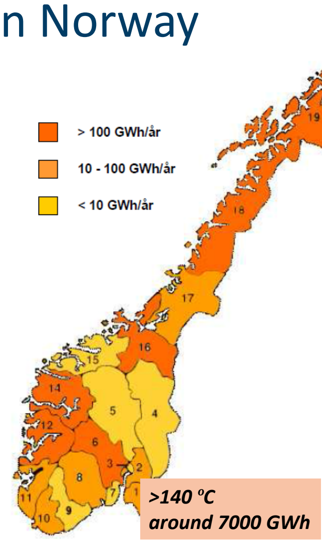
3. Excess heat inventory in Norway



Nr	Fylke	Kilder	GWh
1	Østfold		399,4
2	Akershus		7,5
3	Oslo		130,0
4	Hedmark		11,0
5	Oppland		8,0
6	Buskerud		510,0
7	Vestfold		175,0
8	Telemark		262,0
9	Aust-Agder		
10	Vest-Agder		153,4
11	Rogaland		11,5
12	Hordaland		600,0
14	Sogn og Fjordane		243,0
15	Møre og Romsdal		205,0
16	Sør-Trøndelag		7,0
17	Nord-Trøndelag		
18	Nordland		418,4
19	Troms		
20	Finnmark		
SUM		36	3141,2



Nr	Fylke	Kilder	GWh
1	Østfold		36,1
2	Akershus		70,0
3	Oslo		
4	Hedmark		
5	Oppland		
6	Buskerud		112,0
7	Vestfold		
8	Telemark		748,0
9	Aust-Agder		
10	Vest-Agder		25,8
11	Rogaland		66,0
12	Hordaland		625,0
14	Sogn og Fjordane		408,0
15	Møre og Romsdal		1,0
16	Sør-Trøndelag		743,0
17	Nord-Trøndelag		32,0
18	Nordland		1456,4
19	Troms		700,0
20	Finnmark		2000,1
SUM		38	7023,3

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Ref: ENOVA / Norsk Energi / NEPAS, Utnyttelse av spillvarme fra norsk industry. 2009

3. Excess heat inventory in Norway

From reporting industries only	Reported energy use (TWh/year)	Reported waste heat	Waste heat as steam	Waste heat as steam (GWh/year)	Waste heat as steam vs. energy use
Manufacture of food products, beverages	0.5	14.4 %	18 %	13	2.6 %
Wood, wood products and paper products	11.2	44.2 %	4 %	198	1.8 %
Cement and building block processing	1.9	45.4 %	0 %	0	0.0 %
Chemistry*	2	158.1 %	6 %	190	9.5 %
Aluminium	18.5	12.0 %	0 %	0	0.0 %
Basic metals	8.3	57.8 %	3 %	144	1.7 %

Based on an average steam price of 0.29 NOK/kWh (SSB, 2008) and the total reported waste heat as steam (545 GWh in 2008)

- Reported waste heat as **steam** represents **a loss of about 158 MNOK** for the 72 participating Norwegian industries.
- 158 MNOK is ~**10 % of the district heating sales** incomes in Norway in 2008

Generally underestimated:
- Not all Norwegian Industry
- Steam waste heat may be condensed and not reported

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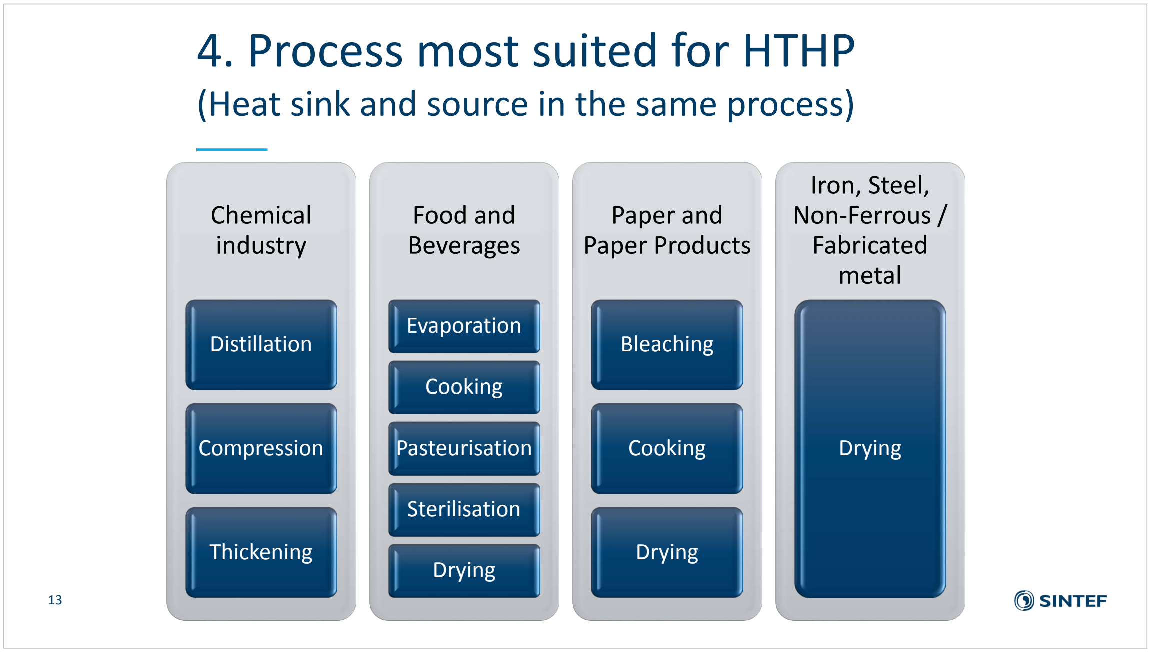
Ref: ENOVA / Norsk Energi / NEPAS, Utnyttelse av spillvarme fra norsk industry. 2009


4. Process most suited for HTHP
(Heat sink and source in the same process)
Chemical industry
Distillation
Compression
Thickening
Food and Beverages
Evaporation
Cooking
Pasteurisation
Sterilisation
Drying
Paper and Paper Products
Bleaching
Cooking
Drying
Iron, Steel, Non-Ferrous / Fabricated metal
Drying
13
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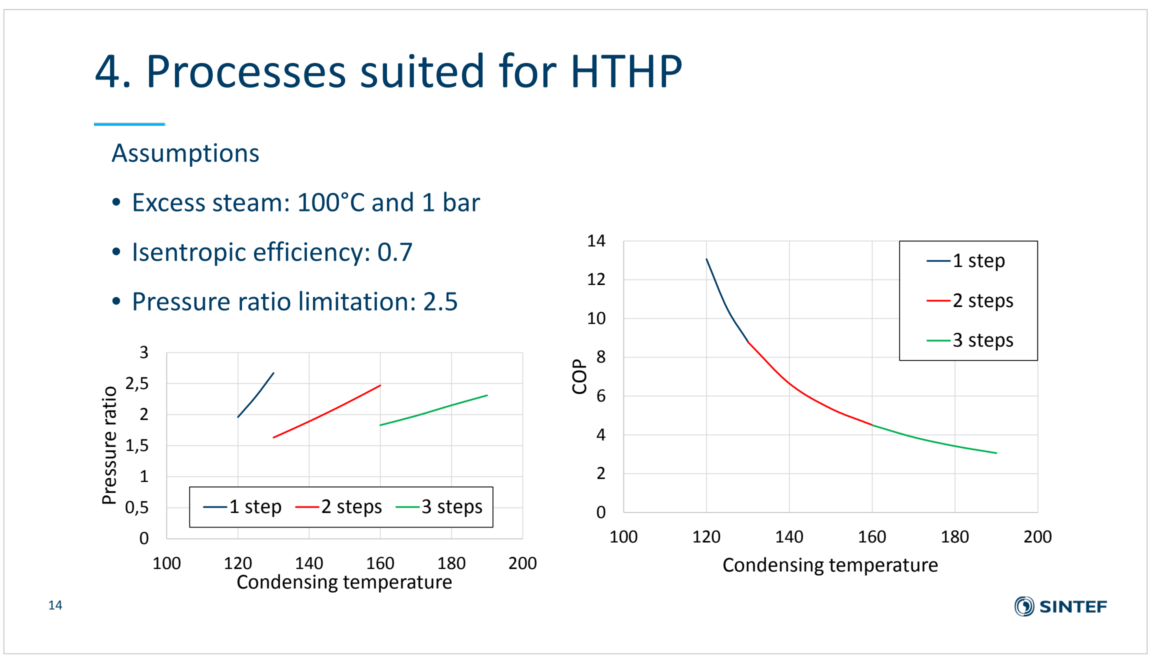
4. Processes suited for HTHP
Assumptions
• Excess steam: 100°C and 1 bar
• Isentropic efficiency: 0.7
• Pressure ratio limitation: 2.5
Pressure ratio
3
2,5
2
1,5
1
0,5
0
100
120
140
160
180
200
Condensing temperature
1 step
2 steps
3 steps
COP
14
12
10
8
6
4
2
0
100
120
140
160
180
200
Condensing temperature
1 step
2 steps
3 steps
14
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5. Return of Investment

		Case 1 Germany	Case 1 Norway	Case 2 Germany	Case 2 Norway
Heat Sink	°C	150	150	180	180
Heat Source	°C	110	110	110	110
Pressure Outlet	BarA	5.0	5.0	10.0	10.0
Steam Flow Rate (inlet)	kg/h	2,000	2,000	2,000	2,000
Electrical Power (system)	kW	304	304	461	461
Heat Recovered	kWh	1,430	1,430	1,552	1,552
COP	W/W	**4.70**	**4.70**	**3.36**	**3.36**
ROI		**+**	**++**	**-**	**+**

Case 1: MVR to 150°C
Case 2: MVR to 180°C

based on:
electricity
0.15€/kWh Germany,
0.07€/kWh Norway;

gas
0.04€/kWh Germany
0.06 €/kWh Norway

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5. Return of investment

	High Temperature Heat Pump	
Investment	**120 000 €**	**1 200 000 €**
Capacity	1300 kW	
steam flow	2000 kg / h	
COP (W/W)	4.25	
net savings	8.48 GWh	
Location	Germany	Norway
net savings**	52 275 €	482 885 €
ROI	**2.5 year**	**2.5 year**

**** based on: electricity 0.15€/kWh Germany, 0.07€/kWh Norway; gas 0.04€/kWh Germany 0.06 €/kWh Norway**

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Conclusion

1. High temperature heat pumps start at **heat sink temperature of 100°C**
   a. Technical limitations above 200°C
2. **Food, Paper, Chemical and Metal industry** have energy demands within this temperature limits
   a. Potential for Norway: estimated 10 TWh could be supplied by HTHP
   b. Reasonable to assume that 20% of this potential is feasible
3. Currently this **energy is primarily supplied by steam** (produced by fossil fuel)
   a. HTHP are benchmarked against **fossil fuel prices**
4. HTHP should supply heat sink in the form of steam
   a. Interesting technology for several industries which are using steam as energy carrier
5. Available **excess heat** is not completely monitored and "missing"
6. Identified some **"ideal" processes for HTHP** where heat sink and heat source are from one process
7. CAPEX and Return of investment give requirements for COP and costs:
   a. COP > 4 (→ challenging in many ways, depending on energy prices)
   b. Investment < 100-200 €/kW$_{installed}$ (at least have the potential at TRL 8-9)

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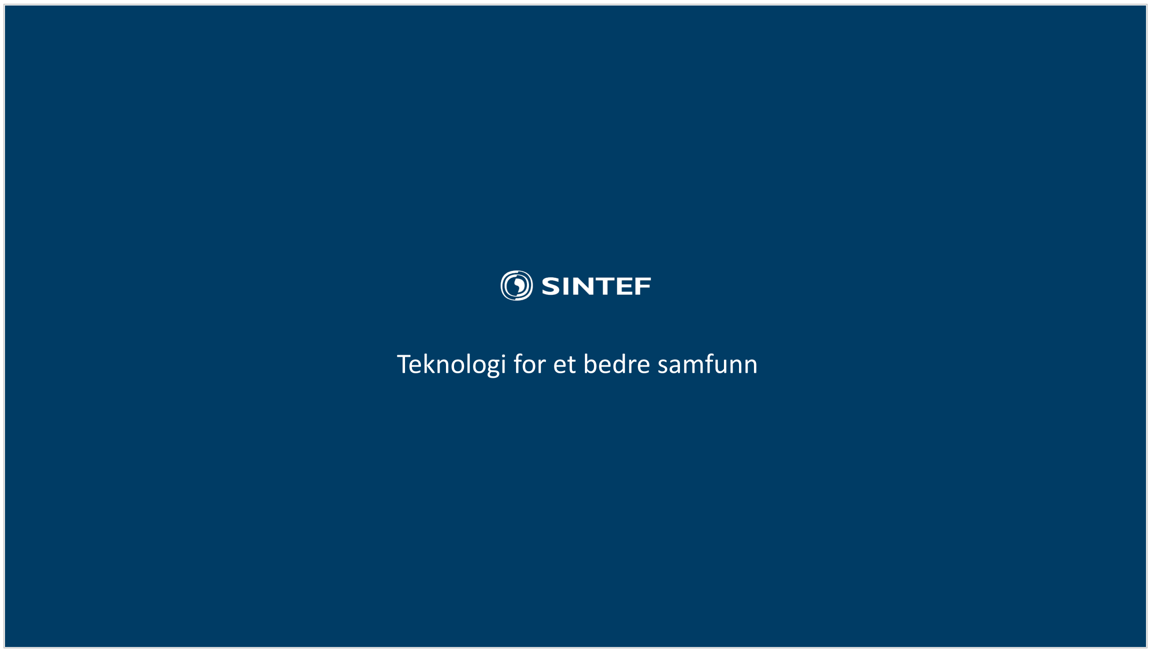
Thank you for your attention

18 SINTEF Energi AS, Michael Bantle SINTEF


SINTEF
Teknologi for et bedre samfunn

DTU

Industrial energy demand and excess heat in Denmark

Fabian Bühler, Benjamin Zühlsdorf and Brian Elmegaard

International Workshop on High Temperature Heat Pumps
September 2017 in Copenhagen, Denmark

DTU Mechanical Engineering
Department of Mechanical Engineering

DTU

Introduction

Motivation

Process heat requirements in the industry and availability of excess heat for the internal and external recovery (using heat pumps).

Approach

- Energy use in Denmark
- Energy saving obligations in Denmark

- Process heat demand in the manufacturing industry
- Profile and availability of industrial excess heat

- Some conclusions for (high temperature) heat pumps

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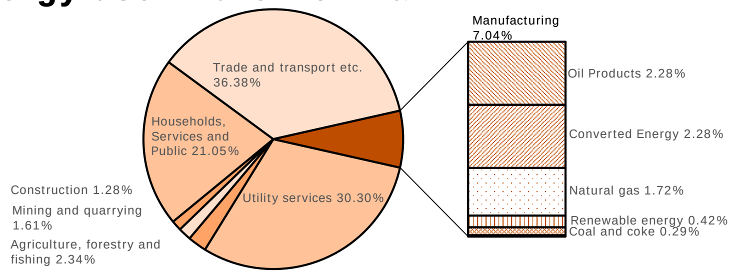
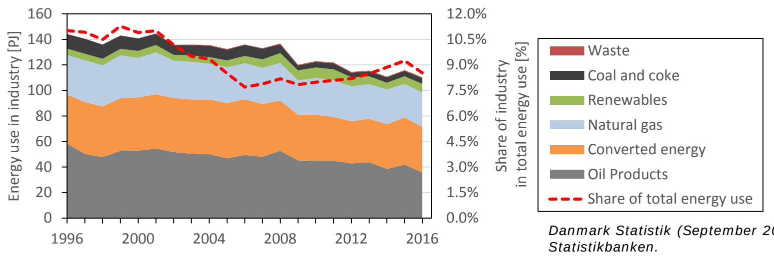
Energy use in the Denmark





Danmark Statistik (September 2017). Statistikbanken.

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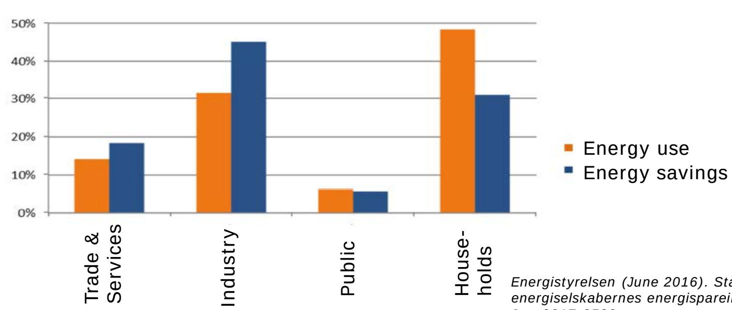
Energy Savings in Denmark

Since 2006:	Network and distribution companies have obligation to realize energy saving projects at end users
Last agreement:	10.1 PJ/year in the period 2016-2020
Since 2017:	Heat pumps for district heating included
In 2015:	43 % of the savings obtained in manufacturing industry



Energistyrelsen (June 2016). Status for energiselskabernes energispareindsats 2016. J.nr.2017-3529.

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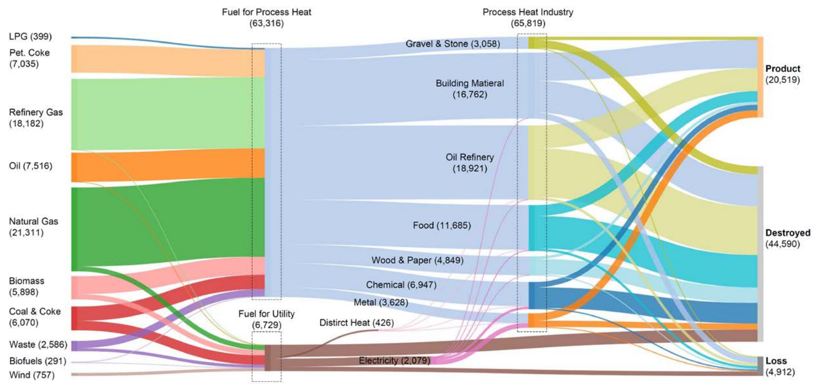
Energy and exergy analysis

Exergy flows [TJ] for thermal process heating in the Danish industry



Bühler F., Nguyen T-V., & Elmegaard B. (2016). Energy and Exergy Analyses of the Danish Industry Sector. Applied Energy, 184, 1447–1459.

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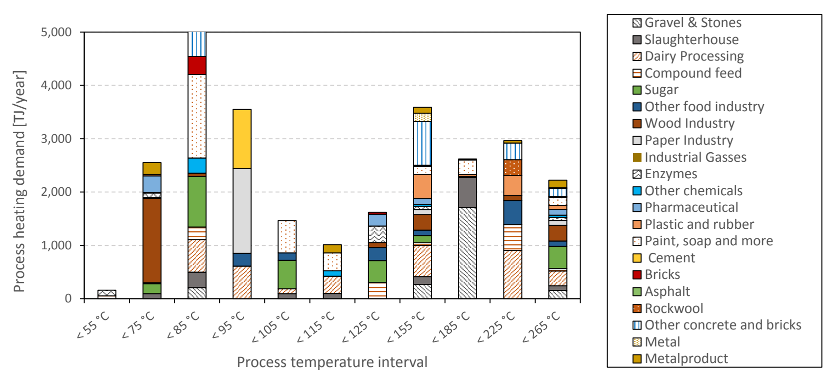
Heating demand in Denmark

- Total energy use 108.7 PJ/year
- District Heating Demand of 96 PJ/ year
  - 2.6 PJ covered by excess heat
  - > 4.9 PJ coverable by industrial excess heat



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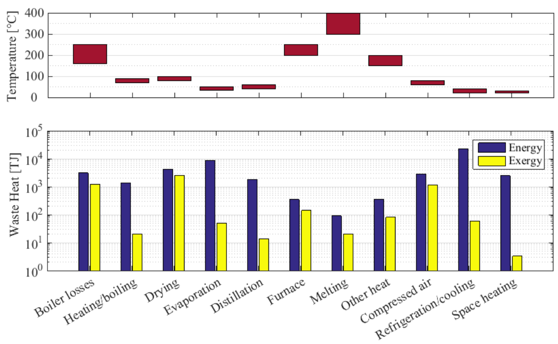
Industrial excess heat in Denmark

- Total of 212 PJ of excess heat per year
- 23% of excess heat from industry and 28% from utility
- Total excess heat in manufacturing industry 22.6 PJ/year



- Drying, Evaporation and refrigeration main excess heat sources
- Highest temperatures from furnaces, boilers and melting operation

Huang B., Bühler F., & Holm F.M. (2015). Industrial Energy Mapping: THERMCYC WP6. Technical University of Denmark.

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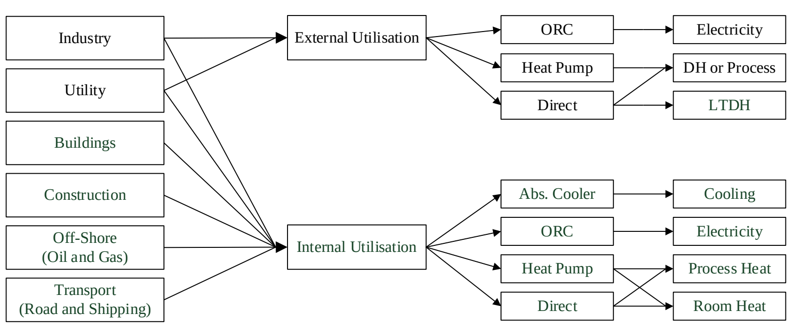
Evaluation of utilization pathways



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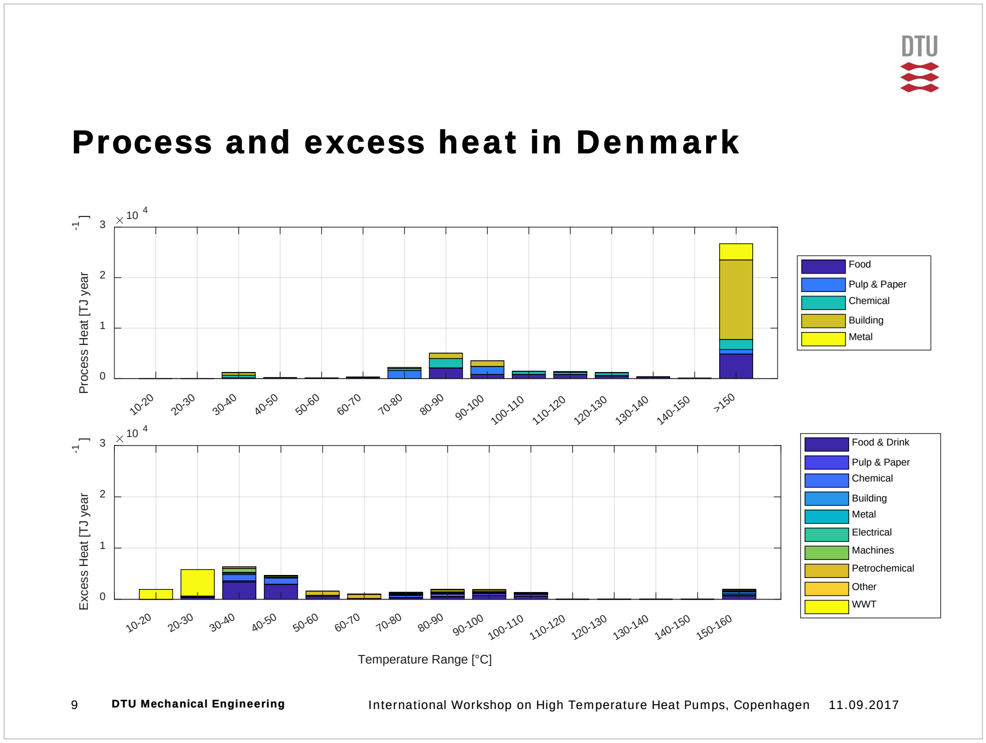
DTU
Process and excess heat in Denmark
Process Heat [TJ year -1]
× 10 4
3
2
1
0
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
100-110
110-120
120-130
130-140
140-150
>150
Food
Pulp & Paper
Chemical
Building
Metal
Excess Heat [TJ year -1]
× 10 4
3
2
1
0
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
100-110
110-120
120-130
130-140
140-150
150-160
Temperature Range [°C]
Food & Drink
Pulp & Paper
Chemical
Building
Metal
Electrical
Machines
Petrochemical
Other
WWT
9
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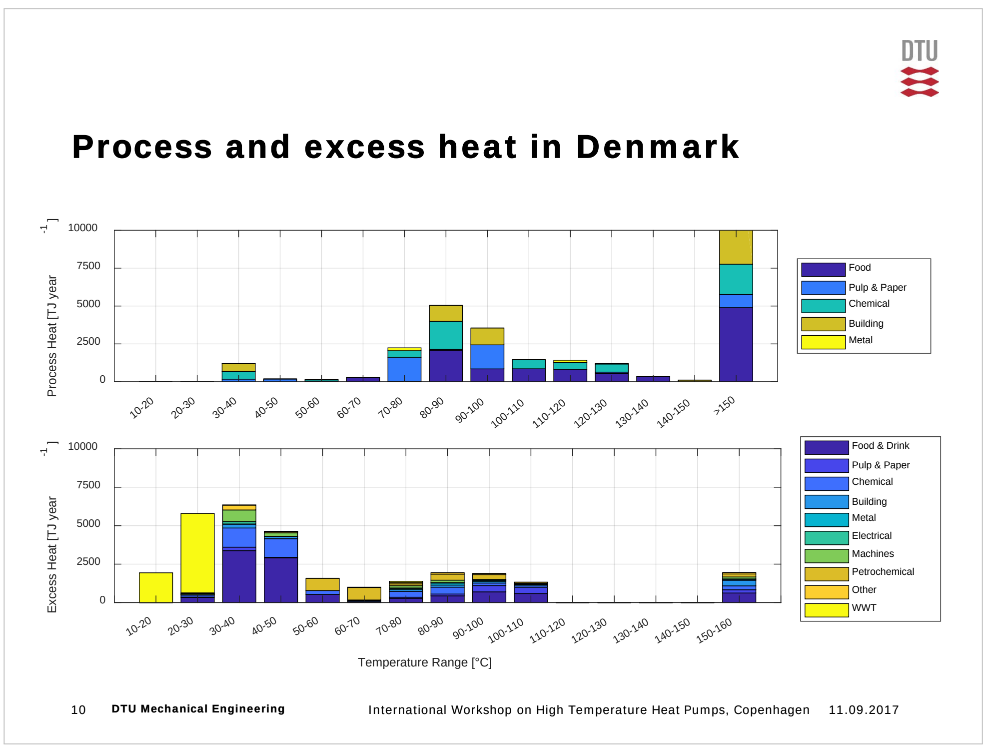
DTU
Process and excess heat in Denmark
Process Heat [TJ year -1]
10000
7500
5000
2500
0
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
100-110
110-120
120-130
130-140
140-150
>150
Food
Pulp & Paper
Chemical
Building
Metal
Excess Heat [TJ year -1]
10000
7500
5000
2500
0
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
100-110
110-120
120-130
130-140
140-150
150-160
Temperature Range [°C]
Food & Drink
Pulp & Paper
Chemical
Building
Metal
Electrical
Machines
Petrochemical
Other
WWT
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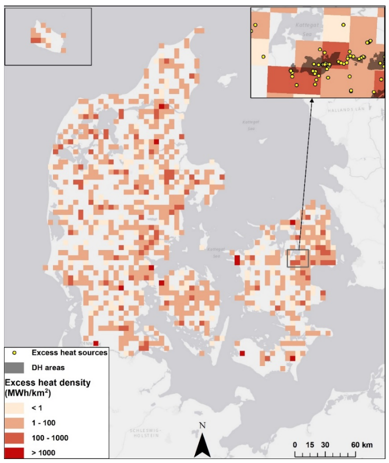
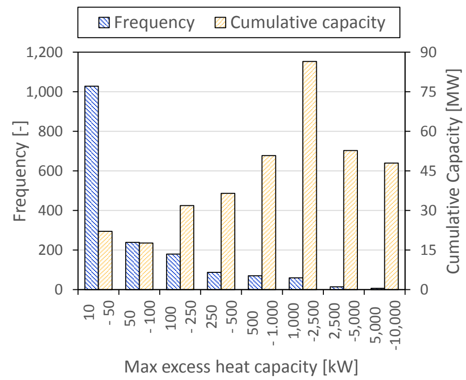
Spatial-analysis of excess heat



Bühler F., Petrovic S., Karlsson K.B. & Elmegaard B. (2017). Industrial excess heat for district heating in Denmark. Applied Energy. 205. 991-1001.

Spatial and temporal analysis of the 22 largest manufacturing industries with 2584 production units.



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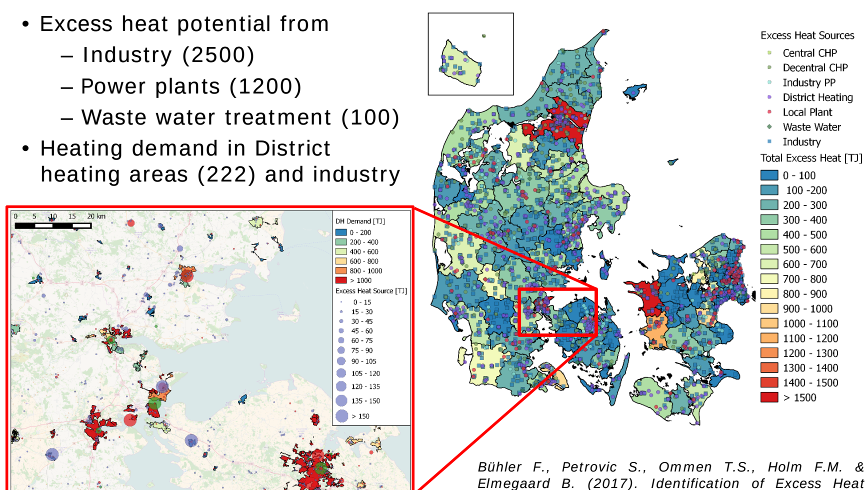
Identifying heating symbiosis

- Excess heat potential from
  - Industry (2500)
  - Power plants (1200)
  - Waste water treatment (100)
- Heating demand in District heating areas (222) and industry



Bühler F., Petrovic S., Ommen T.S., Holm F.M. & Elmegaard B. (2017). Identification of Excess Heat Utilisation Potential using GIS: Analysis of Case Studies for Denmark. In Pro. of ECOS 2017, San Diego USA.

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High Temperature Heat Pumps

Internal vs. external utilization

- Potential to use excess heat in district heating
- Internal recovery potential in industries requires more detailed site-specific process knowledge

Demand and Excess heat mapping

- Potential for heat pumps in district heating
- Temperature profiles of heating demand and excess heat indicate potential for HTHP
- Excess heat size on site level suggests large potential in HP 10- 50 kW

More research on potentials required

- Which part of heating demand is covered by steam/ water/ direct heat?
- Recovery potential in the different processes itself?

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Thank you for you attention!

Fabian Bühler
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DTU Mechanical Engineering

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2 Research and Development Projects

2.1 Review on high temperature heat pumps – Market overview and research status, Cordin Arpagaus (NTB Buch)

2.2 High temperature heat pump development at AIT, Michael Lauermann (AIT)

2.3 Generic fist assessment tool and high temperature heat pump development at DTI, Lars Reinholdt (DTI)

2.4 Development of a Propane-Butane cascade high temperature heat pump, Opeyemi Bamigbetan (NTNU)

2.5 Working fluids for high temperature heat pumps, Benjamin Zühlsdorf (DTU)

NTB Interstate University of Applied Sciences of Technology Buchs
University of Applied Sciences of Eastern Switzerland

IES INSTITUTE FOR ENERGY SYSTEMS

International Workshop on High Temperature Heat Pumps, Sept. 9, 2017, Kopenhagen

Review on High Temperature Heat Pumps – Market Overview and Research Status

Cordin ARPAGAUS[1], Fréderic BLESS[1], Jürg SCHIFFMANN[2], Stefan S. BERTSCH[1]

[1]NTB University of Applied Sciences of Technology Buchs, Switzerland
[2]Ecole Polytechnique Fédérale de Lausanne, Switzerland

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SCCER EFFICIENCY OF INDUSTRIAL PROCESSES

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Outline

1. **Market overview of commercially available industrial HTHP systems**
   - Cycles, refrigerants, application limits, efficiencies
2. **Research status**
   - Screening of research activity
   - Experimental and theoretical studies, cycles, refrigerants, supply temperatures, operating ranges
3. **Refrigerants**
   - Selection criteria, properties, GWP, price, efficiency, safety
4. **Conclusions**

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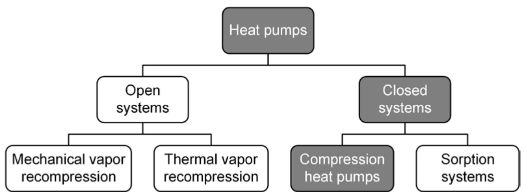
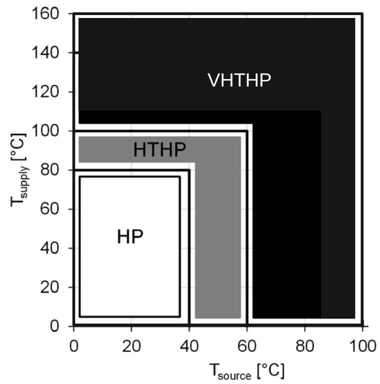
Classification of heat pumps (focus on compression heat pumps) Development of temperature levels



adapted from Nellissen and Wolf (2015)



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

adapted from Bobelin et al. (2012), IEA (2014), Jakobs and Laue (2015), Peureux et al. (2012, 2014)

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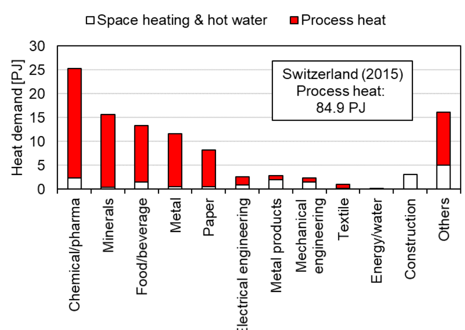
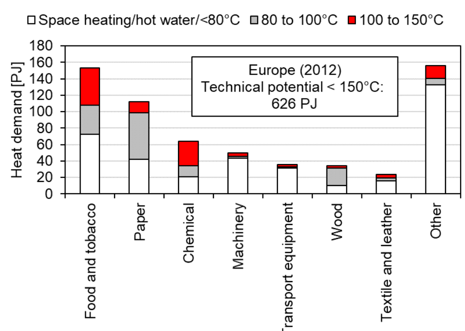
Potential for high temperture heat pumps – Process heat in industry

Theoretical potential for HTHPs in Switzerland



Data from BFE (2016), Pulfer and Spirig (2015)

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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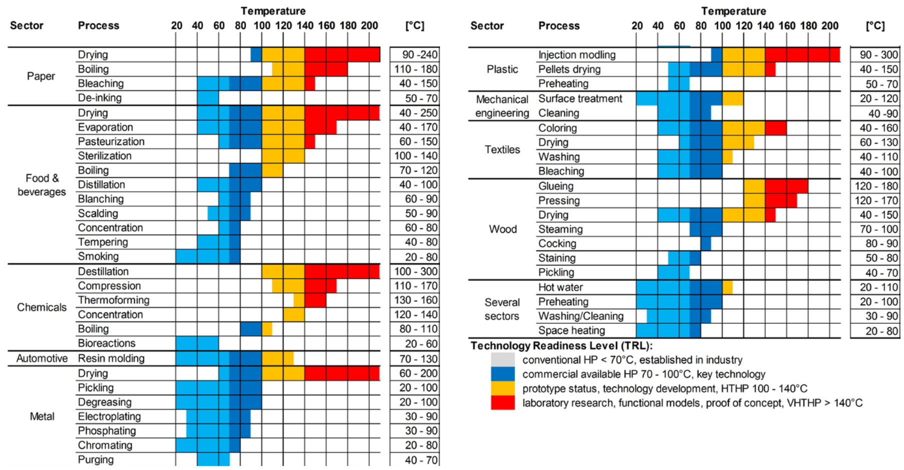
Overview of processes in different industrial sectors
Temperature levels and technology readiness level



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

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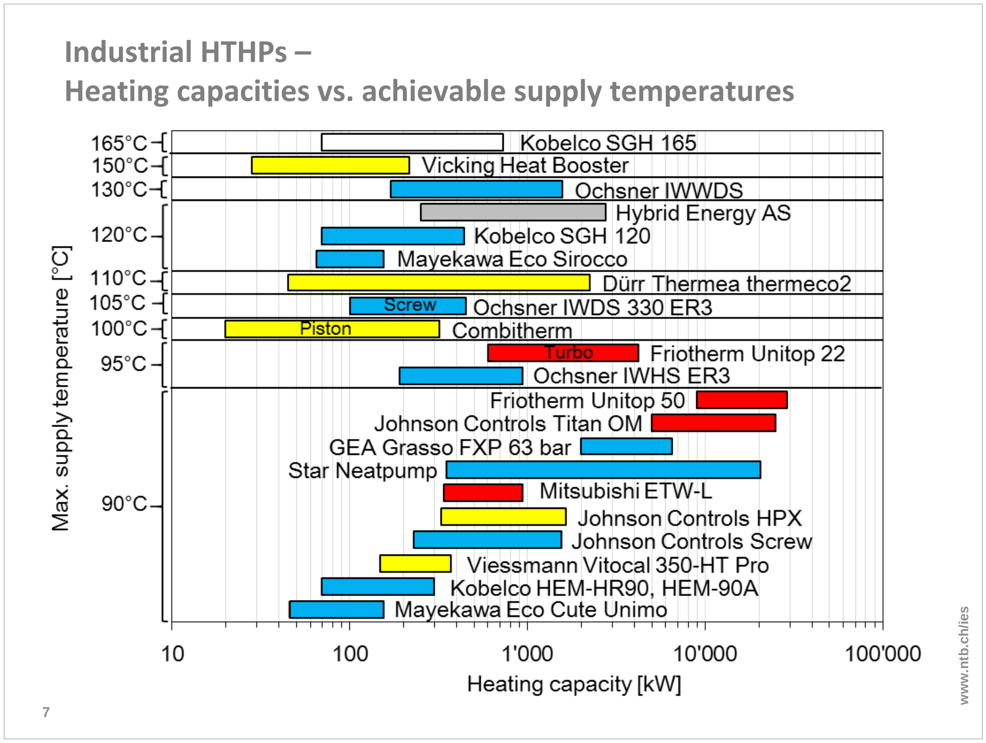
Selection of industrial HTHPs with supply temperatures > 90°C

Manufacturer	Product	Refrigerant	Max. supply temp.	Heating capacity	Compressor type
Kobelco (Steam Grow Heat Pump)	SGH 165 SGH 120 HEM-HR90, HEM-90A	R134a/R245fa R245fa R1r34a/R245fa	165°C 120°C 90°C	70 – 660 kW 70 – 370 kW 70 – 230 kW	Double screw
Vicking Heating Engines AS	HeatBooster	R1336mzz(Z) R245fa	150°C	28 – 188 kW	Piston
Ochsner	IWWDS IWDS 330 ER3 IWHS ER3	R134a/ÖKO1 (R245fa)	130°C 105°C 95°C	170 – 750 kW (twin unit 1.5 MW) 100 – 350 kW 190 – 750 kW	Screw
Hybrid Energy	Hybrid Heat Pump	R717 (NH_3)	120°C	0.25 – 2.5 MW	Piston
Mayekawa	Eco Sirocco Eco Cute Unimo	R744 (CO_2) R744 (CO_2)	120°C 90°C	65 – 90 kW 45 – 110 kW	Screw
Dürr Thermea	thermeco2	R744 (CO_2)	110°C	45 – 2'200 kW	Piston
Combitherm	Sonderanfertigung	R245fa	100°C	20 – 300 kW	Piston
Friotherm	Unitop 22 Unitop 50	R1234ze(E) R134a	95°C 90°C	0.6 – 3.6 MW 9 – 20 MW	Turbo (2-stage)
Star Refrigeration	Neatpump	R717 (NH_3)	90°C	0.35 – 15 MW	Screw
GEA Refrigeration	GEA Grasso FX P 63 bar	R717 (NH_3)	90°C	2 – 4.5 MW	Double screw
Johnson Controls	HeatPAC HPX HeatPAC Screw Titan OM	R717 (NH_3) R717 (NH_3) R134a	90°C 90°C 90°C	326 – 1'324 kW 230 – 1'315 kW 5 – 20 MW	Piston Screw Turbo
Mitsubishi	ETW-L	R134a	90°C	340 – 600 kW	Turbo (2-stage)
Viessmann	Vitocal 350-HT Pro	R1234ze(E)	90°C	148 – 223 kW	Piston (2-3 stages)

6


Industrial HTHPs –
Heating capacities vs. achievable supply temperatures
165°C
150°C
130°C
120°C
110°C
105°C
100°C
95°C
90°C
Kobelco SGH 165
Vicking Heat Booster
Ochsner IWWDS
Hybrid Energy AS
Kobelco SGH 120
Mayekawa Eco Sirocco
Dürr Thermea thermeco2
Screw
Ochsner IWDS 330 ER3
Piston
Combitherm
Turbo
Friotherm Unitop 22
Ochsner IWHS ER3
Friotherm Unitop 50
Johnson Controls Titan OM
GEA Grasso FXP 63 bar
Star Neatpump
Mitsubishi ETW-L
Johnson Controls HPX
Johnson Controls Screw
Viessmann Vitocal 350-HT Pro
Kobelco HEM-HR90, HEM-90A
Mayekawa Eco Cute Unimo
Max. supply temperature [°C]
10
100
1'000
10'000
100'000
Heating capacity [kW]
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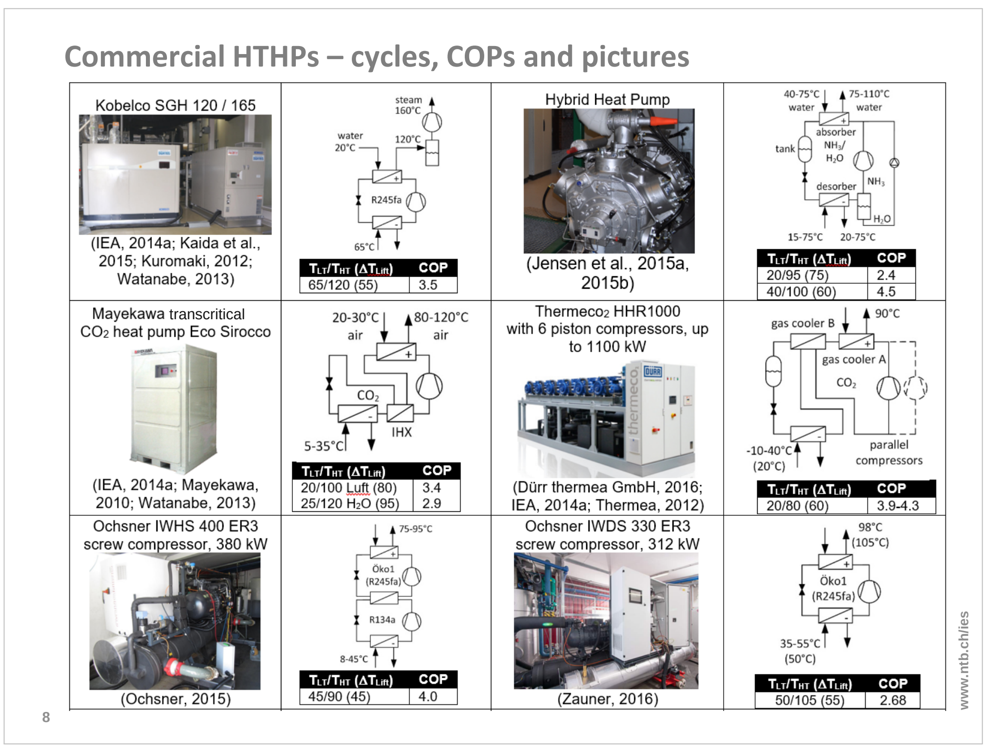
Commercial HTHPs – cycles, COPs and pictures
Kobelco SGH 120 / 165
(IEA, 2014a; Kaida et al., 2015; Kuromaki, 2012; Watanabe, 2013)
steam 160°C
water 20°C
120°C
R245fa
65°C
T_{LT}/T_{HT} (ΔT_{Lift}) COP
65/120 (55) 3.5
Hybrid Heat Pump
(Jensen et al., 2015a, 2015b)
40-75°C water
75-110°C water
absorber
NH_3/ H_2O
tank
desorber
NH_3
H_2O
15-75°C
20-75°C
T_{LT}/T_{HT} (ΔT_{Lift}) COP
20/95 (75) 2.4
40/100 (60) 4.5
Mayekawa transcritical CO_2 heat pump Eco Sirocco
(IEA, 2014a; Mayekawa, 2010; Watanabe, 2013)
20-30°C air
80-120°C air
CO_2
IHX
5-35°C
T_{LT}/T_{HT} (ΔT_{Lift}) COP
20/100 Luft (80) 3.4
25/120 H_2O (95) 2.9
Thermeco$_2$ HHR1000 with 6 piston compressors, up to 1100 kW
(Dürr thermea GmbH, 2016; IEA, 2014a; Thermea, 2012)
gas cooler B
90°C
gas cooler A
CO_2
-10-40°C (20°C)
parallel compressors
T_{LT}/T_{HT} (ΔT_{Lift}) COP
20/80 (60) 3.9-4.3
Ochsner IWHS 400 ER3 screw compressor, 380 kW
(Ochsner, 2015)
75-95°C
Öko1 (R245fa)
R134a
8-45°C
T_{LT}/T_{HT} (ΔT_{Lift}) COP
45/90 (45) 4.0
Ochsner IWDS 330 ER3 screw compressor, 312 kW
(Zauner, 2016)
98°C (105°C)
Öko1 (R245fa)
35-55°C (50°C)
T_{LT}/T_{HT} (ΔT_{Lift}) COP
50/105 (55) 2.68
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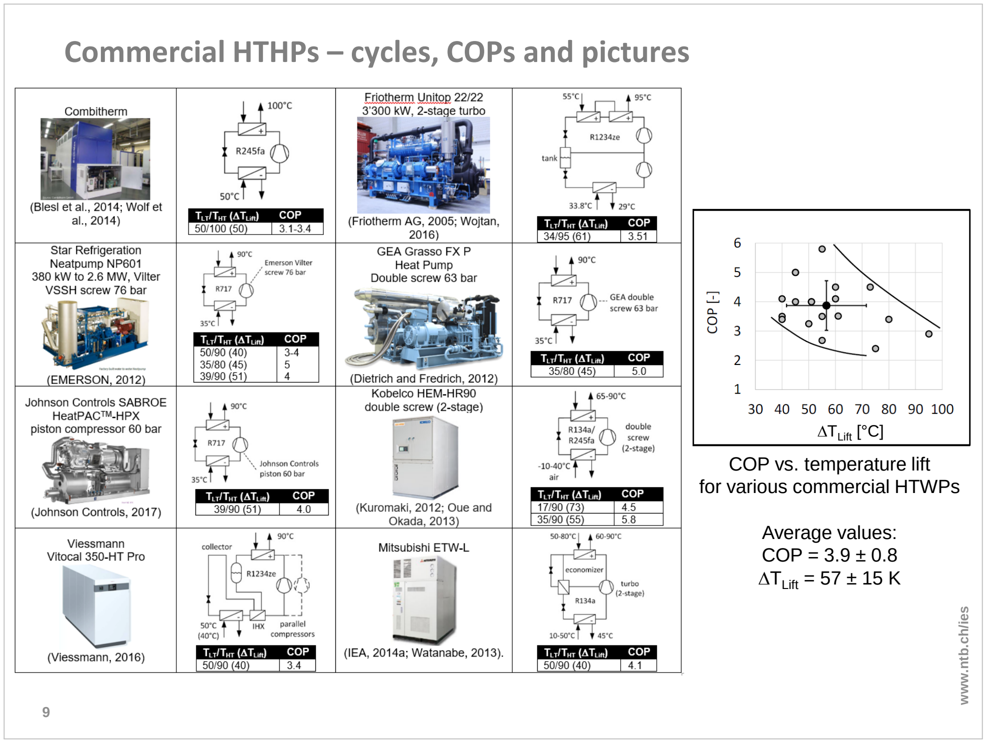
Commercial HTHPs – cycles, COPs and pictures
Combitherm
(Blesl et al., 2014; Wolf et al., 2014)
100°C
R245fa
50°C
T_{LT}/T_{HT} (ΔT_{Lift}) COP
50/100 (50) 3.1-3.4
Friotherm Unitop 22/22
3'300 kW, 2-stage turbo
(Friotherm AG, 2005; Wojtan, 2016)
55°C 95°C
R1234ze
tank
33.8°C 29°C
34/95 (61) 3.51
Star Refrigeration
Neatpump NP601
380 kW to 2.6 MW, Vilter
VSSH screw 76 bar
(EMERSON, 2012)
90°C
Emerson Vilter screw 76 bar
R717
35°C
50/90 (40) 3-4
35/80 (45) 5
39/90 (51) 4
GEA Grasso FX P
Heat Pump
Double screw 63 bar
(Dietrich and Fredrich, 2012)
90°C
R717
GEA double screw 63 bar
35°C
35/80 (45) 5.0
Johnson Controls SABROE
HeatPAC™-HPX
piston compressor 60 bar
(Johnson Controls, 2017)
90°C
R717
Johnson Controls piston 60 bar
35°C
39/90 (51) 4.0
Kobelco HEM-HR90
double screw (2-stage)
(Kuromaki, 2012; Oue and Okada, 2013)
65-90°C
R134a/ R245fa
double screw (2-stage)
-10-40°C air
17/90 (73) 4.5
35/90 (55) 5.8
Viessmann
Vitocal 350-HT Pro
(Viessmann, 2016)
collector
90°C
R1234ze
50°C (40°C)
IHX
parallel compressors
50/90 (40) 3.4
Mitsubishi ETW-L
(IEA, 2014a; Watanabe, 2013).
50-80°C 60-90°C
economizer
turbo (2-stage)
R134a
10-50°C 45°C
50/90 (40) 4.1
COP [-]
ΔT_{Lift} [°C]
COP vs. temperature lift
for various commercial HTWPs
Average values:
COP = 3.9 ± 0.8
ΔT_{Lift} = 57 ± 15 K
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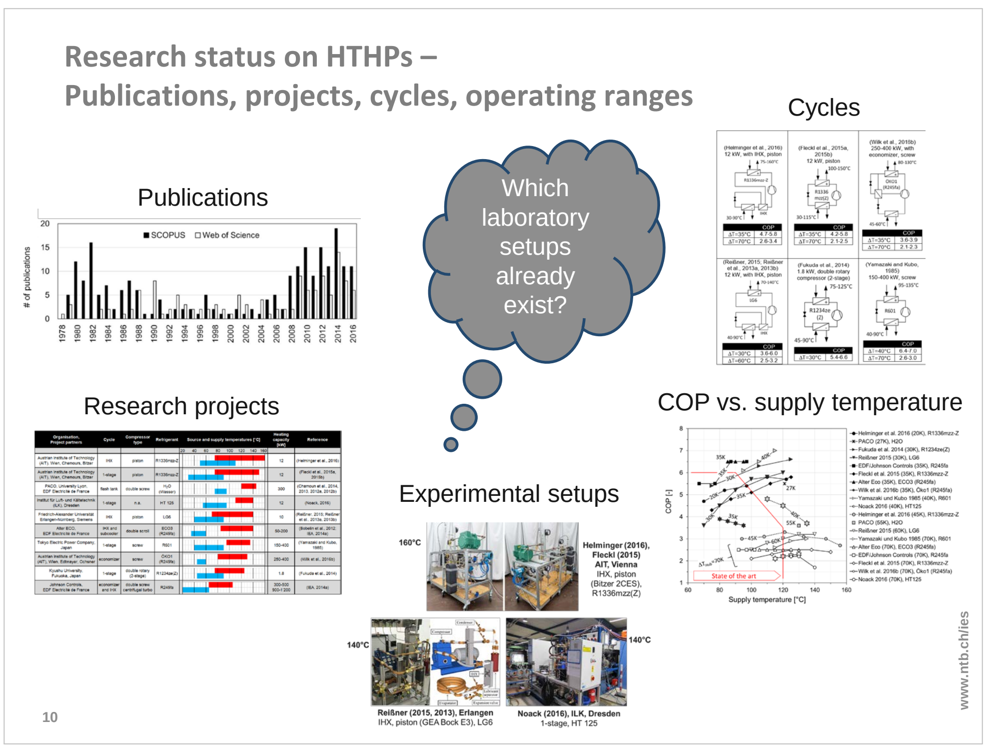
Research status on HTHPs –
Publications, projects, cycles, operating ranges
Publications
SCOPUS Web of Science
# of publications
Research projects
Which laboratory setups already exist?
Cycles
COP vs. supply temperature
Supply temperature [°C]
State of the art
Experimental setups
160°C
Helminger (2016), Fleckl (2015)
AIT, Vienna
IHX, piston
(Bitzer 2CES),
R1336mzz(Z)
140°C
140°C
Reißner (2015, 2013), Erlangen
IHX, piston (GEA Bock E3), LG6
Noack (2016), ILK, Dresden
1-stage, HT 125
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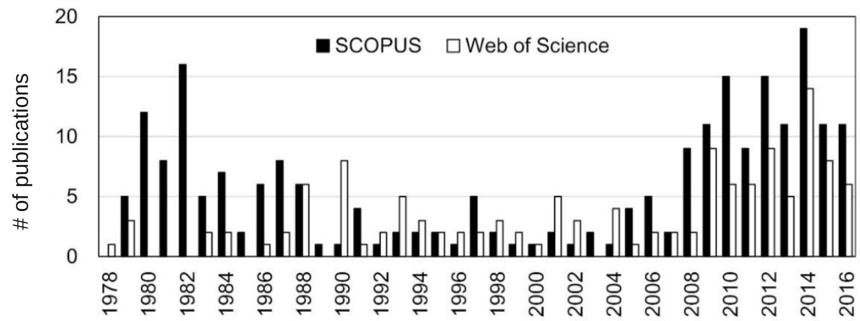
Research activity on HTHPs – Number of publications



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

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Experimental research projects on HTHPs

Organisation, Project partners	Cycle	Compressor type	Refrigerant	Source and supply temperatures [°C]	Heating capacity [kW]	Reference
				20 40 60 80 100 120 140 160		
Austrian Institute of Technology (AIT), Wien, Chemours, Bitzer	IHX	piston	R1336mzz-Z		12	(Helminger et al., 2016)
Austrian Institute of Technology (AIT), Wien, Chemours, Bitzer	1-stage	piston	R1336mzz-Z		12	(Fleckl et al., 2015a, 2015b)
PACO, University Lyon, EDF Electricité de France	flash tank	double screw	H_2O (Wasser)		300	(Chamoun et al., 2014, 2013, 2012a, 2012b)
Institut für Luft- und Kältetechnik (ILK), Dresden	1-stage	n.a.	HT 125		12	(Noack, 2016)
Friedrich-Alexander Universität Erlangen-Nürnberg, Siemens	IHX	piston	LG6		10	(Reißner, 2015; Reißner et al., 2013a, 2013b)
Alter ECO, EDF Electricité de France	IHX and subcooler	double scroll	ECO3 (R245fa)		50-200	(Bobelin et al., 2012; IEA, 2014a)
Tokyo Electric Power Company, Japan	1-stage	screw	R601		150-400	(Yamazaki and Kubo, 1985)
Austrian Institute of Technology (AIT), Wien, Edtmayer, Ochsner	economizer	screw	ÖKO1 (R245fa)		250-400	(Wilk et al., 2016b)
Kyushu University, Fukuoka, Japan	1-stage	double rotary (2-stage)	R1234ze(Z)		1.8	(Fukuda et al., 2014)
Johnson Controls, EDF Electricité de France	economizer and IHX	double screw centrifugal turbo	R245fa		300-500 900-1'200	(IEA, 2014a)

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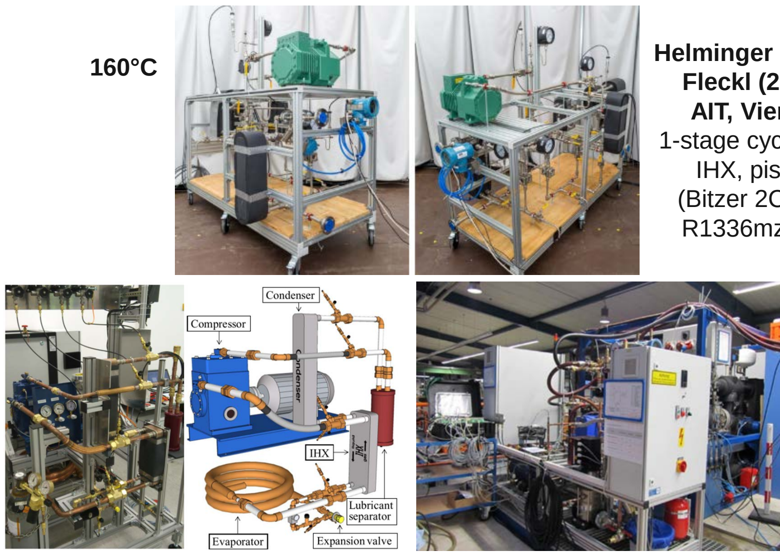
Experimental setups

160°C

Helminger (2016), Fleckl (2015) AIT, Vienna
1-stage cycle with IHX, piston (Bitzer 2CES), R1336mzz(Z)

140°C

140°C



Reißner (2015, 2013), Erlangen
1-stage with IHX,
piston (GEA Bock E3), LG6

Noack (2016), ILK, Dresden
1-stage cycle, HT 125

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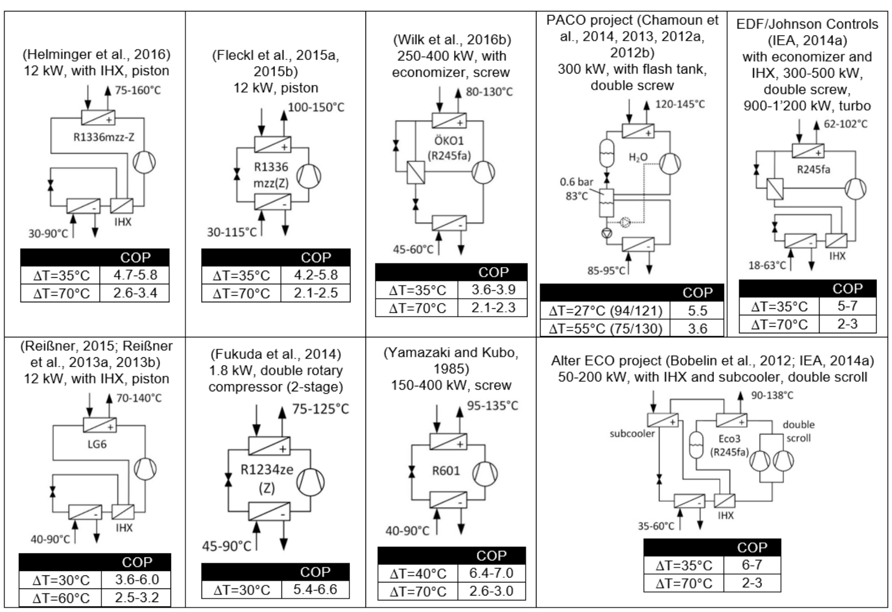
Cycles and achieved COPs of experimental research projects



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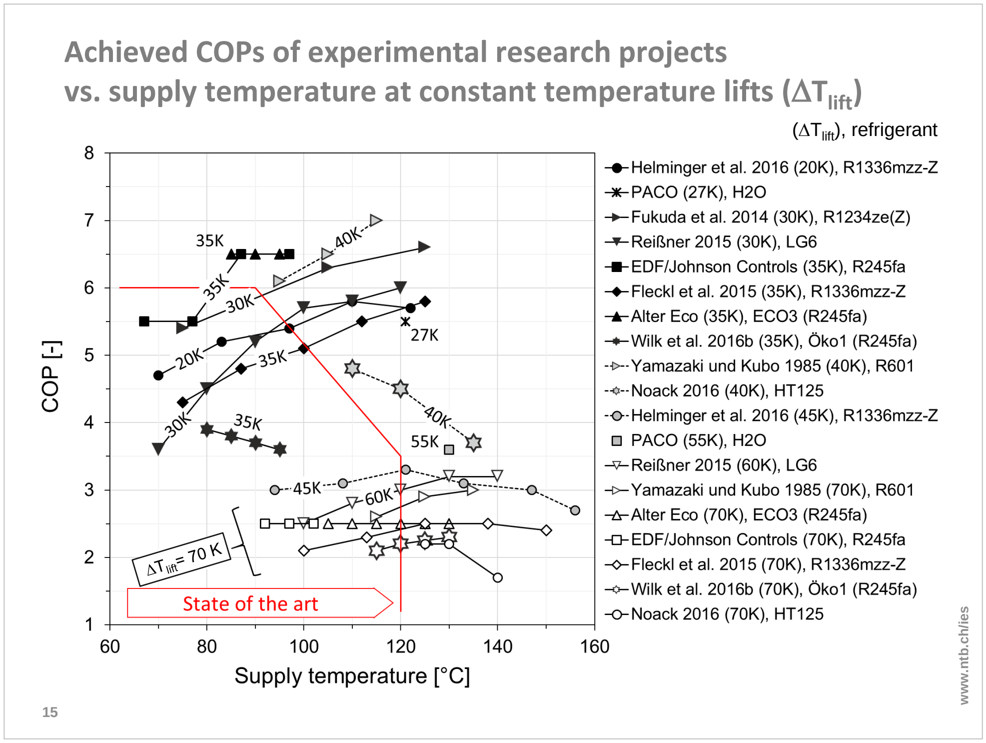
Achieved COPs of experimental research projects
vs. supply temperature at constant temperature lifts (ΔT_{lift})
(ΔT_{lift}), refrigerant
Helminger et al. 2016 (20K), R1336mzz-Z
PACO (27K), H2O
Fukuda et al. 2014 (30K), R1234ze(Z)
Reißner 2015 (30K), LG6
EDF/Johnson Controls (35K), R245fa
Fleckl et al. 2015 (35K), R1336mzz-Z
Alter Eco (35K), ECO3 (R245fa)
Wilk et al. 2016b (35K), Öko1 (R245fa)
Yamazaki und Kubo 1985 (40K), R601
Noack 2016 (40K), HT125
Helminger et al. 2016 (45K), R1336mzz-Z
PACO (55K), H2O
Reißner 2015 (60K), LG6
Yamazaki und Kubo 1985 (70K), R601
Alter Eco (70K), ECO3 (R245fa)
EDF/Johnson Controls (70K), R245fa
Fleckl et al. 2015 (70K), R1336mzz-Z
Wilk et al. 2016b (70K), Öko1 (R245fa)
Noack 2016 (70K), HT125
COP [-]
Supply temperature [°C]
35K
40K
35K
30K
20K
35K
27K
30K
35K
40K
55K
45K
60K
ΔT_{lift} = 70 K
State of the art
15
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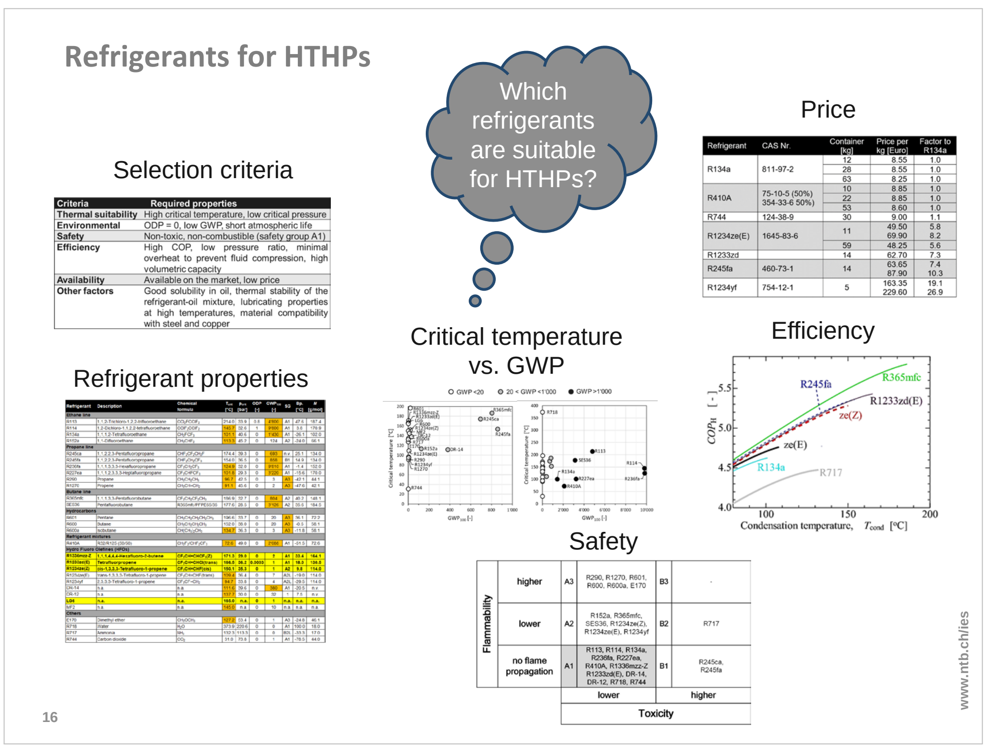
Refrigerants for HTHPs
Which refrigerants are suitable for HTHPs?
Selection criteria
Criteria | Required properties
Thermal suitability | High critical temperature, low critical pressure
Environmental | ODP = 0, low GWP, short atmospheric life
Safety | Non-toxic, non-combustible (safety group A1)
Efficiency | High COP, low pressure ratio, minimal overheat to prevent fluid compression, high volumetric capacity
Availability | Available on 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
Price
Refrigerant | CAS Nr. | Container [kg] | Price per kg [Euro] | Factor to R134a
R134a | 811-97-2 | 12 | 8.55 | 1.0
28 | 8.55 | 1.0
63 | 8.25 | 1.0
R410A | 75-10-5 (50%) 354-33-6 50%) | 10 | 8.85 | 1.0
22 | 8.85 | 1.0
53 | 8.60 | 1.0
R744 | 124-38-9 | 30 | 9.00 | 1.1
R1234ze(E) | 1645-83-6 | 11 | 49.50 69.90 | 5.8 8.2
59 | 48.25 | 5.6
R1233zd | 14 | 62.70 | 7.3
R245fa | 460-73-1 | 14 | 63.65 87.90 | 7.4 10.3
R1234yf | 754-12-1 | 5 | 163.35 229.60 | 19.1 26.9
Refrigerant properties
Critical temperature vs. GWP
Efficiency
R245fa
R365mfc
R1233zd(E)
ze(Z)
ze(E)
R134a
R717
Condensation temperature, T_{cond} [°C]
Safety
Flammability
higher | A3 | R290, R1270, R601, R600, R600a, E170 | B3 | -
lower | A2 | R152a, R365mfc, SES36, R1234ze(Z), R1234ze(E), R1234yf | B2 | R717
no flame propagation | A1 | R113, R114, R134a, R236fa, R227ea, R410A, R1336mzz-Z, R1233zd(E), DR-14, DR-12, R718, R744 | B1 | R245ca, R245fa
lower
higher
Toxicity
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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 on 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

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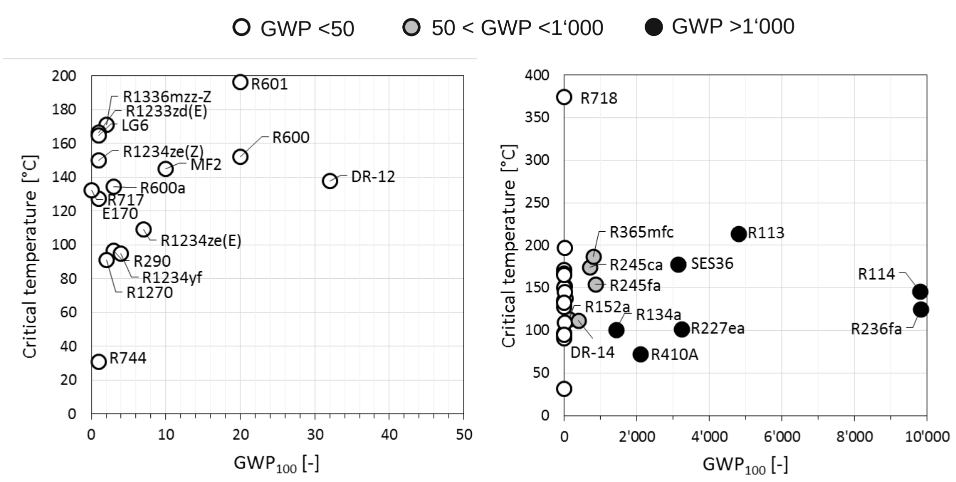
Critical temperature vs. GWP



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Safety Group Classification

Flammability			Toxicity: lower		Toxicity: higher
Flammability	higher	A3	R290, R1270, R601, R600, R600a, E170	B3	-
Flammability	lower	A2	R152a, R365mfc, SES36, R1234ze(Z), R1234ze(E), R1234yf	B2	R717
Flammability	no flame propagation	A1	R113, R114, R134a, R236fa, R227ea, R410A, R1336mzz-Z R1233zd(E), DR-14, DR-12, R718, R744	B1	R245ca, R245fa
			lower		higher
			Toxicity		

according to DIN EN 378-1 (2008) and ASHRAE 34

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Refrigerants – properties

Refrigerant	Description	Chemical formula	T_{crit} [°C]	p_{crit} [bar]	ODP [-]	GWP_{100} [-]	SG	Bp. [°C]	*M* [g/mol]
Ethane line									
R113	1,1,2-Trichloro-1,2,2-trifluoroethane	CCl_2FCClF_2	214.0	33.9	0.8	4'800	A1	47.6	187.4
R114	1,2-Dichloro-1,1,2,2-tetrafluoroethane	$CClF_2CClF_2$	145.7	32.6	1	9'800	A1	3.8	170.9
R134a	1,1,1,2-Tetrafluoroethane	CH_2FCF_3	101.1	40.6	0	1'430	A1	-26.1	102.0
R152a	1,1-Difluoroethane	CH_3CHF_2	113.3	45.2	0	124	A2	-24.0	66.1
Propane line									
R245ca	1,1,2,2,3-Pentafluoropropane	$CHF_2CF_2CH_2F$	174.4	39.3	0	693	n.v.	25.1	134.0
R245fa	1,1,2,2,3-Pentafluoropropane	$CHF_2CH_2CF_3$	154.0	36.5	0	858	B1	14.9	134.0
R236fa	1,1,1,3,3,3-Hexafluoropropane	$CF_3CH_2CF_3$	124.9	32.0	0	9'810	A1	-1.4	152.0
R227ea	1,1,1,2,3,3,3-Heptafluoropropane	CF_3CHFCF_3	101.8	29.3	0	3'220	A1	-15.6	170.0
R290	Propane	$CH_3CH_2CH_3$	96.7	42.5	0	3	A3	-42.1	44.1
R1270	Propene	$CH_3CH{=}CH_2$	91.1	45.6	0	2	A3	-47.6	42.1
Butane line									
R365mfc	1,1,1,3,3-Pentafluorobutane	$CF_3CH_2CF_2CH_3$	186.9	32.7	0	804	A2	40.2	148.1
SES36	Pentafluorobutane	R365mfc/PFPE65/35	177.6	28.5	0	3'126	A2	35.6	184.5
Hydrocarbons									
R601	Pentane	$CH_3CH_2CH_2CH_2CH_3$	196.6	33.7	0	20	A3	36.1	72.2
R600	Butane	$CH_3CH_2CH_2CH_3$	152.0	38.0	0	20	A3	-0.5	58.1
R600a	Isobutane	$CH(CH_3)_2CH_3$	134.7	36.3	0	3	A3	-11.8	58.1
Refrigerant mixtures									
R410A	R32/R125 (50/50)	CH_2F_2/CHF_2CF_3	72.6	49.0	0	2'088	A1	-51.5	72.6
Hydro Fluoro Olefines (HFOs)									
R1336mzz-Z	**1,1,1,4,4,4-Hexafluoro-2-butene**	$CF_3CH{=}CHCF_3$**(Z)**	**171.3**	**29.0**	**0**	**2**	**A1**	**33.4**	**164.1**
R1233zd(E)	**Tetrafluorpropene**	$CF_3CH{=}CHCl$**(trans)**	**166.5**	**36.2**	**0.0003**	**1**	**A1**	**18.0**	**130.5**
R1234ze(Z)	**cis-1,3,3,3-Tetrafluoro-1-propene**	$CF_3CH{=}CHF$**(cis)**	**150.1**	**35.3**	**0**	**1**	**A2**	**9.8**	**114.0**
R1234ze(E)	trans-1,3,3,3-Tetrafluoro-1-propene	$CF_3CH{=}CHF$(trans)	109.4	36.4	0	7	A2L	-19.0	114.0
R1234yf	2,3,3,3-Tetrafluoro-1-propene	$CF_3CF{=}CH_2$	94.7	33.8	0	4	A2L	-29.5	114.0
DR-14	n.a.	n.a.	111.6	39.6	0	380	A1	-20.5	n.v.
DR-12	n.a.	n.a.	137.7	30.0	0	32	1	7.5	n.v.
LG6	**n.a.**	**n.a.**	**165.0**	**n.a.**	**0**	**1**	**n.a.**	**n.a.**	**n.a.**
MF2	n.a.	n.a.	145.0	n.a.	0	10	n.a.	n.a.	n.a.
Others									
E170	Dimethyl ether	CH_3OCH_3	127.2	53.4	0	1	A3	-24.8	46.1
R718	Water	H_2O	373.9	220.6	0	0	A1	100.0	18.0
R717	Ammonia	NH_3	132.3	113.3	0	0	B2L	-33.3	17.0
R744	Carbon dioxide	CO_2	31.0	73.8	0	1	A1	-78.5	44.0

T_{crit} = critical temperature

p_{crit} = critical pressure

ODP = Ozone Depletion Potenial (R11=1.0)

GWP = Global Warming Potential (CO2=1.0, 100 years EU F-Gas regulation 517/2014)

SG = Safety group (DIN EN 378-1, 2008, ASHRAE 34)

Bp. = Boiling point at 1.013 bar

M = Molecular weight

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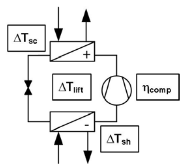
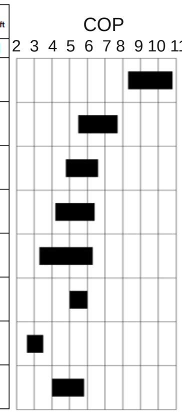
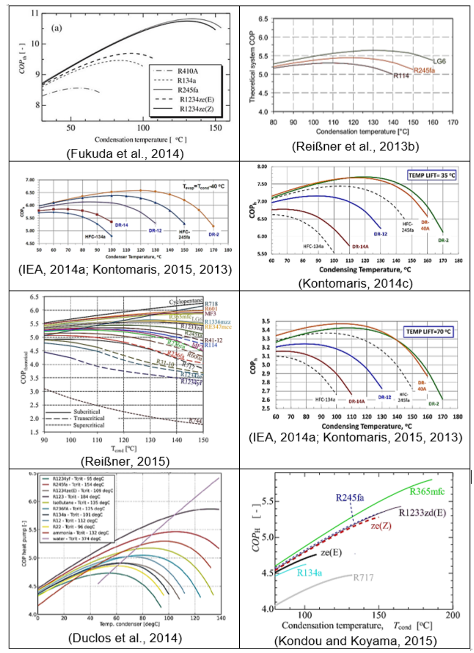
Theoretical studies – Efficiency range for 1-stage cycles with different refrigerants



ΔT_{lift}: temperature lift
ΔT_{sh}: superheating
ΔT_{sc}: subcooling
η_{comp}: isentropic compressor efficiency

Reference	ΔT_{sh} [K]	ΔT_{sc} [K]	η_{comp} [-]	ΔT_{lift} [K]
Fukuda et al. (2014)	3	20	1	35
Kontomaris (2014)	5	5	0.8	35
IEA (2014), Kontomaris (2015, 2013)	11	5	0.8	40
Duclos et al. (2014)	10	5	0.75	45
Reißner (2015)	5	5	0.8	50
Reißner et al. (2013)	5	5	0.8	50
IEA (2014), Kontomaris (2015, 2013)	20	5	0.8	70
Kondou and Koyama (2015)	3	60	1	80





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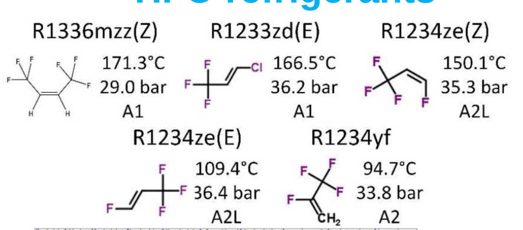
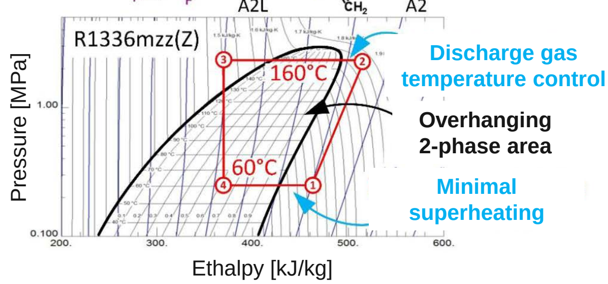
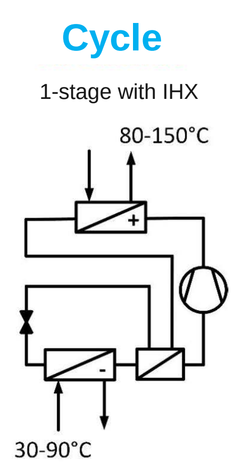
Possible concept for a HTHP laboratory prototype







Decition criteria:
1) Thermodynamic suitability (T_{crit} > 150°C, allows subcritical, good efficiency at high temperatures)
2) Environmental compatibility (GWP <10, ODP = 0, future-proof according to F-Gas regulation)
3) Safety (no or only low flammability)
4) Natural refrigerants R600 and R600a excluded due to flammability (A3), other refrigerants due to lack of information and availability

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Conclusions – Market overview

- **More than 20 HTHP models** identified with supply temperatures > 90°C from 13 manufacturers (e.g. Vicking HeatBooster with 150°C, Ochsner IWWDS with 130°C, Kobelco SGH120, Mayekawa Eco Sirocco, and Hybrid Energy Heat Pump with 120°C)
- **Heat source:** water, brine, waste heat (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 turbo, pistons (parallel)
- **Cycles:** usually 1-stage, optimization by IHX, parallel compressors, economizer, intermediate injection, 2-stage cascade (R134a/R245fa) or with a flash economizer

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Conclusions – Research status

- **Highest supply temperature of 160°C** at AIT (Vienna), 1-stage cycle with IHX and R1336mzz(Z)
- **At least 10 research projects** reached > 100°C
- **Heating capacity:** lab 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:** piston in lab systems
- **HFO refrigerants:** thermodynamic suitable, good efficiency, GWP <10, ODP = 0, safe, future-proof according to F-Gas regulation

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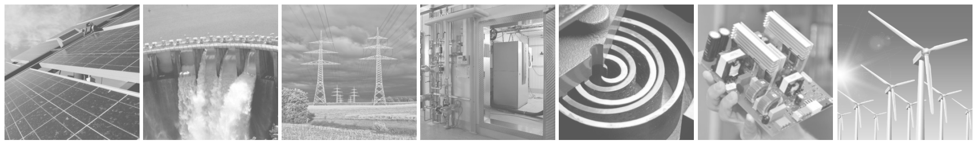

Thank you for your attention!

Contact details: *cordin.arpagaus@ntb.ch*
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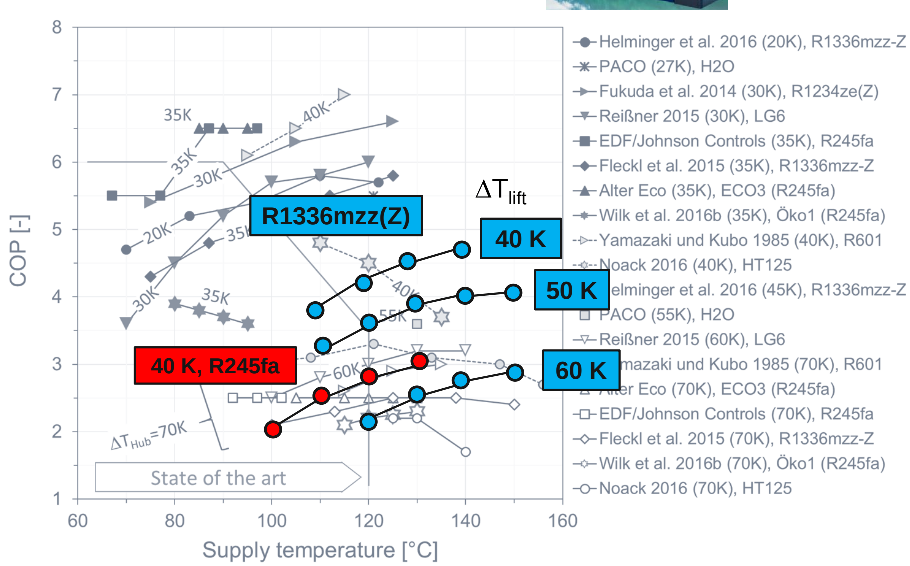
Vicking HeatBooster operation map compared to research projects



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Barriers to the wider spread of industrial HTHPs

- **Low level of awareness** about the technical possibilities and application potentials among main actors
- **Lack of knowledge** about the integration into processes
- **Requirements of low payback times** (< 3 years)
- **Competing technologies** generating high temperatures using fossil fuels at low energy prices
- **Lack of available refrigerants** in the high temperature range with low GWP
- **Lack of pilot and demonstration systems**

According to Fleckl et al. (2015), Hartl et al. (2016), IEA (2014), Jakobs et al. (2010), Noack (2016), Rieberer et al. (2014)

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TOMORROW TODAY

HIGH TEMPERATURE HEAT PUMP DEVELOPMENT

at Austrian Institute of Technology GmbH

MICHAEL LAUERMANN
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Energy Department
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- Molecular Diagnostics
- Biomedical Systems
- Digital Health Information Systems

Digital Safety & Security
- Security & Communication Technologies
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- Smart Sensor Solutions
- Dependable Systems Engineering
- Information Management

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- High-Performance Image Processing
- Autonomous Systems
- Complex Dynamical Systems

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- Transportation Infrastructure Technologies
- Dynamic Transportation Systems

Low-Emission Transport
- Electric Drive Technologies
- Light Metals Technologies Ranshofen

Technology Experience
- Capturing / Measuring Experience
- Future Interface Paradigms
- Experience Orientated Thinking

Innovation Systems & Policy
- Digital Innovation
- Foresight & Institutional Change
- Policies for Change

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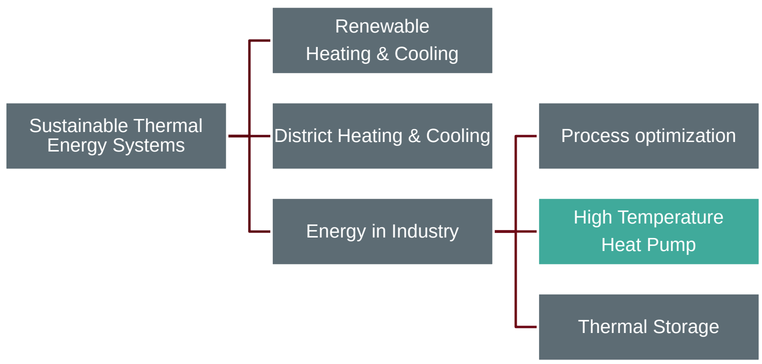

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MARKET TRENDS AND DEVELOPMENT NEEDS

- General Framework
  - Energy efficiency directive
  - Load flexibilisation
  - Reduction of energy requirements and CO_2 emmissions
  - F-Gas regulation
- Industrial heat pump as market chance for Europe
  - 45% of industrial heat demand lower than 150ºC
  - Relevant sectors: Food, Chemical, Pulp&Paper, Non metal mineral, Metals
  - Relevant processes: Pre-heating, Drying, Destillation, Evaporation, Cooking, Sterilisiation, etc.

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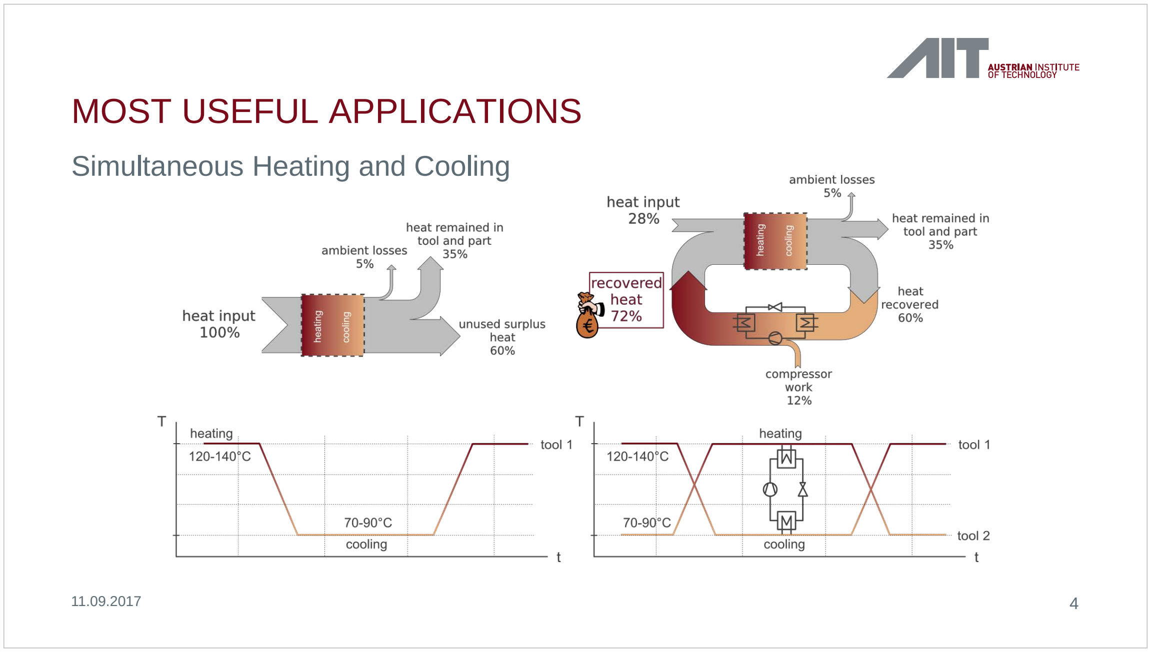
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MOST USEFUL APPLICATIONS
Simultaneous Heating and Cooling
heat input 100%
heating
cooling
ambient losses 5%
heat remained in tool and part 35%
unused surplus heat 60%
heat input 28%
ambient losses 5%
heat remained in tool and part 35%
recovered heat 72%
heat recovered 60%
compressor work 12%
T
heating
120-140°C
70-90°C
cooling
tool 1
t
T
heating
120-140°C
70-90°C
cooling
tool 1
tool 2
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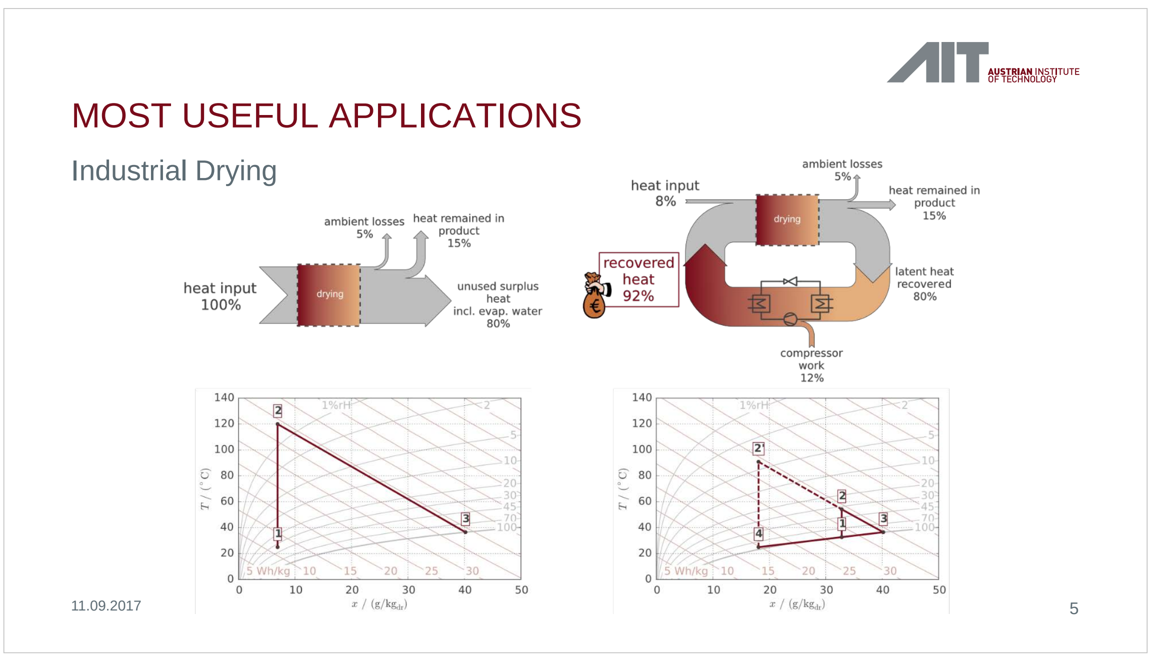
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MOST USEFUL APPLICATIONS
Industrial Drying
heat input 100%
drying
ambient losses 5%
heat remained in product 15%
unused surplus heat incl. evap. water 80%
heat input 8%
ambient losses 5%
heat remained in product 15%
recovered heat 92%
latent heat recovered 80%
compressor work 12%
T / (°C)
x / (g/kg$_{dr}$)
1%rH
5 Wh/kg
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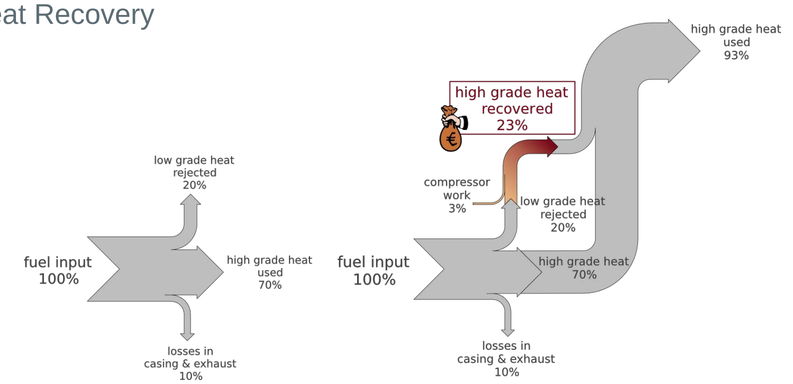
MOST USEFUL APPLICATIONS

Waste Heat Recovery



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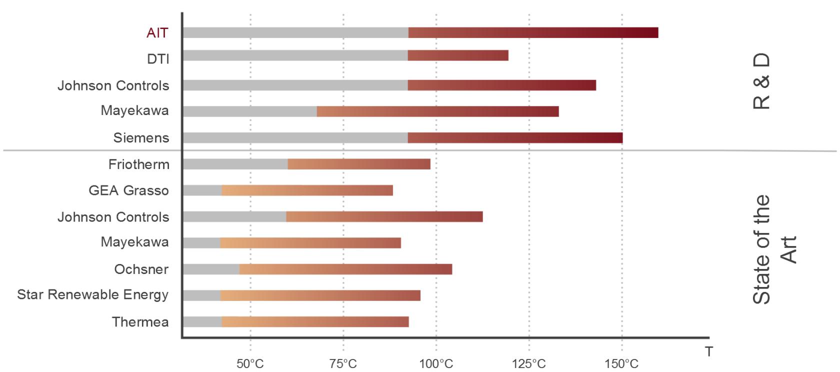
STATE OF THE ART & ONGOING RESEARCH - USEFUL TEMPERATURE ABOVE 80ºC



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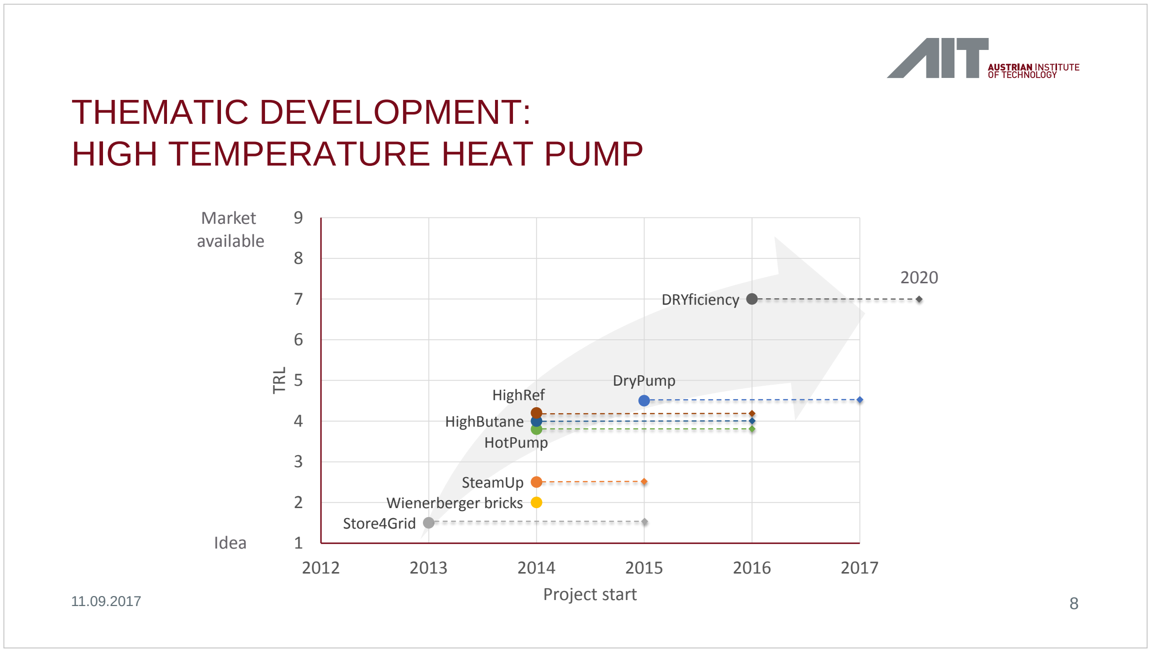
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THEMATIC DEVELOPMENT:
HIGH TEMPERATURE HEAT PUMP
Market available
Idea
TRL
9
8
7
6
5
4
3
2
1
2020
DRYficiency
DryPump
HighRef
HighButane
HotPump
SteamUp
Wienerberger bricks
Store4Grid
2012
2013
2014
2015
2016
2017
Project start
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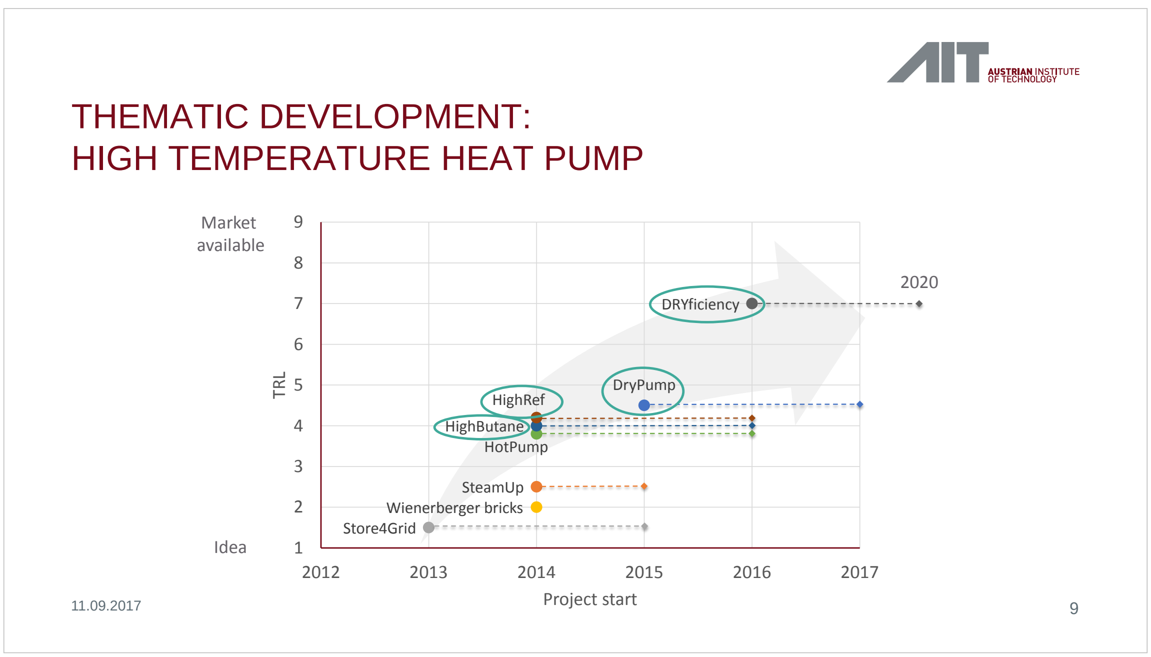
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Wienerberger bricks
Store4Grid
2012
2013
2014
2015
2016
2017
Project start
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HIGHBUTANE

Concept of a new butane high temperature heat pump

Motivation

- Industrial heating processes account for 25 % of Austria's final energy demand. An industrial heat pump lifting waste heat beyond 100 °C is needed to realize more efficient processes, thus reduce energy demand and CO_2 emissions.

Aim

- Butane shall be used in a single-stage heat pump process to lift industrial waste heat from 60 °C to 130 °C. Heat exchangers will be evaluated with respect to the charge and system configurations of use cases will be developed and experimentally validated

Highlights

- Identifying suitable processes
- Validated Dymola model
- Ejector utilisation
- CFD-heat & mass transfer
- Experimental

Results

- Performance increase with Ejector
- CFD model is being validated
- Potential cost saving of 300.000 EUR per year

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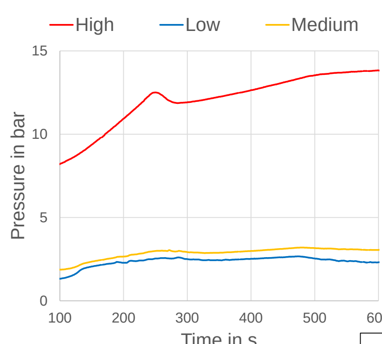
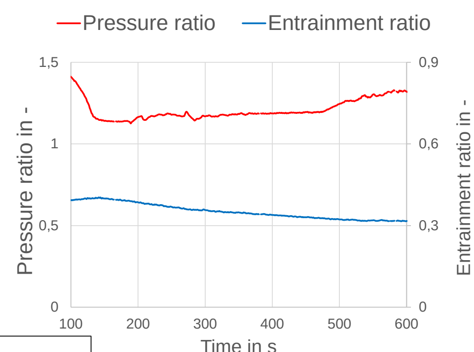
HIGHBUTANE

Concept of a new butane high temperature heat pump

Results





→ Pressure ratio: **1,3**

→ Entrainment ratio: **0,3**

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HIGHREF

Investigation of a novel high temperature refrigerant

Motivation

- Industrial heating consumes a significant fraction of the energy consumed globally. Heating at temperatures higher than about 100 °C is predominantly provided through combustion of fossil fuels with uncertain prices and well recognized environmental impacts. A significant fraction of industrial input energy is lost as low temperature waste heat that could be lifted by high temperature heat pumps to process relevant temperatures.

Aim

- Validation of a novel high temperature refrigerant (DR-2) in process heat pumps with condensation temperatures up to 160 °C .

Highlights

- Novel high temperature refrigerant (DR-2)
- Lab scale heat pump
- Experimental analysis with condensation temperatures up to 155 °C
- Energetic and economic evaluation

Results

- Short term operation of a lab scale machine with a heating capacity of around 12kW.
- Experimental investigation of the coefficient of performance (COP) at different temperature levels.
- Economic evaluation including the CO_2 savings potential for selected industrial applications.

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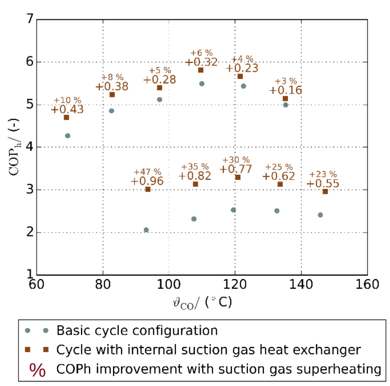
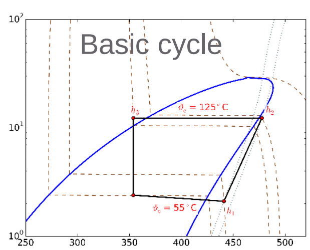
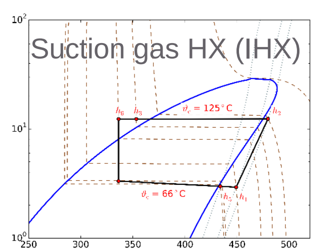
HIGHREF

Investigation of a novel high temperature refrigerant

Results







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DRYPUMP

Efficient drying with heat pumps

Aim

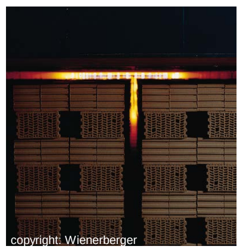
- To solve substantial industrial research issues in the context of using compression heat pumps for industrial drying
- To achieve energy savings up to 80 %, CO_2 emission savings up to 68 % and primary energy savings up to 65 % in the medium term

Results

- Development of technical viable concepts
- Experimental proof of concept of three heat pump installations
- Optimized discontinous drying process

Highlights

- Large industrial applications
- Useful temperature up to 170 °C
- Heating capacity up to 350 kW
- Energy savings up to 80 %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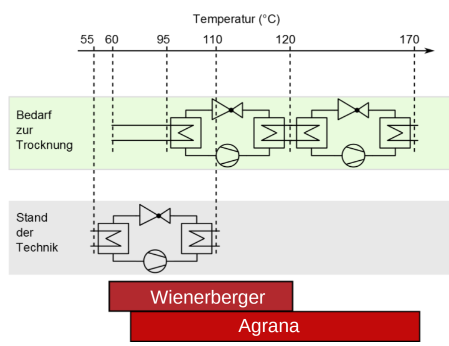
DRYPUMP

Efficient drying with heat pumps

Results



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DRYFICIENCY

Efficient drying with heat pumps on industrial scale

- Overall objective: to lead energy-intensive sectors of the European manufacturing industry **to high energy efficiency** and a **reduction of fossil carbon emissions** by means of waste heat recovery
- Aim: consortium will elaborate technically and economically viable heat pump solutions for upgrading idle waste heat streams to process heat streams at higher temperature levels up to 180 °C and will demonstrate them in three industrial drying processes (brick, pet care/feed and food industry)
- Consortium:
  - **RTOs:** AIT (Michael Hartl): Lead, SINTEF
  - **Technology providers and integrators:** Rotrex, Bitzer Kühlmaschinenbau, Chemours Fluorchemicals, Fuchs Europe Schmierstoffe, EPCON
  - **Demonstration partners**: Wienerberger, Agrana, Mars Petcare
  - **Dissemination exploitation partners**: RTDS, EHPA
- Project volume: € 6,5 Mio. (EC Funding: € 5 Mio.)

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SUMMARY

- Heat Pumps are a mature technology. Carefully integrated, they are highly reliable and lifetime up to 40 years is proven.
- Heat Pumps for Industrial applications are still widely unknown
- AIT works together with technology providers to bring high temperature heat pumps to the industry.
- DRYficiency will demonstrate high temperature heat pump solutions for drying processes.

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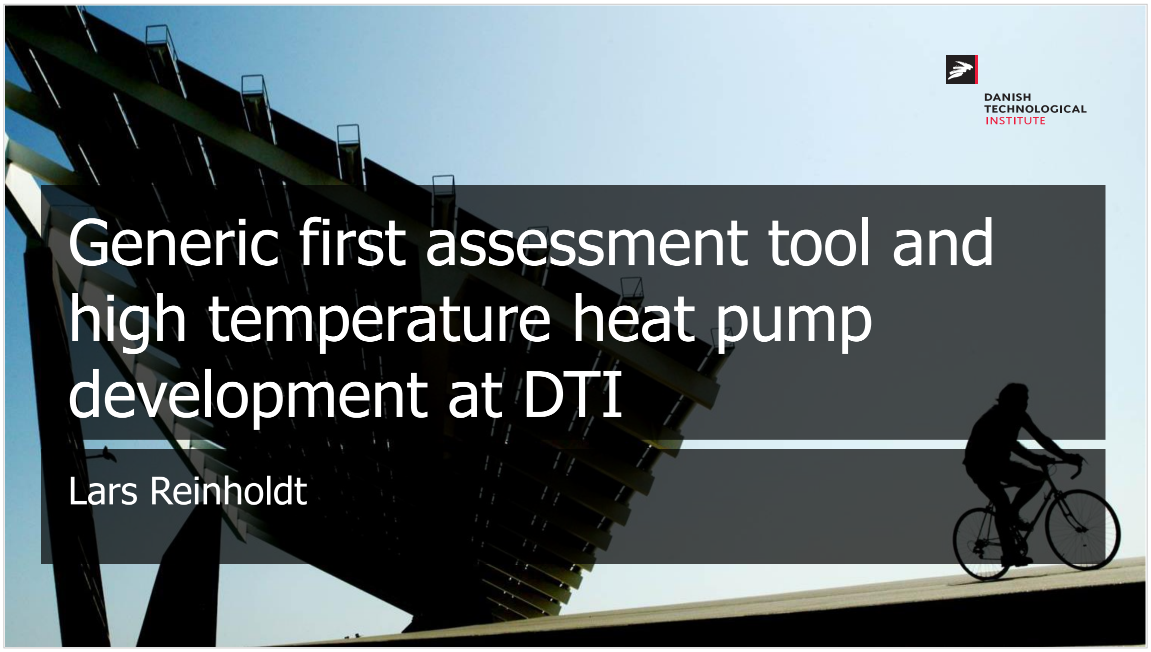

Generic first assessment tool

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Motivation

Postulate: *Heat pumps are just "nice to have"*

- *The only purpose is heat supply in a more appropriate way (like cost (incl. taxes), CO_2 foot print, CSR, …)*
- *They do not solve technical problems*

It is "all" about COP…
(….and first cost, maintenance…)

- Many heat pump solutions exists
- A way to first assessment is needed…????

Heat pump COP and system design calculations

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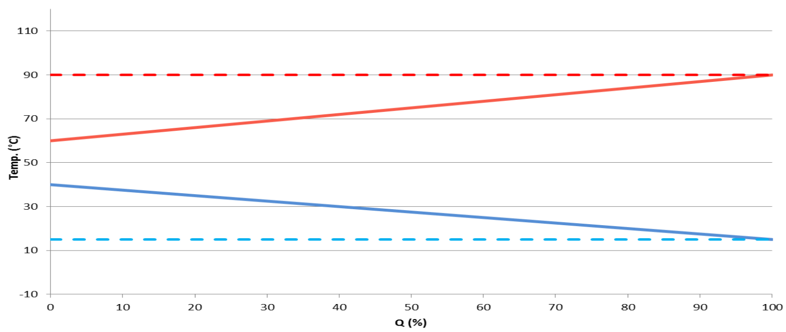
Theoretical limit: Carnot cycle

$$COP_{HP,Car} = \frac{T_H}{T_H - T_L} \quad \text{(T in K)}$$



Constant temperature source and sink: 15/90°C > COP_C = 4,84

3

Higher COP by splitting up

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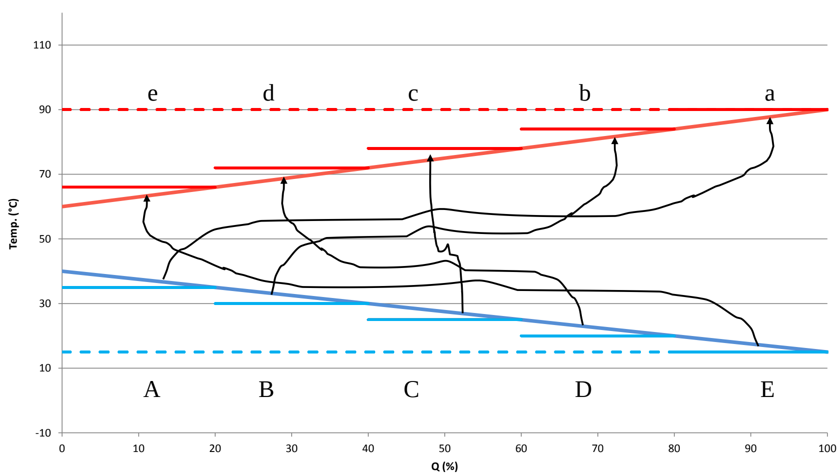

Higher COP by splitting up

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Process	T_L [°C]	T_H [°C]	$COP_{HP,Car}$ [-]	Q_H [kW]	P [kW]
A-a	35	90	6,60	1	0,1515
B-b	30	84	6,61	1	0,1513
C-c	25	78	6,62	1	0,1510
D-d	20	72	6,63	1	0,1507
E-e	15	66	6,65	1	0,1504
			Total	5	0,7549

COP = 6,62 (+37%)

Lorenz COP

$$COP_{HP,Lor} = \frac{T_{lm,H}}{T_{lm,H} - T_{lm,L}}$$

No.	Heat source (°C)	Heat sink (°C)	COP_C	COP_L
Ex.	40 > 15	60 > 90	4,84	7,33
A	8 > 4	85 > 95	4	4,3
B	40 > 15	60 > 90	4,8	7,3
C	25 > 20	70 > 110	4,3	5,4
D	80 > 20	85 > 90	5,2	9,4

(+ 51%)

5

Theoretical maximum COP

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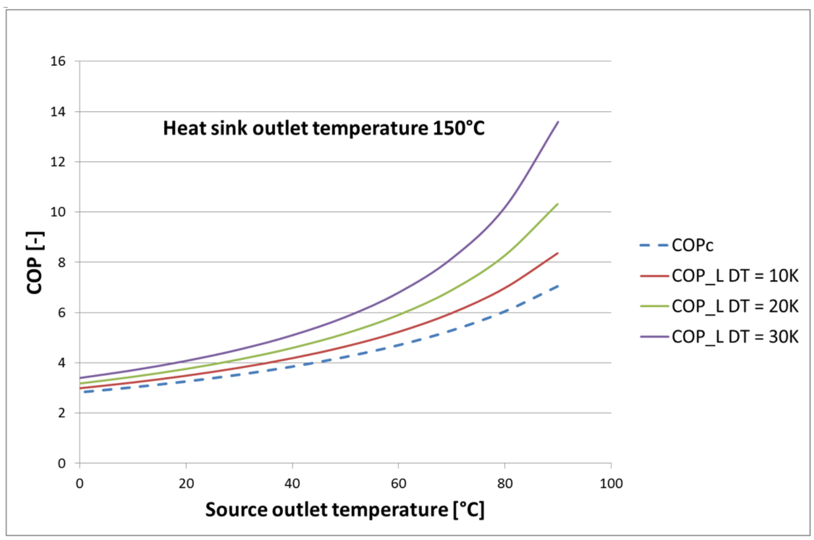

(First) system design calculation

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Theoretical COP can be used for first assessment analysis of system design without knowing the heat pump technology.

Carnot and Lorenz efficiency:

- *How good a real heat pump system is compared to theoretical maximum*

$$\eta_{Car} = \frac{COP_{HP}}{COP_{HP,Car}} \qquad \eta_{Lor} = \frac{COP_{HP}}{COP_{HP,Lor}}$$

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(First) system design calculation

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- In the best industrial refrigeration systems 60% of COP_C have been realized, so high COP can also be expected by heat pumps…

$$COP_{HP} = COP_{HP,Lor}\eta_{Lor} \quad > \quad COP_{HP,Lor} = \frac{COP_{HP}}{\eta_{Lor}}$$

Example:

- System requirement to the heat supply: 150°C
- Based on the precalculations (energy cost etc.) COP = 3,0 is needed.
- Using η_{Lor} = 60% > $COP_{HP,Lor} = \frac{3,0}{0,6} = 5$

8

(First) system design calculation

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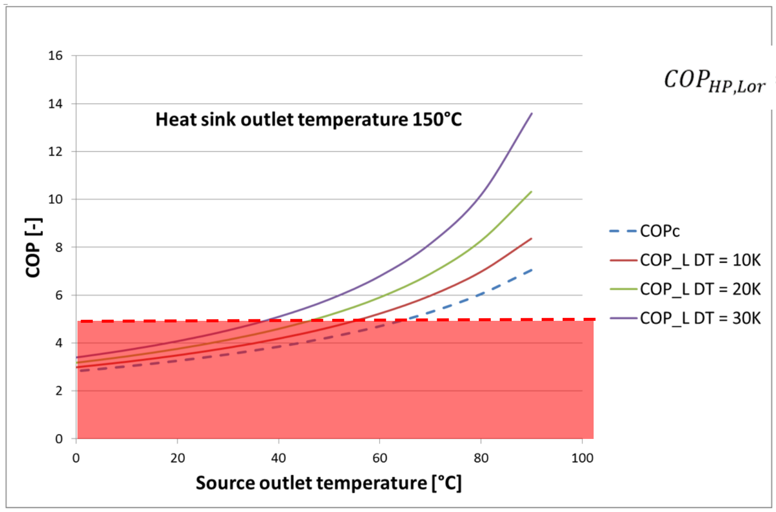


$$COP_{HP,Lor} = \frac{3{,}0}{0{,}6} = 5$$

Fundamental process analysis

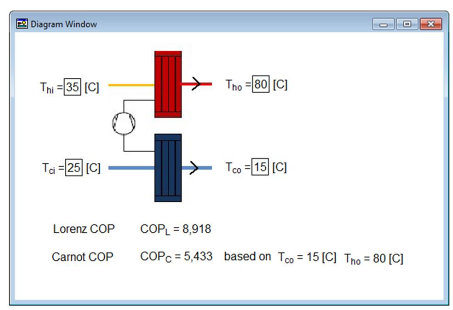
Case:

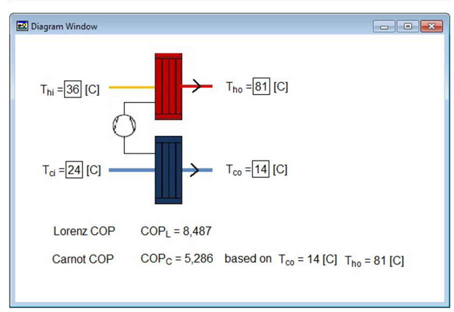
- Sink: Heating from 35 to 80°C
- Source: Cooling from 25 to 15°C

- COP_C = 5,4, COP_L = 8,9

Pinch temperature 1K

- COP_C = 5,3 > -2,7%
- COP_L = 8,5 > -4,8%





Industrial heat pump development at DTI

- Flexible Energy Optimized Split Condenser Ammonia Heat Pump - Foscap
- Mixed Refrigerant Heat Pump - MiReHP
- Ultra-high temperature hybrid heat pump for process application - HighHeat
- Development of Rotrex turbocompressor for steam compression
- Experimantal Development of Electric Heat Pumps in Greater Copenhagen District Heating System – SVAF 2
- Direct contact heat exchangers (water vapor, heat uptake at freezing)
- Projects on COP optimization of heat pump cycles
- Heat pumps and storage (hot and/or cold)

Development of ultra-high temperature hybrid heat pump for process application - HighHeat

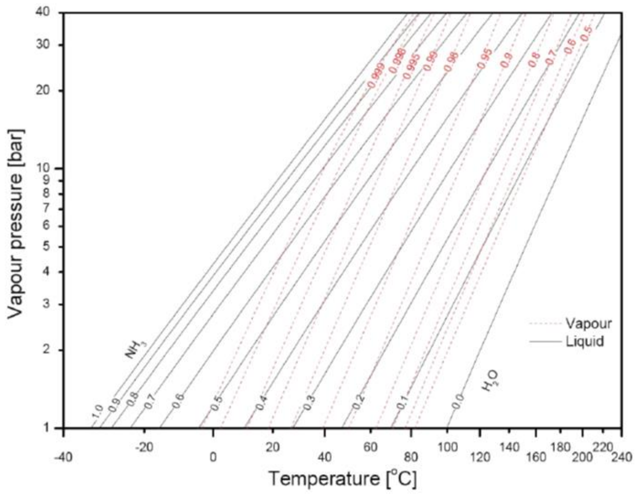
Objective

- to increase the operating limits of the hybrid process by using the new standard components for higher pressures.
- demonstrate that it is possible to develop an efficient and reliable heat pump process for high temperatures up to 180-250°C.
- Investigation of possible implementation into the processes at the end users in the consortium and the conduction of a general market survey.
- Demonstration at an end user in the consortium.

Funded by the Danish EUDP program no. 64011-0351. Ends Dec 2018.

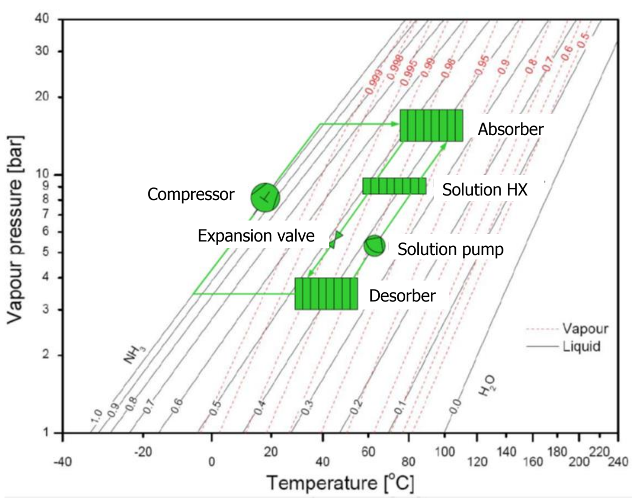
Absoption compression heat pump process

DANISH TECHNOLOGICAL INSTITUTE



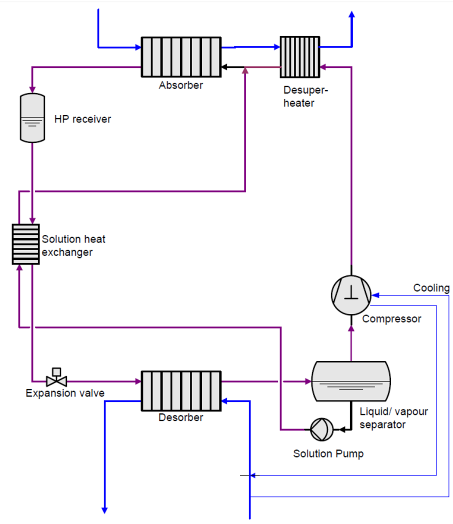
Absoption compression heat pump process

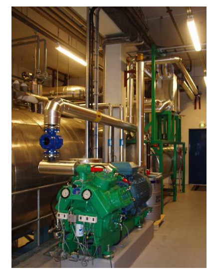
DANISH TECHNOLOGICAL INSTITUTE



Absoption compression heat pump process

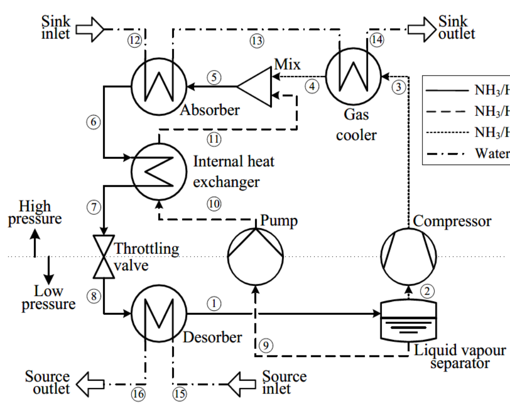
DANISH TECHNOLOGICAL INSTITUTE

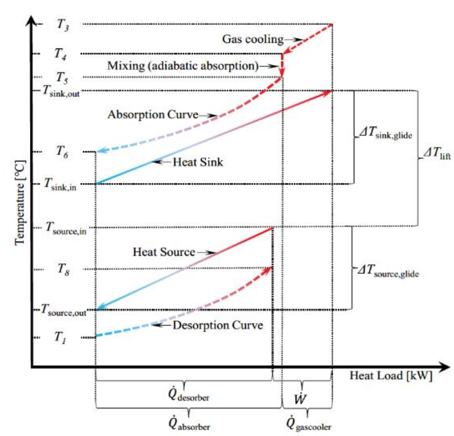




Absoption compression heat pump process

DANISH TECHNOLOGICAL INSTITUTE

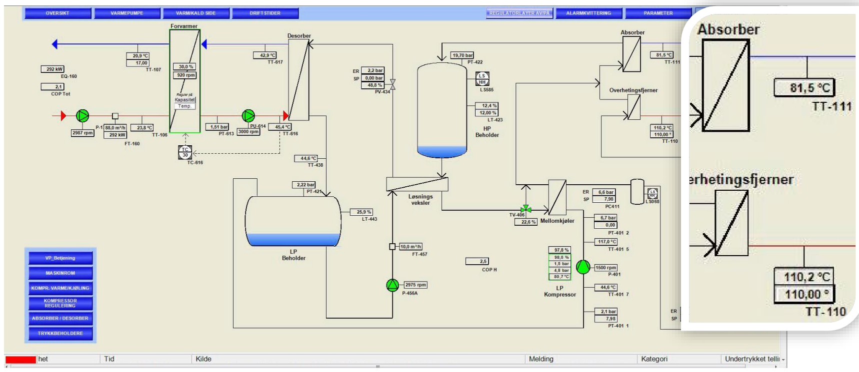




16

800kW three-stage system in sewage treatment plant

DANISH TECHNOLOGICAL INSTITUTE



$T_{L,i}$ = 22.5°C, $T_{L,o}$ = 19.4°C, $T_{H,i}$ = 79.1°C, $T_{H,o}$ = 108.4°C,
Q_H = 540 kW, P_{tot} = 198 kW.
COP_{HP} = 2.72, η_{Car} = 63%, η_{Lor} = 54%

17

Summing up

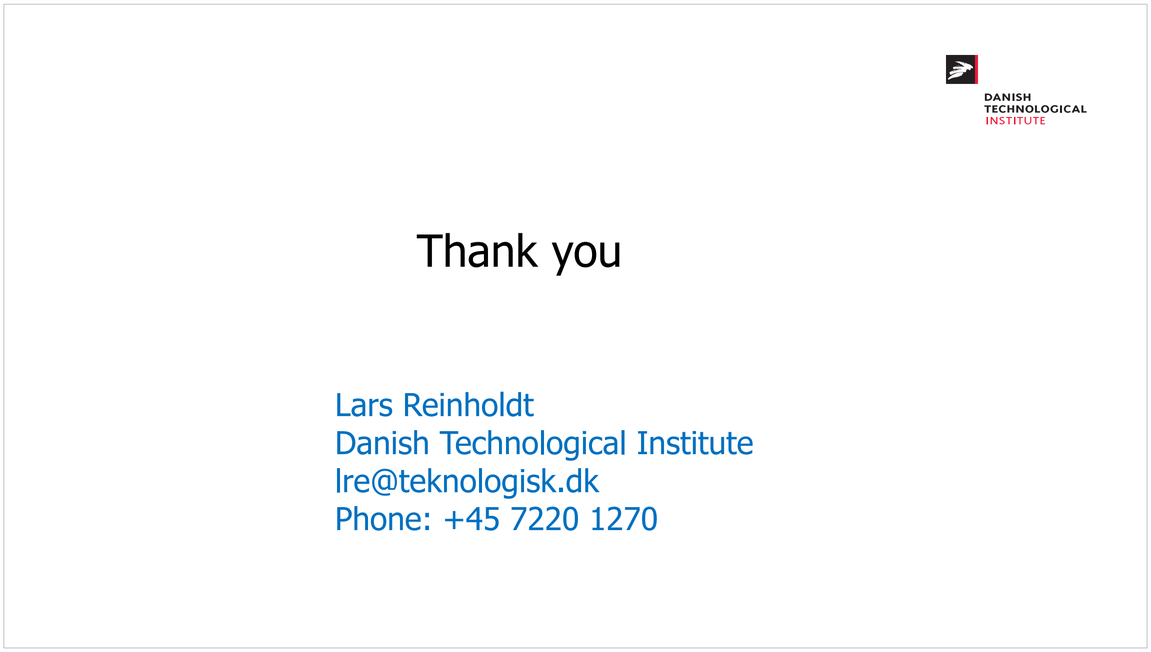
DANISH TECHNOLOGICAL INSTITUTE

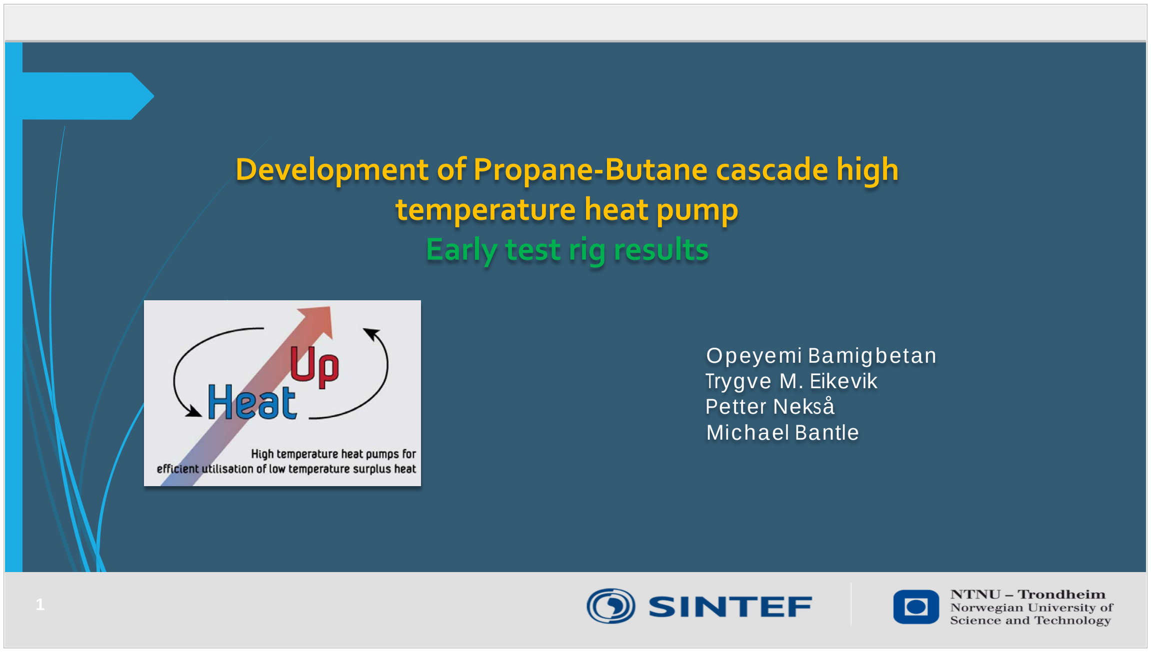
- It is suggsted to use COP_{Lor} for comparing actual heat pump performance (η_{Lor})
- It is suggested to use COP_{Lor} and η_{Lor} as base for system analysis including ecomonics

Question:

- Is (first assessment) tools needed?

18


DANISH
TECHNOLOGICAL
INSTITUTE
Thank you
Lars Reinholdt
Danish Technological Institute
lre@teknologisk.dk
Phone: +45 7220 1270


Development of Propane-Butane cascade high temperature heat pump
Early test rig results
Heat Up
High temperature heat pumps for efficient utilisation of low temperature surplus heat
Opeyemi Bamigbetan
Trygve M. Eikevik
Petter Nekså
Michael Bantle
1
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Norwegian University of Science and Technology


Research motivation
Industrial processes with heat demand between 110 – 150 °C
Process water, Pasteurization, Sterilization, Cleaning, Drying, Distillation
Industrial processes with excess heat between 30 – 100 °C
E.g. Heat at condensers of ammonia refrigeration unit
2
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Research motivation, current solution
• Boilers
Industrial processes with heat demand between 100 – 150 °C
Process water, Pasteurization, Sterilization, Cleaning, Drying, Distillation
• Cooling towers, Dry coolers
Industrial processes with excess heat between 30 – 100 °C
E.g. Heat from condensers of ammonia refrigeration unit
3
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Research motivation, HTHP
Industrial processes with heat demand between 100 – 150 °C
Process water, Pasteurization, Sterilization, Cleaning, Drying, Distillation
Industrial processes with excess heat between 30 – 100 °C
E.g. Heat from condensers of ammonia refrigeration unit
4
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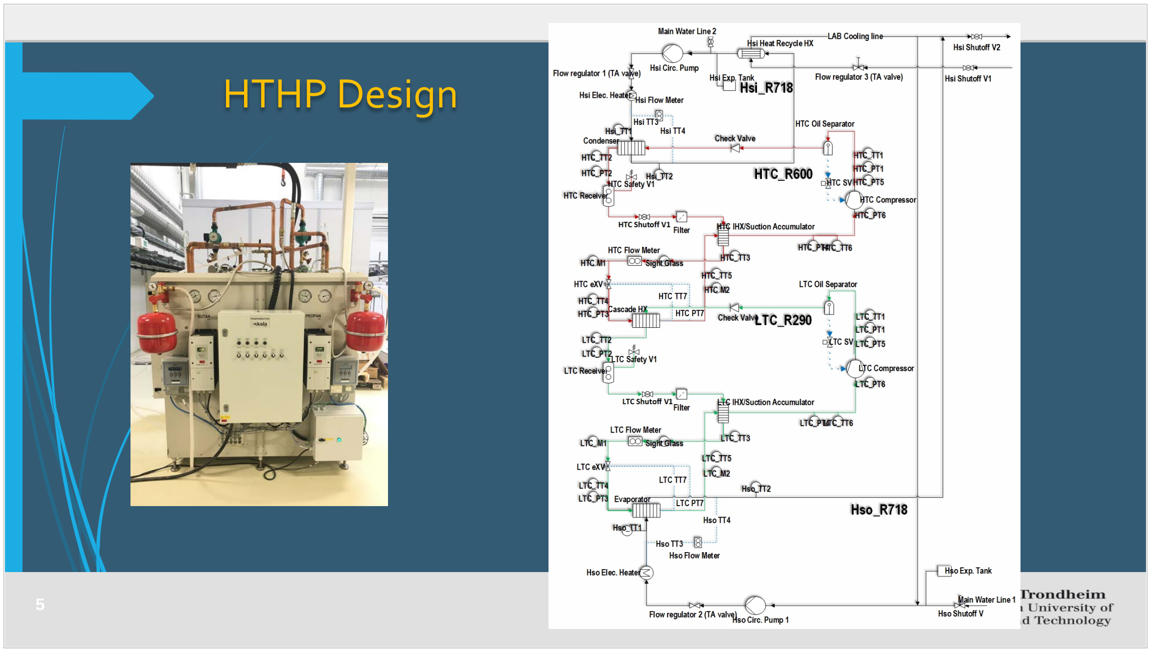
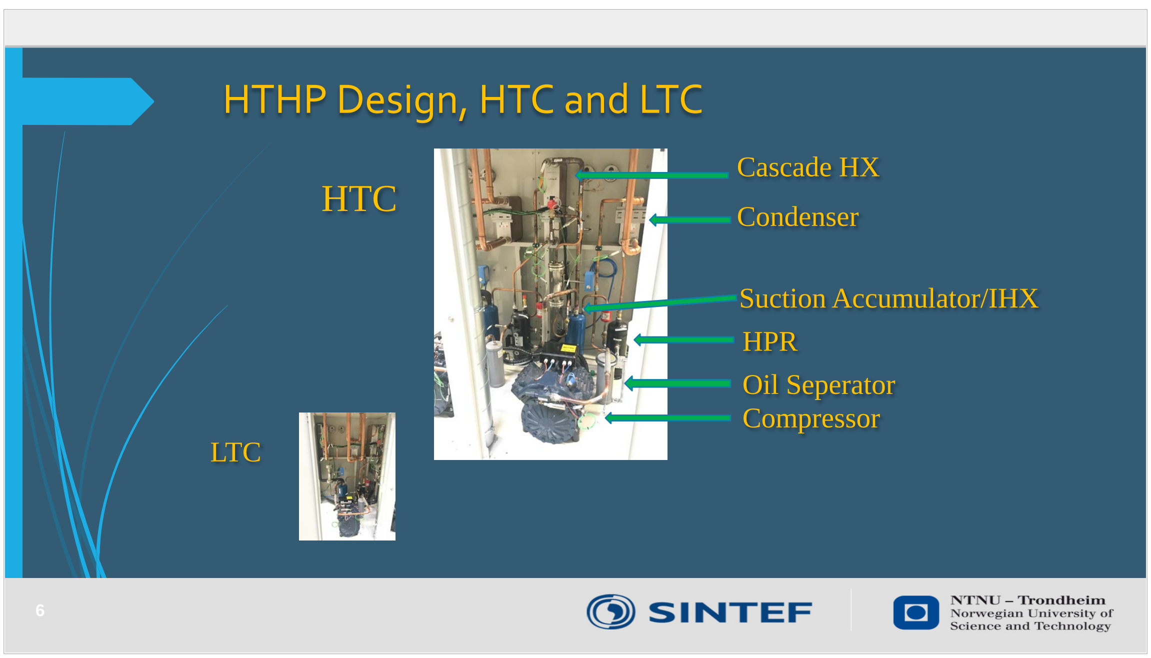

HTHP Design
Hsi_R718
HTC_R600
LTC_R290
Hso_R718
Main Water Line 2
LAB Cooling line
Hsi Heat Recycle HX
Hsi Circ. Pump
Hsi Exp. Tank
Flow regulator 1 (TA valve)
Flow regulator 3 (TA valve)
Hsi Shutoff V2
Hsi Shutoff V1
Hsi Elec. Heater
Hsi Flow Meter
HTC Oil Separator
Check Valve
Condenser
HTC Receiver
HTC Safety V1
HTC Shutoff V1
Filter
HTC Compressor
HTC IHX/Suction Accumulator
HTC Flow Meter
Sight Glass
Cascade HX
LTC Oil Separator
LTC Receiver
LTC Safety V1
LTC Shutoff V1
LTC Compressor
LTC IHX/Suction Accumulator
LTC Flow Meter
Evaporator
Hso Flow Meter
Hso Elec. Heater
Hso Exp. Tank
Main Water Line 1
Hso Shutoff V
Flow regulator 2 (TA valve)
Hso Circ. Pump 1
5


HTHP Design, HTC and LTC
HTC
LTC
Cascade HX
Condenser
Suction Accumulator/IHX
HPR
Oil Seperator
Compressor
6
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Science and Technology

HTHP Design, Water cycle

- Requires modification

7

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HTHP Design, Instrumentation

Sensor Type	Number of units
Temperature	16
Pressure	10
Flowmeters	4
Electricity (Compressors)	2
Speed (Compressors)	2

8

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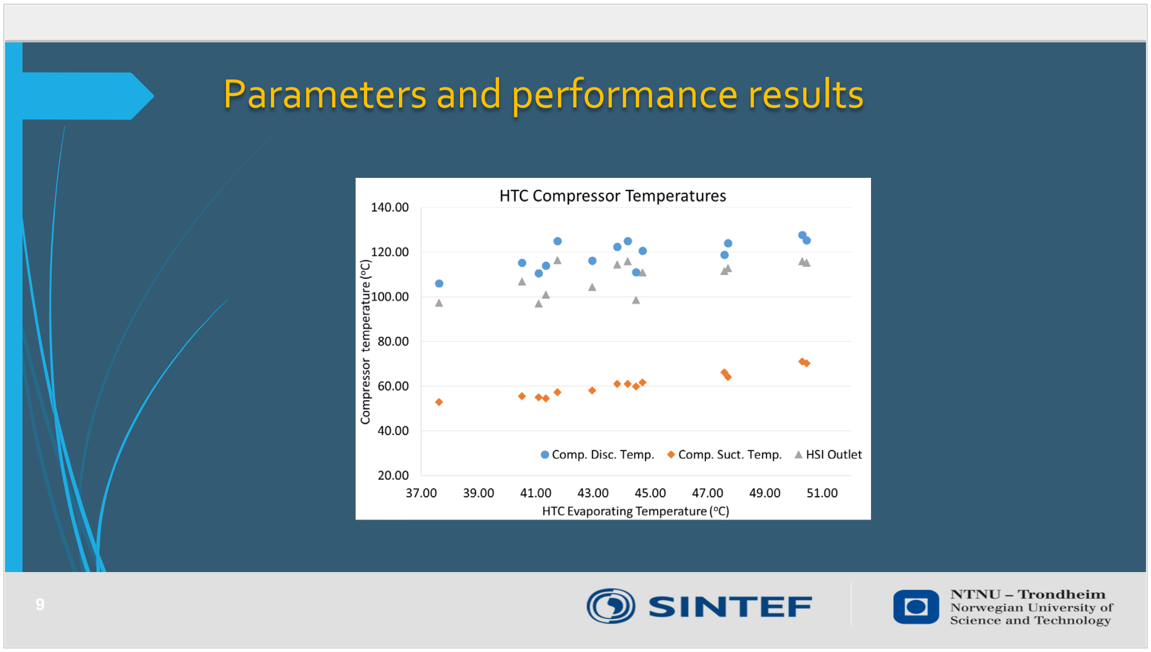
Parameters and performance results
HTC Compressor Temperatures
Compressor temperature (°C)
140.00
120.00
100.00
80.00
60.00
40.00
20.00
37.00
39.00
41.00
43.00
45.00
47.00
49.00
51.00
HTC Evaporating Temperature (°C)
Comp. Disc. Temp.
Comp. Suct. Temp.
HSI Outlet
9
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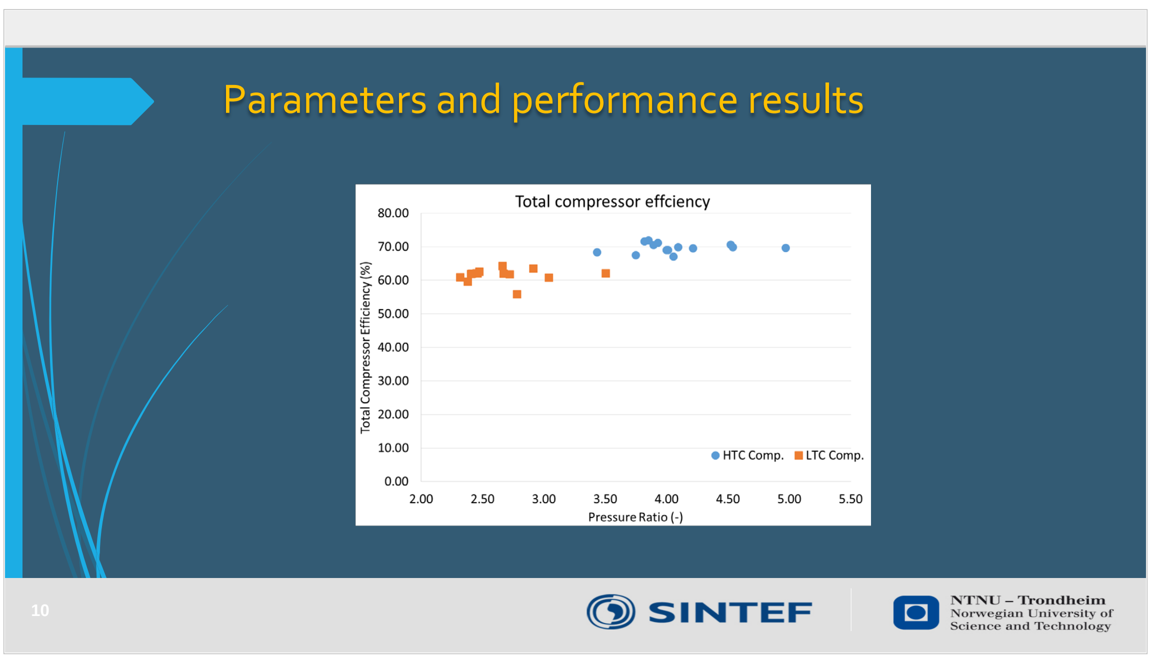
Parameters and performance results
Total compressor effciency
Total Compressor Efficiency (%)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
Pressure Ratio (-)
HTC Comp.
LTC Comp.
10
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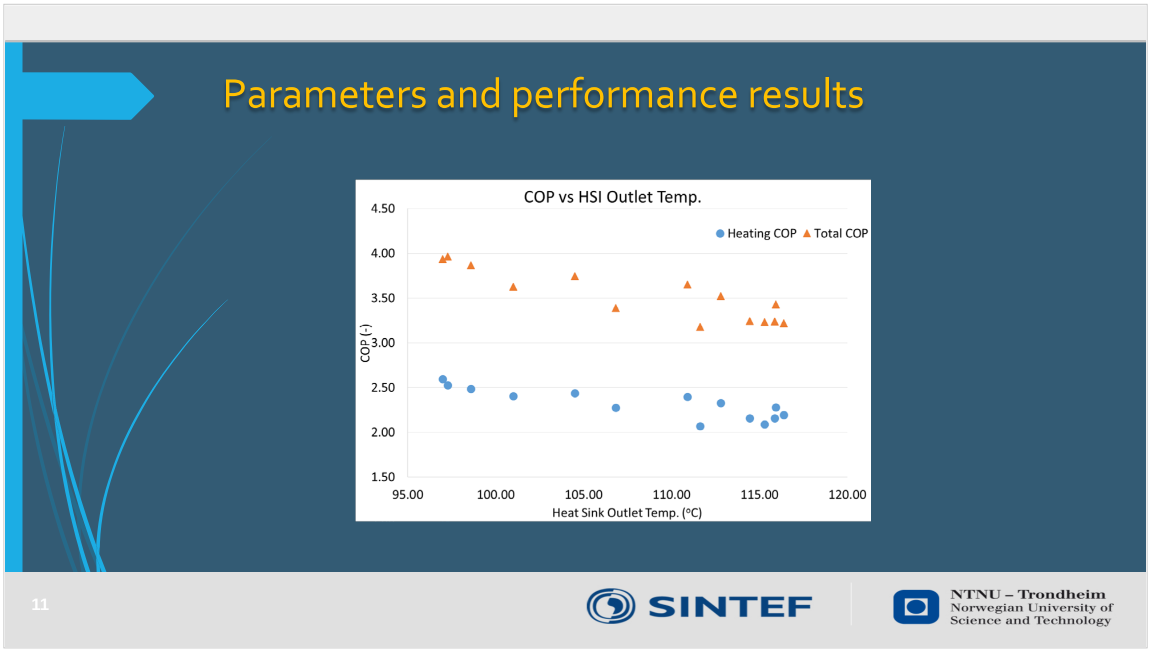
Parameters and performance results
COP vs HSI Outlet Temp.
Heating COP
Total COP
COP (-)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
95.00
100.00
105.00
110.00
115.00
120.00
Heat Sink Outlet Temp. (°C)
11
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Summary
Operating conditions are still random. Unable to accurately and independently adjust the inlet temperatures
Simple modification required
Results are not sufficient for proper evaluation
High temperature heat delivery up to 115 °C from a heat source at 30 °C
High temperature difference at heat sink from 35 °C to 115 °C
Stable operation of prototype compressor with an average total compressor efficiency of 70 %
12
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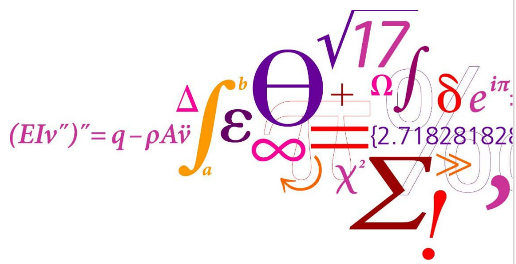
Working fluids for high temperature heat pumps

International Workshop on High Temperature Heat Pumps
11.09.2017 - Copenhagen

Benjamin Zühlsdorf, Brian Elmegaard

Section of Thermal Energy
Email: bezuhls@mek.dtu.dk
Tlf.: +45 452 54103

DTU Mechanical Engineering
Department of Mechanical Engineering



Agenda

- Motivation
- Screening Method
- Case I: Heat recovery at spray dryer (Arla)
- Case II: Excess heat to DH
- Conclusions

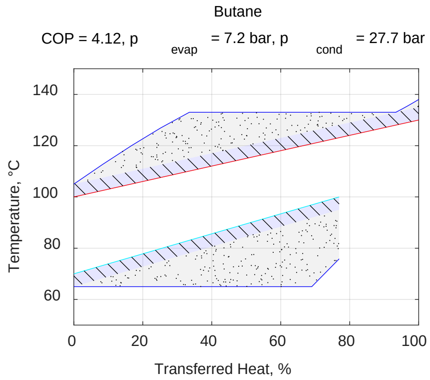
DTU

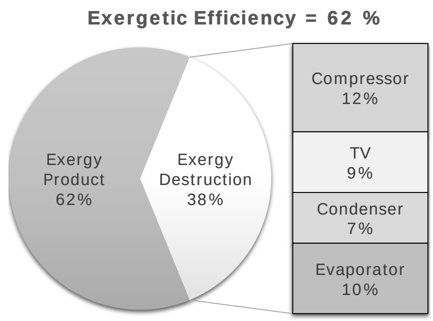
Motivation

Heat Pump:

Heat Source: 100 °C → 70 °C

Heat Sink: 100 °C → 130 °C





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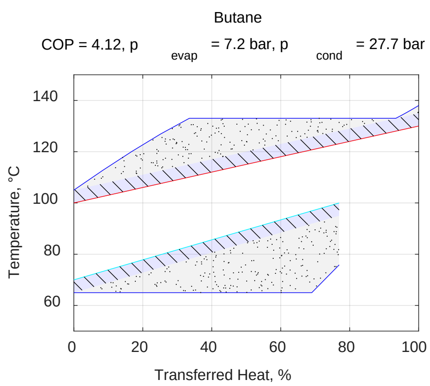
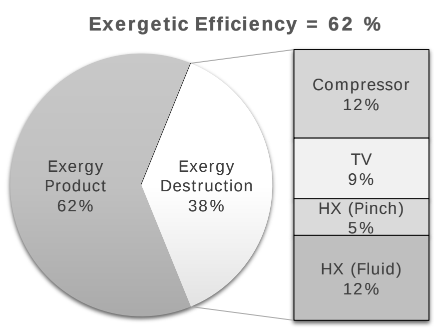
Motivation

Heat Pump:

Heat Source: 100 °C → 70 °C

Heat Sink: 100 °C → 130 °C





4 DTU Mechanical Engineering International Workshop on High Temperature Heat Pumps - Copenhagen 11/09/2017

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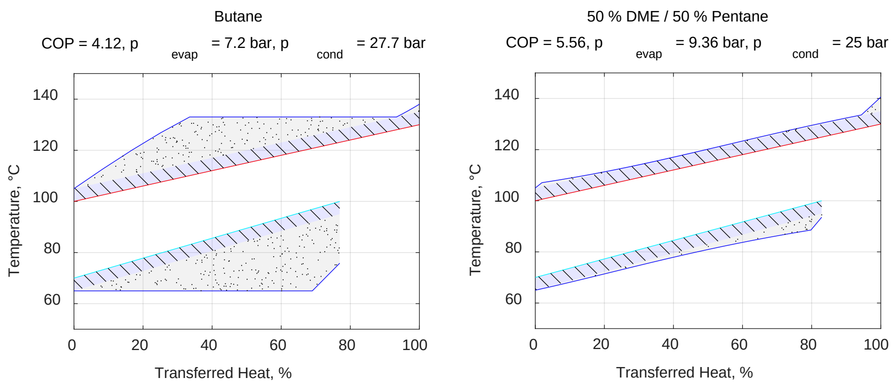
Motivation

<u>Heat Pump:</u>

Heat Source: 100 °C → 70 °C

Heat Sink: 100 °C → 130 °C



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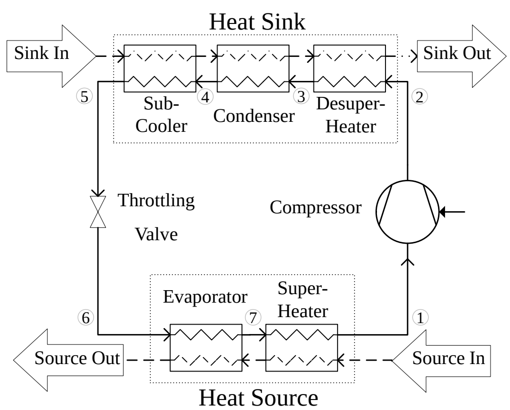
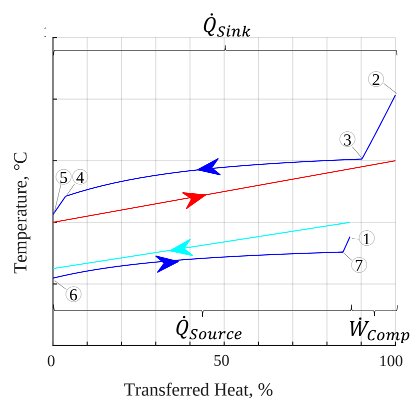
Working Fluid Screening: Thermodynamic Model





→ Simulation of all possible binary mixtures, considering 14 HCs + 4 HFOs

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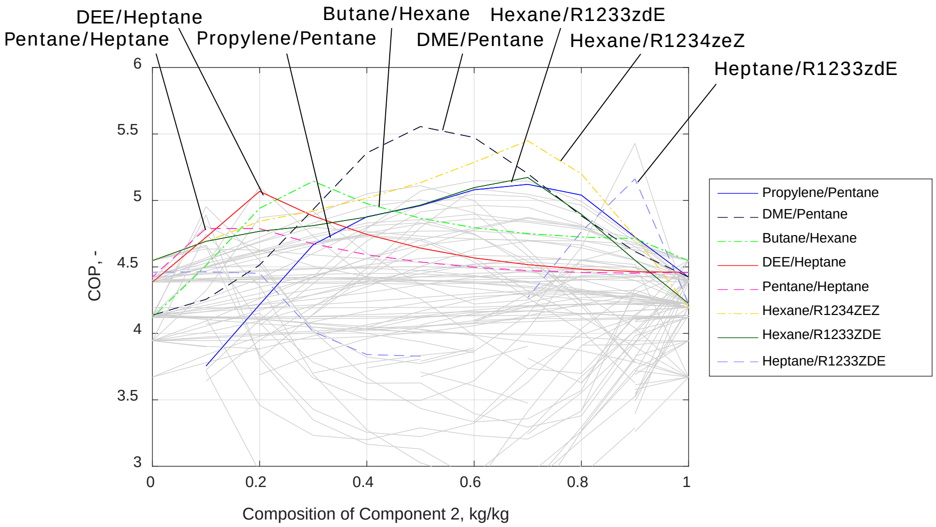
Working Fluid Screening: Results (5K SH)



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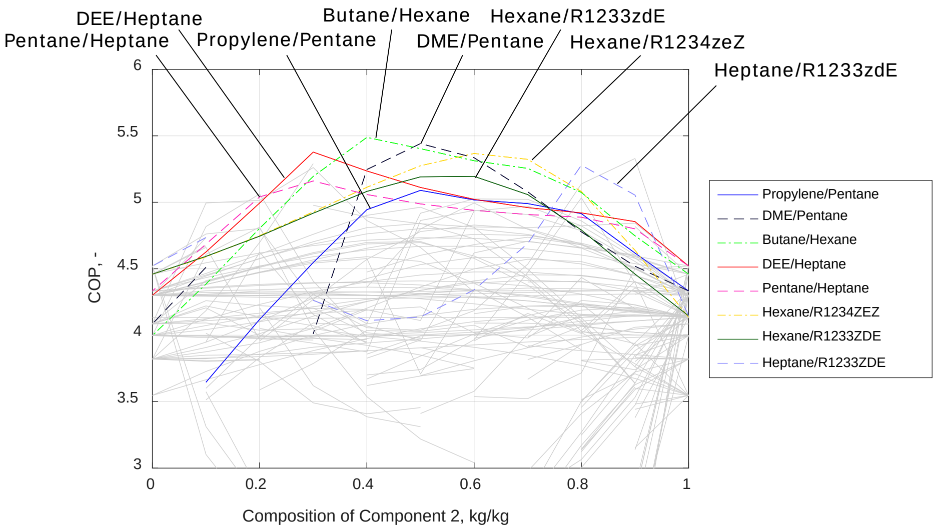
Working Fluid Screening: Results (no SH)



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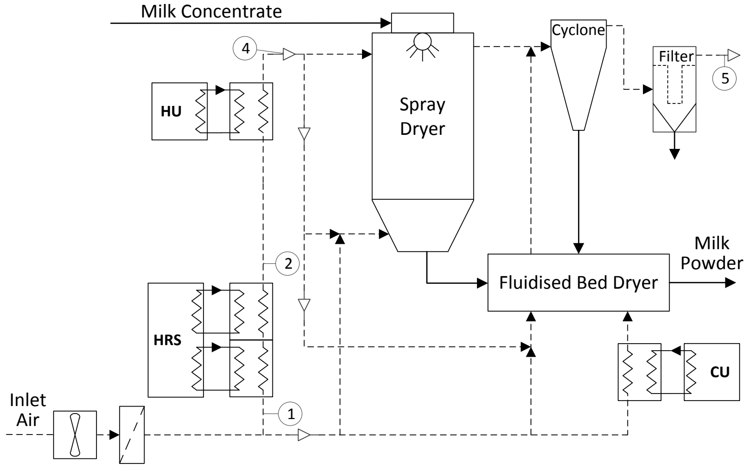
Case I:
Heat recovery at spray dryer (Arla)



	T [°C]	$\dot{m}$ [kg/s]
Drying Air		
1	15	43.7
2	70	43.7
4	210	43.7
Excess Air		
5	70	61.5

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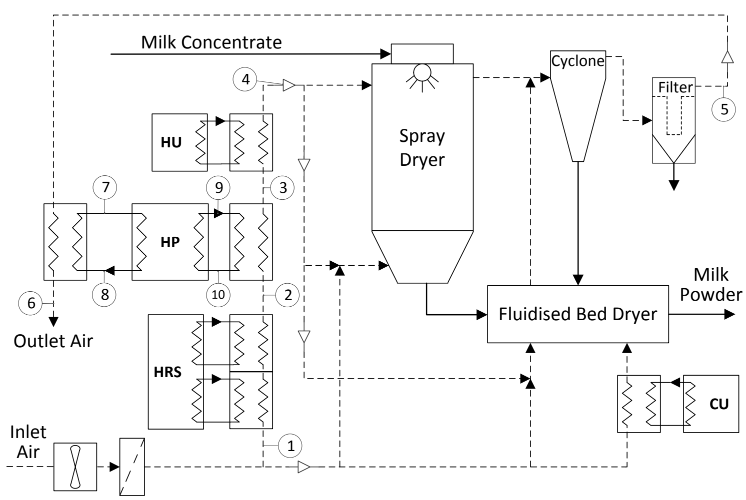
Case I:
Heat recovery at spray dryer (Arla)



	T [°C]	$\dot{m}$ [kg/s]
Drying Air		
1	15	43.7
2	70	43.7
3	125	43.7
4	210	43.7
Excess Air		
5	70	61.5
6	≈45	61.5
Secondary Cycle Source		
7	65	14.8
8	≈40	14.8
Secondary Cycle Sink		
9	75	10.6
10	130	10.6

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Case I: Heat recovery at spray dryer (Arla)

Heat Pump:

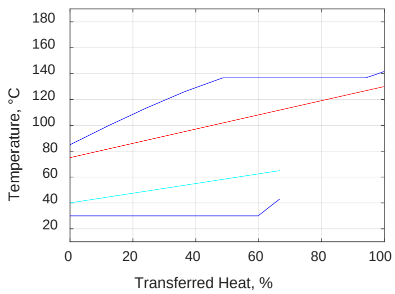
Heat Source: 65 °C → 40 °C, excess heat

Heat Sink: 75 °C → 130 °C, air preheating, $\dot{Q}_{sink} = 2.25$ MW

Butane

COP = 2.86, $V_{flow,Comp,in}$ = 3415 m3/h

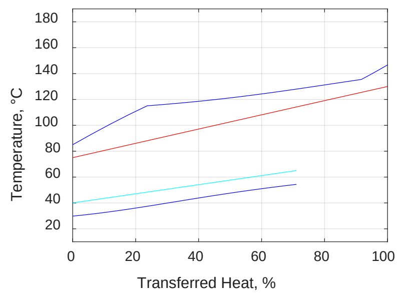
p_{evap} = 2.83 bar, p_{cond} = 29.5 bar



60 % DME / 40 % Pentane

COP = 3.28, $V_{flow,Comp,in}$ = 2135 m3/h

p_{evap} = 4.57 bar, p_{cond} = 31.7 bar



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Case II: Excess heat to DH

Heat Pump:

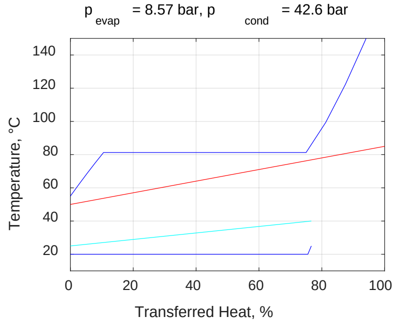
Heat Source: 40 °C → 25 °C, e.g. excess heat from air liquefaction process

Heat Sink: 50 °C → 85 °C, e.g. district heating (DH), $\dot{Q}_{sink} = 1$ MW

Ammonia

COP = 4.07, $V_{flow,Comp,in}$ = 410.6 m3/h

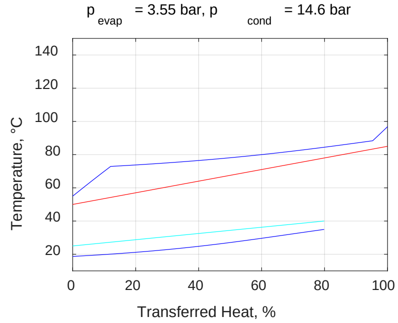
p_{evap} = 8.57 bar, p_{cond} = 42.6 bar



60 % DME / 40 % Isopentane

COP = 4.72, $V_{flow,Comp,in}$ = 1136 m3/h

p_{evap} = 3.55 bar, p_{cond} = 14.6 bar



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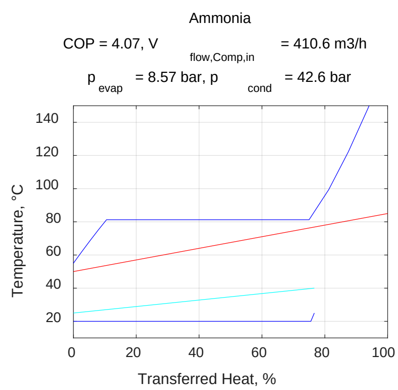
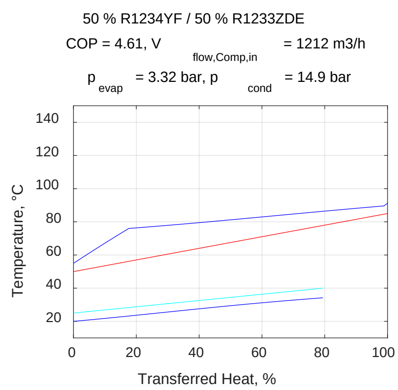
Case II:
Excess heat to DH

Heat Pump:

Heat Source: 40 °C → 25 °C, e.g. excess heat from air liquefaction process

Heat Sink: 50 °C → 85 °C, e.g. district heating (DH), $\dot{Q}_{sink} = 1$ MW





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Conclusions

- Utilization of mixtures:
  - Enhances range of applications for limited set of fluids
  - Possibility of matching temperature glides
  - Glide matching in evaporator has dominating influence
  - Reduction of superheating improves the glide match
  - Significant performance increase possible by use of mixtures
    - Case in introduction: COP = 4.12 → 5.49 **(+33 %)**
    - Case I (Spray Dryer): COP = 2.86/2.99 → 3.28 **(+10/15 %)**
    - Case II (DH): COP = 4.07 → 4.72 **(+16 %)**
- Future work:
  - Experimental validation at DTI: ThermCyc/MIREHP

3 Heat pump developments – Market ready products

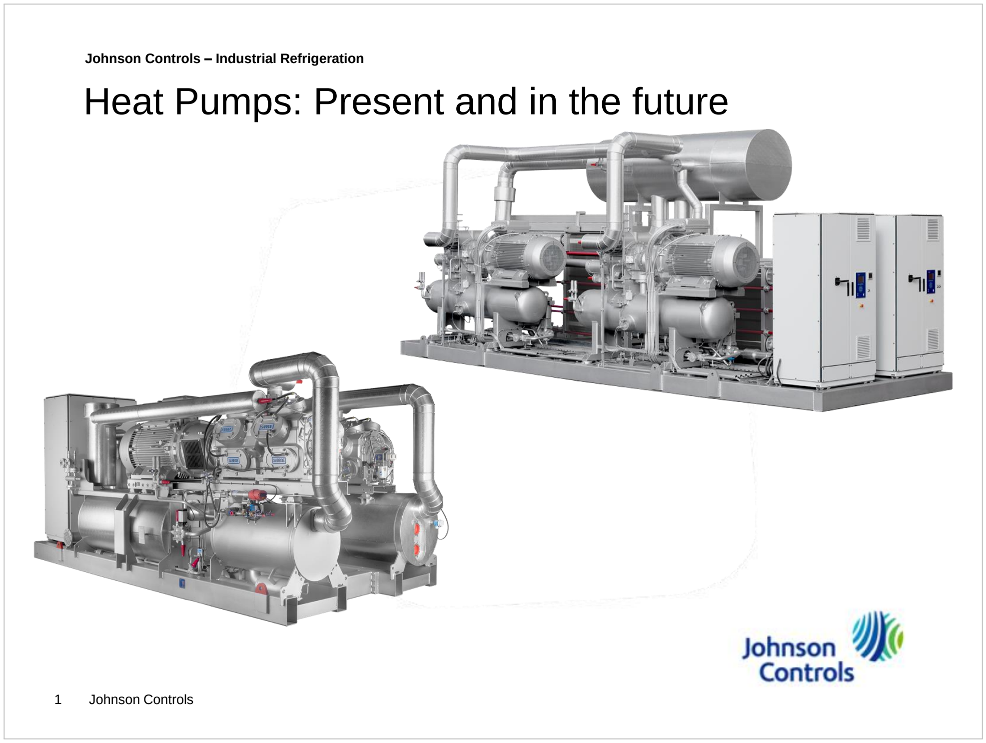
3.1 Industrial heat pumps: Present and in the future, Morten Deding (Johnson Controls)

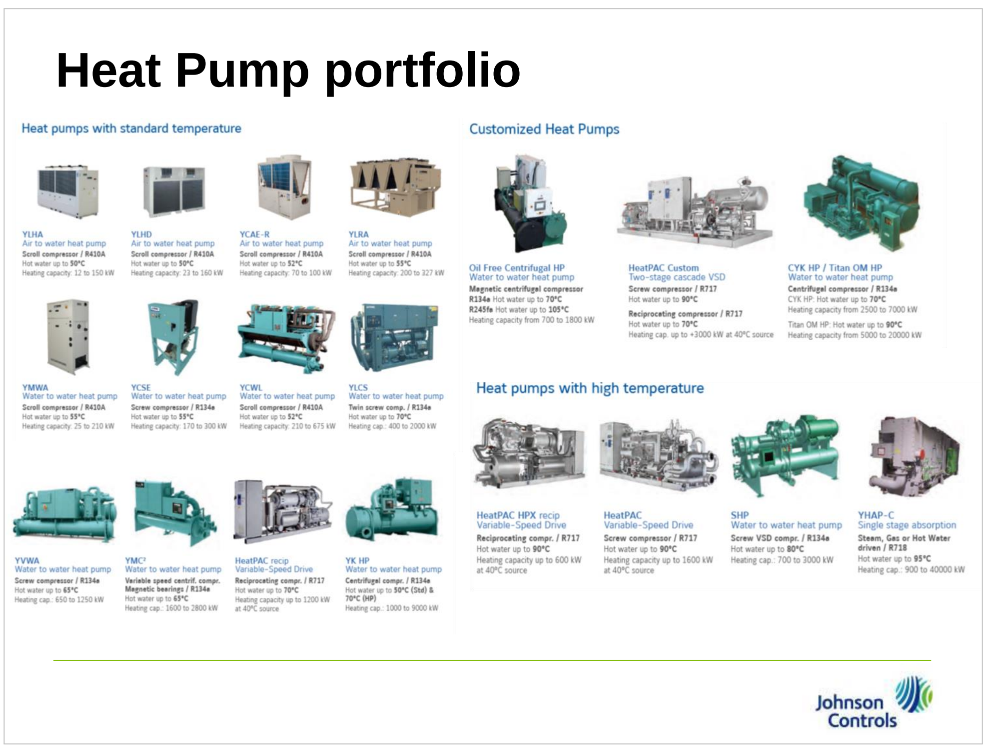
3.2 Temperature limitations for large ammonia heat pumps in district heating, Kenneth Hoffmann (GEA)

3.3 16 years with high temperature hybrid heat pumps, Bjarne Horntvedt (Hybrid Energy)

3.4 Steam compression and the development of a cost effective turbo compressor, Lars Reinholdt (DTI) & Michael Bantle (SINTEF)

3.5 Development and testing of HeatBooster, Mattias Nilsson (Viking Heat Engines)

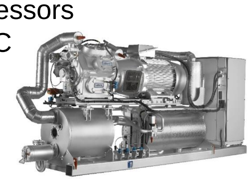

Johnson Controls – Industrial Refrigeration
Heat Pumps: Present and in the future
Johnson Controls
1
Johnson Controls


Heat Pump portfolio
Heat pumps with standard temperature
YLHA
Air to water heat pump
Scroll compressor / R410A
Hot water up to 50°C
Heating capacity: 12 to 150 kW
YLHD
Air to water heat pump
Scroll compressor / R410A
Hot water up to 50°C
Heating capacity: 23 to 160 kW
YCAE-R
Air to water heat pump
Scroll compressor / R410A
Hot water up to 52°C
Heating capacity: 70 to 100 kW
YLRA
Air to water heat pump
Scroll compressor / R410A
Hot water up to 55°C
Heating capacity: 200 to 327 kW
YMWA
Water to water heat pump
Scroll compressor / R410A
Hot water up to 55°C
Heating capacity: 25 to 210 kW
YCSE
Water to water heat pump
Screw compressor / R134a
Hot water up to 55°C
Heating capacity: 170 to 300 kW
YCWL
Water to water heat pump
Scroll compressor / R410A
Hot water up to 52°C
Heating capacity: 210 to 675 kW
YLCS
Water to water heat pump
Twin screw comp. / R134a
Hot water up to 70°C
Heating cap.: 400 to 2000 kW
YVWA
Water to water heat pump
Screw compressor / R134a
Hot water up to 65°C
Heating cap.: 650 to 1250 kW
YMC²
Water to water heat pump
Variable speed centrif. compr.
Magnetic bearings / R134a
Hot water up to 65°C
Heating cap.: 1600 to 2800 kW
HeatPAC recip
Variable-Speed Drive
Reciprocating compr. / R717
Hot water up to 70°C
Heating capacity up to 1200 kW
at 40°C source
YK HP
Water to water heat pump
Centrifugal compr. / R134a
Hot water up to 50°C (Std) &
70°C (HP)
Heating cap.: 1000 to 9000 kW
Customized Heat Pumps
Oil Free Centrifugal HP
Water to water heat pump
Magnetic centrifugal compressor
R134a Hot water up to 70°C
R245fa Hot water up to 105°C
Heating capacity from 700 to 1800 kW
HeatPAC Custom
Two-stage cascade VSD
Screw compressor / R717
Hot water up to 90°C
Reciprocating compressor / R717
Hot water up to 70°C
Heating cap. up to +3000 kW at 40°C source
CYK HP / Titan OM HP
Water to water heat pump
Centrifugal compressor / R134a
CYK HP: Hot water up to 70°C
Heating capacity from 2500 to 7000 kW
Titan OM HP: Hot water up to 90°C
Heating capacity from 5000 to 20000 kW
Heat pumps with high temperature
HeatPAC HPX recip
Variable-Speed Drive
Reciprocating compr. / R717
Hot water up to 90°C
Heating capacity up to 600 kW
at 40°C source
HeatPAC
Variable-Speed Drive
Screw compressor / R717
Hot water up to 90°C
Heating capacity up to 1600 kW
at 40°C source
SHP
Water to water heat pump
Screw VSD compr. / R134a
Hot water up to 80°C
Heating cap.: 700 to 3000 kW
YHAP-C
Single stage absorption
Steam, Gas or Hot Water
driven / R718
Hot water up to 95°C
Heating cap.: 900 to 40000 kW
Johnson Controls

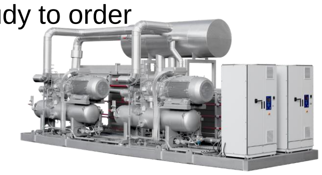
Present portfolio

Present products trends
Split in technology towards segment

- Traditional refrigeration segments
  - Single stage products on reciprocating compressors
  - Capacity <2MW and temperature 55-75-90° C
  - ROI/CAPEX is often the barrier
  - Heat pumps is not primary heat supply



- District heating segment
  - Large capacity above 10MW screws or centrifugal
  - Small capacity below 10MW two-stage reciprocating
  - 3-5 years project cycle from feasibility study to order
  - Temperature 72-85° C
  - Multiple running conditions
  - FAT +SAT test
  - Strict terms and conditions



4 Maj 2010 | Confidential and Proprietary

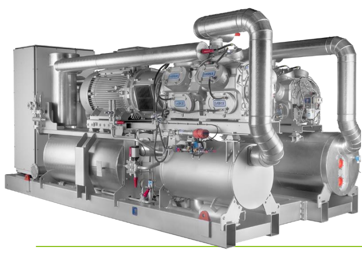
Johnson Controls

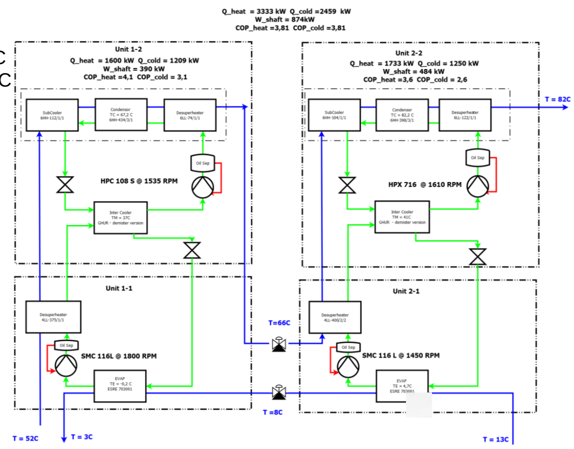
Kalundborg fjernvarme

Production of heating from cold sewage water:

6 pcs Dual PAC SMC108/HPX716 two-stage heat pumps

Design specifications	
Cold side	= +13° C / +3° C
Hot side	= +52° C / +82° C
Cooling capacity	= 7.380 kW
Heating capacity	= 10.000 kW
Power consumption	= 2622 kW
COP_{heat}	= 3,24

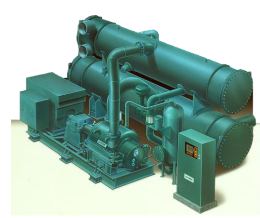




5

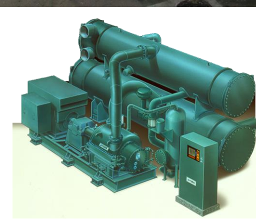
– ENERTHERM Heat Pump Case
District heating / cooling application in Paris La Defense

OM TURBO MASTER – Heat Pump
Industrial HP **(combined chilling and heating)**
Heating capacity 11.3 MW 800 m3/h from 77.5° C to 90° C Cooling capacity 7.3 MW 780 m3/h from 12° C to 4° C Absorbed Power 4.2 MW COP: 4.4 (11.3 + 7.3) / 4.2
•York Multi stage compressor : M 438 (4 stages compression) • Motor : 4.5 MW - 6KV - 1450 rpm – Soft starter • Gear Box: 1 450 to 5 400 rpm • 3 Interstages cooling for thermodynamic cycle efficiency • Integrated sub cooler • Shell & Tube condenser (CS plain tubes) • Shell & Tubes evaporator (enhanced copper tubes) •Weight : Empty 90 T Operating 113 T • MWP water side 23 barg Refrigerant side 41.3 barg



7

ENERTHERM Heat Pump Case
District heating / cooling application in Paris La Defense



Johnson Controls

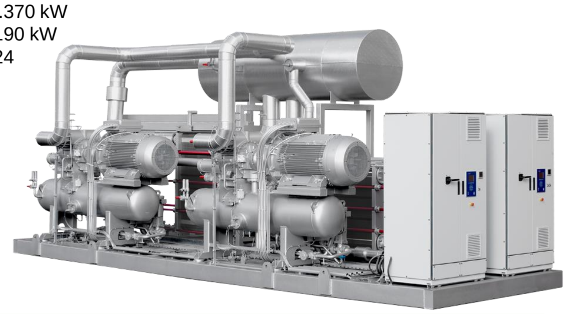
Vestmanner Iceland

Production of heating from cold seawater:

4 stk. Twin Heat PAC 193S single-stage heat pumps Sabroe
Single stage cycle with economizer

Design specifications

Cold side	= +6/+2° C
Hot side	= +38/+77° C
Cooling capacity	= 7.370 kW
Heating capacity	= 10.370 kW
Power consumption	= 3.190 kW
COP_{heat}	= 3,24



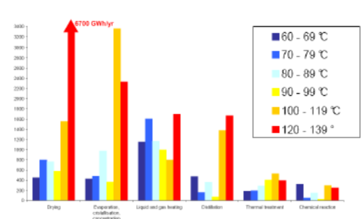
8

Johnson Controls

Product pipeline

Future products trends

- Traditional refrigeration segments
  - Bring down running cost and improve service life
  - Lot of heating demands at 100-150 ° C
  - Steam re-compression
  - Reduce charge



- District heating segment
  - Waste heat from industry
  - Low GWP and Natural refrigerants preferable
  - Low charge
  - High temperatures for transmission circuits >85° C

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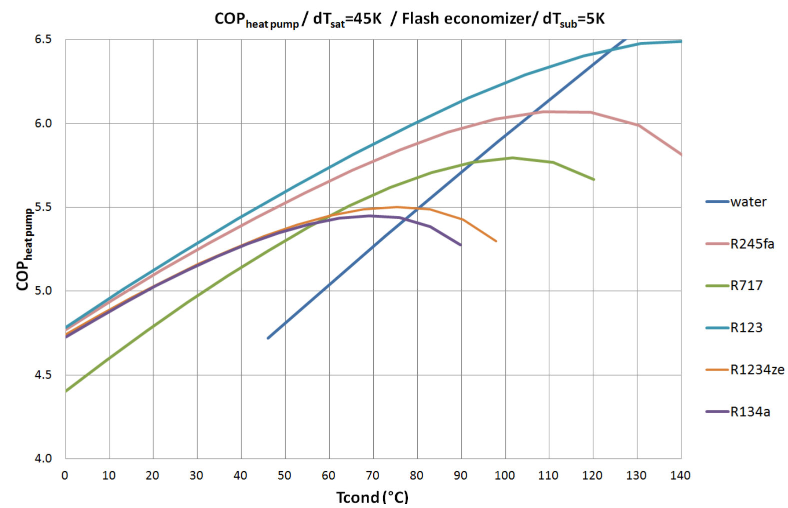
Refrigerants for all temperature levels



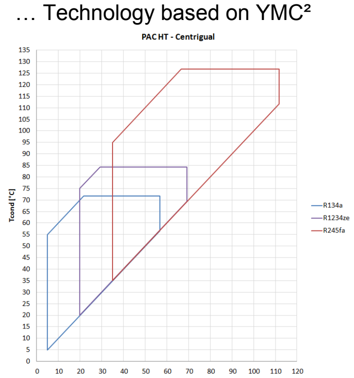
11

Johnson Controls

« Valenthin » project

VALorisation
ENergétique des rejets
THermiques
INdustriels

⇒ Evaporation up to 110ºC
⇒ Condensation up to 125ºC
⇒ Capacity: 800kW to 10MW
⇒ R245fa
… Technology based on YMC²



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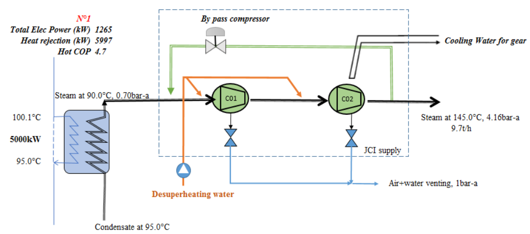
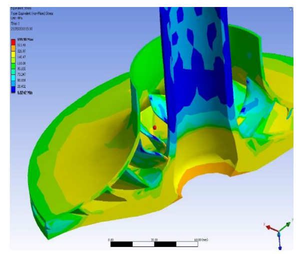
PACO2 project
Steam re-compression

⇒Evaporation 90 - 110ºC
⇒Condensation up to ~150ºC
⇒25K per stage
⇒Capacity: 1000kW to 3MW
… Technology based on YK
R718





3

Johnson Controls

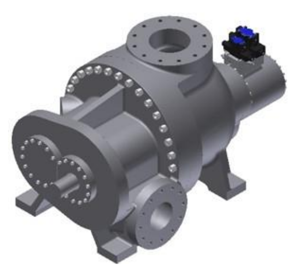
Screw compressors next generation
HPSH 2709+2712

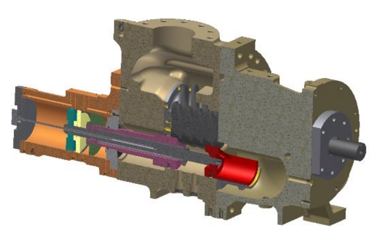
Business Opportunity

- Heat pumps for Europe – ammonia refrigerant
- Fuel gas booster compressor feeding natural gas to power generation turbines
- Process gas compression for higher pressures
- District heating Europe or Asia

Product Description

- High pressure screw compressor with 273 mm rotor diameter
- Max water temp ~ 195 ° F / (95 ° C)
- Targeting 1300 psi (90bar) discharge / 1000 psi (69bar) suction

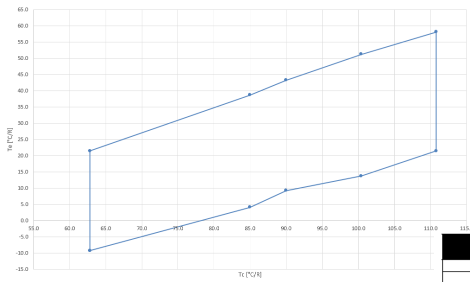




Johnson Controls

Screw compressors

HPSH 2709+2712



L/D	Pressure	English	Metric
all	Design (psig); (barg)	1300	90
0.9	Disch. max (psia); (bar)	900	62
1.2	Disch. max (psia); (bar)	800	55
0.9	Suction max. (psia); (bar)	675	47
1.2	Suction max. (psia); (bar)	600	41

	HPS SERIES MODEL				
	1510	2709		2712	
Approx. Compressor Weight	810 lb (367 kg)	4,700 lb (2,132 kg)		4,940 lb (2,241 kg)	
Rotor Diameter	157 mm	273 mm			
Drive Arrangement	Directly driven by the male rotor in the clockwise direction as viewed from the driver				
Minimum Driver Speed(1)(2)	600(1)(2) RPM				
Maximum Driver Speed	6,000 RPM	3,600 RPM			
Minimum Breakaway Torque	7 ft-lb (9.5 Nm)	[illegible] ft-lb (24.4 Nm)			
Mass Moment of Inertia(3) ft²-lbm (m²-kg)	1.63 (0.069)(3)	19.5 ([illegible]82)(3)		26.0 (1.10)(3)	
Suction Flange	4 in. (102 mm)	8 in. (203 mm)			
Discharge Flange	3 in. (76 mm)	6 in. (152 mm)			
Theoretical Displacement (7)	0.05847 (.0016[illegible]	0.27428 (.007767)		0.36570 (.010355)	
Displacement at 3550 rpm Driver Speed (8)	207.6 (35[illegible]	974 (1,655)		1,298 (2,206)	
Displacement at 2950 rpm Driver Speed (8)	[illegible]	809 (1,375)		1,079 (1,833)	
Displacement at 1750 rpm Driver Speed (8)	[illegible]	480 (816)		640 (1,088)	
Displacement at 1450 rpm Driver Speed (8)	[illegible] (144.4)	398 (676)		530 (901)	
Capacity Control	From [illegible] to 600 RPM (6)	Infinitely adjustable from 100% to approx. 15% (9)			
Volume Ratio	Fixed: 1.4, 1.7, 2.2, 2.85, 4.0	3 Ranges: 1.3 to 1.96 / 1.7 to 3.0 / 2.2 to 5.0			
		HPSB	HPSH	HPSB	HPSH
Maximum Inlet Operating Pressure (4)	363 psia (25 bara) (4)	935.0 psia (64.5 bara)(4)	630 psia (43.4 bara)(4)	935.0 psia (64.5 bara)(4)	630 psia (43.4 bara)(4)
Maximum Outlet Operating Pressure (4)	725 psia (50 bara) (4)	1,100 psia (75.8 bara)(4)	900 psia (62 bara)(4)	1,100 psia (75.8 bara)(4)	900 psia (62 bara)(4)
Design Working Pressure	970 psia (67 bara)	1,300 psia (90 bara)			

Preliminary

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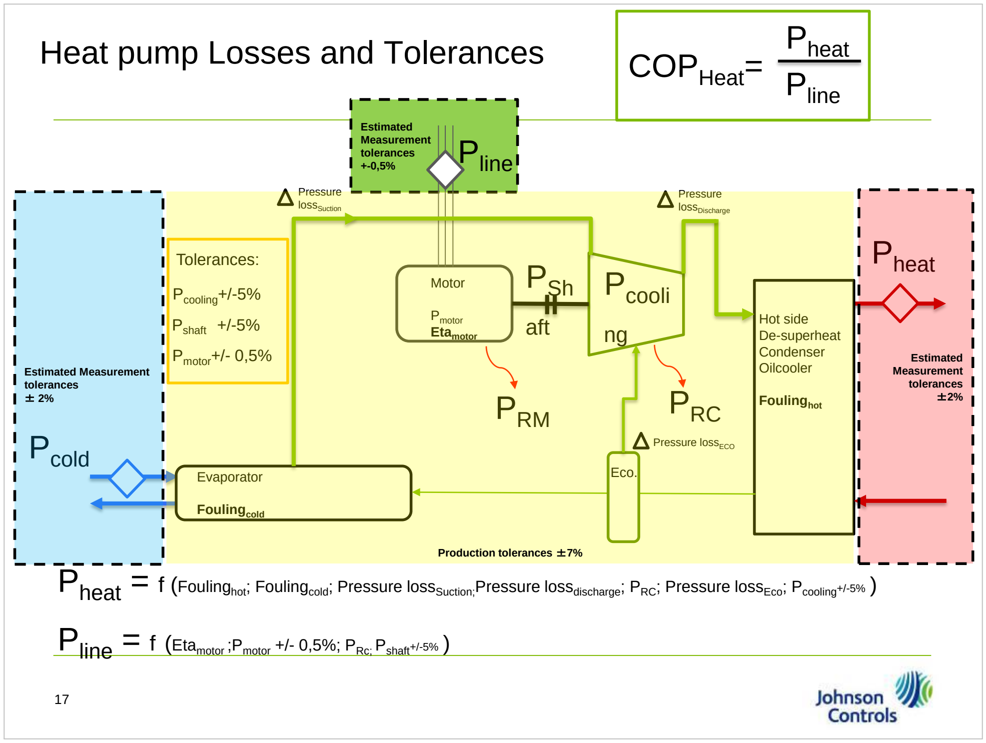
On-site performance


Heat pump Losses and Tolerances
COP_Heat = P_heat / P_line
Estimated Measurement tolerances +-0,5%
P_line
Δ Pressure loss_Suction
Δ Pressure loss_Discharge
Tolerances:
P_cooling +/-5%
P_shaft +/-5%
P_motor +/- 0,5%
Motor
P_motor
Eta_motor
P_Shaft
P_cooling
P_RM
P_RC
Δ Pressure loss_ECO
Hot side
De-superheat
Condenser
Oilcooler
Fouling_hot
P_heat
Estimated Measurement tolerances ±2%
Estimated Measurement tolerances ± 2%
P_cold
Evaporator
Fouling_cold
Eco.
Production tolerances ±7%
P_heat = f (Fouling_hot; Fouling_cold; Pressure loss_Suction; Pressure loss_discharge; P_RC; Pressure loss_Eco; P_cooling +/-5%)
P_line = f (Eta_motor; P_motor +/- 0,5%; P_RC; P_shaft +/-5%)
17
Johnson Controls


Heat pump Losses and Tolerances
Capacity and Performance
Heat capacity each unit, kW
Preliminary
COP heat
Preliminary
Water inlet temperature evaporator, °C
18
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Temperature limitations for large ammonia heat pumps in district heating

KENNETH HOFFMANN, SEPTEMBER, 2017

GEA engineering for a better world

Why do we need heat pumps in district heating

GEA engineering for a better world

- Why burn gas at 600^0C to create 21^0C in your home – Waste of exergy
- Decarbonisation of electricity grid makes heat pumps a zero carbon heat source
- Heat pumps is the most efficient use on natural energy source.
- Sustainable biomass only harness 1% of the solar energy
- Using seawater, sewage water, waste water, ground source water, cooling tower water etc, gives high efficient heating all year, independent on ambient temperature.
- Proven technology, competitive investment
- District heating / District cooling is key to improved energy optimisation for carbon neutral EU by 2050
- District heating converting from steam to water based system across Europe
- Temperatures of network at getting reduced each year.

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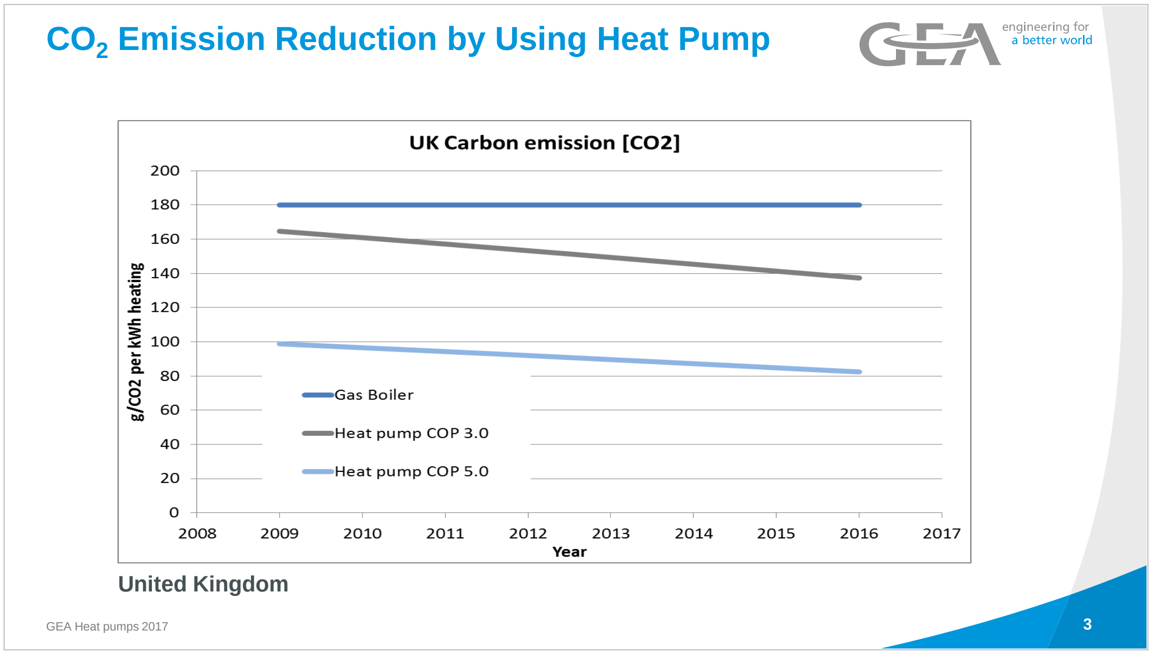
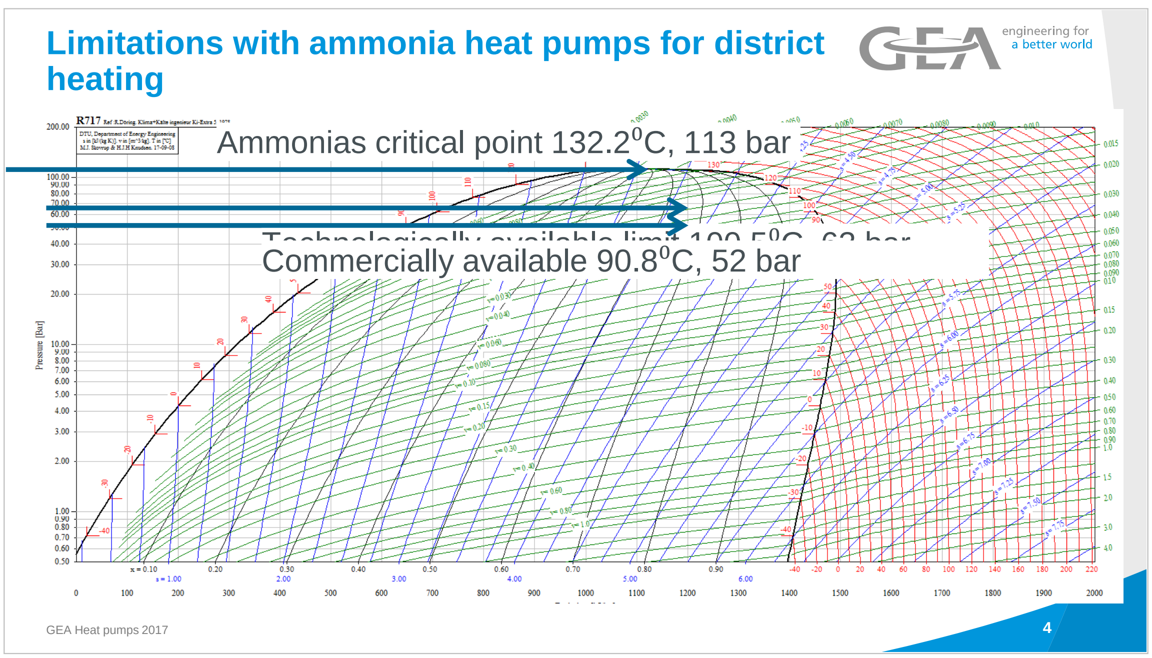

CO₂ Emission Reduction by Using Heat Pump
engineering for a better world
UK Carbon emission [CO2]
g/CO2 per kWh heating
200
180
160
140
120
100
80
60
40
20
0
Gas Boiler
Heat pump COP 3.0
Heat pump COP 5.0
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Year
United Kingdom
GEA Heat pumps 2017
3


Limitations with ammonia heat pumps for district heating
engineering for a better world
Ammonias critical point 132.2⁰C, 113 bar
Commercially available 90.8⁰C, 52 bar
R717
Pressure [Bar]
GEA Heat pumps 2017
4

Old PED limitations when using ammonia screw compressors

engineering for a better world

- For 52 bar ammonia heat pump PED describes that a 10% margin is required

52 bar -10% = 46.8 bar (86.7^{0}C) – set point for safety valve

45.8 bar (85.7^{0}C) Internal safety valve

45.3 bar (85.2^{0}C) alarm

44.3 bar (84.1^{0}C) compressor limiting

= Maximum design point: 83^{0}C condensing pressure

= 80 - 82^{0}C hot water from heat pump

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New PED limitations when using ammonia screw compressors

engineering for a better world

- For 52 bar ammonia heat pump PED describes that a less than 10% margin is required by applying good safety device

52 bar -10% = 50.5 bar (90.3^{0}C) – set point for safety valve

49.0 bar (88.8^{0}C) Internal safety valve

48.5 bar (88.4^{0}C) alarm

48.0 bar (87.9^{0}C) compressor limiting

= Maximum design point: 87^{0}C condensing pressure

= 85^{0}C hot water from heat pump

Commercial range of ammonia heat pumps have now increased to supply temperature of 85^{0}C

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Small district heating schemes

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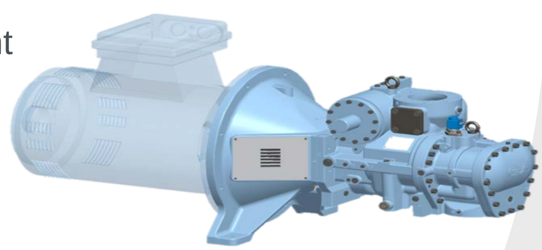
GEA M-screw compressor

engineering for a better world

- Greatly improved efficiency in part load and full load
- New valves with lower pressure drop
- Wider speed range enables 1000 - 4500 rpm screw packages
- Larger Vi range enables higher efficiency
- 5 – 7% efficiency improvement

Now in 52 bar design



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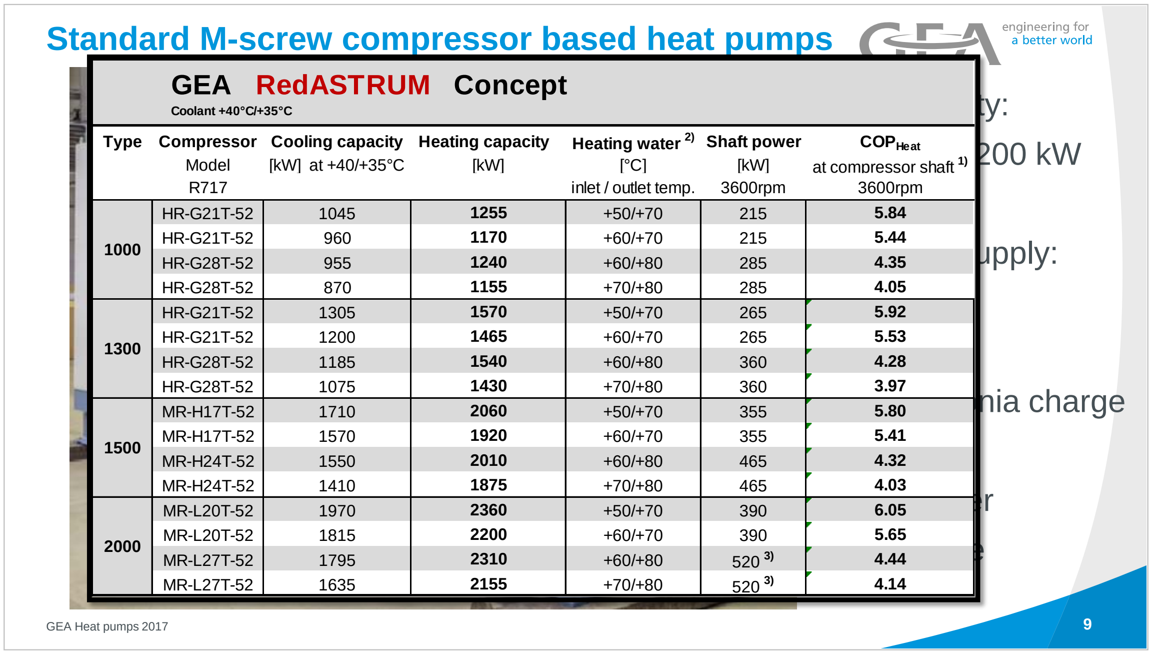
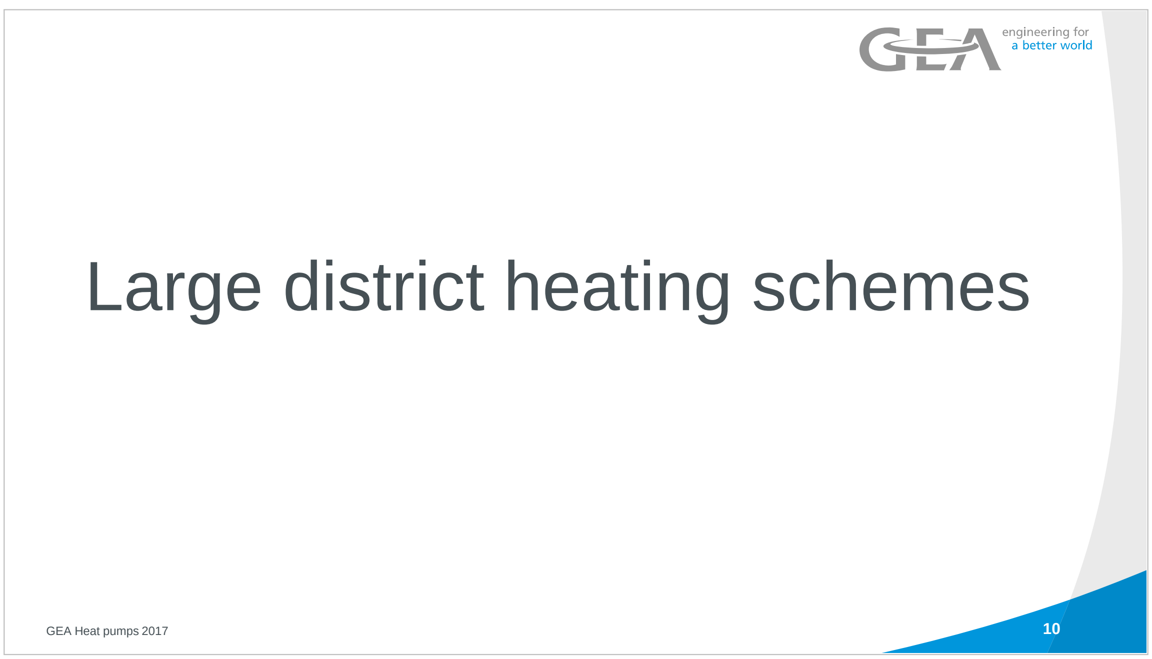
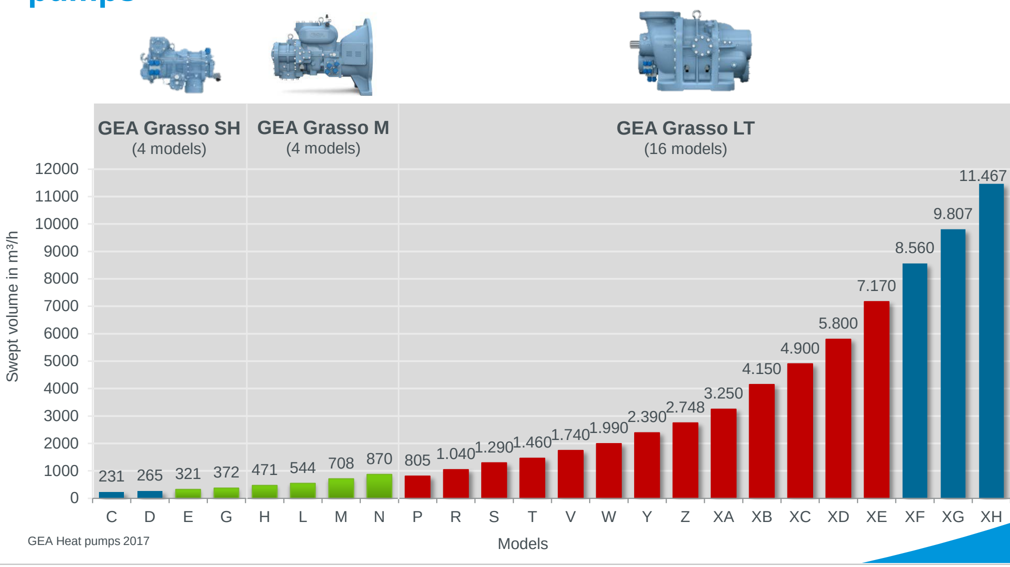


Type	Compressor Model R717	Cooling capacity [kW] at +40/+35°C	Heating capacity [kW]	Heating water [2] [°C] inlet / outlet temp.	Shaft power [kW] 3600rpm	COP_{Heat} at compressor shaft [1] 3600rpm
1000	HR-G21T-52	1045	**1255**	+50/+70	215	**5.84**
	HR-G21T-52	960	**1170**	+60/+70	215	**5.44**
	HR-G28T-52	955	**1240**	+60/+80	285	**4.35**
	HR-G28T-52	870	**1155**	+70/+80	285	**4.05**
1300	HR-G21T-52	1305	**1570**	+50/+70	265	**5.92**
	HR-G21T-52	1200	**1465**	+60/+70	265	**5.53**
	HR-G28T-52	1185	**1540**	+60/+80	360	**4.28**
	HR-G28T-52	1075	**1430**	+70/+80	360	**3.97**
1500	MR-H17T-52	1710	**2060**	+50/+70	355	**5.80**
	MR-H17T-52	1570	**1920**	+60/+70	355	**5.41**
	MR-H24T-52	1550	**2010**	+60/+80	465	**4.32**
	MR-H24T-52	1410	**1875**	+70/+80	465	**4.03**
2000	MR-L20T-52	1970	**2360**	+50/+70	390	**6.05**
	MR-L20T-52	1815	**2200**	+60/+70	390	**5.65**
	MR-L27T-52	1795	**2310**	+60/+80	520 [3]	**4.44**
	MR-L27T-52	1635	**2155**	+70/+80	520 [3]	**4.14**



Screw compressors used for ammonia heat pumps

engineering for a better world



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Large Heat pump references

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Project	Date	Country	Temperature (Chilled water flow / hot water flow)	Heating capacity	COP_H
Fynsvaerket	2008-06	DK	+30°C / +55°C	2,815 kW	7.20
Copenhagen Towers	2008-10	DK	+10°C / +60°C	2,955 kW	4.51
Tetra Pak 2	2009-12	SWE	+25°C / +70°C	1,430 kW	4.47
Sarpsborg	2010-01	NO	+27°C / +80°C	2,000 kW	3.81
Nestlé Biessenhofen 2	2010-01	GER	+30°C / +70°C	1,170 kW	4.88
Valldal Fjernvarme	2011-01	NO	+1°C / +70°C	1,285 kW	2.60
Skagerak Energi	2011-09	NO	-2°C / +70°C	1,225 kW	3.02
Bio Energi	2011-12	CZ	+28°C / +80°C	4,090 kW	4.93
Unilever	2011-12	NL	+17°C / +68°C	1,416 kW	5.32
Sogndal 1	2012-06	NO	-2°C / +68°C	2,450 kW	3.03
Brista	2012-08	SWE	+31°C / +65°C	7,250 kW	6.51
Sarpsborg II	2012-07	NO	+20°C / +80°C	3,080 kW	3.05
Kalnes Energisentral	2012-12	NO	-10°C / +56°C	1,250 kW	2.45
NTNU	2013-07	NO	+4°C / +81°C	1,315 kW	2.64
Holmen	2014-07	NO	+27°C / +71°C	2,450 kW	5.79
HP Oatly	2014-07	SWE	+7°C / +78°C	560 kW	3.11
Kronoply	2015-01	GER	+30°C / +83°C	4,500 kW	4.70
Vietnam	2016-06	VTN	+6°C / +60°C	12,000 kW	4.62
Copenhagen Markets	2016-06	DK	+6°C / +75°C	3,200 kW	3.05
EON Malmoe	2017-10	SWE	+8 / +66°C	40,000 kW	3.50

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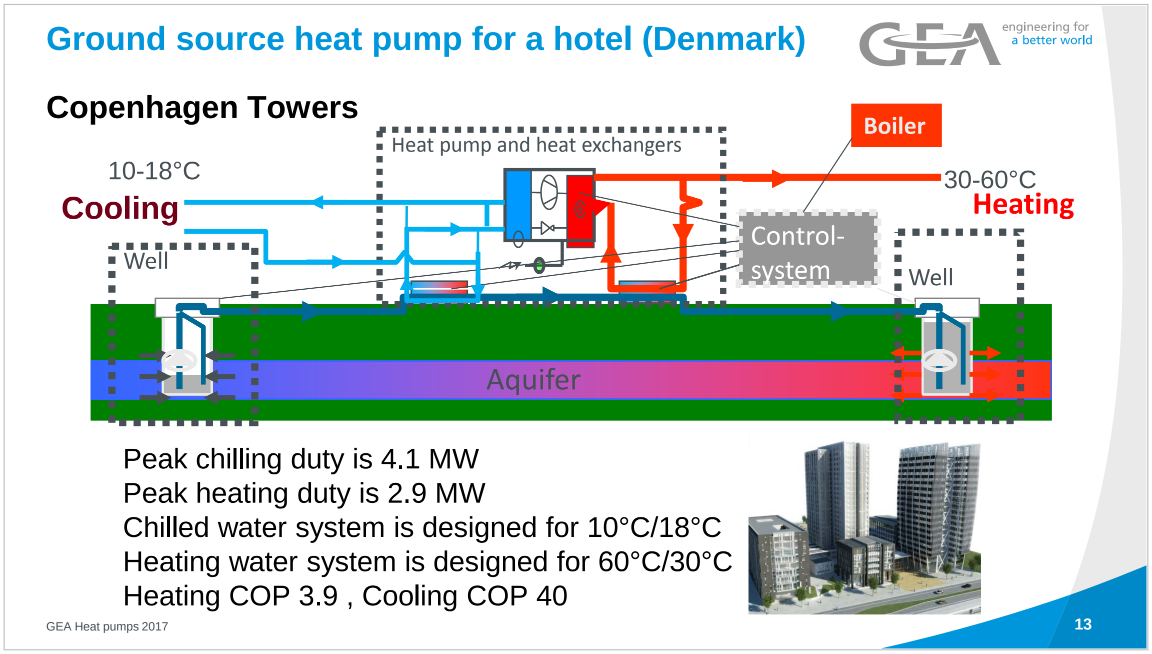
Ground source heat pump for a hotel (Denmark)
GEA engineering for a better world
Copenhagen Towers
Heat pump and heat exchangers
Boiler
10-18°C
Cooling
30-60°C
Heating
Control-system
Well
Well
Aquifer
Peak chilling duty is 4.1 MW
Peak heating duty is 2.9 MW
Chilled water system is designed for 10°C/18°C
Heating water system is designed for 60°C/30°C
Heating COP 3.9 , Cooling COP 40
GEA Heat pumps 2017
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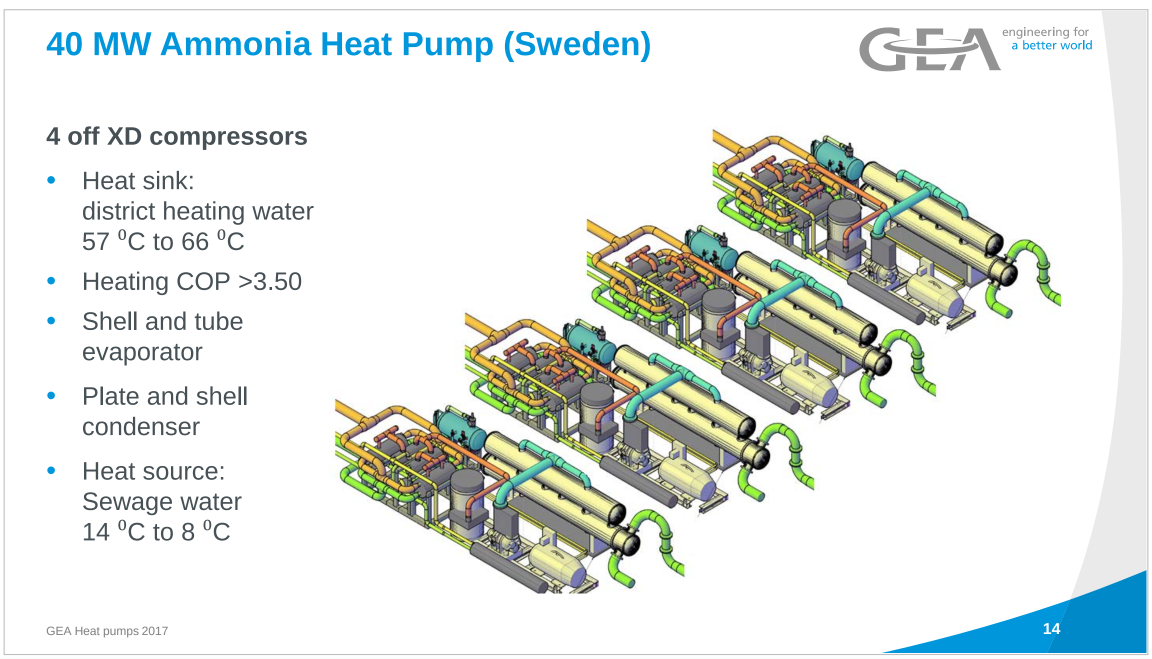
40 MW Ammonia Heat Pump (Sweden)
GEA engineering for a better world
4 off XD compressors
• Heat sink: district heating water 57 °C to 66 °C
• Heating COP >3.50
• Shell and tube evaporator
• Plate and shell condenser
• Heat source: Sewage water 14 °C to 8 °C
GEA Heat pumps 2017
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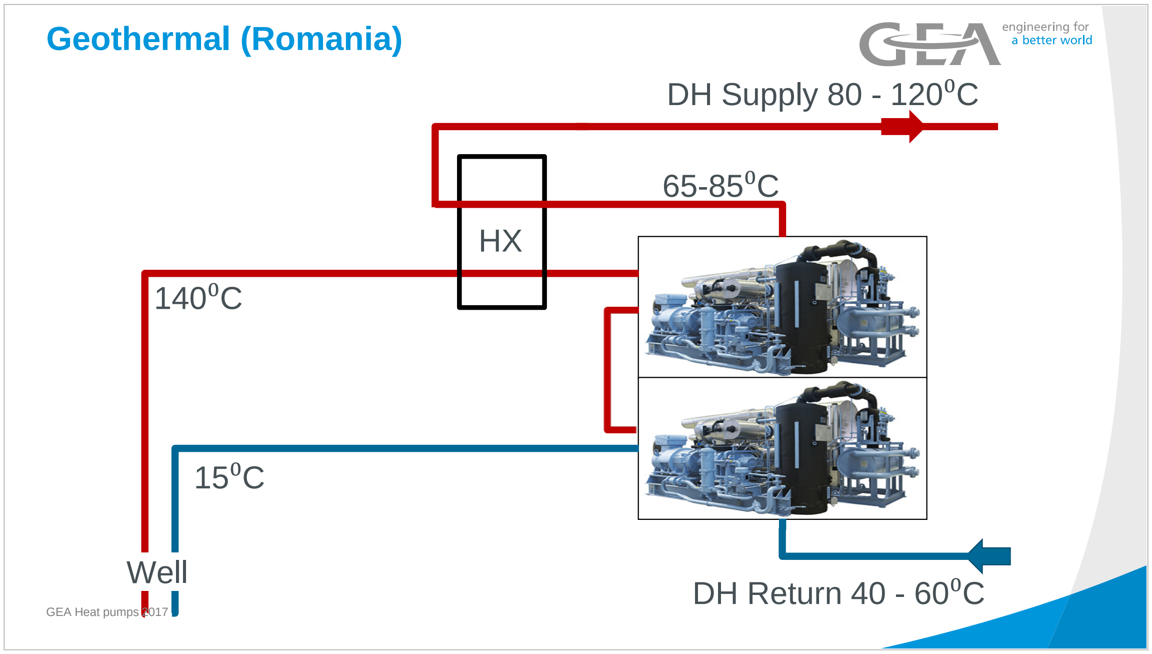
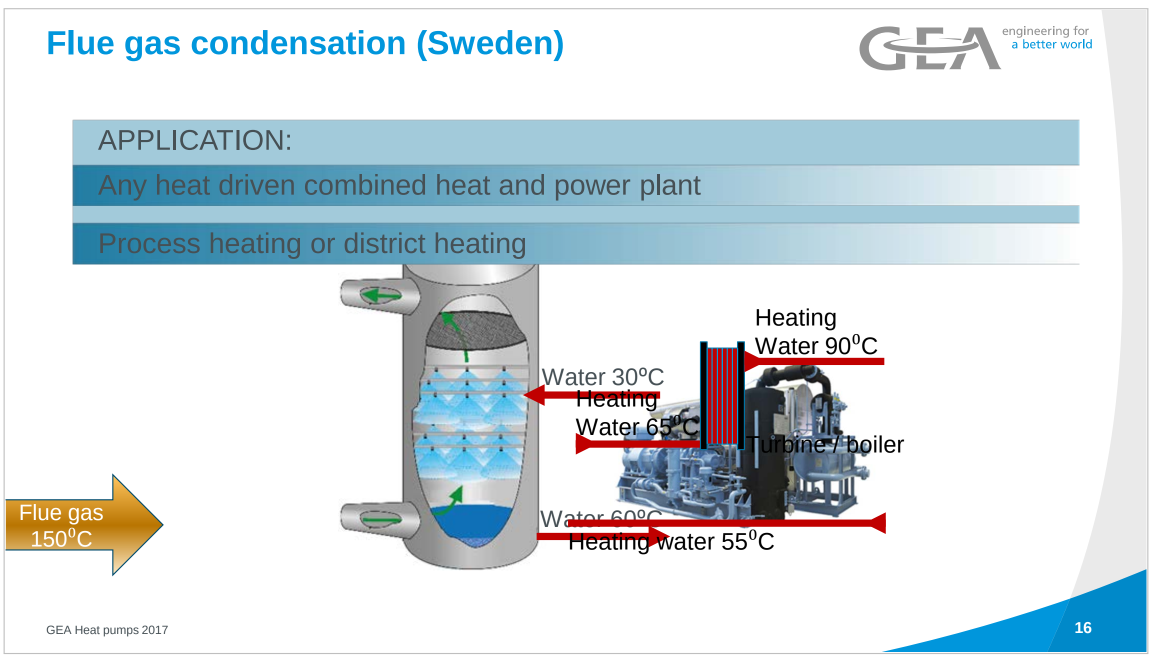

Geothermal (Romania)
GEA engineering for a better world
DH Supply 80 - 120^{0}C
65-85^{0}C
HX
140^{0}C
15^{0}C
Well
DH Return 40 - 60^{0}C
GEA Heat pumps 2017


Flue gas condensation (Sweden)
GEA engineering for a better world
APPLICATION:
Any heat driven combined heat and power plant
Process heating or district heating
Heating
Water 90^{0}C
Water 30ºC
Heating
Water 65^{0}C
Turbine / boiler
Flue gas
150^{0}C
Water 60ºC
Heating water 55^{0}C
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Conclusion

GEA engineering for a better world

1. Heat pumps only need a **little electrical energy** to raise the temperature of the waste heat to useful level.
2. By using heat pumps the decarbonisation of the electricity grid will ensure **future reduction in CO_2 emissions**.
3. Using water based heating system instead of steam makes implementation of **heat pumps cheaper and improve efficiency**.
4. It is now possible to achieve **85°C water with a 52bar** design heat pump
5. Large heat pumps in the building services sector can help communities **reach their zero emission targets**

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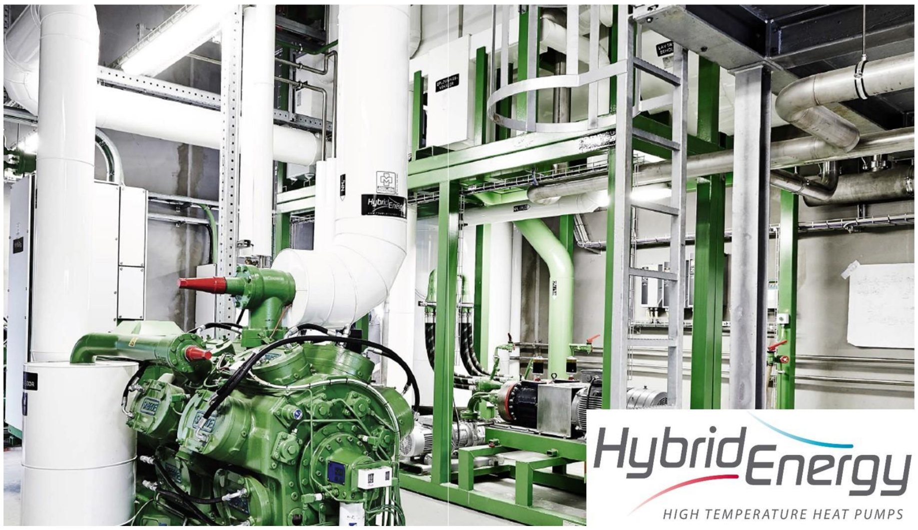
17



Bjarne Horntvedt - CEO

Our Challenge at the start

Selling expensive, unfamiliar technology, replacing an existing energy solution in a field of business often characterized by optimistic, half-baked technologies.

HybridEnergy
HIGH TEMPERATURE HEAT PUMPS

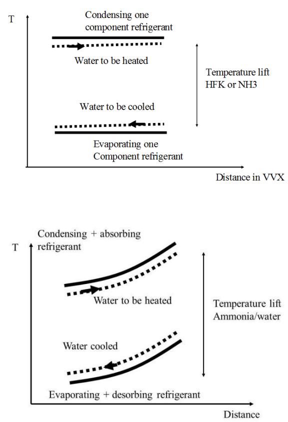
The Company: History

- Founded in 2004
- Institute for Energy Technology (IFE) in Norway
- Commissioned plants in dairies, slaughter houses, fish feed producers, bio gas production plants, district heating and process industries
- More than 400.000 hours economic running in industry – equal to 46 years continues running

The Technology: What is a Hybrid Heat Pump?

- Natural working medium (50/50 water and ammonia)
- Uses Standard refrigeration equipment for ammonia
- Can deliver 120 °C at low pressure (25 bar)
- Offers unique flexibility <u>after</u> commissioning (by changing mixing ratio and circulation number)
- Yields exceptional COP's, especially with large glides (Δt's) on hot and cold side

The Technology: COP – Carnot vs. Lorenz



No.	Heat Source	Heat Sink	COP_{carnot}	COP_{lorenz}
A	8 > 4	85 > 95	4.0	4.3
B	40 > 15	60 > 90	4.8	7.3
C	25 > 20	70 > 110	4.3	5.4
D	80 > 20	85 > 90	5.2	9.4
E	55 > 20	50 > 90	5.2	10.5

- COP_{Carnot}: Constant temperature heat source and sink
- COP_{Lorenz}: Heat source and sink with glide

HybridEnergy

Experiences: Commercial Challenges

- Significant CAPEX
- Elaborate and complex procurement and decision making processes
- Technological skepticism
- Small company

HybridEnergy

Experiences: Solutions

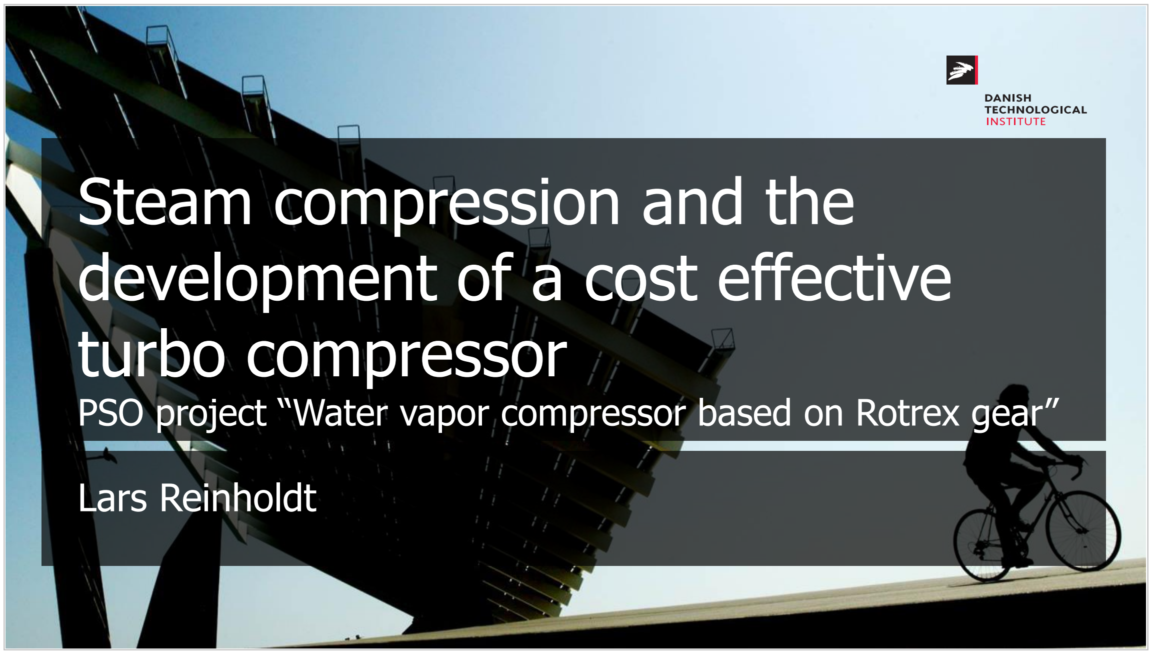
- Holistic approach to the total energy system
- Tailor made solutions
- Project ownership & user commitment
- High commercial focus, strong sales organization
- Bold and competent partners

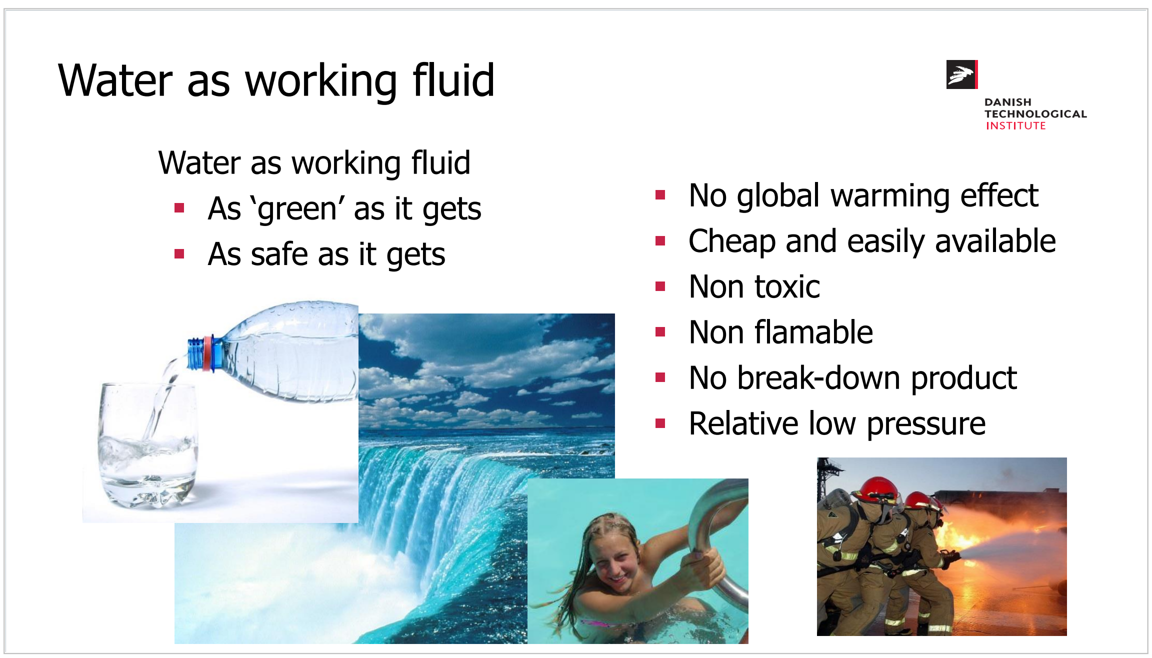
Hybrid Energy

16 years, where are we?

- Hybrid Energy have most experience by tailor fitting high temperature heat pumps into industrial processes.
- Generation 3 hybrid heatpump with water/ammonia optimizes COP at different running conditions.
- Just delivered largest ever hybrid heat pump unit commissioned in Norway in 2017 at Borregaard (2 MW).
- First installation in the French dairy market will be commissioned this fall (2017) in cooperation with our strategic partner Engie Axima in France.
- Green shift offers new possibilities
- Increased environmental commitments in blue-chip companies
- Increased awareness among consultants about existing well proven and market ready solutions for high temperature heat pumps.

Hybrid Energy


DANISH TECHNOLOGICAL INSTITUTE
Steam compression and the development of a cost effective turbo compressor
PSO project “Water vapor compressor based on Rotrex gear”
Lars Reinholdt


Water as working fluid
DANISH TECHNOLOGICAL INSTITUTE
Water as working fluid
As ‘green’ as it gets
As safe as it gets
No global warming effect
Cheap and easily available
Non toxic
Non flamable
No break-down product
Relative low pressure

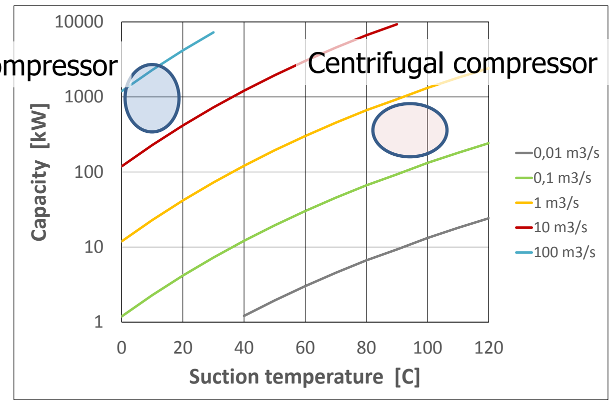
Water as working fluid

DANISH TECHNOLOGICAL INSTITUTE

Physical properties

- Low working pressure
  - 60°C: 0.2 bar a
  - 85°C: 0.6 bar a
  - 100°C: 1 bar a
  - 120°C: 2 bar a
  - 180°C: 10 bar a
- High heat of evaporation
  - ~2200 kJ/kg @ 100°C

Swept volume

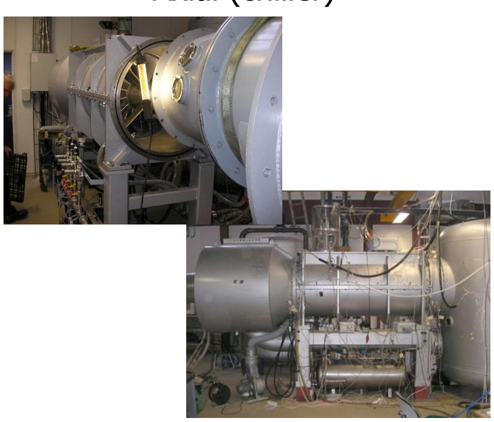


Water Vapor Compressor

DANISH TECHNOLOGICAL INSTITUTE

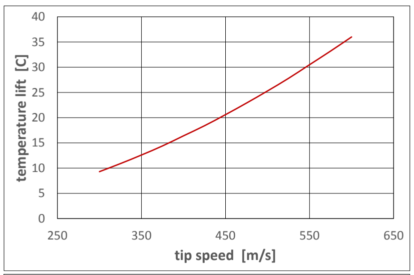
- Two types of prototype turbocompressors developed

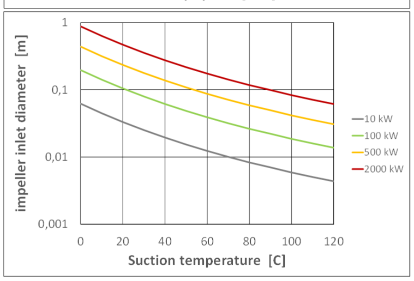
Axial (chiller)

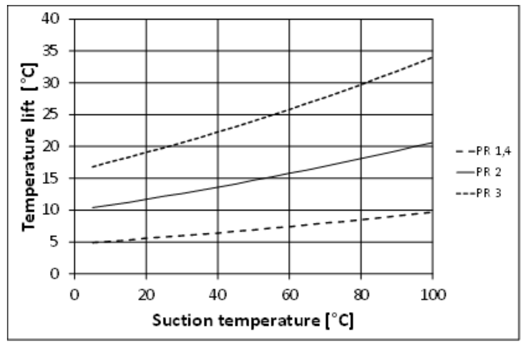


Centrifugal (HP)

Turbo compressor: Design base





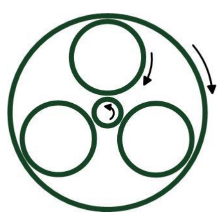


Different optimal design for different application

Cost effective radial air compressor

Rotrex planetary gear

How it works:



Programme:

C8: 240.000 rpm - 5 kW input power
C15: 200.000 rpm - 15 kW input power
C30: 120.000 rpm - 30 kW input power
C38: 90.000 rpm - 50 kW input power

Compressor design

DANISH TECHNOLOGICAL INSTITUTE

PSO project no. 344-009 ”Water vapor compressor based on Rotrex gear”

- DTI, Rotrex, Weel & Sandvig, Spirax Sarco, Xvaporator, Union Engineering, Johnson Controls Denmark

- Specifications by the project group:

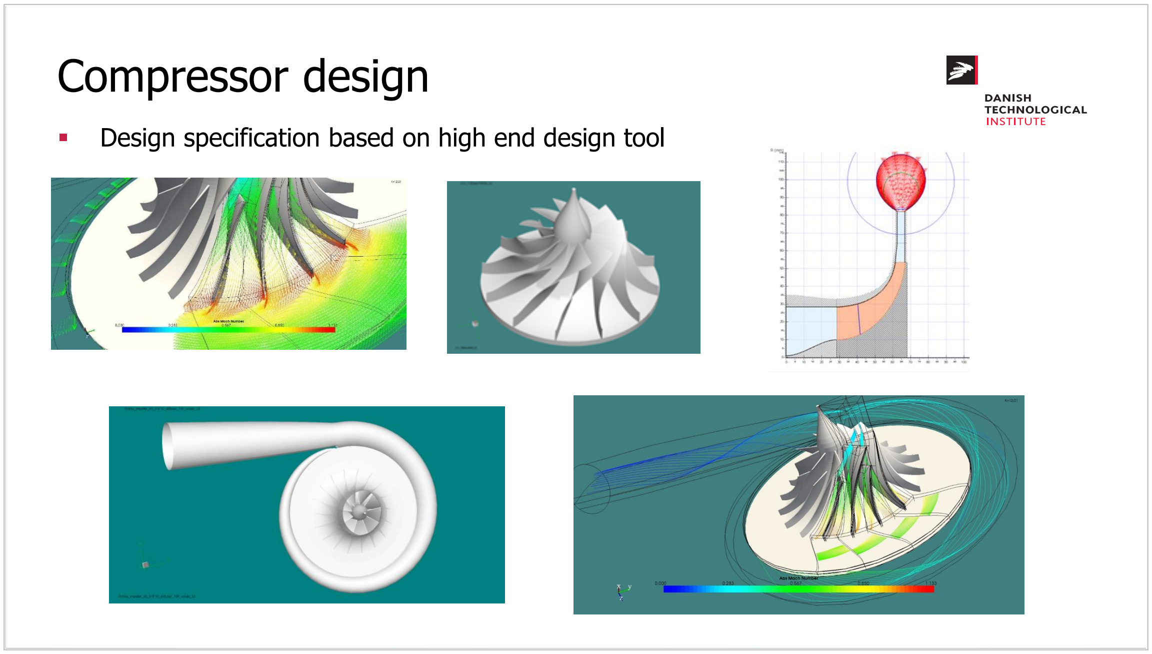
Type of user	Inlet conditions	Capacity	Temperature difference
Heat pump Unit supplier	65 – 85 C	100 – 1000 kW	20 – 30
Steam system supplier	65 – 144 C	500 – 1000 kg/h	15 – 20
Process Industry	90 - 110	100 – 1200 kW	15 – 35
Waste recovery, concentration	85 - 110	500 – 1000 kg/h	15 – 20
Process Consultants	65 - 150	0,4 – 3 MW	15 – 30
Drying consultants	30 - 130	200 – 2500 kg/h	5 – 30

Compressor design

DANISH TECHNOLOGICAL INSTITUTE

Specifications is a trade between

- Efficiency
- Pressure ration (temperture lift)
- Capacity (maximum load on gear and matrial)
- Lifetime
- Specification:
  - Speed 90,000 RPM
  - PRts 2.6
  - ΔT 25°C
  - Efficiency h_{ts} 75%
  - Volume flow 0,45 m^3/s
  - Capacity (at 90°C inlet) 360 kW


Compressor design
Design specification based on high end design tool
DANISH
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INSTITUTE


Final compressor and testrig
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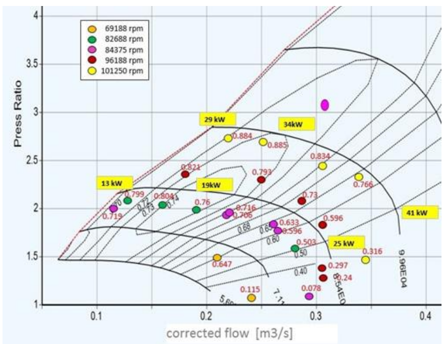
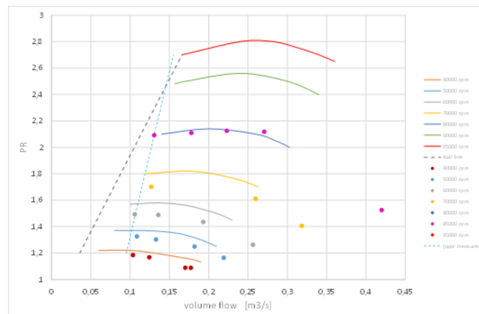
INSTITUTE

Compressor design

- Test results

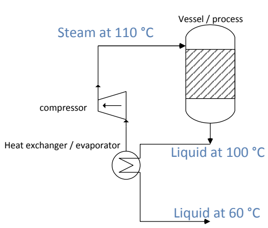




- Efficiency documented
- Gear oil temperature little higher that expected > lower max. RPM

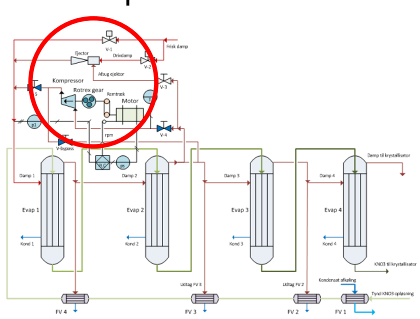
Application examples

Steam generation…

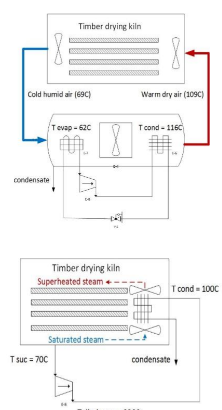


concentration…

recompression…



Drying…



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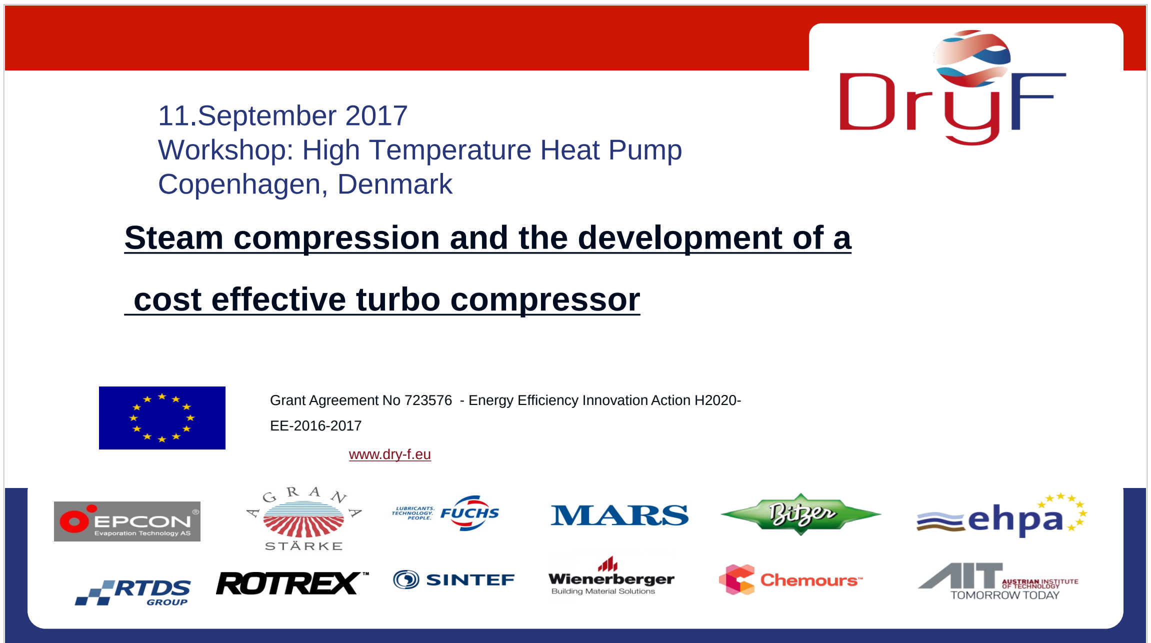
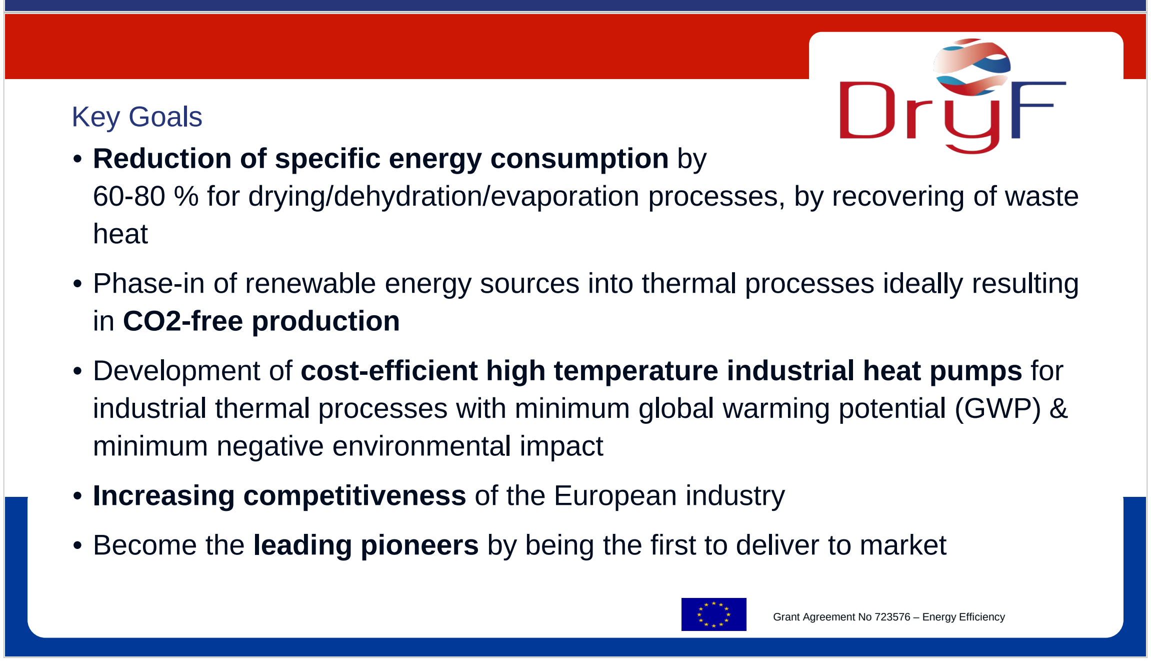
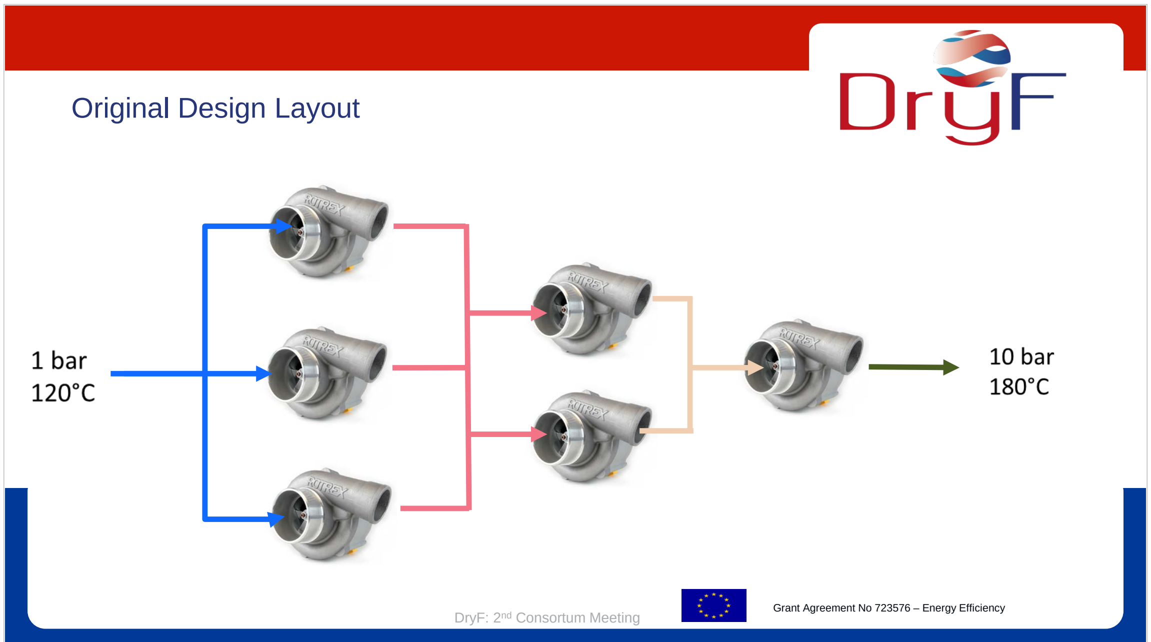
Thank you

Lars Reinholdt
Danish Technological Institute
lre@teknologisk.dk
Phone: +45 7220 1270


DryF
11.September 2017
Workshop: High Temperature Heat Pump
Copenhagen, Denmark
Steam compression and the development of a
cost effective turbo compressor
Grant Agreement No 723576 - Energy Efficiency Innovation Action H2020-
EE-2016-2017
www.dry-f.eu
EPCON
Evaporation Technology AS
AGRANA
STÄRKE
FUCHS
MARS
Bitzer
ehpa
RTDS
GROUP
ROTREX
SINTEF
Wienerberger
Building Material Solutions
Chemours
AIT
AUSTRIAN INSTITUTE OF TECHNOLOGY
TOMORROW TODAY

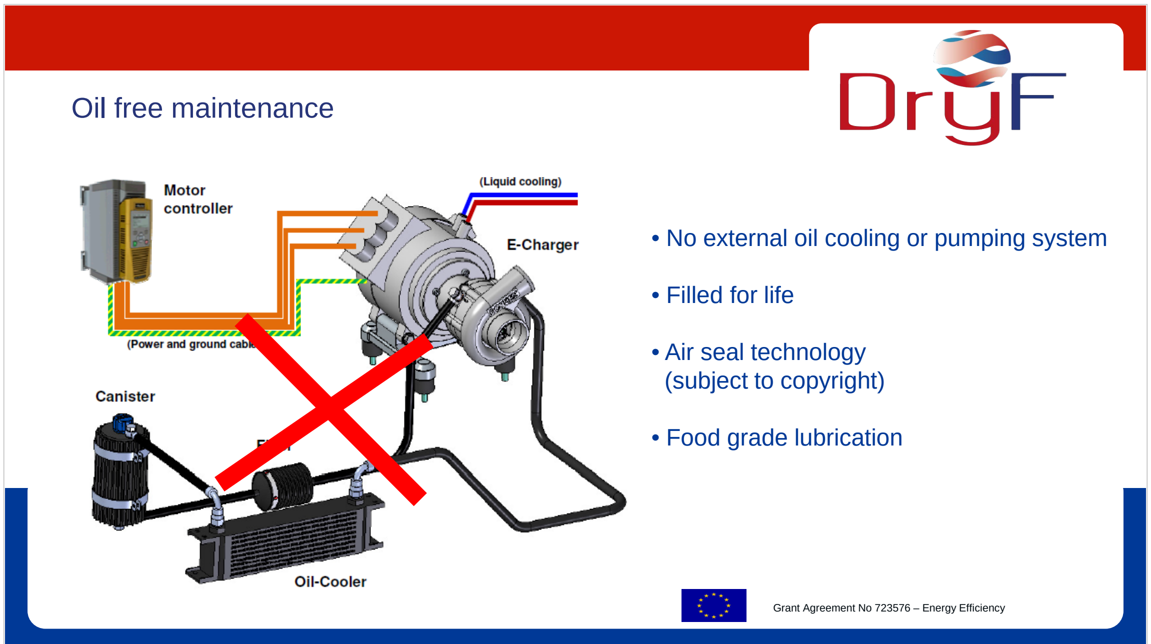

DryF
Key Goals
• Reduction of specific energy consumption by 60-80 % for drying/dehydration/evaporation processes, by recovering of waste heat
• Phase-in of renewable energy sources into thermal processes ideally resulting in CO2-free production
• Development of cost-efficient high temperature industrial heat pumps for industrial thermal processes with minimum global warming potential (GWP) & minimum negative environmental impact
• Increasing competitiveness of the European industry
• Become the leading pioneers by being the first to deliver to market
Grant Agreement No 723576 – Energy Efficiency

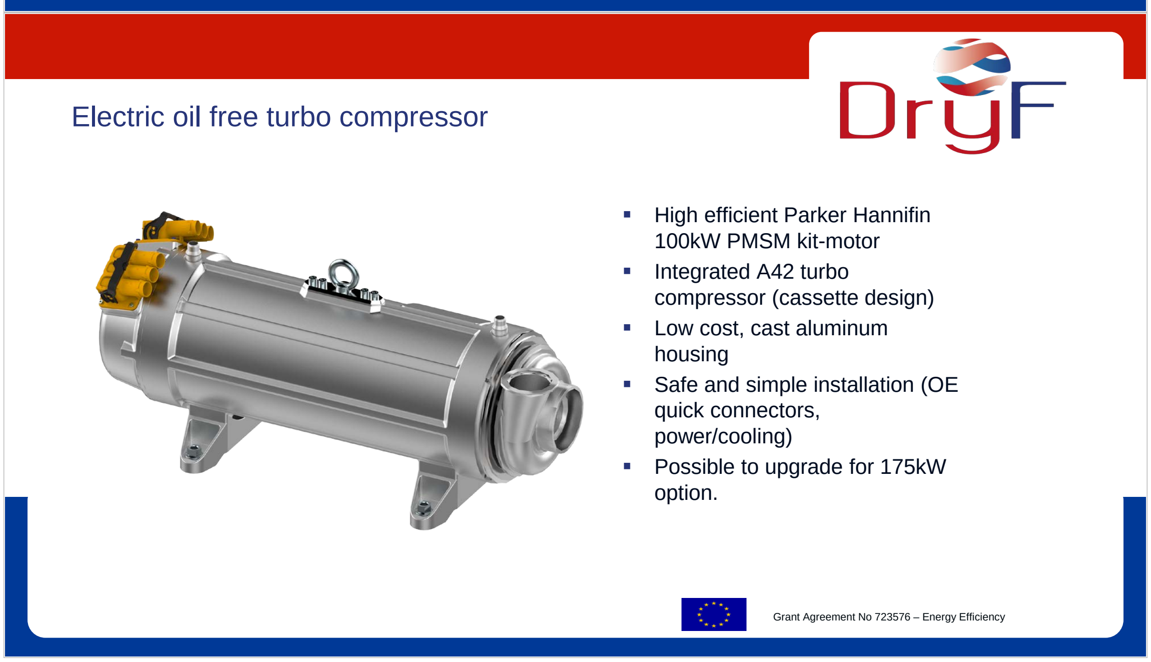


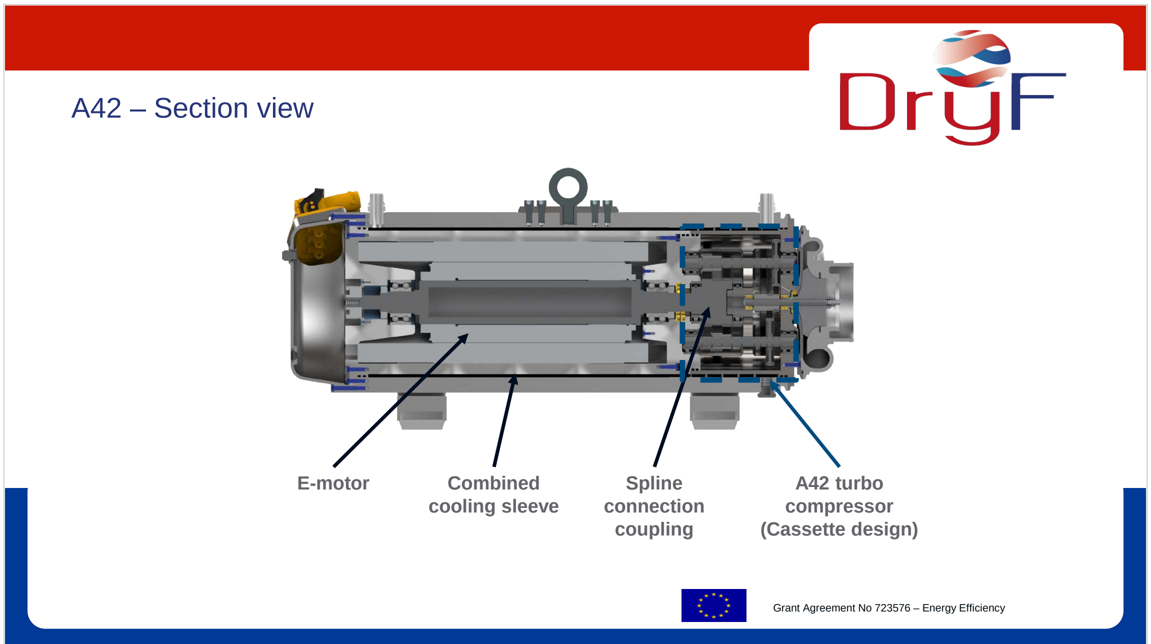
Boundary conditions for steam dryer (full scale)

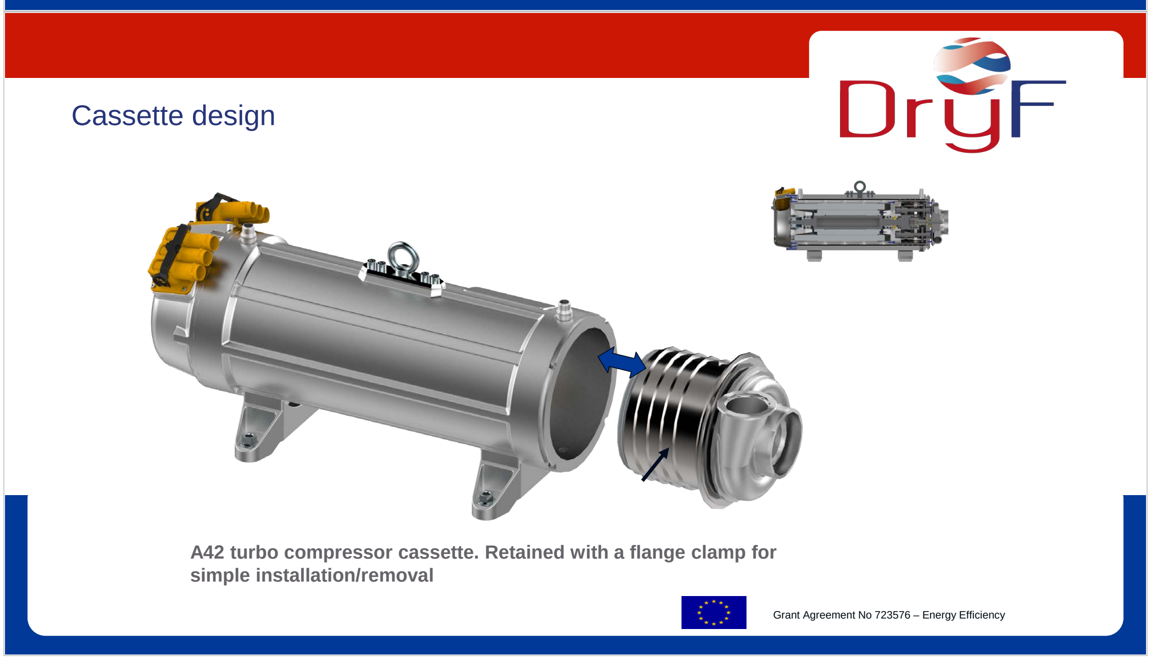
Product			
Mass flow in: $\dot{m}_{in}^{P}$	Moisture content in: MC_{in}	Mass flow out, $\dot{m}_{out}^{P}$	Moisture content out MC_{out}
10000 kg/h	25%	7895 kg/h	5%
Drying agent (process steam)			
Mass flow in: $\dot{m}_{in}^{DA}$	Temperature in: T_{in}^{DA}	Mass flow out: $\dot{m}_{out}^{DA}$	Temperature out: T_{out}^{DA}
65684 kg/h	155±5°C	67789 kg/h	110°C
Mechanical vapor recompression (MVR)			
Mass flow: $\dot{m}_{MVR}$	Temperature in: T_{MVR}	Pressure in: p_{MVR}	
2105 kg/h	110°C	1 bar	
Water out			
Mass flow: $\dot{m}_{water}$	Temperature: T_{water}	Pressure: P_{water}	
2105 kg/h	<100°C	1 bar	
Drying process (MC 25% →5% at 155±5°C)			
$f(\dot{m}_{in}, MC_{in}, \dot{m}_{DA}, T_{DA})$		0.2105 kg water/kg product	
SEC		0.78 kWh/kg	

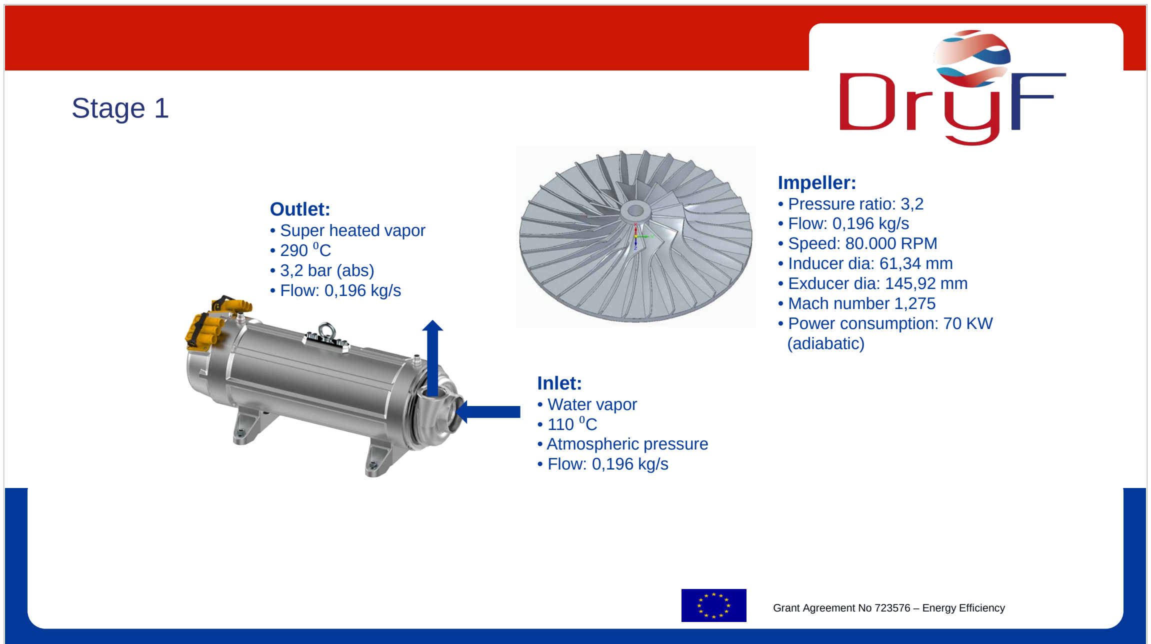
Grant Agreement No 723576 – Energy Efficiency

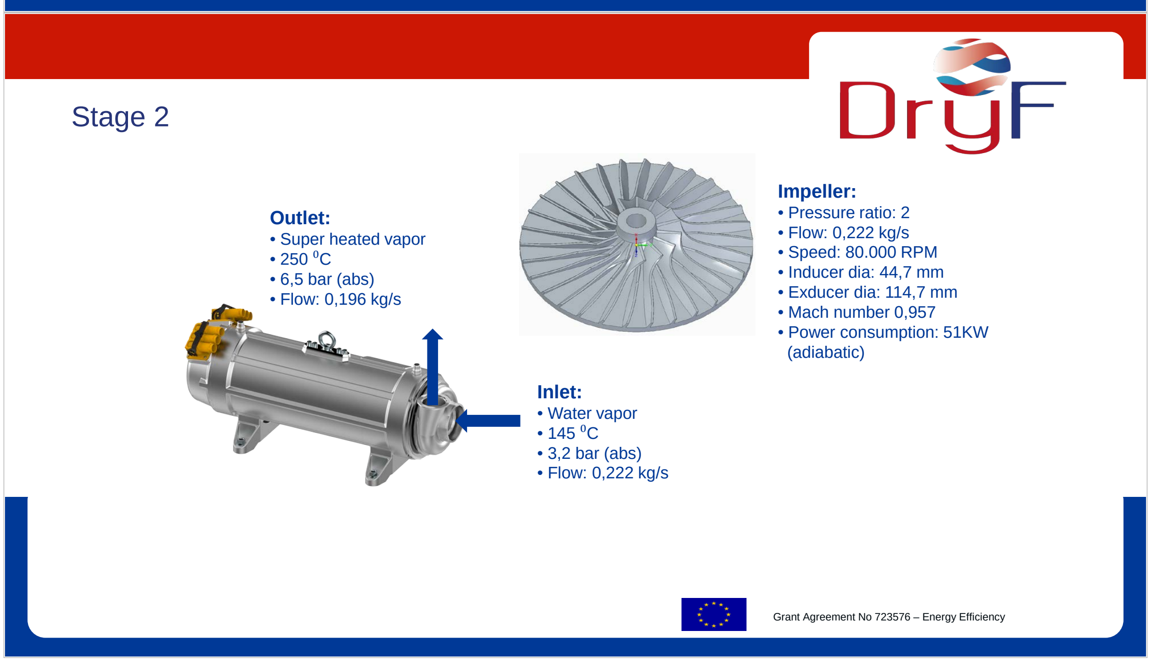

Oil free maintenance
DryF
Motor controller
(Liquid cooling)
E-Charger
Canister
Oil-Cooler
• No external oil cooling or pumping system
• Filled for life
• Air seal technology (subject to copyright)
• Food grade lubrication
Grant Agreement No 723576 – Energy Efficiency

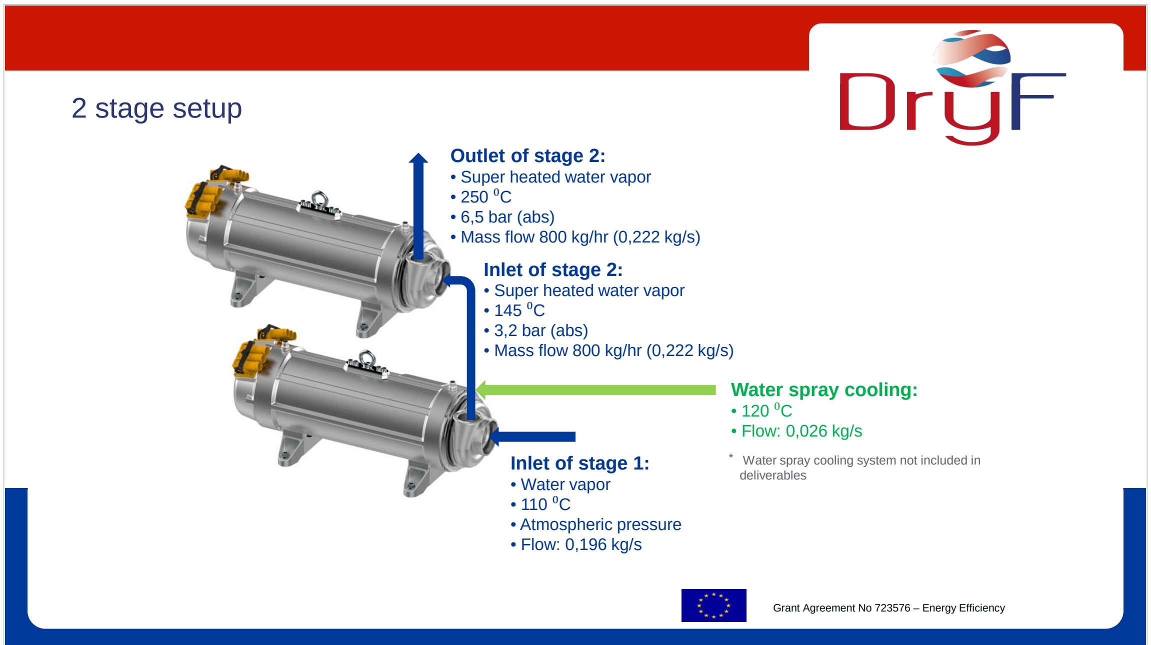

Electric oil free turbo compressor
DryF
▪ High efficient Parker Hannifin 100kW PMSM kit-motor
▪ Integrated A42 turbo compressor (cassette design)
▪ Low cost, cast aluminum housing
▪ Safe and simple installation (OE quick connectors, power/cooling)
▪ Possible to upgrade for 175kW option.
Grant Agreement No 723576 – Energy Efficiency


A42 – Section view
DryF
E-motor
Combined cooling sleeve
Spline connection coupling
A42 turbo compressor (Cassette design)
Grant Agreement No 723576 – Energy Efficiency


Cassette design
DryF
A42 turbo compressor cassette. Retained with a flange clamp for simple installation/removal
Grant Agreement No 723576 – Energy Efficiency


Stage 1
DryF
Outlet:
• Super heated vapor
• 290 °C
• 3,2 bar (abs)
• Flow: 0,196 kg/s
Impeller:
• Pressure ratio: 3,2
• Flow: 0,196 kg/s
• Speed: 80.000 RPM
• Inducer dia: 61,34 mm
• Exducer dia: 145,92 mm
• Mach number 1,275
• Power consumption: 70 KW (adiabatic)
Inlet:
• Water vapor
• 110 °C
• Atmospheric pressure
• Flow: 0,196 kg/s
Grant Agreement No 723576 – Energy Efficiency


Stage 2
DryF
Outlet:
• Super heated vapor
• 250 °C
• 6,5 bar (abs)
• Flow: 0,196 kg/s
Impeller:
• Pressure ratio: 2
• Flow: 0,222 kg/s
• Speed: 80.000 RPM
• Inducer dia: 44,7 mm
• Exducer dia: 114,7 mm
• Mach number 0,957
• Power consumption: 51KW (adiabatic)
Inlet:
• Water vapor
• 145 °C
• 3,2 bar (abs)
• Flow: 0,222 kg/s
Grant Agreement No 723576 – Energy Efficiency


2 stage setup
Outlet of stage 2:
• Super heated water vapor
• 250 °C
• 6,5 bar (abs)
• Mass flow 800 kg/hr (0,222 kg/s)
Inlet of stage 2:
• Super heated water vapor
• 145 °C
• 3,2 bar (abs)
• Mass flow 800 kg/hr (0,222 kg/s)
Water spray cooling:
• 120 °C
• Flow: 0,026 kg/s
* Water spray cooling system not included in deliverables
Inlet of stage 1:
• Water vapor
• 110 °C
• Atmospheric pressure
• Flow: 0,196 kg/s
Grant Agreement No 723576 – Energy Efficiency


WP2: Deliverables
Grant Agreement No 723576 – Energy Efficiency

De-Supeheating

- Requires a certain pipe-length (=residue time for the water to evaporate
- Pipe diameter is smaller than we would like to have it
  - Increase pressure loss for our compressors
    - Loss if efficiency
    - Start-up procedure?
- Evaluated as necessary
  - between stage 1 and stage 2
  - after stage 2 and before MVR-condenser

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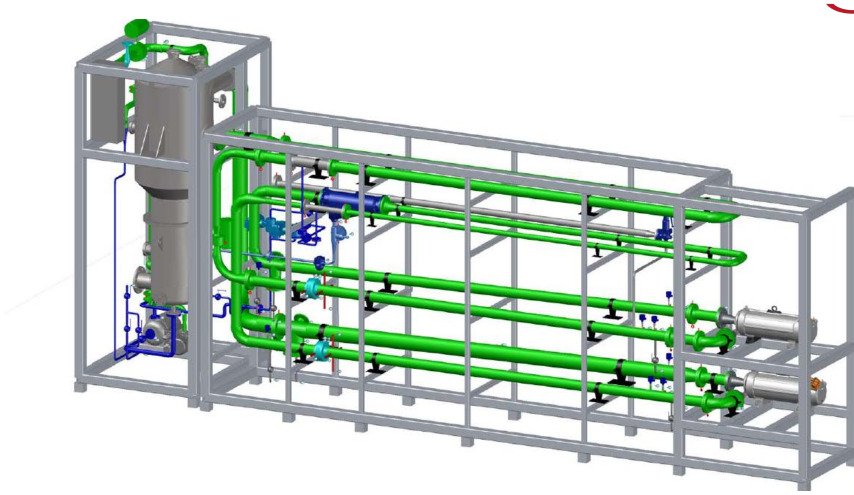
Heat Pump Demonstration Unit



Conclusions and Discussion Open Loop

DryF

- Overall: good progress on the development
- Currently building together the prototype unit
- Until end of October testing in single stage
- From November 2017 testing in multistage (target 2000 hours)
- Questions ? Comments ?

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Viking Heat Engines
HeatBooster
Mattias Nilsson
Development Engineer
Viking Heat Engines
mattias.nilsson@vikingheatengines.com
Phone no: +49-(0)170 6942 185
Industrial High-Temperature Heat Pump System
HeatBooster
20160405/HNR: V1.0
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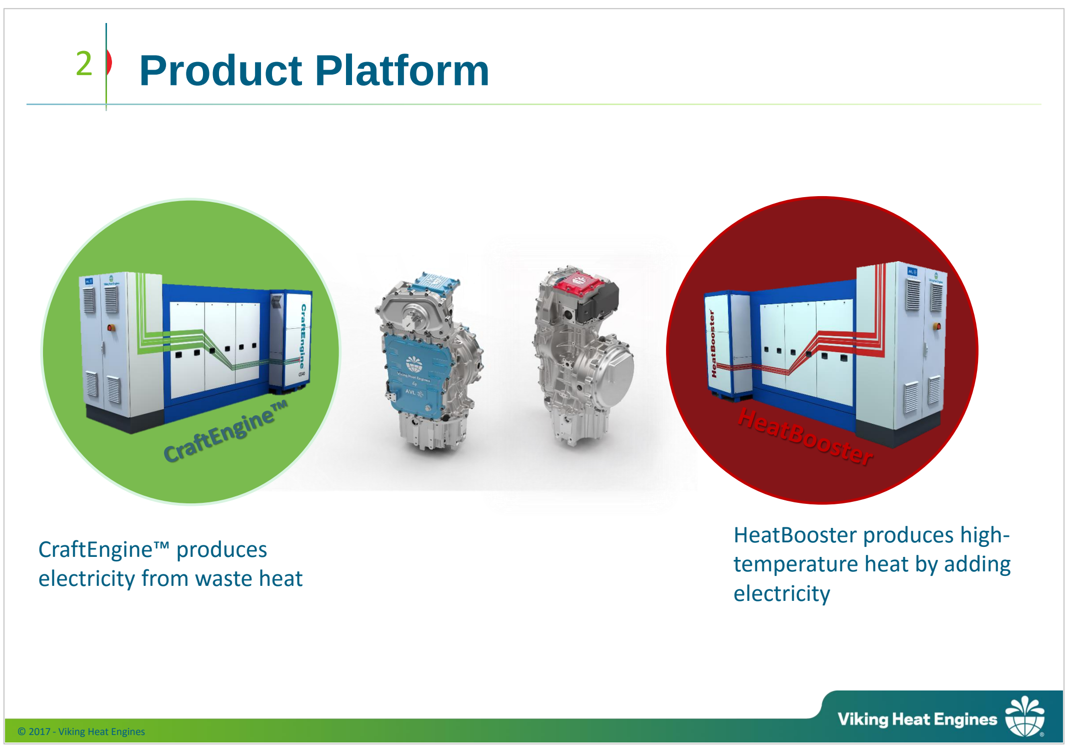
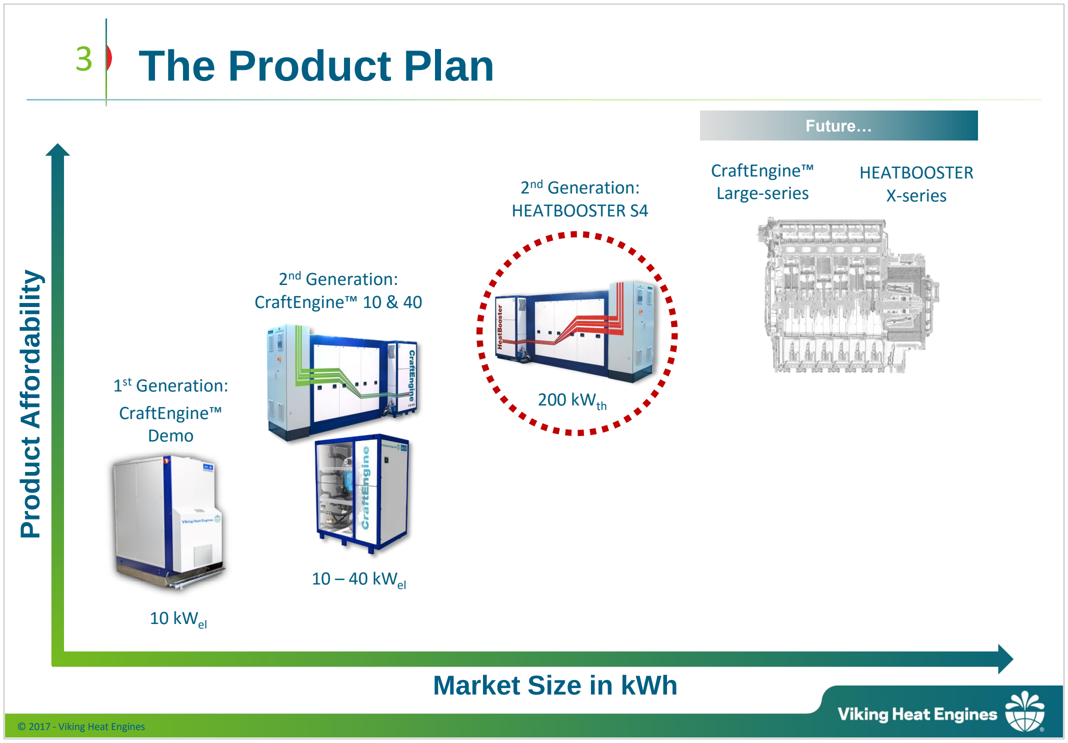

2
Product Platform
CraftEngine™
HeatBooster
CraftEngine™ produces electricity from waste heat
HeatBooster produces high-temperature heat by adding electricity
© 2017 - Viking Heat Engines
Viking Heat Engines


3
The Product Plan
Future…
CraftEngine™ Large-series
HEATBOOSTER X-series
2nd Generation: HEATBOOSTER S4
200 kWth
2nd Generation: CraftEngine™ 10 & 40
10 – 40 kWel
1st Generation: CraftEngine™ Demo
10 kWel
Product Affordability
Market Size in kWh
Viking Heat Engines
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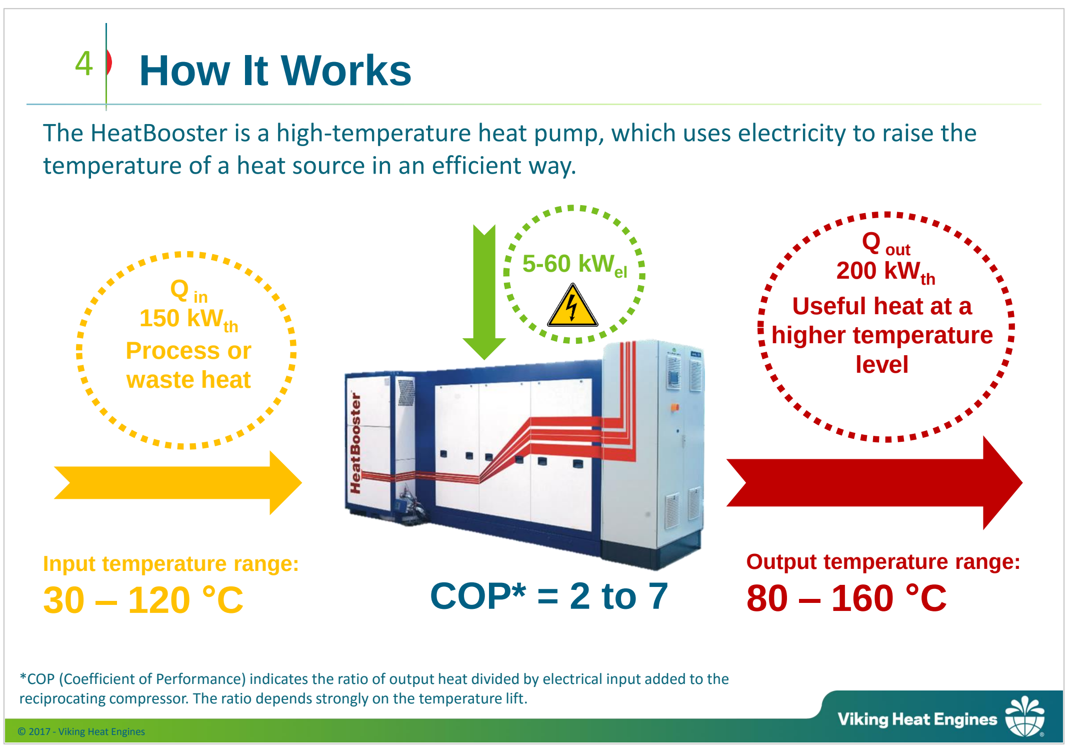
4
How It Works
The HeatBooster is a high-temperature heat pump, which uses electricity to raise the temperature of a heat source in an efficient way.
Q in
150 kWth
Process or waste heat
5-60 kWel
Q out
200 kWth
Useful heat at a higher temperature level
HeatBooster
Input temperature range:
30 – 120 °C
COP* = 2 to 7
Output temperature range:
80 – 160 °C
*COP (Coefficient of Performance) indicates the ratio of output heat divided by electrical input added to the reciprocating compressor. The ratio depends strongly on the temperature lift.
Viking Heat Engines
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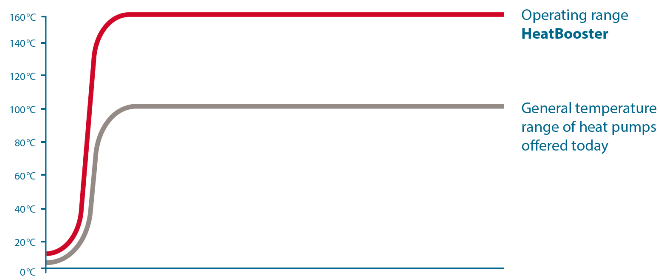
5 Unique Advantage



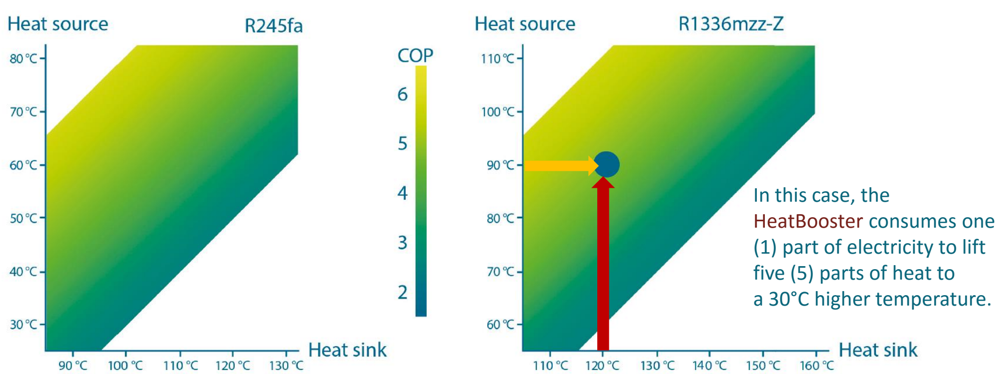
Energy source	CO_2 emissions
HeatBooster (COP=5)	12 kg CO_2 per MWh **
Diesel	280 kg CO_2 per MWh*
Fuel oil	270 kg CO_2 per MWh*
Natural gas	200 kg CO_2 per MWh*
Direct electricity	60 kg CO_2 per MWh**

Sources:
*Fachbuch Regenerative Energiesysteme and UBA
**EU-28 average power grid

Viking Heat Engines

6 Performance Overview

Performance examples of different working fluids:



Example, see above (blue mark):
A 90°C heat source and 120°C heat sink result in a COP of 5

Viking Heat Engines

7 Possible Applications

The industry needs large amounts of process heat

- Coal, oil, gas or electric heaters are usually used for this purpose
- These kinds of heaters can be replaced by the HeatBooster

Industrial heat pumps increase energy efficiency

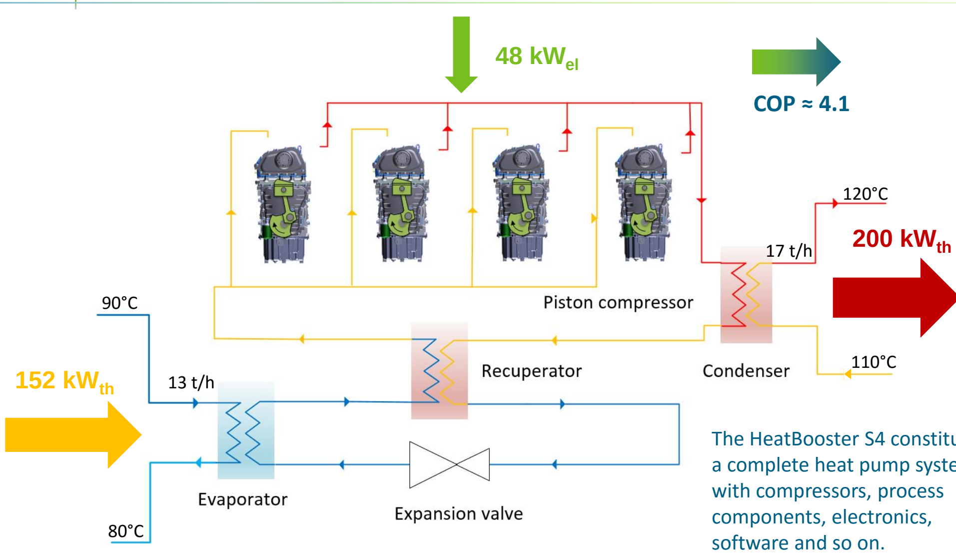
- Costs and emissions can be reduced
- Payback periods of 1 to 3 years are possible

HeatBooster reaches the highest temperatures (> 150 °C)

- Commercial HTHPs generally reach < 90 °C
- HeatBooster uses gas compression
- Flexible integration with regards to temperature change in water loops and possibilities for steam production

Viking Heat Engines

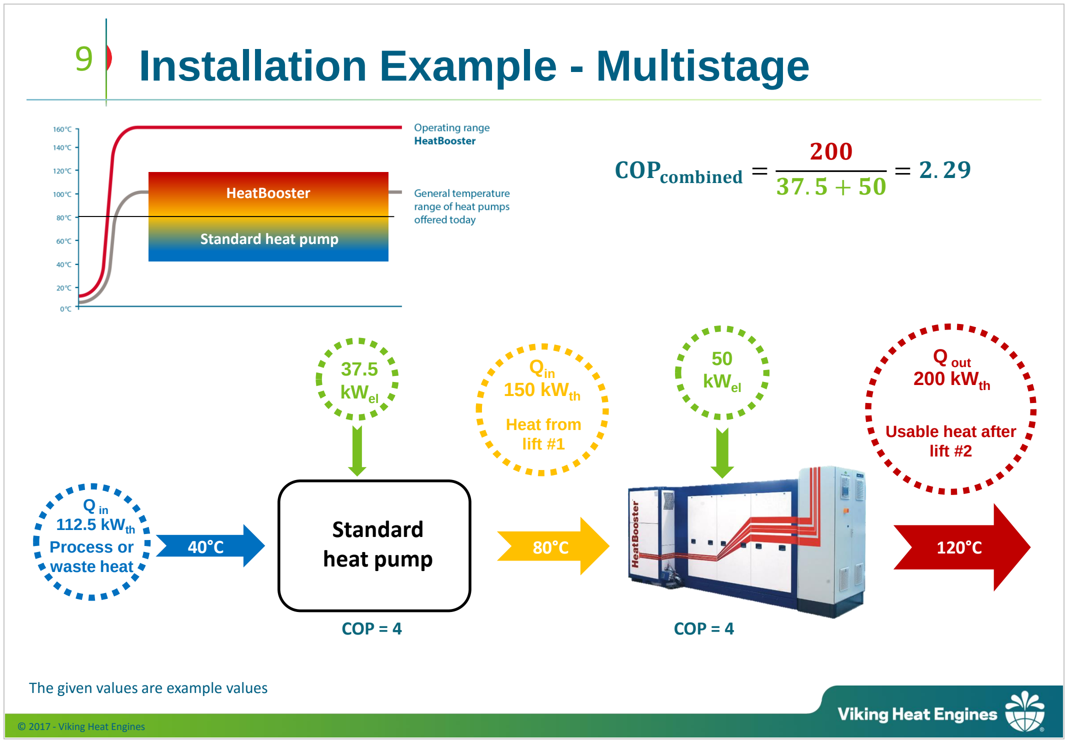
8 Installation Example



The HeatBooster S4 constitutes a complete heat pump system with compressors, process components, electronics, software and so on.

The given values are example values

Viking Heat Engines


9
Installation Example - Multistage
Operating range
HeatBooster
HeatBooster
Standard heat pump
General temperature range of heat pumps offered today
$\mathrm{COP}_{\mathrm{combined}} = \frac{200}{37.5 + 50} = 2.29$
37.5 kWel
Qin 150 kWth
Heat from lift #1
50 kWel
Q out 200 kWth
Usable heat after lift #2
Q in 112.5 kWth
Process or waste heat
40°C
Standard heat pump
80°C
120°C
COP = 4
COP = 4
The given values are example values
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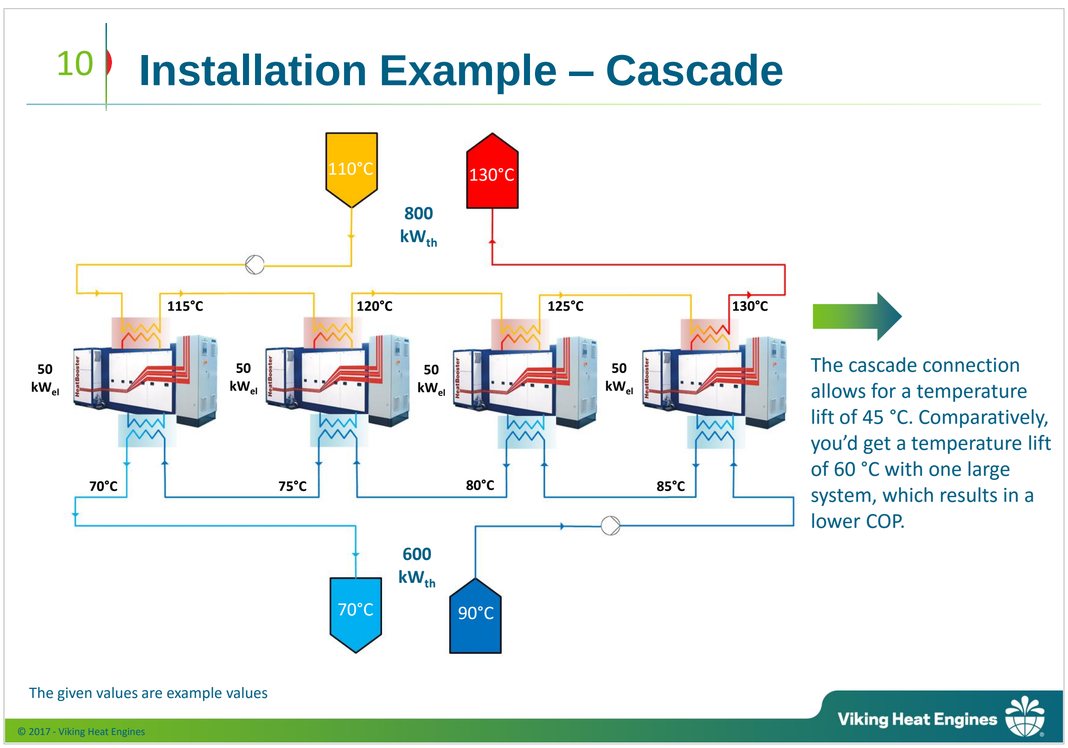
Viking Heat Engines


10
Installation Example – Cascade
110°C
130°C
800 kWth
115°C
120°C
125°C
130°C
50 kWel
50 kWel
50 kWel
50 kWel
70°C
75°C
80°C
85°C
600 kWth
70°C
90°C
The cascade connection allows for a temperature lift of 45 °C. Comparatively, you'd get a temperature lift of 60 °C with one large system, which results in a lower COP.
The given values are example values
© 2017 - Viking Heat Engines
Viking Heat Engines

11

Our Key Partners

AVL

- Collaborated since 2011
- World's largest independent engine design company
- > 8,000 employees and revenue of € 1.3 Billion (2015)
- AVL has invested in Viking Heat Engines

The Chemours Company

- Collaborated since 2015
- Large chemical company developing and producing environmentally friendly working fluids / refrigerants and more

GWK

- Supplier of high-quality cooling and heating technology products
- Current manufacturer of CraftEngine/HeatBooster process modules

Viking Heat Engines

12

Unique High-Temp. Heat Pump Technology

The future is electric

- The HeatBooster can reduce electricity consumption from 50 to 85 %
- The COP of the HeatBooster is typically around 50 % of the Carnot limit
- The HeatBooster can power a process without any CO_2 emissions

A potent, durable and highly flexible piston engine technology

- Used as a reciprocating piston expander in the CraftEngine™ and compressor in the HeatBooster
- Runs at 20-100 % load without significant efficiency penalty
- Durability of 80,000 hours
- Low maintenance requirements
- Can reach 160°C with current working fluids
- Suitable with environmentally friendly working fluids and thus part of a new technology generation

About Viking Heat Engines

- Over 40 employees in three locations around the world
- Highly qualified and experienced sales and development team
- € 50 Million Technology (research, development, testing, commercialization, etc.)

Viking Heat Engines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4 Case studies – Realized and not realized projects – Experiences – Economics

4.1 5 years of strategic sale of large heat pumps to the industry, Palle Lemminger (Innoterm)

4.2 TINE's road to get the (high temperature) heat pump, Kim Andre Lovas (TINE)

4.3 Integration of high temperature heat pumps in industry, Fridolin Müller Holm (Viegand Maagøe) & Søren Gram (Svedan Industri Køleanlæg)

4.4 Steam Generation from district heating, Stefano Vittor (Olvondo Technology)

INNOTERM
DEDICATED ENERGY FOCUS

"5 years of strategic sale of large heat pumps
to the industry"

Palle Lemminger – Innoterm A/S
Owner & CEO

ISO 9001:2008 • ISO 14001:2004 • OHSAS 18001:2008

INNOTERM
DEDICATED ENERGY FOCUS

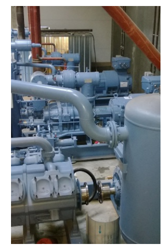
In 2010-2012 consulting engineers concluded:
250-300 industrial high temperature heat pumps needed and wanted in Denmark.

Technically: Innoterm moves the sensor from the cold to the warm side.
Same materials and personnel for the heat pumps.

INNOTERM
DEDICATED ENERGY FOCUS

High temperature heat pump references:

- Arla Arinco, milk powder production in Videbæk
- Danish Crown, slaughterhouse in Holsted
- Tican, slaughterhouse in Thisted
- TDC, heat recovery from datacenter in Slet
- Løgumkloster district heating
- Dronninglund district heating
- Ringkøbing district heating
- Tønder district heating



INNOTERM
DEDICATED ENERGY FOCUS

Reference plant: 1200 kW heat pump, Arla Arinco, Videbæk, 2012

Two-step hybrid heat pump:

Cooling capacity:	950 kW
Heating capacity:	1200 kW
Source temp.:	45 °C / 22 °C
Outlet temp.:	55 °C / 85 °C
COP(heat) :	4,5

Equipped with:

- 1 Sabroe SMC 116L piston compressor
- 1 Sabroe SMC 108L piston compressor
- Refrigerant: R717 / R718

On the 1'st of september 2017, have the heat pump been running for 33.500 hours, and delivered 35.400 MWh heat with an average COP of 4,57

This project is supported by EUDP

EUDP
Energiteknologisk udvikling og demonstration

Reference plant: 988 kW heat pump, Danish Crown, Holsted, 2013

Supercharge heat pump:

- Heating capacity: 988 kW
- Evaporator temp.: 28 °C
- Condensing temp.: 61 °C
- COP(heat): 8

Equipped with:

- 2 Grasso 65HP piston compressors
- Refrigerant: R717

The heat pump is integrated in a 4,5 MW ammonia refrigeration plant built by Innoterm. The plant refrigerates the 120 cattle being slaughtered at the slaughterhouse every hour.

Reference plant: 1350 kW heat pump, TDC district heating, Slet, 2015

Two-step heat pump:

- Heating capacity: 1350 kW
- Source temp.: 16/9 °C
- Outlet temp.: 45/78 °C
- COP(heat): 4,0

Equipped with:

- 3 GEA piston compressors
- Refrigerant: R717

The heat pump is projected and built on-site in Slet, by Innoterm.

The heat from rooms and server cooling is raised in temperature and used for heating and/or sale for the district heating.

The heat pump supplements and replaces existing district heating as well as the existing cooling plant.

INNOTERM DEDICATED ENERGY FOCUS

Reference plant: 1100 kW heat pump, Løgumkloster district heating, 2015

Two-step hybrid heat pump:

- Cooling capacity: 844-1005 kW
- Heating capacity: 1089 - 1207 kW
- Source temp.: 23 °C/17 °C
- Outlet temp.: 35 °C/60-85 °C
- COP(heat) : 4,0 – 5,3

Equipped with:

- 1 Sabroe SMC 116L piston compressor
- 1 Sabroe SMC 112S piston compressor
- Refrigerant: R717 / R718

This heat pump is used for either direct heating the district or to move energy around in the plant between storage, sunpanels or return water

This project is supported by EUDP

EUDP Energiteknologisk udvikling og demonstration

INNOTERM DEDICATED ENERGY FOCUS

Reference plant: 4,5 mW air to water heat pump, Ringkøbing district heating and Tønder district heating

Two-step heat pumps:

- Heating capacity: 3.360/4500 kW
- Source temp.: Varying outdoor air
- Outlet temp.: 35/70 °C
- COP(heat): 4,5

Equipped with:

- 4 Sabroe piston compressors in 2 parallel two-step plants
- The compressors can be driven by gasmotors or electrical motors
- Kølemiddel: R717

Air is cooled in air cooler area, and the district heating is heated by both condensation- and motor heat.

The heat pump supplements the existing district heating.

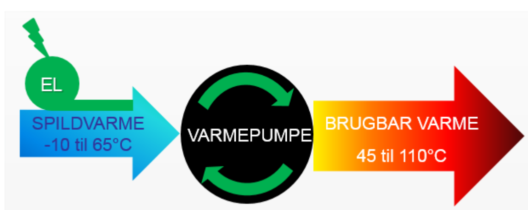
INNOTERM DEDICATED ENERGY FOCUS

Overview: wants and reality

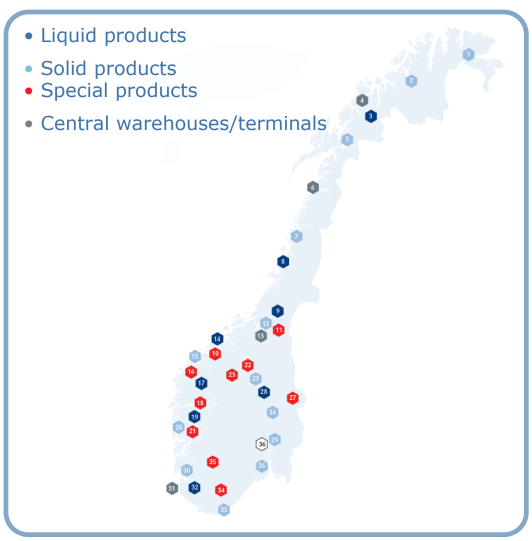
- 5 different ministers since 2010
- Several different studies (Universities, consulting engineers, technical institutes), EUDP, VE, Rejseholdet, etc.
- Funding added / funding removed .
- A lot of 'talk' on re-using the energy for district heating and electricity from windmills for HTHP
- Reality is different with taxes and fees, removing focus from the visions
- Today: most of the HTHP supported by EUDP or other funding
- If Denmark needs to be fossil free in 2050, we need to motivate the industry and district heating plants to invest in HTHP!

INNOTERM DEDICATED ENERGY FOCUS

Questions?



The TINE Group 2015



Good profit performance in 2015

- Revenues of NOK 22,2 billion
- Operating income NOK 1678 million
- Profit before tax NOK 1579 million

Industry

- 31 dairies
- 2 central warehouses
- 2 terminals
- Wholly and partly owned subsidiaries

Employees

- 5362

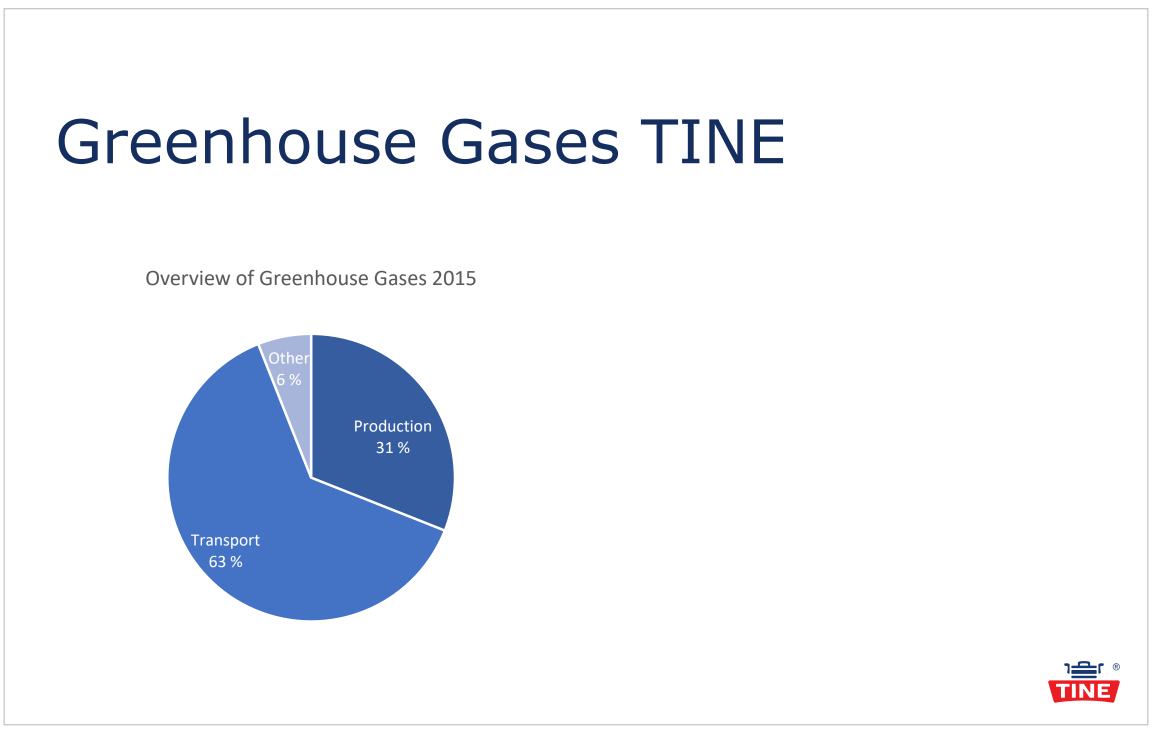
Owners

- 12,092 farmers (cows and goats)

Raw materials delivered (cows' and goats' milk)

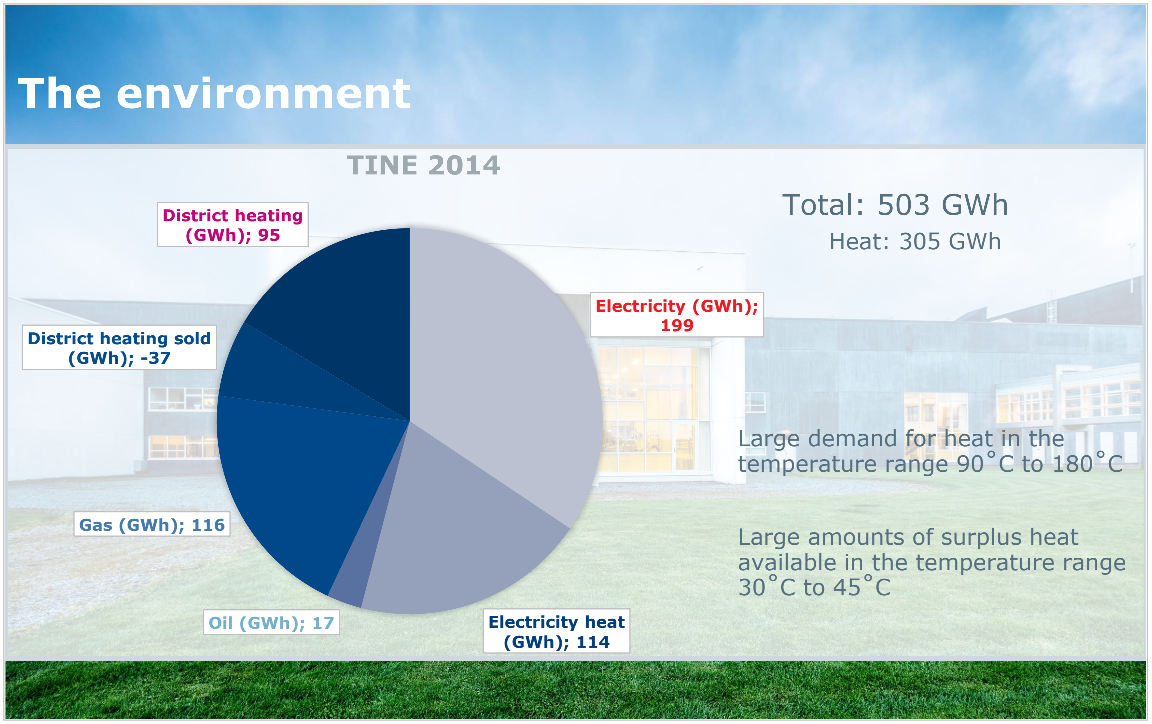
- 1474 million litres


Corporate social responsibility and the environment
TINE
TINE's climate objectives: Reduce greenhouse gas emissions by 30 per cent by 2020 (compared with the 2007 level)
• Conversion to bioenergy and district heating
• Energy efficiency
• Transport
• Food waste


Greenhouse Gases TINE
Overview of Greenhouse Gases 2015
Other 6 %
Production 31 %
Transport 63 %
TINE

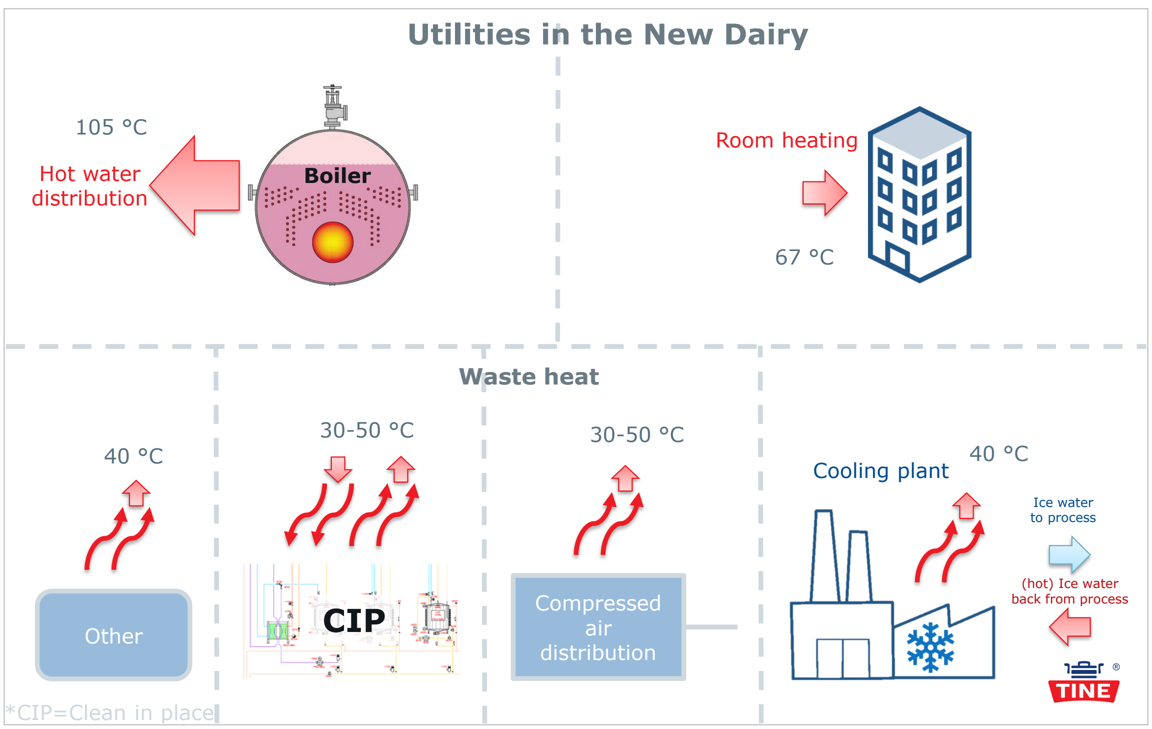

Our **success** depends on efficient transport, logistics and distribution
- Extreme requirements for quick processing, quality and hygiene when the raw material is fresh milk
- Collection of milk from 220,000 cows and 30,000 goats from about 10,000 locations, followed by delivery to 24,000 stores and delivery sites within a geographical area corresponding to Oslo–Rome
- Secure the consumers' requirements and expectations of Norwegian dairy products
TINE

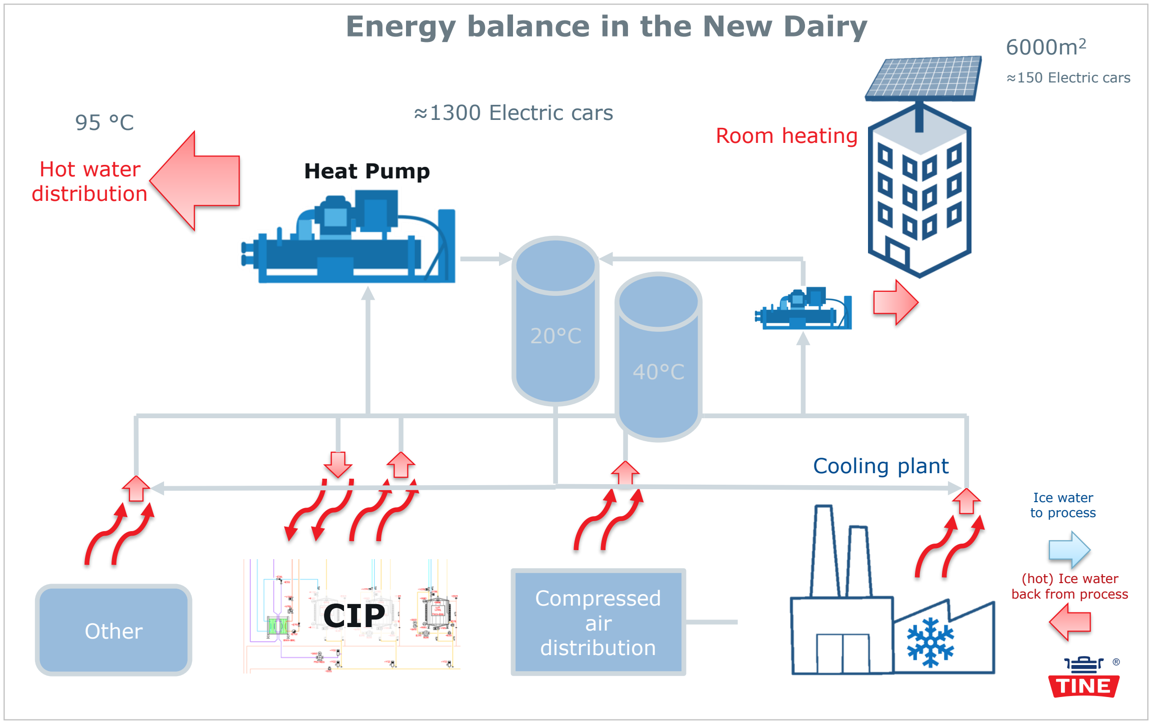

On the road to Climate Neutral transport by 2020
TINE

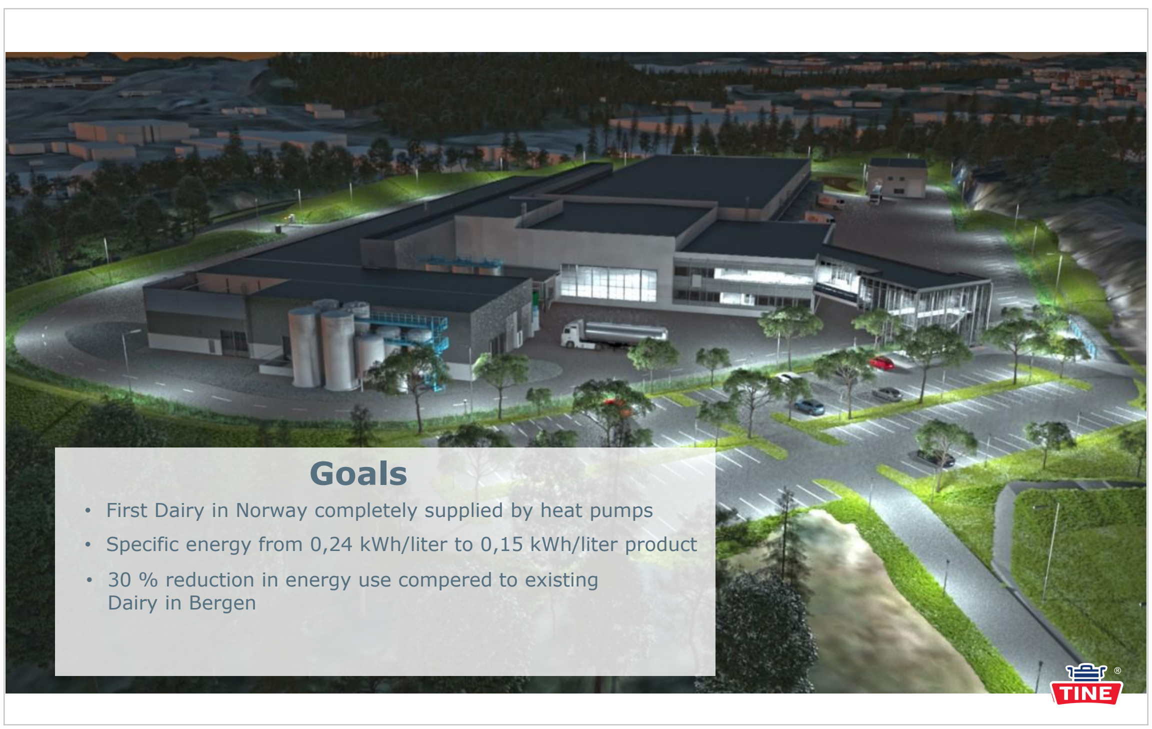

The environment
TINE 2014
District heating (GWh); 95
District heating sold (GWh); -37
Gas (GWh); 116
Oil (GWh); 17
Electricity heat (GWh); 114
Electricity (GWh); 199
Total: 503 GWh
Heat: 305 GWh
Large demand for heat in the temperature range 90˚C to 180˚C
Large amounts of surplus heat available in the temperature range 30˚C to 45˚C


New Dairy Bergen
18.000 m²
Capacity 300.000 liter milk/daily
Will be completed in 2019
Shall be the most efficient, future-oriented and profitable plant in the Nordic region


Challenges
✓ Relative small Dairy
✓ Operational stability
✓ Innovation/Technology readiness level


Utilities in the New Dairy
105 °C
Hot water distribution
Boiler
Room heating
67 °C
Waste heat
40 °C
Other
30-50 °C
CIP
30-50 °C
Compressed air distribution
Cooling plant
40 °C
Ice water to process
(hot) Ice water back from process
TINE
*CIP=Clean in place


Energy balance in the New Dairy
6000m²
≈150 Electric cars
95 °C
Hot water distribution
≈1300 Electric cars
Heat Pump
Room heating
20°C
40°C
Cooling plant
Ice water to process
(hot) Ice water back from process
Other
CIP
Compressed air distribution
TINE


Goals
• First Dairy in Norway completely supplied by heat pumps
• Specific energy from 0,24 kWh/liter to 0,15 kWh/liter product
• 30 % reduction in energy use compered to existing Dairy in Bergen
TINE


Key Success Factors
• Research projects like HighEff/HeatUp
• State Aid ENOVA
• Research partners like SINTEF
• Good Supplyers
TINE

viegand maagøe
energy people

INTEGRATION OF HIGH TEMPERATURE HEAT PUMPS IN INDUSTRY

INTERNATIONAL WORKSHOP ON HIGH TEMPERATURE HEAT PUMPS, 11TH OF SEPTEMBER 2017

SVEDAN
Industri Køleanlæg A-S

viegand maagøe
energy people

AGENDA

1. Background
2. Project Development
3. Integration of disciplins
4. Heat pump design

SVEDAN
Industri Køleanlæg A-S

4.3. Integration of high temperature heat pumps in industry, Fridolin Müller Holm (Viegand Maagøe) & Søren Gram (Svedan Industri Køleanlæg)

BACKGROUND

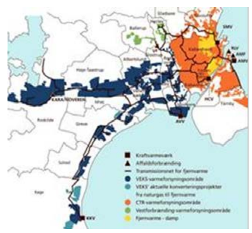
viegand maagøe energy people

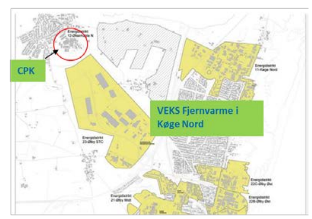
History 2013- 2017

- Energy symbiose Køge spring 2014: VEKS - CP KELCO, Sun Chemical, Fef Chemicals and Junckers
- VEKS is expanding the district heating grid in the Køge region.
- CP Kelco produces ingrediencies for the food sector. As a part of the production substantial amount of heat needs to be cooled, which is today done primarily by cooling towers.
- CP Kelco is very focused on reducing the environmental load and is constantly optimizing there production in order to become more efficient

What makes this project flying?

- Expansion of the district heat grid
- High temperature surplus heat
- Huge interest from both CP Kelco and VEKS
- Energy saving subsidy
- Government support
- A number of similar business cases
- …





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PROJECT DEVELOPMENT

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Initial design phase

- Energy Symbiose Køge
- Substituting one cooling tower
- Increasing the heat recovery system temperature
- Extending the system with an additional cooling tower
- Designing a buffer system
- Optimizing system efficiency
- ...

Production

- Condenser redesign
- Integration with exciting recovery systems
- Integration with existing systems and piping
- Working on flow and pressure issues
- Securing sufficient redundancy

District heat

- Expansion of the system
- Temperature demands
- Pipe routing – ownership of property
- Agreement between VEKS and CP Kelco

Technology

- Heat pumps
- Heat storages
- Condenser type and design

Integration

- Integration with the district heating system – balancing supply and demand

SVEDAN Industri Køleanlæg A-S

PROJECT DEVELOPMENT

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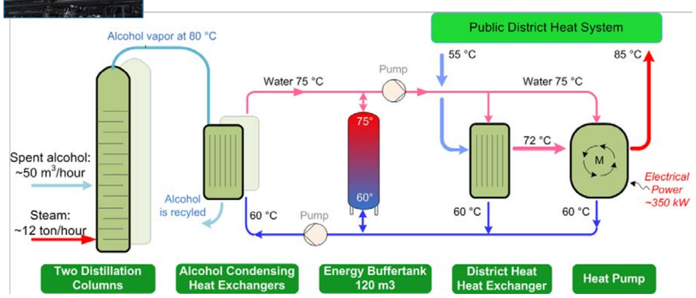
Power	Energy	System COP
4-7 MJ/s	140 TJ/year (38,700 MWh/year)	18.5



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INTEGRATION OF DISCIPLENES

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Authorities

- Municipality
- Project proposal
- Application for dispensation
- Application for construction
- Binding answer from the tax authorities
- Danish Working Environment Authority

Client

- In house engineering
- Maintenance
- Production
- Procurement
- Management
- EHS

Suppliers

- Mechanical
- Electrical
- Building
- Civil
- HEAT PUMP

District heat

- Management
- In house engineering
- Subcontractors

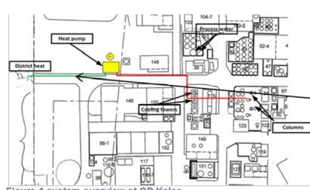

Figure 1 system overview at CP Kelco

Figure 2 district heating piping

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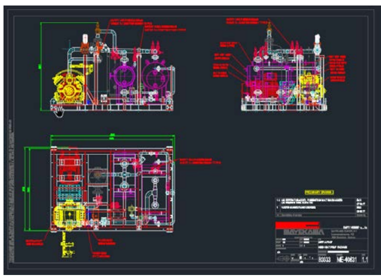
HEAT PUMP DESIGN

viegand maagøe
energy people



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HEAT PUMP DESIGN

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High process water temperatures

- High process water temperatures: 75 / 60°C
- Small lift with hot water temperatures: 72 / 85°C
- Variable water flow both sides: 100 – 50%
- Small or no sub cooling and super heating
- Two units for flexibility and optimum efficiency

- Need for suction pressure protection
- Need for closing off to compressor during stand still

HEAT PUMP PERFORMANCE DATA				
Capacity	[-]	100%	75%	50%
UNIT No. 1 MAYEKAWA N4HS				
CAPACITY	[kW]	1.510	1.126	752
ABSORBED POWER	[kW]	176	126	89
SPEED	[min-1]	1.170	870	775
LOAD	[%]	100	100	75
PROCESS WATER TEMP. IN/OUT	[degC]	75/67,5	75/67,5	75/67,5
DISTRICT HEATING WATER TEMP. IN/OUT	[degC]	78,5/85	78,5/85	78,5/85
HEATING CAPACITY	[kW]	1.676	1.241	833
COPh electricity	[-]	9,0	9,2	8,6
UNIT No. 2 MAYEKAWA N4HS				
CAPACITY	[kW]	1.504	1.1254	752
ABSORBED POWER	[kW]	163	116	83
SPEED	[min-1]	1.235	920	820
LOAD	[%]	100	100	75
PROCESS WATER TEMP. IN/OUT	[degC]	67,5/60	67,5/60	67,5/60
DISTRICT HEATING WATER TEMP. IN/OUT	[degC]	72/78,5	72/78,5	72/78,5
HEATING CAPACITY	[kW]	1.658	1.243	835
COPh electricity	[-]	9,6	9,9	9,0
TOTAL HEAT	[kW]	3.334	2.484	1.668
COPh electricity	[-]	9,8	10,3	9,6

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Application of an industrial heat pump for steam generation using district heating as heat source

Stefano Vittor

Steam Production from District Heating

The issue

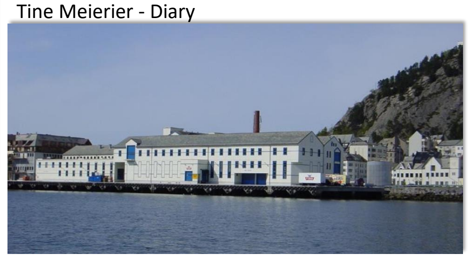
- District heating operators are looking for new revenue streams within their footprint
- Industrial customers offer an attractive demand for energy, but often at temperatures above district heating grid level
- Commercial available high temperature heatpumps can be used to meet industrial customers demand for temperatures up to 200ºC enabling district heating operators to tap into new revenue streams

Steam Production from District Heating – Case study

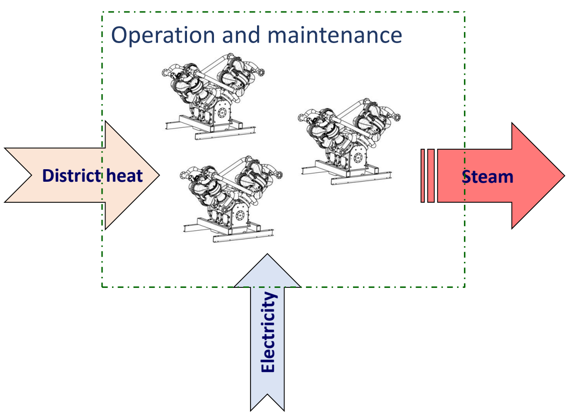
City of Ålesund - Northwest cost of Norway

Tafjord Kraftvarme – District heating operator

Tine Meierier - Diary



Steam Production from District Heating – Case study



Business model

- Tafjord Kraftvarme supplies district heating to Olvondo technology
- Olvondo Technology uses district heating as source for steam production, lifting the temperature from 85ºC to 184ºC using its own SPP HighLift Heatpump technology
- Tine Meierier purchases the steam produced by the Olvondo Technology heatpumps
- Long term fixed energy supply contract
  - 10y duration
  - Fixed energy prices
  - Remote operated steam production

Steam Production from District Heating – Case study

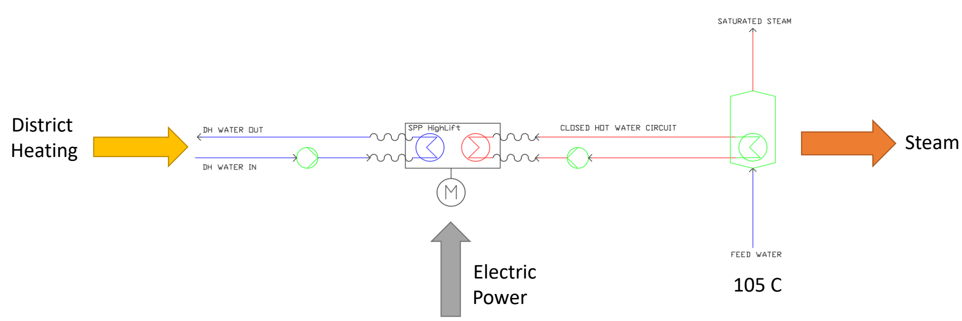
Facts & Figures:

- 12 GWh/y steam consumption (naturalgas)
- Steam temperature 184 °C (10 bar_g)
- Constant consumption 51 weeks per year
- Heatpump energy supply up to 9,6 GWh/y
- Energy sourced from District Heating up to 5,2 GWh/y
- District heating temperature 85°C
- 3x SPP HighLift 104-6 Heatpumps

SPP HighLift heatpumps installed at AstaZeneca in Mölndal, Sweden

Steam Production from District Heating – Case study

Basic system principle

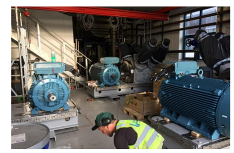


Steam Production from District Heating – Case study

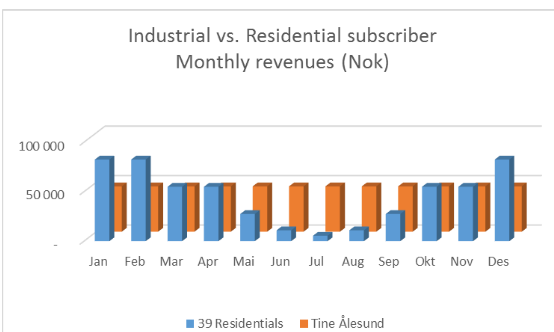
Deliverables

- Increased energy consumption in the district heating grid of Tafjord Kraftvarme
- Reduced energy cost for steam production at Tine Meierier
- Significantly reduced carbon emissions from the diary by 1.800 t/y less CO_2 counting for 60% of total CO_2 emissions from the diary

The heatpump project with Tine in Ålesund is under construction and will be in operation from Q4'2017



Tine Ålesund in a District Heating Perspective



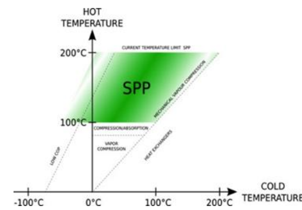
Assumptions:

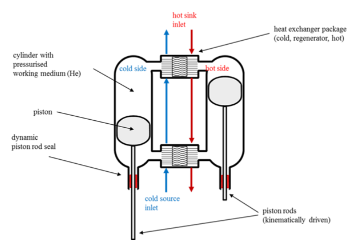
- Energy consumption residential subscriber of 20.000 kWh per year
- Rough estimate of monthly distribution

Steam Production from District Heating – SPP HighLift technology

SPP HighLift Heatpump

- Stirling principle
- Helium (R704) refrigerant
- Temperature lift > 100ºC
- Source temperatures in the range 0 - 100ºC
- Sink temperatures up to 200ºC
- 500 kW heat + 250 kW cooling in the same process

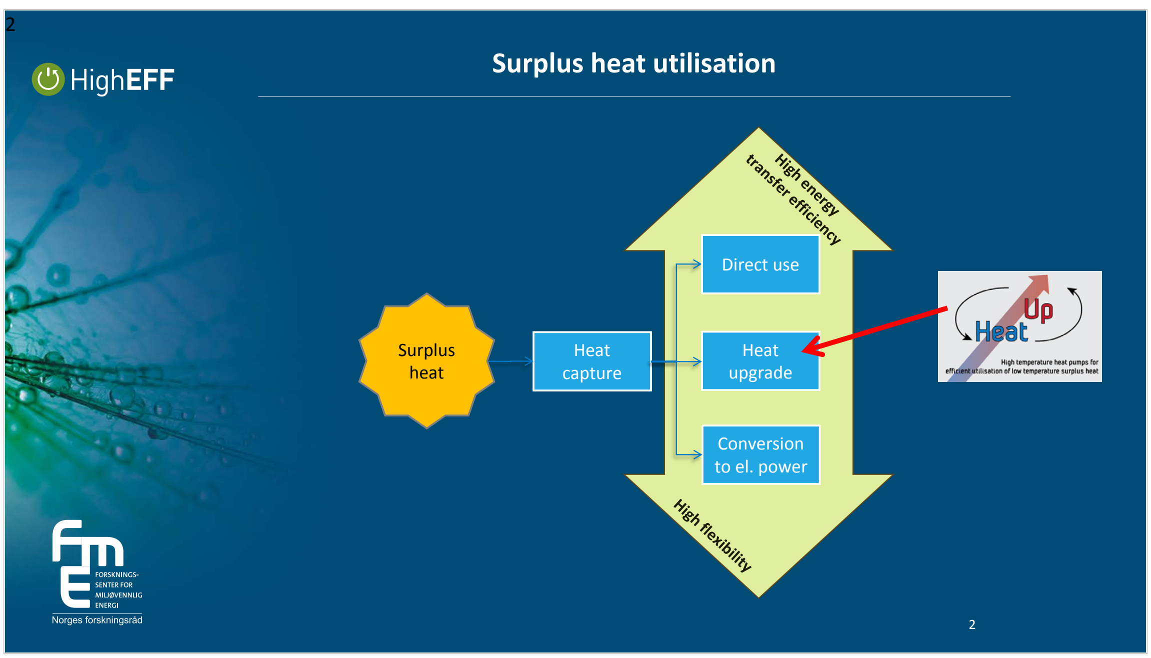


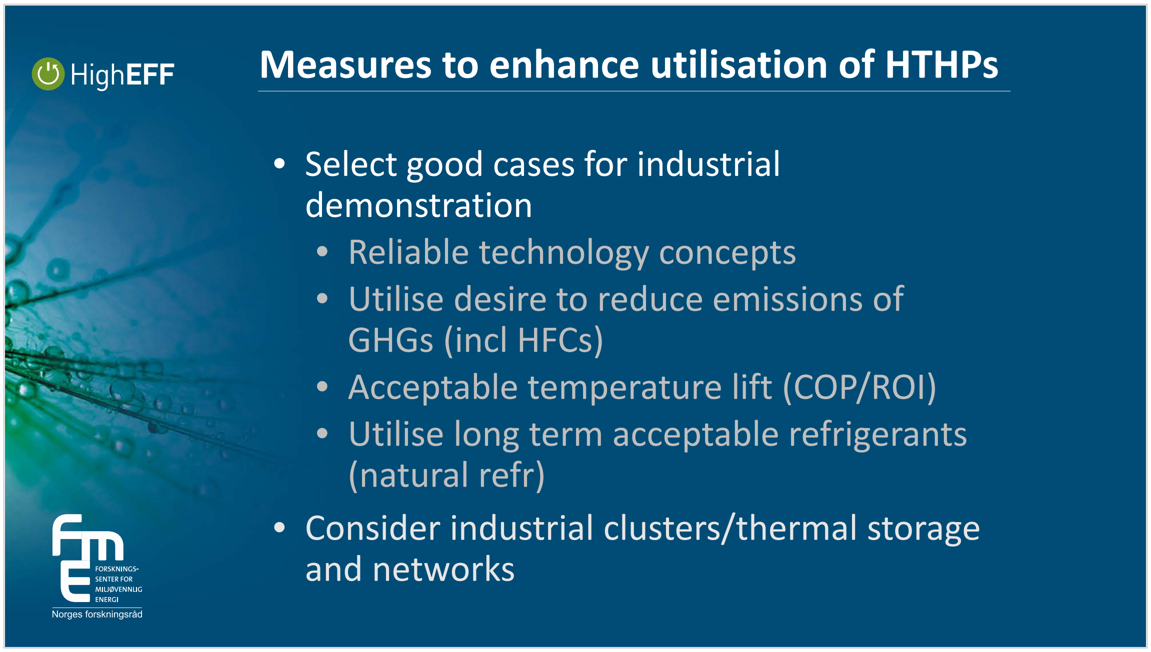


5 Plenary Discussion: "What measures will enhance the utilization of (high temperature) heat pumps in industry?"

4.1 What measures will enhance the utilisation of HTHPs in industry, Petter Nekså (SINTEF)


HighEFF
FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd
What measures will enhance the utilisation of HTHPs in industry
Petter Nekså, SINTEF Energy Research, Trondheim


2
HighEFF
Surplus heat utilisation
High energy transfer efficiency
Direct use
Surplus heat
Heat capture
Heat upgrade
Conversion to el. power
High flexibility
Heat Up
High temperature heat pumps for efficient utilisation of low temperature surplus heat
FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd
2


HighEFF
Measures to enhance utilisation of HTHPs
• Select good cases for industrial demonstration
• Reliable technology concepts
• Utilise desire to reduce emissions of GHGs (incl HFCs)
• Acceptable temperature lift (COP/ROI)
• Utilise long term acceptable refrigerants (natural refr)
• Consider industrial clusters/thermal storage and networks
FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

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Section of Thermal Energy
Technical University of Denmark

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