Technology Collaboration Programme
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Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Annex 48

Industrial Heat Pumps, Second Phase

Final Report

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Preface

This project was carried out within the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP), which is a Technology Collaboration Programme within the International Energy Agency, IEA.

The IEA

The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of nearly 40 Technology Collaboration Programmes.

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) forms the legal basis for the implementing agreement for a programme of research, development, demonstration and promotion of heat pumping technologies. Signatories of the TCP are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the TCP, collaborative tasks, or “Annexes”, in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and work plans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex.
The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

Disclaimer

The HPT TCP is part of a network of autonomous collaborative partnerships focused on a wide range of energy technologies known as Technology Collaboration Programmes or TCPs. The TCPs are organised under the auspices of the International Energy Agency (IEA), but the TCPs are functionally and legally autonomous. Views, findings and publications of the HPT TCP do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.

The Heat Pump Centre

A central role within the HPT TCP is played by the Heat Pump Centre (HPC).

Consistent with the overall objective of the HPT TCP, the HPC seeks to accelerate the implementation of heat pump technologies and thereby optimise the use of energy resources for the benefit of the environment. This is achieved by offering a worldwide information service to support all those who can play a part in the implementation of heat pumping technology including researchers, engineers, manufacturers, installers, equipment users, and energy policy makers in utilities, government offices and other organisations. Activities of the HPC include the production of a Magazine with an additional newsletter 3 times per year, the HPT TCP webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:
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Whilst the information was supplied by representatives from various companies and sources a number of assumptions, simplifications and transformations have been made in order to present information that is easily understood. Therefore, information should only be used as guidance.

The market of industrial heat pumps (IHPs) is developing fast and at the moment of publication some information can already be overtaken by new developments.

In compiling, editing and writing this report we would like to thank all Annex participants for their support.

Contents

1 Executive Summary

What does industrial heat pump actually mean? What expectations does it create for the actual business? What are the drivers and what are the barriers? What are the challenges for the industrial heat pumps? High temperature heat pumps are covering the temperature range from 100 to 160 °C, what is expected in the future? District heating is changing from fossil fuel boilers to industrial heat pumps.

Researchers, technicians, product developers, decision-makers and consulting engineers, component manufacturers and suppliers, designers and architects, refrigerant plant and heat pumps operators need to be able to understand the possibilities and challenges of industrial heat pumps (IHPs) in the industrial processes.

Securing a reliable, economic and sustainable energy supply as well as environmental and climate protection are important global challenges of the 21st century. Increasing the production and use of renewable energy and improving energy efficiency are the most important steps in order to achieve these goals of energy policy.

While the residential heat pump market may be satisfied with standardised products and installations, most IHP applications need to be adapted to unique conditions. In addition a high level of expertise is crucial. The main goal is to overcome still existing difficulties and barriers for the larger scale market in industrial applications. IHPs are active heat-recovery devices that increase the temperature of waste heat in an industrial process to a higher temperature to be used in the same process or another adjacent process or heat demand.

The IEA Technology Collaboration Programme on Heat Pumping Technologies, HPT TCP, has contributed with four Annexes since the 80s of the last century in the field of heat pumps for industrial applications:

Annex 09: High Temperature Industrial Heat Pumps (before 1990)

Annex 21: Global Environmental Benefits of Industrial Heat Pumps (1992-96)

Annex 35: Application of Industrial Heat Pumps (2010-2014)

Annex 48: Industrial Heat Pumps Second Phase (2016-2019).

Whereas the first two Annexes contribute in a broad variety on research and development activities to the technology of IHPs, the last two Annexes focus more on the practical application and integration of IHPs in many different industries around the globe.

The aim is to understand the worldwide activities of industrial heat pumps which have to contribute actively to the reduction of energy consumption and GHG emissions through the increased utilization in industry.

The Annex definition of IHPs: Heat pumps in the medium and high power range and temperatures up to 200 °C, which can be used for heat recovery and heat upgrading in industrial processes, but also for heating, cooling and air-conditioning in commercial and industrial buildings.

Objectives:

-Development of a framework which structures information on IHP applications, using existing and new case studies, selecting excellent application opportunities and approved examples

-Best available technologies and best practices should be selected based on the matrix (sorted by type of installation, of technology and system), selecting a limited number of industries with large potential, focused on special areas with high product quality
-Models for a consistent integration of a heat pump into a process, e.g. Pinch Analysis PA (Methodology to identify the true thermodynamic needs of a process, considering heat recovery), OSMOSE (Tool for process integration and optimization) or CERES (platform en--ables pinch method-based studies to be carried out on energy integration)
-Arranging the information on heat pumping technologies for industry, for policymakers, industrial planers and designers, stake holders as well as heat pump manufacturers
-Creating information material for IHP training courses.

-Waste heat recovery by industrial heat pumps

Through the use of industrial heat pumps for waste heat recovery is a great possibility to develop so far inactive potential in utilization of waste heat and by this to avoid CO_2 - emissions. Figure 1-1 shows the principle of waste heat recovery by IHPs

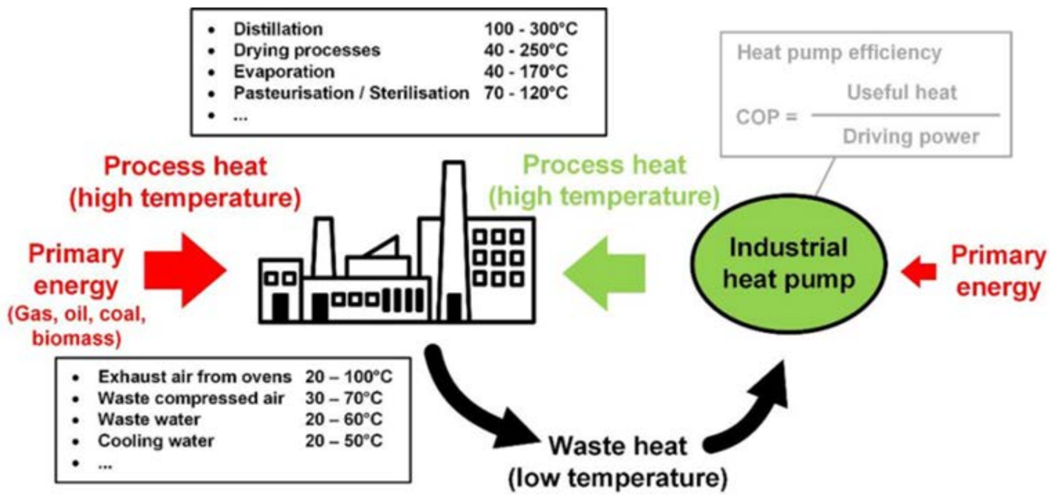

Figure 1-1: Efficient transformation of useful heat to higher temperatures [Arpagaus 2019-08]

-Market overview:

The market reports from member countries give a good insight in market developments and the different general conditions. (Direct links to the reports see chapter 2 Annex work on IHPs).

Some key findings from the country reports:

-Energy demand for the different industrial sectors in Switzerland

The theoretical application potential for the use of heat pumps in industrial processes can be estimated from the heat demand of the individual industrial sectors and the temperature levels of the applied industrial processes.

The graphs in figure 1-2 show the distribution of the industrial heat demand in Switzerland by sector and temperature level. In addition to space heating and hot water, industry has a great need for process heat for manufacturing, processing and refining products. In general, process heat is supplied above about 80 °C.

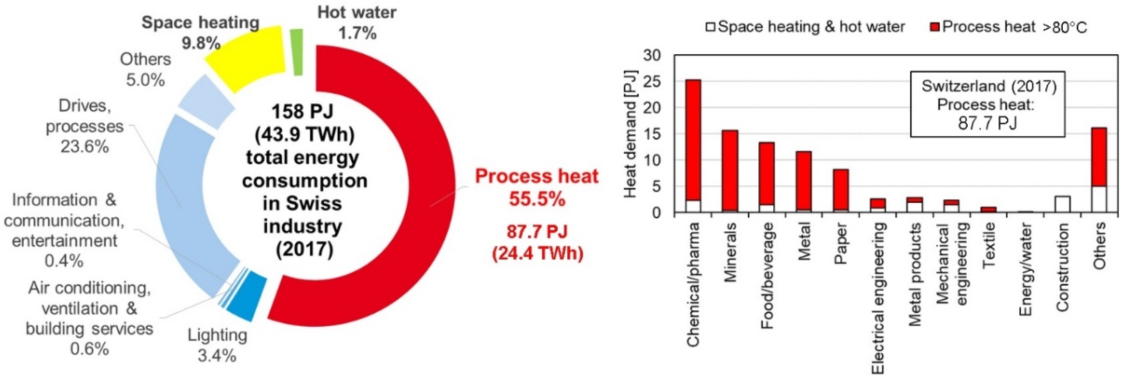

Figure 1-2: Industrial energy demand in Switzerland (2017) by intended use and process heat demand [Source Report Switzerland]

-Industrial energy consumption in Austria

In Austria, surveys on useful energy analyses are conducted annually since 2015 to take account of the rapid technical progress. Useful energy analyses aim to subdivide the final energy consumption of the energy balance at sector level into so-called useful energy categories.
In figure 1-3, the useful energy analysis of the Austrian industry is summarized. The pulp and paper industry consumes the most energy, followed by the chemical and petrochemical industry, stone and earth and glass production, as well as the iron and steel production.

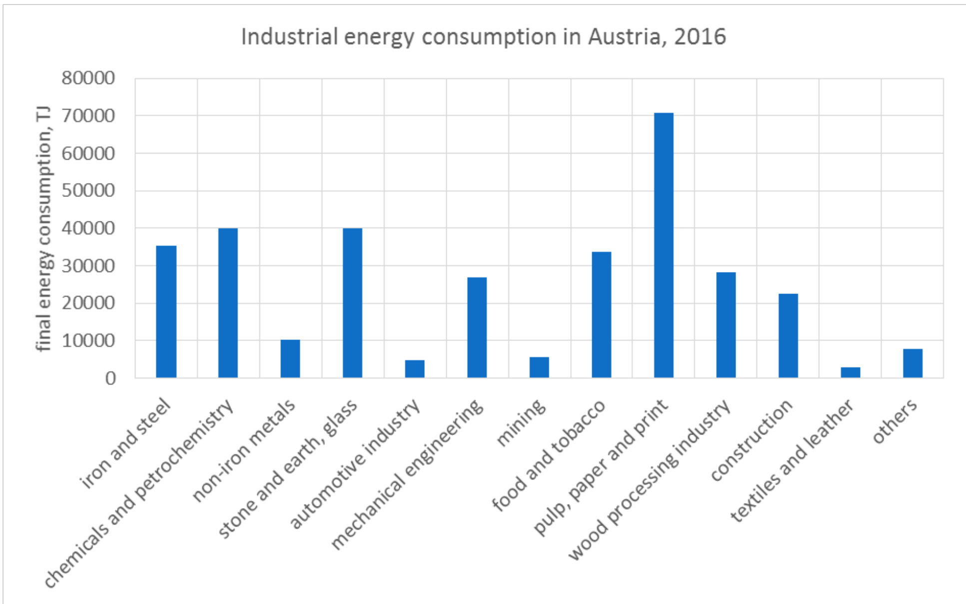

Figure 1-2: Industrial energy consumption in Austria by sector [Source Report Austria]

In figure 1-4, the fractions of six different applications are compiled. A total of 109 PJ were consumed in industrial ovens, followed by steam generation, stationary engines, space heating and air conditioning. Minor fractions are attributable to lighting, information technologies (IT) and electro-chemical applications.

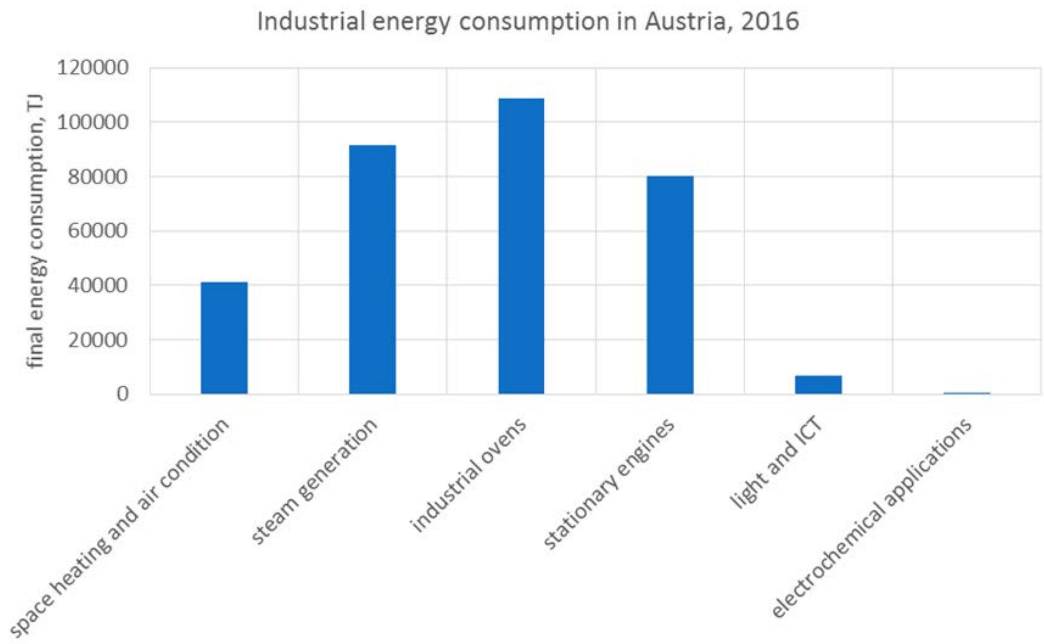

Figure 1-4: Industrial energy consumption in Austria by application [Source Report Austria]

-Industrial energy consumption in France by sector

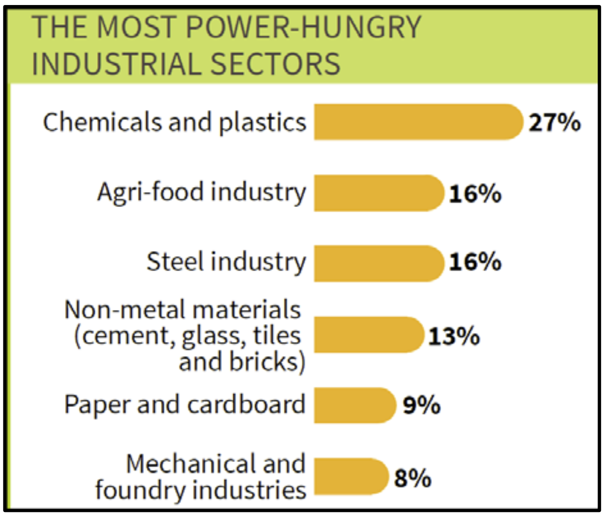

Figure 1-5 Industrial energy consumption in France [Source Report France]

The French industry is accounting for over 20 % of the country's energy consumption. Supporting industry efforts to reduce energy consumption will be crucial in taking up the challenges of the energy transition. In this context, recovering and recycling excess heat generated by industry is a promising source of significant energy savings. Figure 1-5 shows the most power-hungry industrial sectors.
Waste heat in industry is an important matter for heat pumps. This waste energy can be used as a heat source within the same industrial site. The definition given for excess heat or waste heat is the following: this is the heat generated by a process that is not used for the main purpose of the process and that is not recovered.
In France in 2016, the total waste heat from industrial activities was 109.5 TWh, i.e. 36 % of fuel consumption, see figure 1-6. About 50 % of this heat is over 100 °C as given in figure 1-6.
It means that 50 % is wasted below 100 °C and then can be considered as a good source for industrial heat pumps.

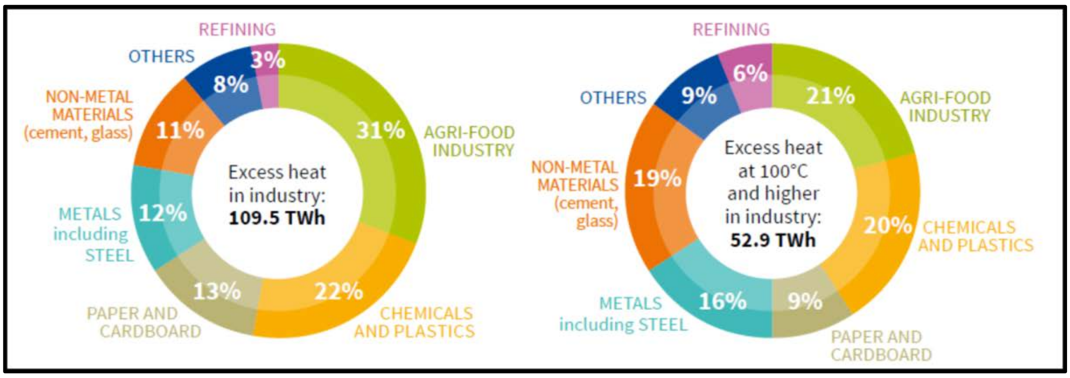

Figure 1-6: Distribution of waste heat in France [Source Report France]

-Energy carriers for the industrial energy consumption in Austria:

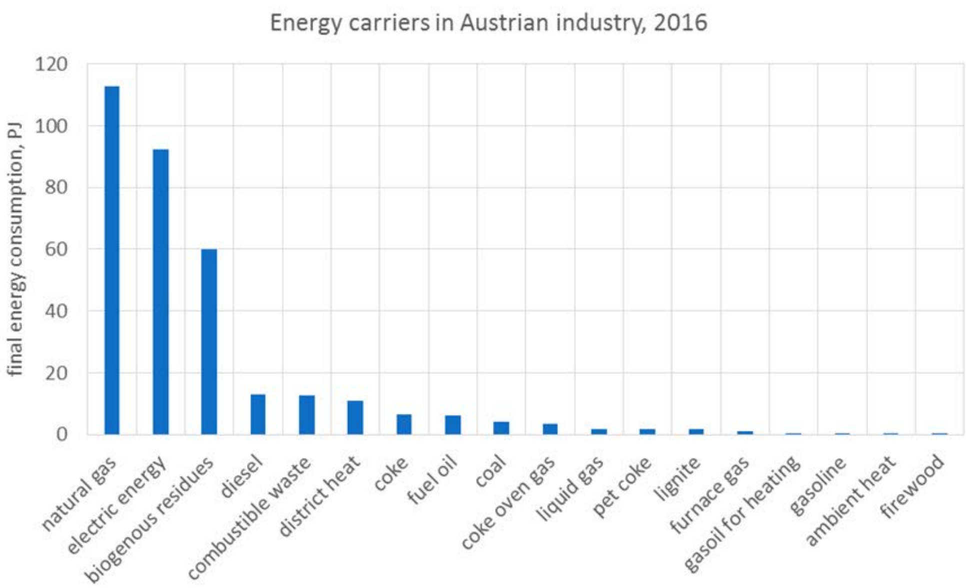

Figure 1-7: Industrial energy consumption in Austria by energy carriers [Source Report Austria]

According to figure 1-7, the most important energy carrier is natural gas (113 PJ = 34%), which is used in all sectors. Electric energy is also used in all sectors; it is the main energy carrier in the chemical and petrochemical industry and in mechanical engineering.
Biogenous residues amount for 60 PJ (= 18%) and are predominantly used in the pulp and paper industry.

-Energy carriers for the industrial energy consumption in France:

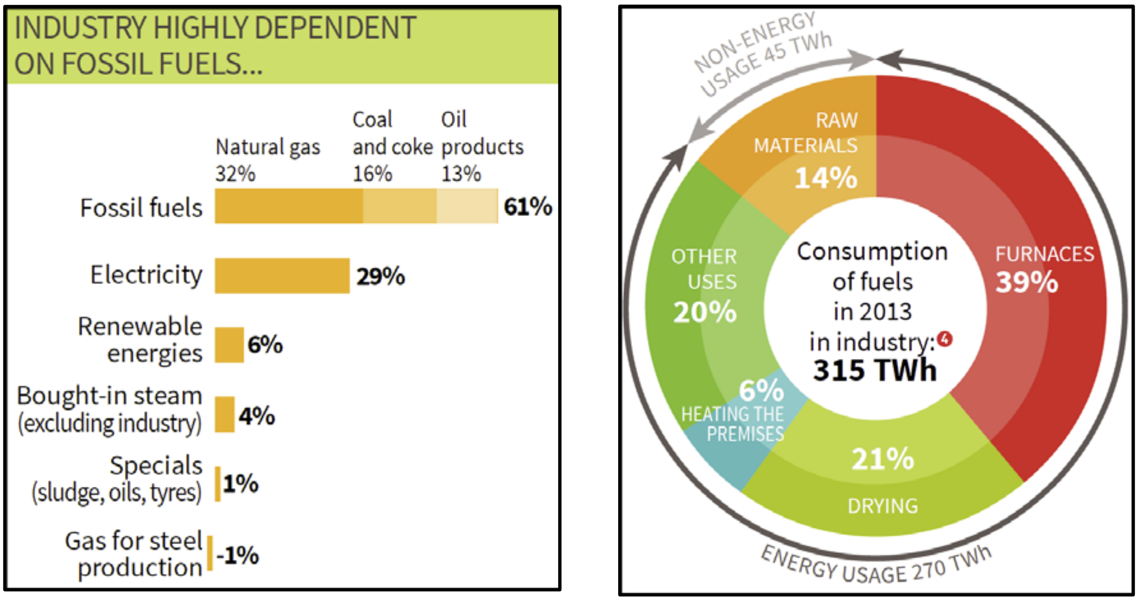

Figure 1-8: Final energy consumption in France (2016) [Source Report France]

The industry in France is highly dependent on fossil fuels, see figure 1-8. Imported fossil fuels are the main energy source used to produce heat in industry with a total consumption of 270 TWh (without raw materials). The energy use of drying processes (21 %) is one of the promising future potentials for IHP.

-Case Studies in Austria

Findings on the successful process integration of industrial heat pumps are processed and documented. For this purpose, case studies are prepared on heat pumps in industrial sectors.
By desk research and expert discussions with manufacturers and industrial companies, a further 68 examples of industrial heat pumps are described in the following figure.

Heat pumps which are integrated into an industrial or commercial process on the heat source and/or supply side were taken into account.

Only heat pumps, which are already in operation, were considered.

The examples come from various industries whose good suitability for heat pumps is already known, such as the food industry (17 examples), utility companies (11 examples) and the metalworking industry (11 examples). Figure 1-9 gives an overview of the different sectors.

Different heat sources are used, see figure 1-10. The most common heat sources are processes that require cooling and waste heat flows from which heat can still be extracted. In addition,

the waste heat from refrigeration machines and compressed air systems as well as flue gas condensation is used.
IHPs are most commonly used for heating buildings (33 examples) or for providing district heating (19 examples). Process heat supply occurs in 13 examples (Figure 1-10 right).
Among the examples there are 88 % compression HPs and 9 % absorption HPs. In 3 % of the cases both absorption and compression HPs are used.

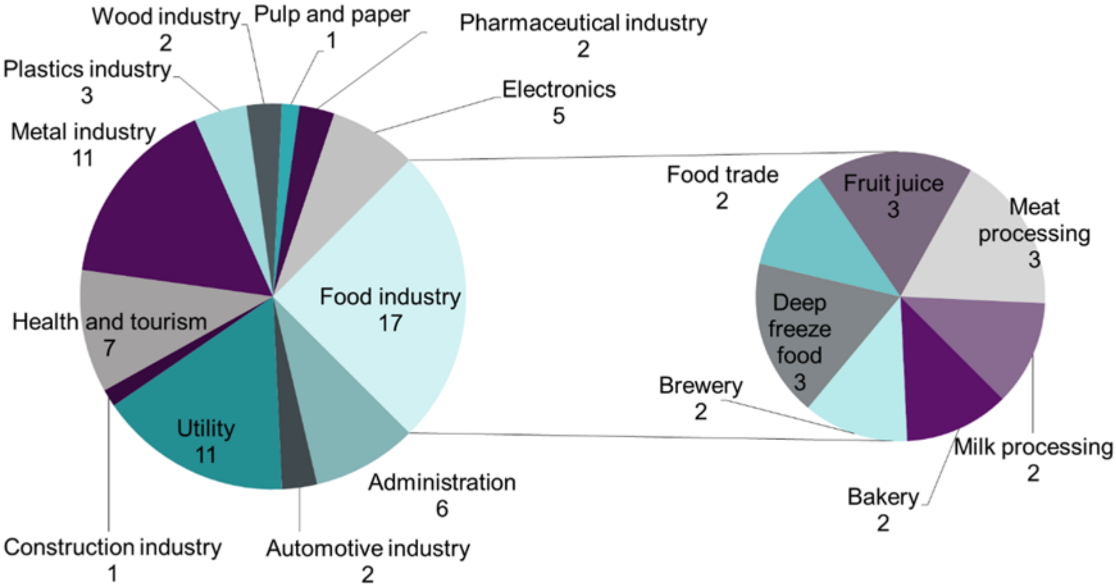

Figure 1-9: Breakdown of Austrian case studies for IHP by sector [Source Report Austria]

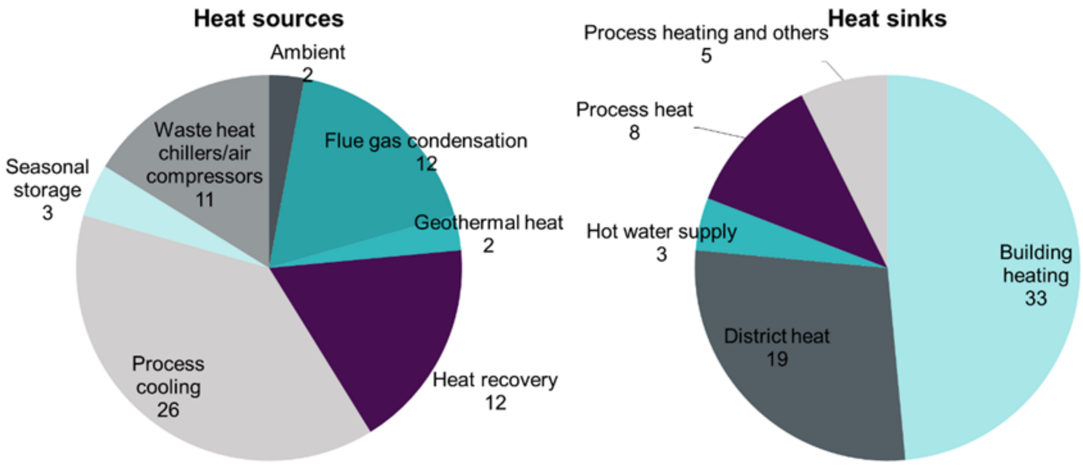

Figure 1-10: Heat source and sink for IHP (Austrian case studies) [Source: Report Austria]

-Case Studies in France:

In the frame of this Annex we selected IHP cases. Information was found from different sources: Internal EDF (utility) documents, EDF R&D developments, manufacturer references, Internet research, French workshop and conferences.

Statistical analysis of the cases as given in figure 1-11 must not be relevant as these numbers are small and these cases may not be representative for the total existing application market in France. Actually, it’s very difficult to find data of sales from the manufacturers. They are often subjected to non-disclosure agreements (NDA) by their customers who consider their HP project as part of their competitiveness.

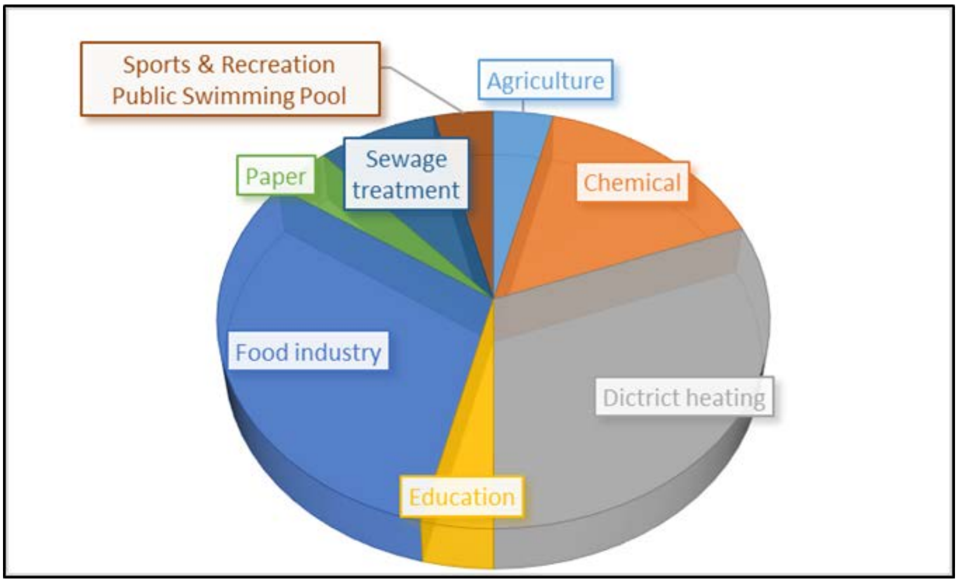

Figure 1-11: Pie chart of the 30 cases in France sorted by sectors [Source Report France]

Database analysis

Industrial sector installed	Total capacity kW
Agriculture	440
Chemical	3 164
District heating	89 535
Education	419
Food industry	18 112
Malt industry	4 500
Sports & recreation	500
Total	**116 700**

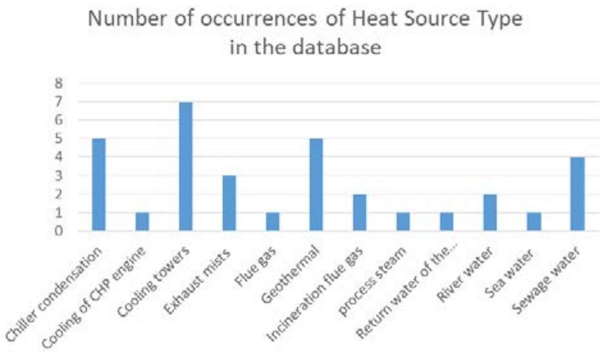

Figure 1-12 Database analysis Installed capacity and heat sources [Fourmigué 2019-05]

Conclusion of the database analysis:
IHP plays an important role in France in heating district network. For these networks the main heat source are geothermal and sewage water, see figure 1-12.
The food industry is the largest industry sector for IHPs.
The heat sources are cooling towers and waste heat of chillers.

-Case Studies in Japan:

Figure 1-13 shows the quantity of cases installed in different industrial sectors. The food product sector is suitable for IHP application on temperature level and heat demand. The share is dominant in the quantity, approximately 40 % among the total cases, followed by machinery, chemicals, and electronics in that order.

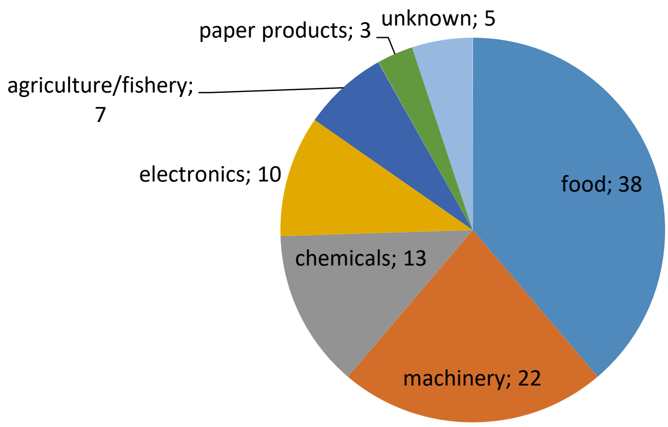

Figure 1-13: Industrial sectors of IHP application in Japan (total: 98 cases) [Source Report Japan]

Figure 1-14 shows the quantity of cases for each applied process. HVAC is the most basic system of HP application, indicated as the largest number among the processes; heating and heating and cooling follow in that order. These three processes occupy approximately 70 % of the total number.

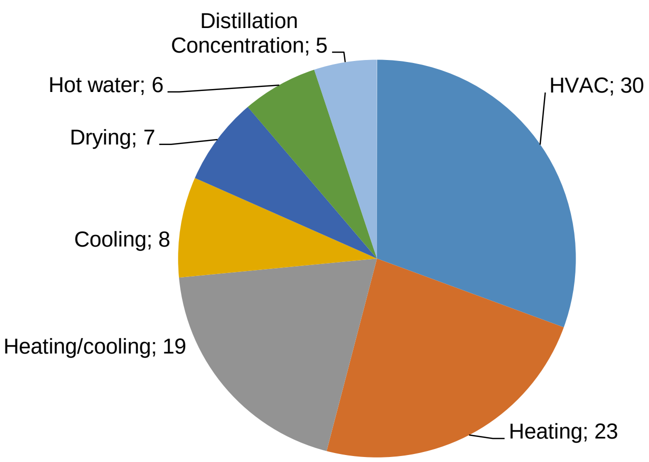

Figure 1-14: Processes applied of IHP in Japan (total: 98 cases) [Source Report Japan]

-Case studies:

The collected case studies of industrial sectors with large potential were analysed and elaborated for a clear understanding of the benefit and advantage of the application. This is shown in a simple table form as a web-based information platform for heat pumps in industrial and commercial applications. Interested users should have the possibility to find their application with meaningful data of existing case studies from global sources.

- Website: heat pumping technologies

The website presents the reports from the different countries and maps with the selected best practices including descriptions of the cases.

Japan and Europe are shown in separate maps.

IHP cases are identified:

Country	**Amount**	**Total**
Austria	69	
Denmark	74	
France	33	
Germany	23	
Japan	101	
Switzerland	24	
The Netherlands	8	
United Kingdom	10	342

Research and practical applications show increasingly clear that IHPs can provide heating/cooling to industrial applications and district grids. The outcomes show more than three hundred good practices of IHPs of applications, such as drying, washing, evaporation, and distillation processes. More than 25 cases were selected as best practice in different industrial sectors and added with detailed description and information.

The website presents 60 presentations (2017-2019) from workshops, forums, congresses and summits and further publications (< 2016-2019) around the Annex 48.

-Best practice example:

Application of heat pumps to cutting and washing processes are shown as the best practice of machinery industry in Japan.

The heat pump has a total with a COP of 5 under the simultaneous cooling and heating condition. The heat pump can accommodate unbalanced cooling and heating demands.

To begin with, a heat pump for a washing process and a cutting process was installed in 2009. After the effect was verified through field tests, thirteen more heat pumps were installed in 2010. These fourteen heat pumps consist of six cooling/heating type machines with a heating capacity of 22 kW, and eight heating-only type machines with a heating capacity of about 44 kW.

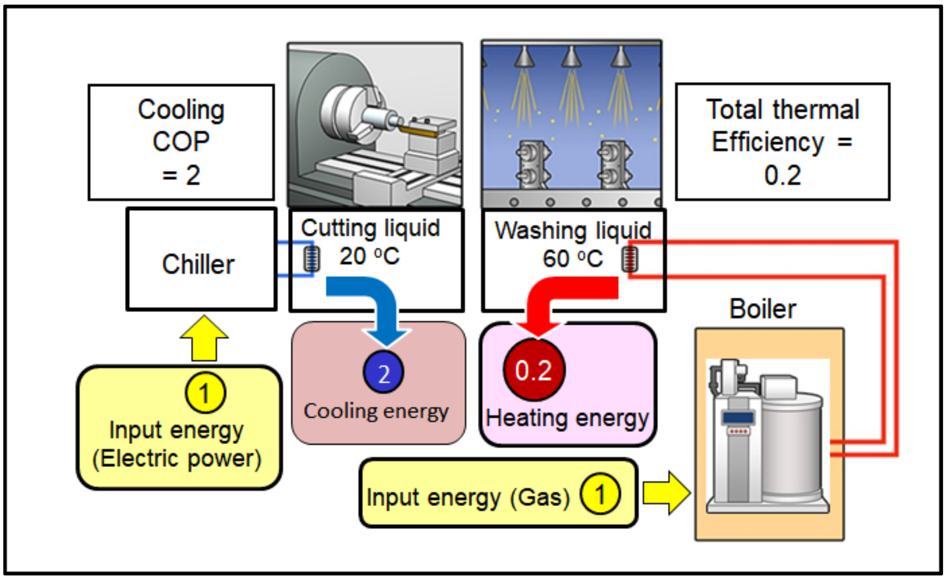

Figure 1-15: Conventional system for the cutting and washing process [Source Report Japan]

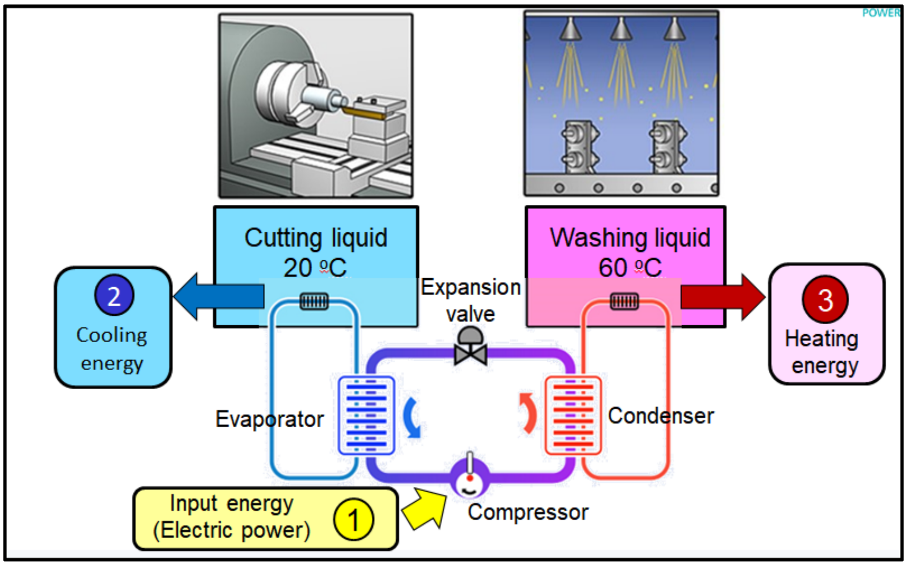

Figure 1-16: Heat Pump for the cutting and washing process [Source Report Japan]

	Before application of heat pumps	After application of heat pumps	Reduction achieved
Power consumption (MWh/ year)	193 (100%) <Boiler auxiliary equipment, Cooler>	570 (295%) <Heat pump>	+377 (+195%)
Fuel oil consumption (Kilo Litters/ year)	470 (100%) <Boiler fuel oil>	0 (0%) <Heat pump>	-470 (-100%)
Water consumption (KL/ year)	6,953 (100%) <Steam>	0 (0%) <Heat pump>	-6,953 (-100%)
Energy saving (Fuel oil equivalent, KL/year)	522 (100%) < Boiler, Cooler>	85 (16%) <Heat pump>	-437 (-84%)
CO_2 emissions (Tons of CO_2/ year)	1,364 (100%) <Boiler, Cooler>	270 (20%) <Heat pump>	-1,094 (-80%)

Figure 1-17: Effects of the application of heat pumps [Source Report Japan]

The application of heat pumps to cutting and washing processes is shown as the best practice of the machinery industry in Japan.

Mechanical part manufacturing plants have cutting processes followed by washing processes. The conventional system for cutting and washing processes is shown in figure 1-15. In the cutting processes, cutting liquid is cooled and the temperature is maintained at approximately 20 or 30 °C. Cold water at approximately 15 or 25 °C is necessary to cool the cutting liquid. Cutting liquid was conventionally cooled by small chillers. The coefficient of performance (COP) of the small chillers was 2.

Exhaust heat from the chiller was released to the atmosphere. In the washing processes, washing liquid is heated and the temperature is maintained at approximately 60 °C. Hot water at approximately 65 °C is necessary to heat the washing liquid.

Washing liquid was heated by electric heaters or hot steam from boilers. Generally, boiler rooms are located far from factory buildings in which the washing processes are installed.

In this case, steam is supplied from the boiler to the washing machines located 300 m away. Not only combustion loss and drain recovery loss but also huge heat loss from the steam piping substantially lowered total energy efficiency. The total thermal efficiency of the steam supply system was 0.2.

To improve energy efficiency, high-efficiency heat pumps were desired to be installed near washing processes for energy saving as shown in figure 1-16.

Figure 1-17 shows the effects of the application of heat pumps regarding cost. Comparing the results before and after the application of heat pumps, the investment cost decreased by 33 % and annual running cost decreased by 79 %.

When the heat pump system is added to the conventional system, the initial equipment investment cost is 91,000,000 JPY; running cost reduction is 26,030,000 JPY per year; and subsequently the pay-back time becomes 3.5 years. When a factory is newly founded, both initial investment cost and running cost of the heat pump system are lower than those of the conventional steam supply system and chillers.

Approximately 110 heat pumps had been installed in Japan as well as Japan's neighbors by 2017. See more in the report task 4 from Japan (Link).

-**Application of existing models**:

A holistic guide for considering heat pump integration with industrial processes is presented with technical detail and insights which are relevant for many levels of plant personnel, consultants and practitioners. Additional resources are provided throughout this report to provide readers with deeper details on many aspects of the approach described herein. See chapter 5.

-Barriers:

One of the main barriers for application of IHPs is the very different situation concerning the energy prices in the countries. Especially the ratio of electricity/gas price is important. Sweden, Finland, Netherlands, France and Switzerland have favourable price ratios; Germany, Ireland and UK have inconvenient price ratios.

Conclusion

The project IEA HPT TCP Annex 48 (Industrial Heat Pumps, Second Phase) initiated by the IEA HPT TCP (Technology Collaboration Programme on Heat Pumping Technologies of the International Energy Agency) attempts to overcome existing market barriers for industrial heat pumps.

The Annex 48 presents a special website for the reader who is interested in industrial heat pumps and their application:

- Comprehensive literature e.g. the connected material to all IEA HPP and HTP TCP Annexes with Industrial Heat Pumps since the 90ties of the last century
- The direct results of the Annex by more than 60 presentations (2017-2019) and more than 60 publications (All literature directly connected via links)
- Country reports with detailed information about the specific situation in the country, insights in market developments, additional information about industrial sectors, and energy policies
- Energy carriers, energy demand by industrial sectors, IHP potential
- Energy situation in the different countries especially the ratio of the electricity/gas price
- Type of heat sources and heat sinks with temperatures in connection with the application
- Integration of IHPs in industrial applications/processes, the case studies are in practice and have a high multiplication potential, as their integration solutions can be transferred to other processes and industries.
- Market situation about the IHPS in the different countries, status and outlook
- More than 300 documented case studies of successful applications of IHPs
- Comprehensive material about the selected case studies in the different sectors/countries (e.g. industry, application, process, location, end user, HP technology, capacity, cost …)
- Efficiencies, energy savings, reduction of CO_2 emission
- For IHP training: The Annex 48 contains information and tools, as well organizations and events; e.g. guidebook for the district heating sector, heat pump calculator, assessment tools, concepts for design, hydraulic, and controls.

For the users of the Annex

Researchers, technicians, product developers, industrial planers and designers, consulting engineers, component/system manufacturers and suppliers will use the Annex 48:

- As actual source for basic information, motivation and suggestion for possible applications
- As information about trends and developments (systems, applications, refrigerants…)
- As information about energy situation/policies/carriers/price ratios/savings
- As source for training material

Refrigerant plant and heat pumps operators will use the Annex 48:

- As the technicians will do
- As source for comparison and inspiration with similar applications/sectors/processes

Policymakers, stake holders, and decision-makers will use the Annex 48:

- As a “reference book” or “book of facts” to have a more detailed understanding about the great possibilities and challenges of IHPs in the industrial processes for electrification, reduction of energy, reduction of greenhouse gas emission and avoiding waste heat.

Status in the markets

Industrial heat pumps are a mature technology - carefully integrated, they are highly reliable and enhance process efficiency. The findings confirm that heat pumping technology is today a key technology for the commercial and industrial processes in almost all industrial sectors. The IHP is an active part of the current markets, in some countries more, in other less. The market penetration is good but the market share has to increase.
IHPs are currently most frequently used in the food sector. These heat pumps are usually used for simultaneous heating and cooling, such as refrigeration machines with waste heat recovery. The second sector is the integration of IHPs in district grids. We will see in the future more district heating, district cooling, combined grids and low temp-grids. The general trend to avoid waste heat will support the development in the direction of systems with simultaneous heating and cooling.
Industrial heat pumps have a great potential for more efficient use of energy (energy reduction 40-80 %) and reduction of CO_2 emissions (30-80 %) in industrial processes. In the drying process the HPs additionally create quality improvement.

Applications of IHPs with good prospects

- Hot air generation and air preheating for drying processes (i.e. wood, paper, sewage sludge, starch, bricks, and pet food) through waste heat recovery
- Process steam generation (low pressure steam) for the sterilisation and pasteurisation of food (e.g. milk) using cooling water or humid exhaust air
- Hot water generation for washing and cleaning processes (i.e. food, meat, product washing) in combination with cooling generation
- Heat recovery by flue gas condensation in biomass incinerators
- Production of injection moulded components from plastics (heating in the extruder and cooling in the injection mould)

Outlook Future work

The aim is to further overcome existing market barriers. The energy transition and the climate debate have a significant impact on industry and increase the use of renewable energies to reduce greenhouse gas emissions. Here the IHPs have a good market opportunity.

By intensifying public relation, information and training of experts in this field of energy supply for industrial companies, efforts are being made to make heat pump technology more visible and to highlight its application potential.

The case studies are useful in order to identify possible multiplication effects of similar HP systems in other companies with similar heating and cooling situations.

A learning effect is expected from more than 350 case studies all over the world. The case studies are in practice and have a high multiplication potential, as their integration solutions can be transferred to other processes and industries.

2 Annex work on industrial heat pumps (IHPs)

The IEA Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) has contributed with four Annexes since the 80s of the last century in the field of heat pumps for industrial applications:

2.1 Annex 09: High Temperature Industrial Heat Pumps

Annex 09 (before 1990) Summary (extract):
"In this report the state of the art of high temperature industrial heat pumps is described. Overviews are given of the different types of heat pumps on the market including where possible listings of manufacturers. A detailed description is also given of the R & D efforts going on in the field.
It is found from these overviews that open cycle compression heat pumps are able to reach temperature levels of up to 200 °C. The closed cycle compression systems in actual use are limited to temperatures of some 130 °C. For sorption machines in actual use only the heat transformer is able to reach temperatures significantly higher than 100 °C. However here also the temperature limit presently is located at some 135 °C.
The economics of high temperature heat pumps is investigated. It is found that under the present conditions of fuel oil costs heat pumps can be applied in only a few countries where the cost of electricity to drive the heat pumps is extremely low (e.g. Norway). The run time of heat pumps must be as high as possible and must typically be of the order of at least 6.000 hours per annum in order to give rise to acceptable payback periods.
The report concludes with detailed case studies in which the energetic and economic performance of existing heat pump systems are analysed. In general it is found that the systems perform according to expectations except for the economics. Several systems built a few years ago would be deemed uneconomical under the present cost conditions."

Direct link to the report part I report part II

2.2 Annex 21: Industrial heat Pumps

Annex 21 (1992- 1996) Summary (extract):
"Experiences, Potential and Environmental Benefits of IHPs
Industrial heat pumps (IHPs) can provide a number of process-related benefits, including:
- reduced energy consumption for process heating;
- increased capacity of existing process heating systems;
- improved plant-wide environmental performance;
- expanded production capacity through debottlenecking;
- improved product quality

Despite these potential benefits, the number of IHPs installed to date is relatively low compared to the number of existing technically and economically viable opportunities. IHPs have been implemented on a wide scale in only a few industrial processes, such as lumber drying and some food, chemical, and pulp and paper industry evaporation and distillation processes.
Several reasons have been identified that have contributed to the level of IHP use thus far:
- lack of knowledge on the potential processing benefits of IHPs;

- lack of experience or familiarity with IHP technology ;
- lack of combined process and heat pump technology experience or knowledge.

The last factor is particularly important because some early IHP installations were poorly designed and have created some negative perceptions about the technology and its potential use and benefits. In addition, combined process and heat pump knowledge is necessary to identify potential IHP opportunities that are properly integrated within a process and that take into account other potential energy conservation opportunities, such as heat exchanger network optimization.

To illustrate the potential energy saving and environmental benefits of IHPs, and provide industry with more information on how to properly identify potential IHP opportunities, eight countries jointly sponsored and undertook Annex 21 work. The specific objectives of the Annex were to:

- increase awareness of the energy savings potential associated with heat pumping;
- expand the information base available to help identify IHP applications;
- illustrate current and potential future IHP applications;
- estimate the potential global environmental benefits of IHPs ...”

Direct link to the report

2.3 Annex 35: Application of Industrial Heat Pumps

Annex 35 (2010-2014) Summary (extract):

The programme and work has been mainly concentrated on the collection of statistical energy and environmental data and information related to industry as well as the present status of R&D and the application of heat pumps in industry. In total 39 R&D projects and 115 applications of heat pumps in industry, in particular the use of waste process heat as the heat source, have been presented and analyzed by the participating countries.

See also: chapter 3.2 Annex 35 Review

Direct link to the report part I report part II

2.4 Annex 48: Industrial Heat Pumps, Second Phase

Annex 48 (2016-2019)

Direct link to the website

Whereas the first two Annexes contribute in a broad variety on research and development activities to the technology of IHPs, the last two Annexes focus more on the practical application and integration of IHPs in many different industries around the globe.

Other running Annexes under the TCP of Heat Pumping Technologies and other TCP’s are partially working in the same area. These Annexes under the HPT TCP are:

Annex 47: Heat Pumps in District Heating Direct link to the website
Annex 50: Heat Pumps in Multi-Family Buildings Direct link to the website

The main goal of this Annex 48 is to overcome still existing difficulties and barriers for the larger scale market introduction of industrial heat pumps. The results should be concentrated on the development and distribution of condensed and clear information material for policy makers, associations and industries. Focus will be concentrated on a limited number of process industries with large potential.

The objectives will be achieved by common studies performed by the participants for each country. The main focus of the Annex will be on arranging the information on heat pumping technologies for industry to designers, decision- and policymakers in such a way that it will lead to a better understanding of the opportunities and to use these in the right way in order to reduce the use of primary energy consumption and the CO_2-emisions as well the economy of industrial processes.

2.4.1 Task structure

Task 1: Analysis of the collected case studies and successful applications of IHPs

Analysis of case studies / applications of IHPs:
Selection of excellent application opportunities and success applications and approved examples
To select a limited number of industries with large potential focused on special areas with high product quality

Task 2: Structuring information on industrial heat pumps and preparation of guidelines

A heat pump data base to be used for the structuring the information of task 1 for each industry with best available technologies and best practices

Task 3: Application of existing models for the integration of a heat pump into a process

Models for a consistent integration of a heat pump into a process, e.g.:
OSMOSE integration tool for the integration of heat pumps into industrial process (EPFL University Lausanne)
CERES a strategy for the recovery and reuse of waste heat in industrial processes

Task 4: Communication of the IHP potential for policy makers, designers and decision makers

Arranging the information on heat pumping technologies for industry, for policymakers, industrial planers and designers, stake holders as well as heat pump manufacturers
Providing a better understanding of the opportunities for the reduction of primary energy consumption, CO_2-emissions as well as the economy of industrial processes
Develop marketing and communication instruments and potentially support and advises on legislative
Holding workshops, participating with presentations in forums, conferences…
Publishing articles, publishing reports, communicating with the HP community
Developing a website with the results of the Annex

2.4.2 Reports for the Task 1-4

For Task 1 and Task 2 the following reports are published:

Case studies and structured information:

Austria	2019 1	Direct link	Austria	2019 2	Direct link
Denmark	2019 1	Direct link	Denmark	2019 2	Direct link
France	2019 1	Direct link	France	2019 2	Direct link

Germany	2019	2	Direct link			
Japan	2019	1	Direct link	Japan	2019 2	Direct link
Netherlands	2019	2	Direct link			
Switzerland	2019	1	Direct link			
United Kingdom	2019	1	Direct Link			

For Task 3 the following report was published:

Application of existing models for the integration of a heat pump into a process:

Switzerland 2020 3 Direct Link

See also chapter 6 Application of existing models

For Task 4 the following reports are published:

Communication **See also chapter 7 Communication**

Austria	2019	4	Direct Link
Denmark	2019	4	Direct Link
Japan	2019	4	Direct Link

3 Market overview

The goal was to get insight in market developments in the different countries. It should collect additional information about industrial sectors, energy situation and energy policies, possibilities for IHPs and High Temperature Heat Pumps (HTHPs). An Annex 35 review complements the market overview.

3.1 Industrial sectors with IHP application

Industry	Application	Total	Austria	Denmark	France	Japan	Switzerland	UK	Germany	Netherlands
Total		**342**	69	74	33	101	24	10	23	8
Agriculture/Fishing		**12**		1	1	7	1		1	1
Food:		88	17	8	9	40	5	1	4	4
	Brewery	7	2			3			1	1
	Malt	3			2				1	
	Beverage	4				4				
	Fruit juice	3	3							
	Winery	1				1				
	Dairy	9		6		2			1	
	Milk processing	2	2							
	Cheese	4			2	1	1			
	Cream ice	1				1				
	Bakery	2	2							
	Chocolate	6				5	1			
	Slaughter house	4			1		1		1	1
	Meat processing	5	3		2					
	Deep freeze	3	3							
	Noodle	5				5				
	Sugar	1				1				
	Tabacco	1				1				
	Others	27	2	2	2	16	2	1		2
Chemicals		**20**		2		14			3	1
Pharmaceutical		**4**	2				2			
Electronics		**16**	5	0		10			1	
Machinery:		**22**				22				
	Automotive	**3**	2						1	
	Glass	**1**							1	
	metal processing	**6**							6	
	plastic	**1**	1							
	Others	**4**					1		3	
Metal industry		**12**	11				1			
Plastics industry		**7**	3		4					
Rubber		**1**			1					
Paper/Pulp		**5**	1	0	1	3			0	
Wood industry		**2**	2							
Textile		**4**		2					1	1
Commercial Misc.		**1**							1	
Utility		**11**	11							
District heating		**69**		47	15		6		1	
Warehouse		**2**		1						1
Large Buildings		**27**	7	8	1		2	9		
Health, tourism		**10**	7		1		2			
Others		**14**		5		5	4			

Figure 3-1: Application cases according to the industrial sectors [Source: Annex 48]

The importance of the industrial sectors differs from country to country. The goal is not to evaluate the importance of industry but to select good and best practice of industrial heat pump for the stakeholders who intend to install heat pumps. The best practice is highly influenced by stakeholders' perspectives.

Figure 3-1 illustrates the variety of the IHP applications. Dominating is "Food" and "District heating". District heating is driven by Denmark. The exceptional Danish district heating sector consists of approximately 400 local district heating companies and covers 1.7 million households, which corresponds to coverage of 64 %. Figure 3-1 illustrates furthermore the broad applications of IHPs in all industrial sectors.

An interesting view is a statement about Japan and their view on Europe: "In Japan all industry sectors are important to be developed. It seems different to evaluate importance of industry sectors between EU and Japan. EU has developed a cooperative community among the European countries. They divide work in different countries where the highest productivity could be achieved in industry. Each county can select the importance of industries. However, it is difficult to distinguish importance of industry sectors in Japan. Little industrial cooperation would be structured among most of Asian countries. Japanese industries are maintained with a closed system of industrial activities where every domestic industry is important to be developed as possible. The situation is rather similar to the industrial structure of the USA, China, and Korea. If we ask the importance of industry for managers of the domestic industries, they would answer "yes". They would say that their own industry is the most important to be developed. We could not evaluate the difference of importance for industry like the European community where different works of industry are divided among countries in the EU."

3.2 Annex 35 Review

Background

The world rising greenhouse gas emissions and environmental concern set focus on energy conservation and use of renewable energy sources.
In this context, the IEA HPP Annex 35 "Application of industrial Heat Pumps," has been initiated in order to actively contribute to the reduction of energy consumption and emissions of greenhouse gases by the increased implementation of heat pumps in industry.

While the residential market may be satisfied with standardised products and installations, most industrial heat pump applications need to be adapted to unique conditions. In addition a high level of expertise is crucial. Industrial heat pumps are defined here as heat pumps in the medium and high power ranges which can be used for heat recovery and heat upgrading in industrial processes, but also for heating, cooling and air-conditioning in industrial, commercial and multi-family residential buildings as well as district heating. The main advantage to use heat pumps in industrial application is to recover waste heat, as to use free renewable energy sources.

Annex 35/13 started on April 1, 2010 and was concluded on April 30, 2014, with 15 participating organizations from Austria, Canada, Denmark, France, Germany (Operating Agent), Japan, the Netherlands, South Korea and Sweden.

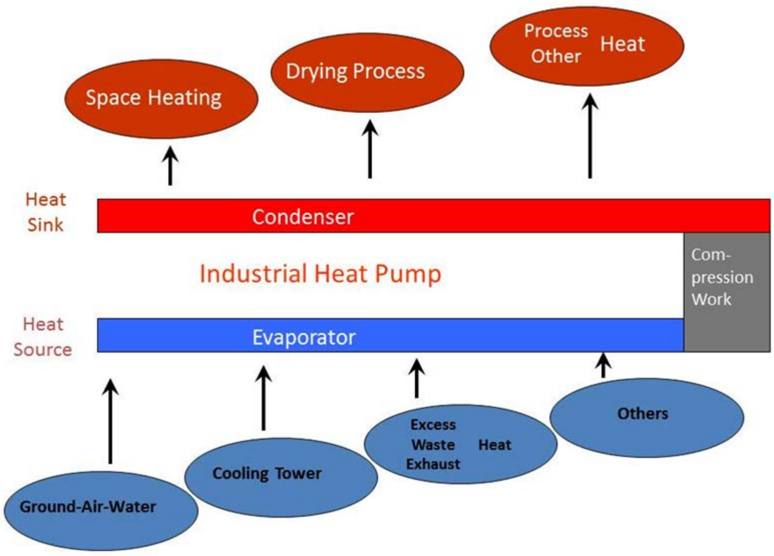

Figure 3-2: Possible heat sources and heat sinks for IHPs [Source: Annex 35/48]

The Annex comprised an overview in the participating countries of the industrial energy situation and use, the state of the art and R&D projects in heat pumping and process technologies and its applications, as well as analysing business cases on the decision-making process in existing and new applications and in the wider application of industrial heat pumping technologies. The annex has been subdivided in the following tasks:

-Market overview, barriers for application

-Modelling calculation and economic models

-Technology

-Application and monitoring

-Communication

The work programme has been mainly concentrated on collection of statistical energy and environmental data and information related to industry, as well as the present status of R&D and the application of heat pumps in industry. A total of 39 R&D projects and 115 applications of heat pump in industry - in particular the use of waste process heat as the heat source - have been presented and analysed by the participating countries.

Market overview, barriers for applications, advantages

The Annex report summarized the energy situation in general and the industrial energy use and related heat pump market subdivided into participating countries. Based upon these findings focus will be given to further work to meet the challenges for the wider application of industrial heat pumping technologies.

Although heat pumps for the industrial use became available on the markets in the participating countries in recent years, just very few carried out applications can be found. To distinguish the reasons for this situation, application barriers were also a part of the survey:

-Lack of knowledge:

The integration of heat pumps into industrial processes requires knowledge of the capabilities of industrial heat pumps, as well as knowledge about the process itself. Only few installers and decision makers in the industry have this combined knowledge, which enables them to integrate a heat pump in the most suitable way.

-Low awareness of heat consumption in companies:

In most companies knowledge about heating and cooling demands of their processes is quite rare. This requires expensive and time consuming measurements to find an integration opportunity for an industrial heat pump.

-Long payback periods:

Compared to oil and gas burners, heat pumps have relatively high investment cost. At the same time companies expect very low payback periods of less than 2 or 3 years. Some companies were willing to accept payback periods up to 5 years, when it comes to investments into their energy infrastructure. To meet these expectations heat pumps need to have long running periods and good COPs to become economical feasible.

-High temperature application:

From the technical point of view one barrier can be identified regarding to the temperature limits of most commercially available heat pumping units. Many applications are limited to heat sink temperatures below 65 °C the theoretical potential for the application range of IHP increases significantly by developing energy efficient heat pumps including refrigerants for heat sink temperatures up to and higher than 100 °C.

-Advantages:

On the other side, IHPs have the following advantages in comparison to heat pumps for space heating:

High coefficient of performance (COP) due to low temperature lift and/or high temperature levels

Long annual operating time

Relatively low investment cost, due to large units and small distance between heat source and heat sink

Waste heat production and heat demand occur at the same time

-Barriers:
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 CO_2-emissions (in some cases more than 50 %), Temperatures higher than 100 °C are possible, supply temperatures < 100 °C are standard.

-Energy consumption:

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:
For pulp and paper in Austria 20 %, in Canada 28 % and Sweden 52 %
Wood needs in Austria, Canada, Denmark and Sweden between 3 and 8 % of the energy
Metal production needs between 10 and 36 % (Germany)
Chemical and petrol industry between 8 and 59 % (Netherlands)
The energy demand of the food industry varies between 1 and 26 % (Denmark)

Case Studies

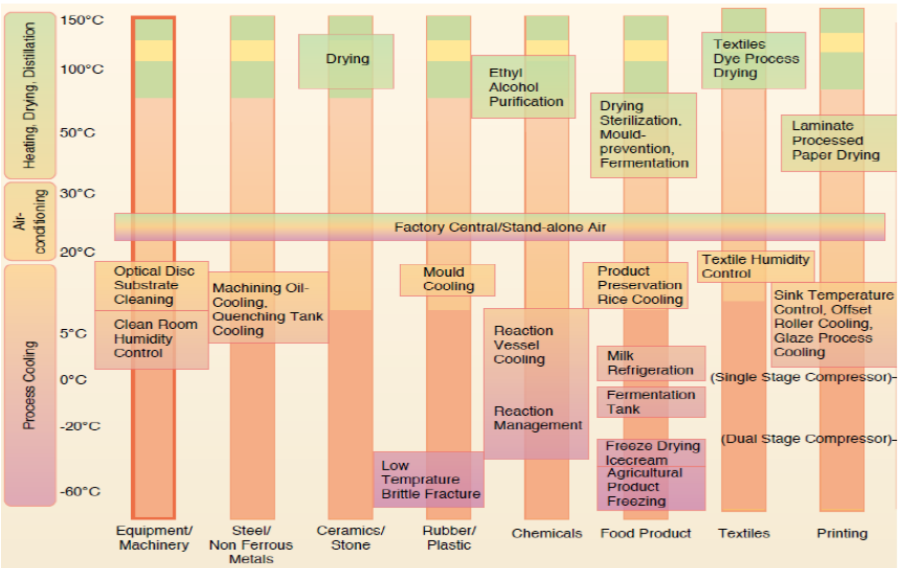

Figure 3-3: Industrial and commercial heat pump application [Source Annex 35]

The report focused on operating experiences and energy effects of representative industrial heat pump implementations, in particular field tests and case studies.
Industrial heat pumps are a class of active heat-recovery equipment that allows the temperature of a waste-heat stream to be increased to a higher, more useful temperature. Consequently, heat pumps can facilitate energy savings when conventional passive-heat recovery is not possible.
The economics of an installation depends on how the heat pump is applied in the process. Identification of feasible installation alternatives for the heat pump is therefore of crucial importance. Considerations of fundamental criteria taking into account both heat pump and process characteristics, are useful. The initial procedure should identify a few possible installation alternatives, so the detailed project calculations can concentrate on a limited number of options.
The commercially available heat pump types each have different operating characteristics and different possible operating temperature ranges. These ranges overlap for some types. Thus, for a particular application, several possible heat pump types often exist. Technical, economic, ecological and practical process criteria determine the best suited type. For all types, the payback period is directly proportional to installation cost, so it is important to investigate possibilities for decreasing this cost for any heat pump installation.
The case studies have tried to present good examples of heat pump technology and its application in industrial processes, field tests and commercial applications along with an analysis of operating data, when available, in accordance with the annex definition of industrial heat pumps, used for heating, ventilation, air-conditioning, hot water supply, heating, drying, dehumidification and other purposes.
The participating countries identify several projects and case studies in different application in which industrial heat pumps are used.
The survey with a total of more than 150 projects and case studies has tried to present good examples of heat-pump technology and its application in industrial processes, field tests and commercial applications along with an analysis of operating data, when available, in accord-

ance with the annex definition of industrial heat pumps, used for heating, ventilation, air-conditioning, hot water supply, heating, drying, dehumidification and other purposes.

Selection of application around the world:

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
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

Figure 3-4: Selection of the case studies of different application and countries [Source Annex 48]

Summary Annex 35:

There is a great potential for industrial heat pumps to reduce the energy consumption and related greenhouse gas emissions in the industry.
The main objectives of the project included market overviews in the participating countries, systems aspects and opportunities, apparatus technologies and system technologies.
The project collected totally 39 examples of R&D projects and 115 case studies worldwide, showing the successful integration of heat pumps in the industry and how to overcome barriers: Short payback periods are possible (less than 2 years), high reduction of CO_2-emissionen

(in some cases more than 50 %), temperatures higher than 100 °C are possible, supply temperatures below 100 °C are standard.
Further main results are the lack of experiences with and the acceptance of industrial heat pumps integrated in industrial processes at different temperature levels, are the main barriers for their larger scale market introduction in many companies (and especially in SMEs).

3.3 Energy situation in different countries

One of the main barriers for application of IHPs is the very different situation concerning the energy prices in the countries. Especially the ratio of electricity/gas price is important. Sweden, Finland, Netherlands and France have favourable price ratios; Germany, Ireland and UK have inconvenient price ratios, see figure 3-5.

	Electricity/Gas Price Ratio			
Country	Households	Small Enterprises	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	→

Figure 3-5: Electricity/Gas Price Ratios in the EU [Source Wolf 16-10a]

Outside of the EU 28 in Switzerland we have also favourable price ratios. In figure 3-6 you see the development of electricity & gas - prices and their ratio. The ratio of 2,1 (2018) is to rank in the top level in comparison with the EU-28 countries.

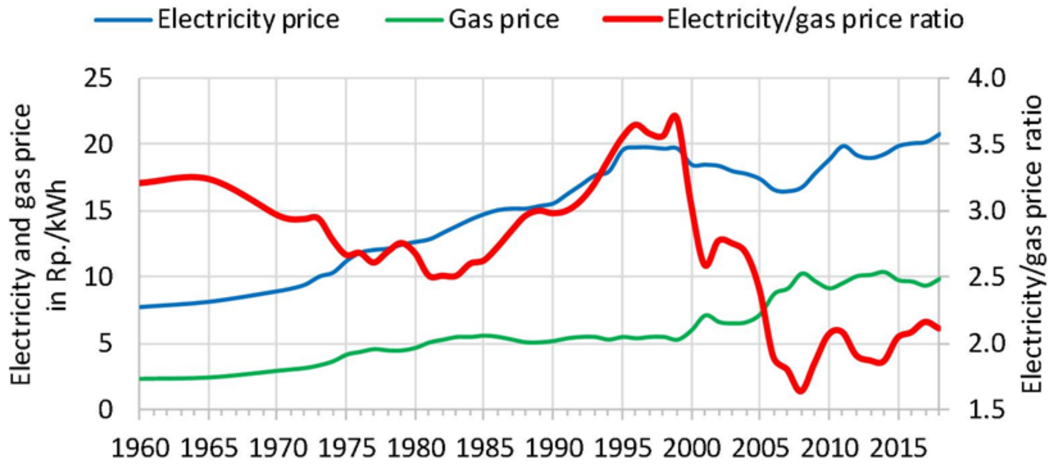

Figure 3-6: Development of electricity & gas prices and price ratio (secondary axis) in Switzerland from 1960 to 2018 [Source: Report Switzerland 2019 1 p 2-8]

3.4 High temperature heat pumps (HTHPs)

High temperature heat pumps with heat sink temperatures in the range of 100 °C to 160 °C are expected to become increasingly commercialized in the coming years. Major applications have been identified, particularly in the food, paper, metal and chemical industries, especially in drying, sterilization, evaporation, and steam generation processes. The actual research gap in the field of HTHPs is to extend the limits of efficiency and heat sink temperature to higher values, while using environmentally friendly refrigerants.

3.5 Refrigerants

With the Kigali amendment to the Montreal protocol and the EU-F-Gas regulations there are not many options at hand regarding suitable refrigerants. Replacement fluids for the currently applied HFCs are required. Especially the demand for HTHPs needs new solutions. Broad theoretical and also experimental studies for the application of HTHPs were done by [Arpagaus 19].

Refrigerant	Brand (manufacturer)	T_{crit} (°C)	p_{crit} (bar)	ODP (-)	GWP_{100} (-)	Lifetime (days)	SG	NBP (°C)
R1336mzz(Z)	**Opteon™MZ (Chemours)**	**171.3**	**29.0**	**0**	**2**	**22**	**A1**	**33.4**
R1234ze(Z)	not yet available	150.1	35.3	0	<1	18	A2L	9.8
R1233zd(E)	**Solstice®zd (Honeywell)** Forane®HTS 1233zd (ARKEMA)	**166.5**	**36.2**	**0.00034**	**1**	**40.4**	**A1**	**18.0**
R1224yd(Z)	AMOLEA®1224yd (AGC Chemicals)	155.5	33.3	0.00012	<1	21	A1	14.0
R365mfc	Solkane®365mfc (Solvay)	186.9	32.7	0	804	8.7 years	A2	40.2
R245fa	Genetron®245fa (Honeywell)	154.0	36.5	0	858	7.7 years	B1	14.9

Figure 3-7: Properties for HFO and HCFO refrigerants suitable for HTHP [Source Arpagaus 19]

There are promising results for the HTHPs, e.g. for the application steam production.

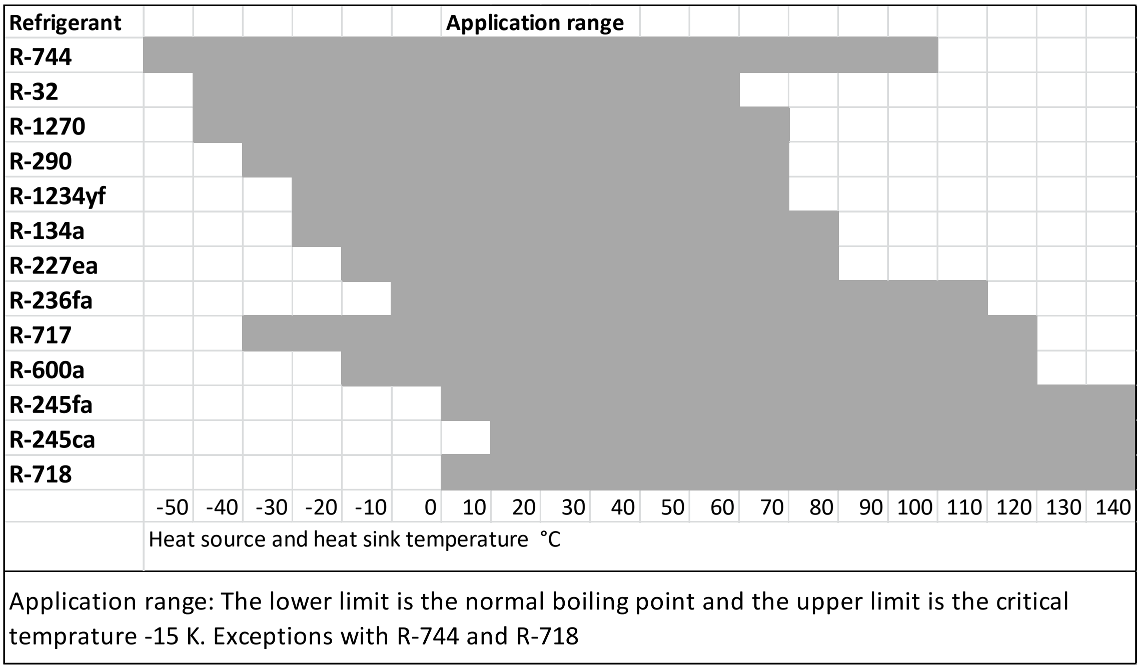

Figure 3-8: Refrigerants for Industrial heat pumps and their application range [Source Annex 48]

In figure 3-8 the current refrigerants are shown for industrial heat pumps with their application range.

In figure 3-9 is the distribution of number for refrigerants for 75 cases (best practices) in Japan. In Japan the number of R-410A is predominant, with R-744 and R-134a following it in that order.

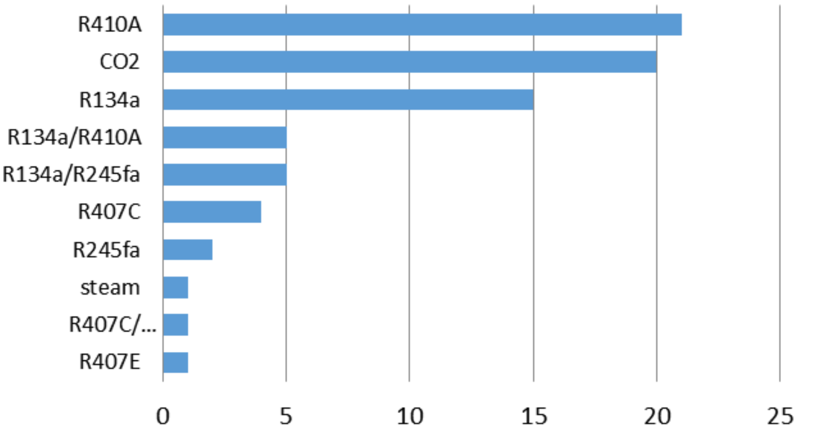

Figure 3-9: Refrigerants of HP systems (total: 75 cases) [Source Report Japan]

Refrigerant charges

Heat exchangers play a vital role in any energy-related system. This also applies to IHPs applications. It is strongly recommended to devise systems that require a minimum amount of refrigerant. By doing so, the price aspect and the potential damage from an accidental leak can be minimized to a greater extent. [Ayub 19]

3.6 Replacement of Steam Boilers

In recent years, Japanese manufactures overcame the difficulty of commercializing heat pumps for industrial use, and installation examples have been reported. Among them, the heat pump system capable of supplying steam with temperatures at 120 °C and above is only the *Steam Grow Heat* pump, which is commercialized in 2011. These IHPs are today under development in different countries.
One significant contributing solution would be to replace industrial boilers, which typically provide hot water or steam at pressures of 20 bar or lower. Applications for such boilers are vast, e.g. within chemical process plants, building heating, humidification, domestic hot water, sterilisation autoclaves, and air makeup coils. If industrial boilers were replaced by HPs, heating would only require electricity and a heat source at lower temperatures (waste heat). Such a heat pump must be able to output the required temperature levels, be economically viable and use working fluids that meet a demanding set of specifications. [Nilsson 2017].

3.7 Integration in District Heating

In Denmark, the political goal is to reach 0 % CO_2 emissions in 2050 and about 55 % renewable energy (RE) share in 2030, including 100 % RE based electrical power, including 100% phase out of coal in power production. District heating is used in 65 % of all dwellings and will be a major contributor to reach this. As the energy system is transforming to be based on electrical power, heat pumps are a central technology. The technology was successfully demonstrated by several installations in district heating, while the number of industrial applications is limited. The political goals support the introduction of heat pumps to the market, and Danish research will develop more efficient systems. [Reinholdt 18]

77 industrial heat pump installations with a total supply capacity of approximately 120 MW were identified, out of which 66 were in district heating. The wide distribution and the currently increasing request of heat pumps in district heating can be associated with several different factors. Certainly, a main aspect is that district heating operators are legally obliged to consider the socioeconomic cost as the main criterion. In addition, it may be noted that the boundary conditions are becoming more beneficial for HPs. The electricity prices are decreasing due to the ongoing phase-out of the public service obligation and the reduction of taxes on electricity used for heating purposes. Heat pumps in district heating systems are furthermore eligible for subsidies for energy efficiency improvements. Another aspect contributing to heat pumps being widely requested is that the technology has reached the status of being known and acknowledged by all involved parties. The district heating network operators know the peculiarities of heat pumps and how to integrate them in the most beneficial way. [Zühlsdorf 19]

The integration process is supported by publicly available information material, such as detailed guidelines and catalogues with realized cases for inspiration and planning tools. [DEA 19]

3.8 Drying Processes

In industrial processes 12-25 % of energy is used for drying. Inefficiency is leading to 11.3 EJ of energy loss in the EU. The goal of the European project, “Dry-Ficiency“ is to develop and demonstrate two high-temperature industrial heat pump for waste heat recovery in industrial drying and dehydration processes. Technically and economically viable solutions for upgrading idle waste heat streams to process heat streams at higher temperature levels up to 160 °C will be elaborated. The key elements are two high temperature vapour compression heat pumps. The solution will be demonstrated and validated under real production conditions in operational industrial drying processes in three leading European manufacturing companies from the pet food, food and brick industries. At the two demo sites of the "DryFiciency" project, CO_2 emission reductions up to 40-90% and primary energy reduction from 20-80% are expected for the drying processes compared to natural gas. If the heat pump technology is spread out to 50% of all drying processes in the EU, they would contribute 3-7% of the CO_2 emission reduction necessary to achieve the EU climate targets. [Wilk 19]

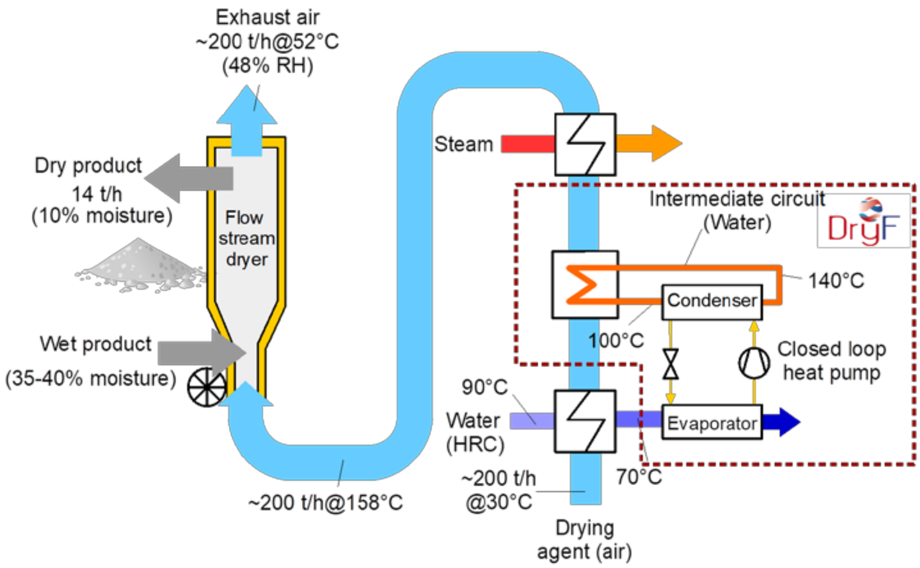

Figure 3-10 Starch drying process at Agrana Starch GmbH in Austria [Source Wilk 19]

Drying air is preheated in a water-air heat exchanger using heat from a heat recovery cycle, which is fed from other drying processes. In the original set up without heat pump, the drying air is heated to around 160 °C in a second heat exchanger with steam. Steam is provided in a natural gas-fired power plant. Figure 3-10 shows the integration of the heat pump. After preheating the drying air, the heat recovery circuit is also used as the source for the evaporator of the heat pump system. The inlet temperature is about 70 °C. In the condenser heat is transferred to the drying air via an intermediate water circuit and a water-air heat exchanger. The heat supply temperature of the heat pump is up to 160 °C. With the heat pump, the use of steam in the third heat exchanger can be reduced or completely eliminated depending on the selected heat supply temperature of the heat pump. Thereby, the heat recovery cycle can be used to a larger extent and the use of natural gas is reduced.

Drying processes are used in different application: agriculture, fishing, malt, dairy, milk, metal processing, paint shop, paper-pulp, wood industry, laundry -shop and -industry, to name but a few. The largest success of the drying process with the heat pump cycle is to be seen with the residential tumble dryers. Energy reduction and quality improvement are the important advantages. Some examples for drying processes:

Jap Chemical-dry process of formed styrol:	7 Dia Chemicals Co. Ltd.
NL Washing plant:	6 Sludge Drying
DK Dairy: Drying air for milk powder:	1 Arla Arinco
D Malt production:	20 Tivoli Malz
Jap Food-confectionary-drying:	79 Kasugai Confectionary Co. Ltd.
NL Drying potatoes:	2 McCain

4 Case studies

4.1 Selection of the collected case studies

An analysis of the collected case studies/applications of industrial heat pumps was examined. The following industrial sectors were selected.

- Chemicals
- Textile
- Machinery
- Food Agriculture
- Utility, Combined Heating and Power (CHP)
- District Heating (District H) District Cooling (District C) District H&C
- Commercial Building (Com. Build.)
- Miscellaneous

Each participant analyses, generalizes and catalogues the case studies and applications of IHPs from the Annex 35 as well as new projects in each country. It was made a selection of all these cases, see figure 4-1. The allocation was done to the country who reported on the case study.

Industrial Sector	Application	Project or user name	Location	Country
Chemicals	Plastic/ synthetic rubber manufacturing	28 Rubber Industry	n.a.	F
Chemicals	Extraction plant	9 Flavex	Rehlingen Siersburg	D
Chemicals	Abrasives	19 Treibacher Schleifmittel	Grafenhainichen	D
Chemicals	chemical-dry process of formed styrol	7 Dia Chemicals Co. Ltd.	Tochigi	Jap
Chemicals	chemical-distillation process of bioethanol, Hokkaido, Japan	43 Hokkaido Bioethanol Co. Ltd.	Hokkaido	Jap
Chemicals	chemical-dry laminating process	47 Kitakami Industry Co. Ltd.	Saitama	Jap
Chemicals	food-methanol distillation process	88 Meito Industry Co. Ltd.	Tokyo	Jap
Chemicals	Separation process, oleine + stearine	1 Unichema/Croda	Gouda	NL
Textile	Printing and dyeing	22 PONGS Seidenweberei	Mühltroff	D
Textile	Washing plant	6 Sludge Drying	Apeldoorn	NL

Industrial Sector	Application	Project or user name	Location	Coun-try
Machinery	Metal industry, Metal processing	3 Gebauer & Griller	Poysdorf	A
Machinery	Electronics	6 Seidel Elektronik	Deutschlandsberg	A
Machinery	Automotive industry	9 Magna	Weiz	A
Building	Construction industry	10 Strabag	Vienna	A
Machinery	washing metal items	4 Grundfos	Bjerringbro	DK
Machinery	Automotive - Paint shop	7 Volkswagen	Emden	D
Machinery	Electronics - electrical drives	10 Ametek	Bonndorf	D
Machinery	Glass	11 Thiele	Wermsdorf	D
Machinery	Mechanical Engineering	12 Kemmerich	Niederau-Gröbern	D
Machinery	Metall processing - wires production	13 Flamm	Aachen	D
Machinery	Metall processing	16 Schraubenwerk Zerbst	Zerbst	D
Machinery	Metall processing	18 Walter Th. Hennecke	Neustadt (Wied)	D
Machinery	Plastic production	23 BIG Spielwaren	Burghaslach	D
Machinery	Metall processing	29 ALUCA	Schwaebisch Hall	D
Machinery	Plastic production	30 Vorbach	Kaufbeuren	D
Machinery	Metall processing	31 Nord Drivesystems	Bargteheide	D
Machinery	Machinery-dry process of transformer produc.	36 Takaoka Electric Mfg. Co. Ltd.	Tochigi	Jap
Machinery	Machinery-cleaning process	95 Fuji Electric Co. Ltd.	Mie	Jap
Machinery	Process heat for hard-ening processes	17 Härterei Gerster AG	Egerkingen	CH
Machinery	Production	20 Georg Fischer AG	Grüsch	CH
Food	Meat processing	4 efef Fleischwaren	Hohenems	A
Food	Brewery	7 Mohrenbrauerei	Dornbirn	A
Food	Deep freeze food	8 dailyService	Asten	A
Food	Dairy: Drying air for milk powder	1 Arla Arinco	Videbaek	DK

Industrial Sector	Application	Project or user name	Location	Coun-try
Food	Distilleries	2 Prototype Water HP	Moret sur Loing	F
Food	Processing and pre-serving of meat	17 Slaughterhouse Monfort	Montfort-sur-Meu	F
Food	Manufacture of starch products	23 Starch products	Bazancourt	F
Food	Chocolate manufact.	4 Nestlé	Halifax, UK	D
Food	Malt production	20 Tivoli Malz	Hamburg	D
Food	Beer brewing	21 Schäffler Bräu	Missen	D
Food	Vinegar fermentation and pasteurization	27 Nutrex, COOP	Buswill-Bueren	D
Food	food-beverage facto-ry	28 Suntory Products Co. Ltd.	Hyogo	Jap
Food	food-snack confec-tionery	29 Calbee Co. Ltd.	Tochigi	Jap
Food	food-ice cream	30 Hokuriku Milk Indus-try Co. Ltd.	Ishikawa	Jap
Food	food-simultaneous heating & cooling	40 Fresh Diner Co. Ltd.	Yamagata	Jap
Food	food-chocolate	66 Kasugai Confection-ary Co. Ltd.	Aichi	Jap
Food	food-confectionary-drying	79 Kasugai Confection-ary Co. Ltd.	Aichi	Jap
Food	food-salt-distillation/ concentration	83 Muroto Deep Sea Water Co. Ltd.	Kochi	Jap
Food	Beer brewing	4 Heineken	Den Bosch	NL
Agriculture	Greenhouses, toma-toes	8 Greenhouses, Toma-toes	Berkel en Ro-denrijs	NL
Agriculture	Greenhouse heating	19 Kellermann	Ellikon	CH
District H	Utility	2 Mühlleiten	Mühlleiten	A
District H	Paper Mill H&C	2 Skjern Paper Mill	Skern	DK
District H	Greenhouse	3 Knud Jepsen Nursery	Hinnerup	DK

Industrial Sector	Application	Project or user name	Location	Coun-try
CHP	Fluegas- District hea-ting	5 Flue gas Bjerringbro 1	Bjerringbro	DK
CHP	Fluegas- District hea-ting	6 Flue gas Bjerringbro 2	Bjerringbro	DK
CHP	Fluegas- District hea-ting	7 Flue gas Bjerringbro 3	Bjerringbro	DK
CHP	Fluegas- District hea-ting	8 Flue gas – Vejen	Vejen	DK
CHP	Fluegas- District hea-ting	9 Rye CSP	Rye	DK
CHP	Flue gas -wood chip boiler-	10 Brande District Hea-ting	Brande	DK
CHP	Flue gas form biogas engine	12 Vinderup District Heating	Vinderup	DK
CHP	Pit thermal energy (PTES)	14 Marstal District Hea-ting	Martstal	DK
District C	Cooling water to factory	15 Bjerringbro District Heating 4	Bjerringbro	DK
CHP	Ngas engine flue gas cooling	16 Hundested District Heating	Hundested	DK
CHP	Flue gas cooling	19 Skaarup District Hea-ting	Skaarup	DK
CHP	Solar heating	22 Gram District Hea-ting	Gram	DK
CHP	Flue gas cooling	24 Spjald Distric Hea-ting	Spjald	DK
District H	Groundwater	29 Broager District Hea-ting	Broager	DK
District H	Sewage water	30 Kalundborg District Heating	Kalundborg	DK
District H	Sewage water	31 Roedkaersbro Dis-trict heating	Roedkaersbro	DK
District H	Hot water, heating	3 Fernwärmeverbund Champagne	Biel	CH
Hot water	District heating grid	4 IWB	St.Jakob-Basel	CH
District H	Hot water, heating	9 Laurana	Thônex	CH
District H	Ground water	10 Les Vergers	Les Vergers	CH
Waste water	Sewage treatment	11 Kläranlage Zürich	Zürich	CH
District H	Lake water	16 Lausanne heat pump	Lausanne	CH

Industrial Sector	Application	Project or user name	Location	Country
Com. Build.	Heating, river water	2 Kingston Heights	London	UK
District H	Sewerage	3 Scot. Borders College	Galashiels	UK
District H	Heating, borehole	4 Wandsworth Riverside	London	UK
	Heating, borehole	5 Enfield, London, UK	London	UK
Com. Build.	Heating	6 Bunhill, London, UK	London	UK
Com. Build.	Heating	7 Bridgford Garden Centre	Nottingham	UK
Com. Build.	Heating	8 Pusey House	Oxford	UK
Leisure, sport	Heating	9 North Kilworth Marina	Lutterworth	UK
District H	Waste treatment, Incineration flue gas	3 Municipality	Le Mans	F
Com. Build.	University, heating, waste heat use	5 University Bourgogne	Dijon	F
n.a.	Sewage Plant, Heating	6 Municipality	Annecy	F
District H	Geothermal	7 Sofrege	Fresnes	F
District H	Geothermal	8 Scuc	Créteil	F
District H	Geothermal	9 Idex	Neuilly-sur-Marne	F
District H	Sewage water	10 Dalkia	Boulogne sur Mer	F
Com. Build.	Airport	11 Dalkia	Blagnac	F
District H&C	Waste heat of cooling towers	18 Enertherm	Paris La Défense	F
District H	Geothermal	19 Dalkia	Le Plessis-Robinson	F
District H	Sea Water	20 Cherbourg	Cherbourg	F
District H	Cooling CHP engine	27 EDF Luminus	Ghent Belgium	B
District H		30 Green Energy	Brive FR	F
District H	River water	31 SEINERGIE	Courbevoie	F
District H	Sewage water	32 SEMPO	Amiens	F
District H	Incineration flue gas	33 VEOLIA	Le Mans	F
District H	Sea water	5 Drammen	Drammen	N
Pulp &paper	Flue gas cooling	1 Pulp and Paper	Hallein	A
Leisure, sport	Icering	5 Kunsteisbahn	Gmunden	A

Industrial Sector	Application	Project or user name	Location	Coun-try
Com. Build.	University hospital	21 Aarhus University	Skejby Aarhus	DK
CHP	Generator cooling	26 Verdo	Randers	DK
Papermill	Prototype for dryers	1 Transcritical HP	Paris	F
Leisure, sport	Public swimming pool	24 Aquarena	Arras	F
Com. Build.	Warehouse	7 Bovendeert	Boxtel	NL
n.a.	n.a.	5 CO2 heat pump	Küsnacht	CH
n.a.	n.a.	6 R134a heat pump	Kerns	CH
n.a.	n.a.	7 R134a heat pump	Kerns	CH
Pharma	n.a.	8 Geistlich	Wolhusen	CH
Leisure, sport	Thermal bath	12 Thermalbad	Nordwest	CH
Com. Build.	Army training hall	18 Army Training Hall	Payerne	CH
Com. Build.	Army troop building	21 Military Barracks	Matt	CH
Com. Build.	Campus, Wellness, Restaurant	22 Kokon Corporate Campus	Ruggell	FL

Figure 4-1: Selection of all collected case studies (Industrial sector, application, project name, location and country) [Source Annex 48]

4.2 Case studies best practices

Based on all collected case studies every group from the different countries evaluated cases with the best available technologies and best practices. The countries decided how to do it.

These cases are described in more detail and should help to overcome barriers for IHP application and help to convince decisions makers with the HP performance and operation.

Every selected "best practice" is described in more detail in the country reports and/or with additional data on the map for Europe and Japan.

Example

J-02, Kosmos Food Hyogo

Hyogo, Japan

Project data — Project data

Project desccription — Project description

The 38 evaluated cases are listed in Figure 4-2

Industrial Sector	Application	Project or user name	Location	Country
Chemicals	Plastics industry	33 Bergs Kunststoff-technik	Ennsdorf / Enns	A
Chemicals	Pharmaceutical industry	65 P&G Health Austria	Spittal an der Drau	A
Chemicals	Pharmaceutical industry	66 Ever Neuro Pharma	Unterach	A
Chemicals	Pektin production	32 CP Kelco	Koege	DK
Chemicals	Coating	8 Emil Frei	Bräunlingen	D
Chemicals	Dry laminating process of package film	32 Suda Industry Co. Ltd.	Shizuoka	Jap
Machinery	Steel and rolling mill	11 Marienhütte	Graz	A
Machinery	Metall processing	14 Ludwig Michl	Waakirchen	D
Machinery	Metall processing	15 Purkart	Großrückerswalde	D
Machinery	Chipboards manufact.	28 Swiss Krono	Heiligengrabe	D
Machinery	Cutting and cleaning processes	21 Aishin A W Co. Ltd.	Aichi	Jap
Food	Brewery	16 Brauerei Puntigam	Graz	A
Food	Milk processing	22 Berglandmilch / Tirol Milch Wörgl	Wörgl	A
Food	Meat processing	61 F. Krainer Fleisch- & Wurstwaren Ges.m.b.H	Wagna	A
Food	Mozzarella cheese	70 ARLA Foods	Rødkærsbro	DK
Agriculture	Flower trade	4 Rosefarm	Var	F
Food	Malt production	21 Malteurop	Nogent sur Seine	F
Food	Cheese production	22 Compagnie des Fromages & RichesMonts	Normandy	F
Food	Cheese production	25 RichesMonts	Brioude	F
Food	Slaughterhouse	26 Slaughterhouse	n.a.	F
Food	Food production line	2 Kosmos Food Co. Ltd.	Hyogo	Jap
Food	Drying potatoes	2 McCain	Lelystad	NL
Food	Margarine production	3 Blue Band	Rotterdam	NL
Food	Slaughterhouse	5 Slaughterhouse Apeldoorn	Apeldoorn	NL
Food	Chocolate	9 Mars Nederland	Veghel	NL

Industrial Sector	Application	Project or user name	Location	Coun-try
Food	Slaughterhouse	1 Slaughterhouse	Zurich	CH
Food	Chocolate	2 Maestrani	Flawil	CH
Food	Cheese production	13 Cheese factory Gaiss	Gaiss Appenzell	CH
Food	Process water for disinfection and cleaning	14 GVS Schaffhausen	Schaffhausen	CH
Food	Vinegar fermentation and pasteurization	15 Nutrex	Busswil	CH
Utiltiy	Flue gas condensati-on	58 Klagenfurt Ost	Klagenfurt	A
Utiltiy	Cooling power plants	64 Wien Energie	Vienna	A
District C	District Cooling	25 Hoje Taastrup Supp-ly	Hoje Taastrup	DK
District H	District heating	37 HOFOR A/S	Kopenhagen	DK
District H	Heat source sump water	25 Erftverband	Bergheim	D
District H	Heat source sump water	26 Bergheim	Bergheim	D
Com. Build.	Hot Water, Heating & Cooling	2 Cafeteria University	Soest	D
Pulp & Paper	Paper products	5 Oji Tokushushi Co. Ltd.	Shizuoka	Jap

Figure 4-2: 25 evaluated cases studies “best practice” [Source Annex 48]

5 Application of existing models

Direct Link to the entire report This report is divided in 5 sections.

The main motivation for this report was drawn from the previous Annex 35 Task 2 report, concluding that wide-scale employment of models and tools for industrial heat pump integration is inhibited by the complexity and specific training required for the use of most available tools as well as the theoretical principles behind them. Therefore, four main points were identified which needed clarification and dissemination.

The theoretical background for systematic heat pump integration into industrial processes was efficiently summarized and presented in a concise manner (in section 2). Here, it was shown that the process synthesis approach requires that internal heat recovery potential in a process should be considered before utility integration. Further, the principles of pinch analysis (PA) were introduced, providing the insight that heat pumps only bring energy savings if they can be installed across the process pinch point. Additionally, simple rules based on these concepts were presented to aid industries and practitioners in quickly determining good integration potentials for heat pumps.

Several categories of tools were identified in this report and a synthesis of the main features of each were summarised in a single comparative table (section 3). The principal categories are defined as:

- Heat pump design (HP) being tools that aid in designing and planning heat pump systems based on selected operating conditions;
- Pinch analysis (PA) and heat exchanger network (HEN) design which are tools that aid in conducting pinch analysis of an industrial process to estimate the heat recovery potential and/or aid in planning and re-designing the heat exchanger network. In these tools, the focus is placed on process heat recovery, not on utility integration;
- PA and heat pump integration tools which allow to analyse the heat recovery potential through PA and heat pump integration without thermodynamic property calculations; and,
- PA and heat pump integration with property calculations which is similar as the previous category but including thermodynamic property calculation options inside the tool.

As a next step, an easy-to-use set of guidelines for practitioners was derived that can be used with or without tools and specific training (section 4). These guidelines were explained in more detail with additional practical insights included.

Application of existing models/tools to a real case study based on the set of guidelines was presented in section 5. A dairy plant was discussed, showing a great heat pump potential across the concentrated milk production unit. A preliminary heat pump design was conducted, and yielded a COP above 10, and a payback time below two years. Some open access tools were tested during the case study and insights on their use and expected results were presented.

In summary, a holistic guide for considering heat pump integration with industrial processes was presented with technical detail and insights which are relevant for many levels of plant personnel, consultants and practitioners. Additional resources are provided throughout this report to provide readers with deeper details on many aspects of the approach described herein.

6 Communication

6.1 Training Materials for IHPs

Austria Direct Link to the material

Integration of heat pumps in industrial processes
- Design
- Hydraulic concepts
- Control strategies

Techno-economic evaluation

- Capital expenditures
  - Capital expenditures of the HP
  - Incidental expenditures
- Consumption-related cost
  - Maintenance and operating cost
  - Energy prices
  - Economic comparison of absorption and compression HPs

CO_2 emissions and primary energy consumption

References

Denmark Direct Link to the material

Introduction

Information material and tools about IHPs

Organizations working with IHPS

Events and courses about IHPs

Summary

Literature

Japan Direct Link to the material

Summary

Selecting of 17 good practices

Creating brief accounts for 17 Good Practices

Creating a table that contains geographic information

Classifying 17 cases by industry and process applied

Schematic Diagram

Attachments 1-4 (best practices)

6.2 Working meetings

- 2016-07-05 Kick-off meeting, Darmstadt, Germany
- 2016-11-04 **1st** Expert meeting, Darmstadt, Germany
- 2017-05-14 **2nd** Expert meeting, Rotterdam, Netherlands
- 2017-10-23 **3rd** Expert meeting, Nuremberg, Germany
- 2018-06-05 **4th** Expert meeting, Vienna, Austria
- 2018-11-14 **5th**Expert meeting, Nuremberg, Germany
- 2019-05-13 **6th** Expert meeting, Tokyo, Japan

6.3 Workshop-Forum-Congress-Summit

(..x contributions)

6.3.1 International:

- 2019-10-23 European Heat Pump Summit, Nuremberg (8x)
- 2019-08-28 Workshop IIR International Congress of Refrigeration, Montréal (8x + 15x)
- 2019-05-14 Workshop IHP, Tokyo (8x)
- 2018-10-15 Chillventa CONGRESS, Nuremberg (12x)
- 2017-10-24 European Heat Pump Summit, Nuremberg (10x)
- 2017-09-11 International Workshop on High Temperature Heat Pumps, Copenhagen (3x)
- 2016-10-10 Chillventa CONGRESS, Nuremberg (10x)

6.3.2 National: Austria-Germany-Switzerland

- 2019-11-22 DE: DKV Annual Meeting, Ulm (8x)
- 2018-11-22 DE: DKV Annual Meeting, Aachen (5x + 4x)
- 2018-05-17 DE: Großwärmepumpenforum, Vienna (3x)
- 2017-11-18 DE: DKV Annual Meeting, Kassel (4x)
- 2017-06-12 DE: Symposium „Solarthermie und Wärmepumpen in der Industrie“, Vienna (2x)
- 2016-05-23 DE: HTI, Burgdorf, Switzerland (2x)

6.4 Presentations

Date+ Link	Author	Title	Event
2017-09	R. M. Jakobs	IEA HPT TCP Annex 35 + 48: Heat Pump Application in Commercial and Industrial Processes	International Workshop on High Temperature Heat Pumps, Copenhagen
2017-10	R. M. Jakobs	Commercial and Industrial Heat Pump Application, Introduction	European Heat Pump Summit 2017 Nuremberg
2017-10	Ch. Watanabe et al.	Application of Heat Pumps to Cutting and Washing Processes	European Heat Pump Summit 2017 Nuremberg
2017-10	V. Wilk et al.	Industrial Heat Pumps in Austria: Applications and research	European Heat Pump Summit 2017 Nuremberg
2017-10	S. A. Wallerand et al.	Methods for estimating heat pump potential in industrial processes	European Heat Pump Summit 2017 Nuremberg
2017-10	J.-M. Fourmigue et al.	Increasing the Heat Pumps dissemination through Energy Database analysis	European Heat Pump Summit 2017 Nuremberg
2017-10	C. Arpagaus et al.	Review on High Temperature Heat Pumps	European Heat Pump Summit 2017 Nuremberg
2017-10	L. Reinholdt	Higher Heat Pump COP through better temperature match	European Heat Pump Summit 2017 Nuremberg
2017-10	M. Nampoothiri	Industrial Heat Pumps in India - Unlocking the potential	European Heat Pump Summit 2017 Nuremberg
2017-10	B. Zühlsdorf et al.	Heat Pump Integration with Zeotropic Working Fluid Mixtures	European Heat Pump Summit 2017 Nuremberg
2018-05	R. M. Jakobs	Gewerbe und Industrie Wärmepumpen weltweit in vielfältigen Anwendungen erfolgreich	Großwärmepumpen Forum 2018 Vienna
2018-05	Th. Fleckl et al.	Wärmepumpen in der Prozessindustrie: Aktuelle Entwicklungen in der Forschung und Herausforderungen in der Anwendung	Großwärmepumpen Forum 2018 Vienna
2018-05	J. Herunter	Hochtemperaturwärmepumpen – praktische Beispiele und Anwendungsfälle für Nah- und Fernwärme	Großwärmepumpen Forum 2018 Vienna
2018-05	St. Irmisch	Großwärmepumpen: die umweltfreundliche und flexible Energielösung für Wohnraum, Gewerbe und Industrie	Großwärmepumpen Forum 2018 Vienna

2018-10	R. M. Jakobs	Introduction Heat pumping Technologies	Chillventa Congress 2018 Nuremberg
2018-10	V. Wilk et al.	Industrial heat pumps in Austria: Current status and future potential	Chillventa Congress 2018 Nuremberg
2018-10	T. Kaida	Industrial Heat Pump Applications in Japan	Chillventa Congress 2018 Nuremberg
2018-10	R. Rudischhauser	Ammonia Heat-Pump for Heating and Cooling in Residential/Commercial Areas	Chillventa Congress 2018 Nuremberg
2018-10	C. Arpagaus	High Temperature Heat Pumps	Chillventa Congress 2018 Nuremberg
2018-10	N. Hewitt	Heat Pumping Technologies for Commercial and Industrial Applications - A UK perspective	Chillventa Congress 2018 Nuremberg
2018-10	L. Reinholdt	Industrial Heat pumps in District Heating (Denmark)	Chillventa Congress 2018 Nuremberg
2018-10	A. Bechem	HeatBooster – High temperature industrial heat pump for up to 160 °C	Chillventa Congress 2018 Nuremberg
2018-10	S. A. Wallerand	Application of models for IHP integration	Chillventa Congress 2018 Nuremberg
2018-10	R. M. Jakobs	Summary	Chillventa Congress 2018 Nuremberg
2018-10	X. Li	Decreasing energy consumption of heating and air conditioning system with energy-efficient heat pump combined with natural energy	Chillventa Congress 2018 Nuremberg
2019-05	C. Arpagaus	Hochtemperatur-Wärmepumpen für indust-rielle Anwendungen de	Großwärmepumpen Kon-gress 2019 Zurich
2019-05	R. M. Jakobs	Annex 48 Overview and Status, Case studies in NL + D	Annex 48 Workshop Tokyo
2019-05	V. Wilk, et al.	Industrial Heat Pumps in Austria: Status, case studies, potentials	Annex 48 Workshop Tokyo

2019-05	B. Zuehlsdorf	Situation in Denmark	Annex 48 Workshop Tokyo
2019-05	J.-M. Fourmigue	IHP Cases in France + Assessment the heat pump market in industry	Annex 48 Workshop Tokyo
2019-05	J.-M. Fourmigue	Assessment IHPs in the industry	Annex 48 Workshop Tokyo
2019-05	Y. Uchiyama et al.	Good and Best Practices of Industrial Heat Pumps in Japan	Annex 48 Workshop Tokyo
2019-05	I. Kantor et al.	Application of existing models and tools for IHP integration	Annex 48 Workshop Tokyo
2019-05	C. Arpagaus	Industrial Heat Pump Applications in Switzer-land	Annex 48 Workshop Tokyo
2019-05	N.J. Hewitt	UK Country Report	Annex 48 Workshop Tokyo
2019-08	R. M. Jakobs	SUCCESSFUL APPLICATIONS OF INDUSTRIAL HEAT PUMPS	International Congress of Refrigeration 2019 Mon-treal WS Annex 48
2019-08	V. Wilk et al.	INCREASING ENERGY EFFICIENCY IN INDUSTRY	International Congress of Refrigeration 2019 Mon-treal WS Annex 48
2019-08	N. J. Hewitt et al.	Taking high temperature heat pumps to the next level – Power to heat and heat to power	International Congress of Refrigeration 2019 Mon-treal WS Annex 48
2019-08	A.S. Wallerand et al.	Identifying optimal industrial heat pump placement	International Congress of Refrigeration 2019 Mon-treal WS Annex 48
2019-08	B. Zühlsdorf et al.	Heat pumps for district heating and industry in Denmark	International Congress of Refrigeration 2019 Mon-treal WS Annex 48
2019-08	Y. Uchiyama et al.	Evaluation of Good Practices for Industrial Heat Pump in Japan	International Congress of Refrigeration 2019 Mon-treal WS Annex 48
2019-08	C. Arpagaus	Industrial heat pump applications in Switzer-land – Heat pump integration case studies	International Congress of Refrigeration 2019 Mon-treal WS Annex 48
2019-08	R. M. Jakobs	Summary	International Congress of Refrigeration 2019 Mon-treal WS Annex 48
2019-08	T. Kaida et al.	Application of R1224yd(Z) as R245fa Alterna-tive for High Temperature Heat Pump	International Congress of Refrigeration 2019 Mon-treal WS 2_IHPs

2019-08	V. Wilk et al.	Decarbonization of industrial processes with heat pumps	International Congress of Refrigeration 2019 Montreal WS 1_IHPs
2019-08	N. N. SHAH et al.	Overview on HCFO-R1233ZD(E) use for high temperature heat pump application	International Congress of Refrigeration 2019 Montreal WS 2_IHPs
2019-08	C. Arpagaus et al.	High temperature heat pump using HFO and HCFO refrigerants – system design and experimental results	International Congress of Refrigeration 2019 Montreal WS 3_IHPs
2019-08	N. J. Hewitt et al.	Industrial Heat Pumps in the UK Current Constraints and Future Possibilities	International Congress of Refrigeration 2019 Montreal WS 4_IHPs
2019-08	C. Arpagaus et al.	High temperature heat pumps – Theoretical study on low GWP HFO and HCFO refrigerants	International Congress of Refrigeration 2019 Montreal WS 5_IHPs
2019-10	R. Rudischhauser	Heat Pumps for District Heating	European Heat Pump Summit 2019 Nuremberg
2019-10	V. Wilk et al.	DryFiciency: high temperature heat pumps for industrial processes	European Heat Pump Summit 2019 Nuremberg
2019-10	E. Perdu et al.	Very High Temperature Heat Pump (120°C) Installed at Ghent, Belgium, Heating District Network	European Heat Pump Summit 2019 Nuremberg
2019-10	M. Nampoothiri	Accelerating the decarbonization of Industrial and Commercial sectors in India using Heat Pumps	European Heat Pump Summit 2019 Nuremberg
2019-10	W. Meesenburg	Flexible operation of heat pumps in district heating systems to unlock synergies between the heating & power sector	European Heat Pump Summit 2019 Nuremberg
2019-10	T. Funder-Kristensen	Evaluation of large heat pumps to decarbonize District Thermal Networks	European Heat Pump Summit 2019 Nuremberg
2019-10	B. Vanslambrouck	ENERGETIC OPTIMIZATION POSSIBILITIES OF INDUSTRIAL DRYING PROCESSES	European Heat Pump Summit 2019 Nuremberg
2019-10	M. Blaser	Three concepts for high efficient, high economic ammonia heat pumps for industrial applications up to 95°C	European Heat Pump Summit 2019 Nuremberg

7 Summary

The main goal is to overcome still existing difficulties and barriers for the larger scale market in industrial applications. Industrial Heat Pumps (IHPs) offer various opportunities to all types of manufacturing processes and operations. They use waste process heat as the heat source, delivering heat at higher temperatures for use in industrial processes, heating or preheating, and industrial space heating and cooling. IHPs can significantly reduce fossil fuel consumption and GHG emissions in a variety of applications.

Research and practical applications show increasingly clear that IHPs can provide heating/cooling to industrial applications and district grids. The outcomes show more than three hundred good practices of IHPs of applications, such as drying, washing, evaporation, and distillation processes. More than 25 cases were selected as best practice in different industrial sectors.

A wide range of industries can benefit from this technology. Information material based on experience across the regions (Europe-Japan) has been assembled and was published in workshops, forums, congresses and summits.

On the website heat pumping technologies the direct results of the Annex are demonstrated by more than 60 presentations (2017-2019) and more than 60 publications.

The reports from the countries contain the selected case studies with good and best practices.

Practical guidelines and insights for the application of existing models and tools to aid systematic heat pump integration with industrial processes are shown in a special report.

Maps of Europe and Japan show a selection of case studies and best practices with detailed information about the cases and the industrial sectors.

A holistic guide for considering heat pump integration with industrial processes is presented with technical detail and insights which are relevant for many levels of plant personnel, consultants and practitioners.

Further reports summarize material for IHP training. They contain information and tools, as well organizations and events: e.g. guidebook for the district heating sector, heat pump calculator, assessment tools, concepts for design, hydraulic, and controls.

Lessons learned:
One of the main barriers for application of IHPs is the very different situation concerning the energy prices in the countries. Especially the ratio of electricity/gas price is important. Sweden, Finland, Netherlands, France and Switzerland have favourable price ratios; Germany, Ireland and UK have inconvenient price ratios.

The industrial process of drying is a very promising application for heat pumps, and is suggested by all Annex members for future work in R&D.
The quality of the process could be improved, and energy cost and CO_2 emissions could be reduced.

High temperature heat pumps (HTHPs) are HPs with heat sink temperatures in the range of 100 to 160 °C. They may become increasingly commercialized during the coming years. Major applications have been identified, particularly in the food, paper, metal and chemical industries.
Simultaneous heating and cooling systems for example in food application or cutting and cleaning processes are besides drying applications a very prominent application.

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9 References/Publications

Author Year Link	Author Title	Source
IEA HPT Annex 09	High Temperature Industrial Heat Pumps (before 1990)	
IEA HPT Annex 21	Global Environmental Benefits of Industrial Heat Pumps (1992-96)	
Becker 12	H.C. Becker, Methodology and Thermo-Economic Optimization for Integration of Industrial Heat Pumps	Thesis, ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
Wolf 12	St. Wolf et al., Industrial heat pumps in Germany: Potentials, technological development and market barriers	Institute for Energy Economics and the Rational Use of Energy (IER) University of Stuttgart
IEA HPT TCP Annex 35	Application of Industrial Heat Pumps (2010-2014)	
IHPS NL Annex 35	Industrial Heat pumps in the Netherlands	
Jakobs 16-6	R. M. Jakobs, Commercial and Industrial Heat Pump application, IEA HPT Annex 35/48	22. WP-Tagung BFE Forschung, Schweiz
Wolf 16-10 a	St. Wolf, How to apply industrial and commercial heat pumps	Chillventa CONGRESS 2016
Biesheuvel 16	K. Biesheuvel, How to apply industrial and commercial heat pumps	Chillventa CONGRESS 2016
Hartl 16	M. Hartl, High temperature heat pumps for drying	Chillventa CONGRESS 2016
Hoffmann 16	K. Hoffmann, Heat pumps for the food industry and the world largest ammonia heat pump	Chillventa CONGRESS 2016
Deding 16	M. Deding, High Efficiency for heat pumps in an industrial application environment	Chillventa CONGRESS 2016
Ommen 16	T. Ommen, US/North America heat pump market status	Chillventa CONGRESS 2016
Feig 16	G. Feig, Energy efficient adsorption chilling technology and projects in commerce and industry	Chillventa CONGRESS 2016

Süss 16	J. Süss, A novel heat pump for high efficient waste heat rejection to ambient with water as working fluid	Chillventa CONGRESS 2016
Wolf 16-10 b	St. Wolf, Summary: Heat Pumping Technologies	Chillventa CONGRESS 2016
Arpagaus 17a	C. Arpagaus, Hochtemperatur Wärmepumpen	Literaturstudie Institut für Energiesysteme
Jakobs 17 a	R. M. Jakobs, IEA HPT TCP Annex 35 + 48: Heat Pump Application in Commercial and Industrial Processes	Int. Workshop on HTHPs, Copenhagen
Jakobs 17 b	R.M. Jakobs, Commercial and Industrial Heat Pump Application, Introduction	European Heat Pump Summit 2017
Watanabe 17	Ch. Watanabe, Application of Heat Pumps to Cutting and Washing Processes	European Heat Pump Summit 2017
Wilk 17	V. Wilk, Industrial heat pumps in Austria - Applications and research	European Heat Pump Summit 2017
Wallerand 17	S. A. Wallerand, Methods for estimating heat pump potential in industrial processes	European Heat Pump Summit 2017
Fourmiguè 17	J.-M. Fourmiguè, Increasing the Heat Pumps dissemination through Energy Database analysis	European Heat Pump Summit 2017
Arpagaus 17b	C. Arpagaus, Review on High Temperature Heat Pumps	European Heat Pump Summit 2017
Reinholdt 17	L. Reinhold, Higher Heat Pump COP through better temperature match	European Heat Pump Summit 2017
Nampoothiri 17	M. Nampoothiri, Industrial Heat Pumps in India - Unlocking the potential	European Heat Pump Summit 2017
Zühlsdorf 17	B. Zühlsdorf, Heat Pump Integration with Zeotropic Working Fluid Mixtures	European Heat Pump Summit 2017
Wolf 17	St. Wolf, Integration von Wärmepumpen in industrielle Produktionsprozesse	Dissertation Universität Stuttgart
Nilsson	M. Nilsson et al., Measured performance of a novel high temperature heat pump with HFO-1336mzz-Z as the working fluid	12th IEA Heat Pump Conference 2017, Rotterdam
Wallerand 18a	Integration of solar energy with industrial processes	Thesis, ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
Jakobs 18	R.M. Jakobs, IEA Heat Pumping Technologies	Chillventa CONGRESS 2018

Wilk 18	V. Wilk, Industrial heat pumps in Austria - Current status and future potential	Chillventa CONGRESS 2018
Kaida 18	T. Kaida, Industrial Heat Pump Applications in Japan	Chillventa CONGRESS 2018
Rudisch-hauser 18	R. Rudischhauser, Ammonia Heat-Pump for Heating and Cooling in Residential/ Com-mercial Areas	Chillventa CONGRESS 2018
Arpagaus 18	C. Arpagaus, High Temperature Heat Pumps	Chillventa CONGRESS 2018
Hewitt 18	N.J. Hewitt, Heat Pumping Technologies for Commercial and Industrial Applications - A UK perspective	Chillventa CONGRESS 2018
Lindahl 18	M. Lindahl, New ways of combining Heat Pumps and District Heating	IEA HPT Magazine 3-2018
Reinholdt 18	L. Reinhold, Industrial Heat pumps in Dis-trict Heating (Denmark)	Chillventa CONGRESS 2018
Bechem 18	A. Bechem, HeatBooster – High tempera-ture industrial heat pump for up to 160 °C	Chillventa CONGRESS 2018
Wallerand 18	S. A. Wallerand, Application of models for IHP integration	Chillventa CONGRESS 2018
DEA 19	Danish Energy Agency, working group large HPs	Energistyrelsen
Zühlsdorf 19	Zühlsdorf et al., Industrial Heat Pumps in the Danish Energy System – Current Situa-tion, Potentials and Outlook	IEA HPT Magazine 3-2019
Arpagaus 19a	C. Arpagaus et al., High temperature heat pumps – Theoretical study on low GWP HFO and HCFO refrigerants	International Congress of Refrigeration 2019 Mon-treal
Jokile 19	M. Jokiel et al., Design of a CO_2 heat pump dryer with dynamic modelling tools	International Congress of Refrigeration 2019 Mon-treal
Hewitt 19	N.J. Hewitt et al., Industrial Heat Pumps in the UK Current Constraints and Future Possibilities	International Congress of Refrigeration 2019 Mon-treal
Arpagaus 19b	C. Arpagaus et al., High temperature heat pump using HFO and HCFO refrigerants – system design and experimental results	International Congress of Refrigeration 2019 Mon-treal
Watanabe 19	Ch. Watanabe et al., Experimental Study on a Water and Air Source High-Temperature Heat Pump Using a Low GWP Refrigerant	International Congress of Refrigeration 2019 Mon-treal

Shah 19	N.N. Shah et al., Overview on HCFO-R1233ZD(E) use for high temperature heat pump application	International Congress of Refrigeration 2019 Mon-treal
Kaida 19	T. Kaida et al., Application of R1224yd(Z) as R245fa alternative for high temperature heat pump	International Congress of Refrigeration 2019 Mon-treal
Helminger 19	F. Helminger et al., Comparison of configu-rations of high-temperature heat pumps for biogas-upgrading	International Congress of Refrigeration 2019 Mon-treal
Wilk 19	V. Wilk et al., Decarbonization of industrial processes with heat pumps	International Congress of Refrigeration 2019 Mon-treal
Arpagaus 19c	C. Arpagaus, From Waste Heat to Cheese	IEA HPT Magazine 2-2019
Arnitz 19	A. Arnitz et al., Waste Heat Recovery at the Steel and Rolling Mill	IEA HPT Magazine 2-2019
Ayub 19	Z. Ayub et al., Low Charge Evaporators for Industrial Heat Pumps	IEA HPT Magazine 2-2019

These references/publications were published as a related paper on the industrial heat pumps at conferences held during the activities of Annex 48. Please note that this final report does not correspond to each article in references/publications.

10 Abbreviations

CERES	platform enables pinch method-based studies to be carried out on energy integration
EDF	Électricité de France
GWP	Global warming potential
HP	Heat pump
HPP	Heat pump programme
HPT	Heat pumping technology
HT HP	High temperature heat pump
IEA	Internationale Energy Agency
IHP	Industrial heat pump
IHPs	Industrial heat pumps
NBP	Normal boiling point
NDA	Non-disclosure agreements
ODP	Ozone depletion potential
OSMOSE	Tool for process integration and optimization
Pinch Analysis PA	Methodology to identify the true thermodynamic needs of a process, considering heat recovery
SG	Safety group
SMEs	Small and medium-sized enterprises
TCP	Technology Collaboration Programme

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