Federal Ministry for Economic Affairs and Climate Action

中德能源与能效合作
Energiepartnerschaft
DEUTSCHLAND - CHINA

Industrial high temperature heat pumps in Germany and Europe – potentials, application cases and support policy

Sino-German Energy Partnership

dena German Energy Agency

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Imprint

The report *"Industrial high temperature heat pumps in Germany and Europe – potentials, application cases and support policy"* introduces the potentials of high-temperature heat pumps in the frame of climate neutrality as well as support policies for promoting their application. It also shares best practices for introducing (high-temperature) heat pumps to a facility and includes case studies from Europe and Germany. It aims at policymakers and policy experts interested in enhancing the energy system decarbonisation policies and strategies, and industry enterprises or industry parks interested in introducing heat pumps to their facilities. The report is published in the framework of the Sino-German Energy Partnership between the German Federal Ministry for Economic Affairs and Climate Action (BMWK) and the National Development and Reform Commission of the People's Republic of China (NDRC). As the central dialogue platform on energy between two countries, the main objective of the partnership is to foster and advance the far-reaching and profound energy transitions ongoing in both countries by exchanging views, best practices and knowledge on the development of a sustainable energy system, primarily centered on improving energy efficiency and expanding the use of renewable energy. The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH implements the project under commission of BMWK. As a German federal enterprise, GIZ supports the German government in the achievement of its goals in international cooperation for sustainable development.

Published by

Sino-German Energy Partnership
commissioned by the German Federal Ministry for Economic Affairs and Climate Action (BMWK)
Tayuan Diplomatic Office Building 1-15, 14
Liangmahe South Street, Chaoyang District
100600 Beijing, P. R. China

c/o

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Torsten Fritsche
Köthener Str. 2
Berlin 10963

Project Management:

Yin Yuxia, Philipp Geres, Yuan Zhen

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Authors:

Martin Albicker

German Energy Agency (dena)

Philipp Geres

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Design

edelman.ergo (on commission of BMWK)

Image:

BMWK/Cover

Layout:

Zhao Yanan

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1. Executive Summary

To achieve climate neutrality, as mandated by many countries' climate laws, industry will have to replace fossil-fuel-based technologies either by electrification or hydrogen. In many use cases, heat pumps offer the most efficient way to replace low-temperature heat, as they can replace several units of combustible with one unit of electricity, drawing energy from the environment or waste heat. Thus, they require significantly less primary renewable energy than other options. Deploying heat pumps also reduces emissions even using the current grid electricity mix, making it an absolute no-regret move.

Industries particularly suitable for adopting heat pumps are those with large amounts of low-temperature process energy usage, such as food processing, pulp and paper, chemicals, and refineries. Heat pumps with heat sink temperatures of up to 100°C have already become mainstream technology, while large pilot applications of temperatures up to 150° exist. With further technological development, higher temperature levels are also expected to become accessible and commercially viable.

There still are multiple barriers to wider adoption of heat pumps:

- Installing heat pumps in plants that already are operating can be a complex matter, as they are usually not a simple drop-in solution. Retrofitting thus requires a comprehensive optimisation of heat flows and process parameters.
- In many markets, electricity is several times more expensive than direct use of fossil fuels (usually coal or gas). Therefore, even when working with high efficiency, heat pumps do not necessarily possess a cost advantage, especially when considering the higher upfront capital expenditures for heat pumps.
- As opposed to the residential sector, where heat pumps are rapidly becoming the "default" solution in many markets, industrial heat pumps still are a relatively "niche" solution, commanding low market shares. Therefore, economies of scale are limited, as is knowledge of heat pumps amongst plant operators and equipment suppliers.

Governments should therefore provide policy support for the roll-out and scale-up of industrial heat pumps. Measures can include support for R&D, subsidies for installation costs, especially for pilot applications, or operation expenses. This can be accompanied by capacity-building, such as information campaigns, or regulation, such as forced fossil fuel phase-out for certain applications. Widespread adaptation, however, will only be successful if companies have a promising business case. The most important factor for this is the ratio between fossil fuel prices and electricity. Regulators should thus look to impose carbon pricing, taxes, or other levies on fossil fuels, while ensuring competitive prices of renewable electricity.

2. Introduction – climate targets, industry emissions and process heat, principle of industrial heat pumps

Both the EU and Germany have set ambitious climate goals which stipulate rapid emissions cuts: The EU Green Deal aims for a 55 % cut in net emissions by 2030, compared to 1990, and overall climate neutrality in 2045, whereas the German Climate Protection Law mandates 65 % reduction in gross emissions by 2030 as well as climate neutrality by 2045. German climate laws also have sector-specific provisions, aiming for a one-third reduction of direct industrial emissions by 2030, after industrial emissions had been mostly flat in the 20 years up to 2019. Currently, direct industrial emissions amount to roughly 20 % of total greenhouse gas (GHG) emissions in both Europe and Germany: 877 Mt CO_2 equivalent in Europe in 2017[1] and 181 Mt CO_2 equivalent in Germany in 2021[2], not counting Scope-2-emissions such as electricity from the power grid. Of these emissions, two thirds are energy-related, and the remainder are process emissions[3]. Two thirds of this industrial energy demand stems from generating process heat. Decarbonisation of process heat is therefore crucial to meet European and national climate targets.

Industrial companies will be required to replace fossil energy sources by renewable energy, particularly in the form of hydrogen and electricity, as well as drastically improve energy efficiency to reduce final energy demand. Minimization of primary energy usage, which national and EU targets aim for, is also desirable to improve energy system efficiency and reduce resource consumption. This will usually mean prioritising direct electrification (Power to Heat) over hydrogen burners where feasible, because the latter involve high losses from energy conversion[4]. In the case of lower-temperature processes, it will most often entail full electrification, using heat pumps where possible.

Heat pumps offer the possibility to switch from fossil fuels as heat source to decarbonised electricity, the share of which is rapidly increasing in most countries. Moreover, heat pumps also are a suitable tool to improve process efficiency through means such as enhanced waste heat recovery[5]: In many processes, the energy content of waste heat is discarded, as its temperature level is too low to be recycled within the process. Heat pumps permit making use of this waste heat by "upgrading" its temperature to the temperature level required within a process, enabling significant primary energy and CO_2 emission savings.

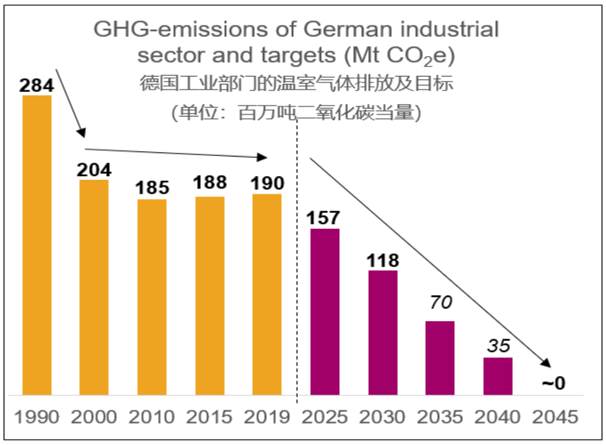


Table: GHG emissions and targets of German industrial sector

10 % of industrial process heat energy (about 200 TWh/a in Europe) is used for low-temperature heat below 100°C, and a further 26 % (500 TWh/a) for heat between 100 and 200°C. In the range up to 100 °C, many heat pumps from various manufacturers are commercially available, with pilot applications using heat pumps up to 150°C. In the coming years, development of new technologies and applications will probably allow surpassing these temperatures. Lab-scale and proof-of-concept projects already study heat pumps with sink temperatures of up to 200°C.[6]

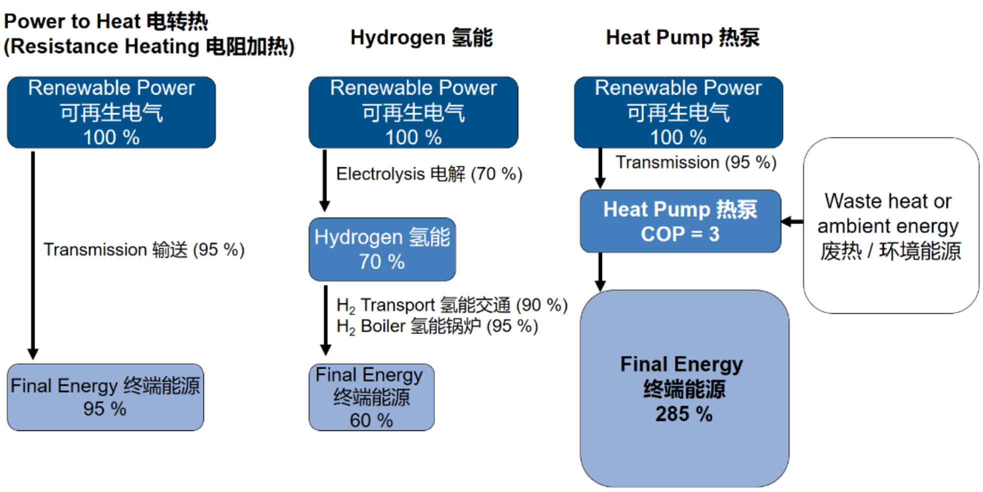
There has been explosive growth in residential heat pumps in recent years[7], which are likely to become the default solution for most housing types. Meanwhile industrial heat pumps still are lagging far behind their potential. To meet that potential, suitable market and regulatory conditions are required.

3. Decarbonisation potentials of heat pumps in industry

Electrification will play a key role in replacing fossil fuels in industry. According to one estimate, up to 60 % of total energy demand in industry, and almost all industrial heating and cooling demand, could be electrified, considering technologies currently available or under development.[8] Heat Pumps could play an important role in the decarbonisation of low-temperature heat: One bottom-up study based on process heat demand and the availability of heat sources estimates a potential for heat pumps to provide 178 TWh/a of process heat in the four biggest sectors (paper, chemical, food, refinery) in Europe alone.[9]

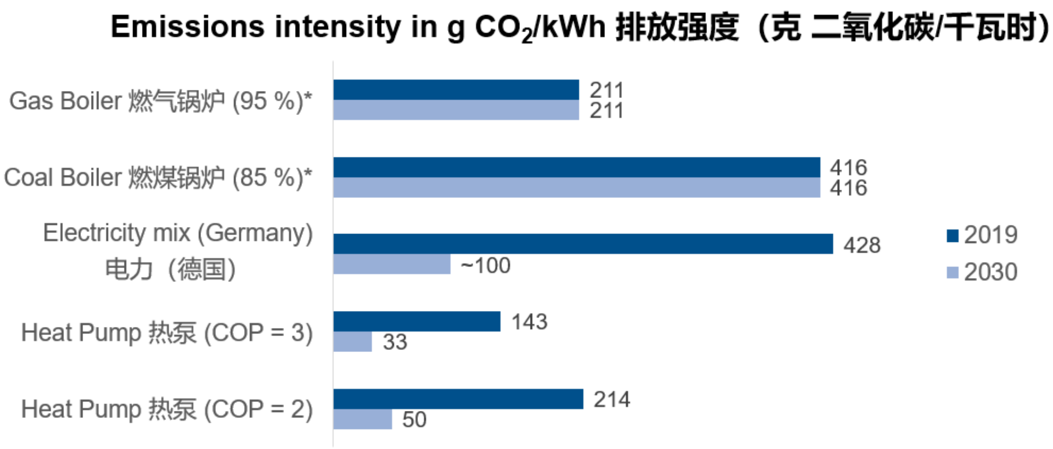
Heat pumps generally work by either "upcycling" exhaust heat within a plant by raising its temperature in order to make use of it within production processes, or by employing external renewable heat sources (typically air/water/geothermal) to provide new process energy. Heat pumps can also make use of otherwise worthless (low-temperature) waste heat in external applications, especially district heating. Hence, in addition to a suitable heat sink temperature (within the range of the heat pump in use), the presence of a suitable heat source (such as exhaust heat) is crucial for viability of heat pumps.

Compared to other decarbonisation options, heat pumps will, where they are suitable, be able to provide process heat with drastically reduced primary energy usage:



Primary energy conversion rate for climate neutral heating technologies

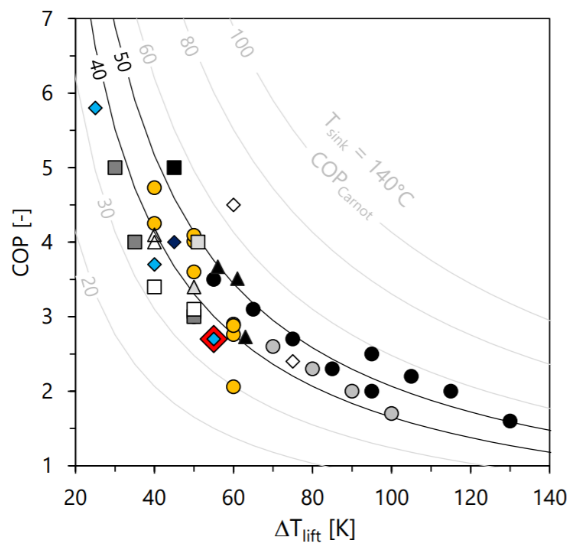
The scale-up of industrial heat pumps brings along further advantages: The implementation of heat pumps can be a driver for innovation by spurring the implementation of "smart" solutions and further energy efficiency improvements. They allow cost reductions and independence from fossil fuel price and carbon price fluctuations, and eliminate local pollution compared to burning fossil fuels. Moreover, in the vast majority of markets, an efficient heat pump will allow GHG emissions reductions even with the current "grey" electricity mix. The higher the low-carbon energy share in the power mix, the lower the emission intensity of a heat pump becomes. When operating with power entirely from renewable energy sources, heat pumps are practically carbon neutral.



Comparison of emission intensity of different heating solutions (*without upstream emissions for gas and coal)

The Coefficient of Performance (COP) measures the efficiency of a heat pump process. It is the factor between useful final energy and electric energy required for heat pump operation. The COP is inversely proportional to **temperature lift ΔT** (difference between heat source and sink), and directly proportional to the device-specific **efficiency factor ν** (the ratio between the COP achieved in reality and the ideal "Carnot" COP. Typically, ν is around 0.5). In most applications, the COP will be between 2 (for ΔT = 100 K) and 6 (for very low temperature lifts). In practice, heat pumps can achieve COP=3 at ΔT=60 K, which is the lower threshold for economic viability in many markets: On average, prior to the current European energy crisis, the average ratio between gas and electricity prices in Europe was around 3[10].

$$COP = \nu * \frac{T_{sink}}{\Delta T}$$



COP of exemplary heat pumps in relation to the temperature lift (different symbols represent different models)

The industries most suitable for heat pumps are those with large amounts of low-temperature heat requirements, as well as sufficient quantities of waste heat. In the EU, this concerns mostly the following four industries.[11]

Industry	Process heat <150°C (TWh)	Process heat >150 and <200°C (TWh)	Main processes
Paper	63	36	Steam generation, drying processes
Chemical	82	17	Distillation, various production processes
Food processing	36	18	Drying, dewatering, fermentation, sterilization, cooling, etc.
Refinery	26	35	Distillation

Low-temperature process energy demand in EU28 in selected industries

The food and beverage processing sector is particularly suitable for early large-scale adoption of heat pumps, as the heat requirements are at relatively low temperatures, and are often simultaneous to cooling needs, permitting both to be coupled in one process through the use of a heat pump with high efficiency. Moreover, a variety of low-temperature processes exist in other industries, especially generation of steam as a heat carrier, and various drying processes. An example is the brick industry, where decoupled dryers will be used to remove water from bricks, which might be run with heat pumps[12].

In other industries, heat pumps could also replace direct electric heating appliances (resistance heating), which accounts for a significant part of low-temperature heating needs, thereby slashing electricity consumption.[13]

4. Business models and integration of heat pumps in industrial processes

The main factor determining the economics of heat pump solutions are energy prices and operational efficiency (COP). In most European countries, the most common alternative to a heat pump is a gas boiler (condensing boiler) with a typical efficiency of around 90-95 %. Prior to the current energy crisis, the electricity price in most European countries tended to be about 3 times as high as the gas price[14], although exceptions and subsidies can lead to very different electricity prices for different industrial consumers. Therefore, heat pumps tend to have an edge over gas boilers in terms of operation expenses (OpEx) when the COP is over 3.

Since heat pumps also tend to have higher installation costs and complexity, a significant advantage in operation costs, as well as a high capacity usage factor, is required in order to meet the amortisation times businesses usually demand (typically within 5 years).

Best practices

Ideally, a comprehensive analysis and optimization of all heat sources and sinks in the plant should accompany integration of a heat pump in industrial processes, including implementation of feasible efficiency measures. Some starting points are questions such as

- Which processes with heat or cooling needs exist, and at which temperature levels?
- Are these processes already optimized with regards to efficiency? Are there further efficiency measures (such as insulation) which could be implemented?
- Which heat sources (especially exhaust heat) are available for the heat pump? Are those heat sources available at the same time (similar load profile) as the required heat sinks?
- Is the temperature lift lower than 60°C, and is there potential to further reduce it, e.g. by decreasing process temperature levels or increasing heat source temperature?
- What is the expected load factor (operating hours per year) of the heat pump?
- Is the previous heating system perhaps nearing its end of life anyway or is there need for refurbishment?
- Which price developments are expected for gas, electricity, and carbon emission certificates for the coming years? How is the emissions factor of utilized electricity going to change? What would hence be the total energy and carbon costs and CO_2 emissions over the lifetime of the solution?

These and other questions should be addressed in a detailed analysis, to find an ideal heat pump solution for the required application.

5. Market trends in industrial heat pumps and best practice examples

Even a few years ago, commercially available high temperature heat pumps were quite rare, with one study from 2018 listing only 20 models worldwide that are capable of a heat sink temperature of 90° or more[15], few of which had more than 1 MW of capacity. Recent years, however, have seen rapid improvements of heat pump technology above 100 °C. Commercially available devices from European manufacturers such as Siemens Energy[16], MAN Energy Solutions[17], or Ochsner[18], can now reach 150°C output temperatures on a multi-MW scale. Various demonstration projects for high-temperature solutions exist (see below for some examples), while new large-scale projects are frequently announced for purposes such as district heating[19] or industry[20].

The EU has passed F-Gas regulation as a consequence of the Kigali Amendment to the Montreal Protocol (signed 2016, effective in 2019), regulating the phase-down of hydrofluorocarbons with high Global Warming Potential (GWP). This has driven many manufacturers to replace fluoroalkanes with low-GWP refrigerants, such as hydrofluoroolefines or "natural" refrigerants such as alkanes, ammonia or even water. The main challenge is that those low-GWP refrigerants might be flammable, toxic, or not suitable for a given temperature range.[21] Following increased market demand and R&D efforts, low-GWP refrigerants now have become accessible for most applications, including high-temperature ones.

Current research and development aim to build larger-scale (>1 MW) heat pumps in various industries at up to 150°C, creating pilot-scale demonstrators at >150°C, as well as pushing temperature boundaries above 200°C in lab-scale devices.[22]

Examples for successful heat pump applications

Use of Waste Heat for Starch Drying

The project in short

Location: Pischelsdorf, Austria

Industry: Food industry

Company: Agrana Stärke GmbH

Year: 2020

Saved CO_2-Emissions: about 600 t (compared to gas burner)

Heating capacity: 374 kW

COP: 2.9-3.2

Refrigerant: OpteonMZ

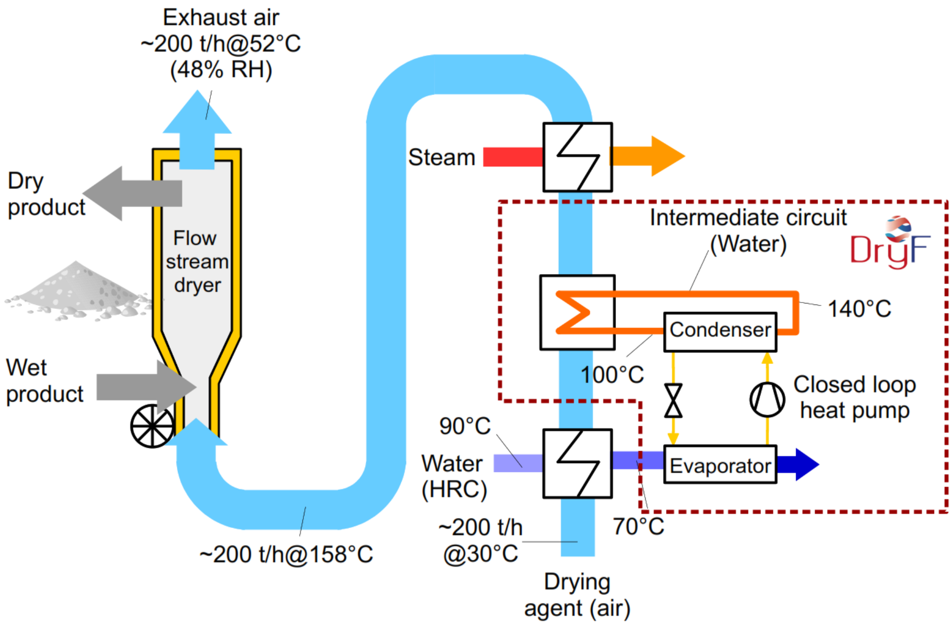
Heating source: Waste heat (water) at 76-80°C

Heat sink temperature: 140-150°C

Refrigerant: R-1336mzz(Z) (GWP=2)

Description

Agrana Stärke GmbH is part of the Agrana Group and produces high-quality starch products from corn, wheat and potatoes for a wide range of applications. Its plant in Pischelsdorf, Lower Austria, uses a high-temperature heat pump in the starch drying process. The continuously operated drying process requires hot air of around 150 °C . The heat pump uses the waste heat from other drying processes in a closed-loop process. The use of the heat pump reduces the steam consumption of the drying process thereby replacing natural gas. The installation of the demonstrator is part of the EU Horizon 2020 project DryFiciency and is coordinated by AIT Austrian Institute of Technology GmbH.



Trial operation started at the beginning of 2020. With a max. heat output of 375 kW, calculations show annual energy savings of up to 3000 MWh and CO_2 savings of 600 tons per year. At a CO_2 price of €60 per ton, this system would save €60,000 per year. If replacing 3000 MWh of gas, the system would safe €300,000 per year in gas costs at a gas price of €100/MWh (2022 gas prices in Europe are even higher).

Sources:

https://dryficiency.eu/demonstrations/agrana-food-industry/

Large scale heat pumps in Europe Vol. 2 (European heat pump association)

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Heat Pumps for Brick Drying

The project in short

Location: Uttendorf, Austria

Industry: Construcion materials

Company: Wienerberger Group

Year: 2019

Saved CO_2-Emissions: 590 t/a

Heating capacity: 300 kW

COP: 5.0 (at 110°C), 2.2 (at 160°C)

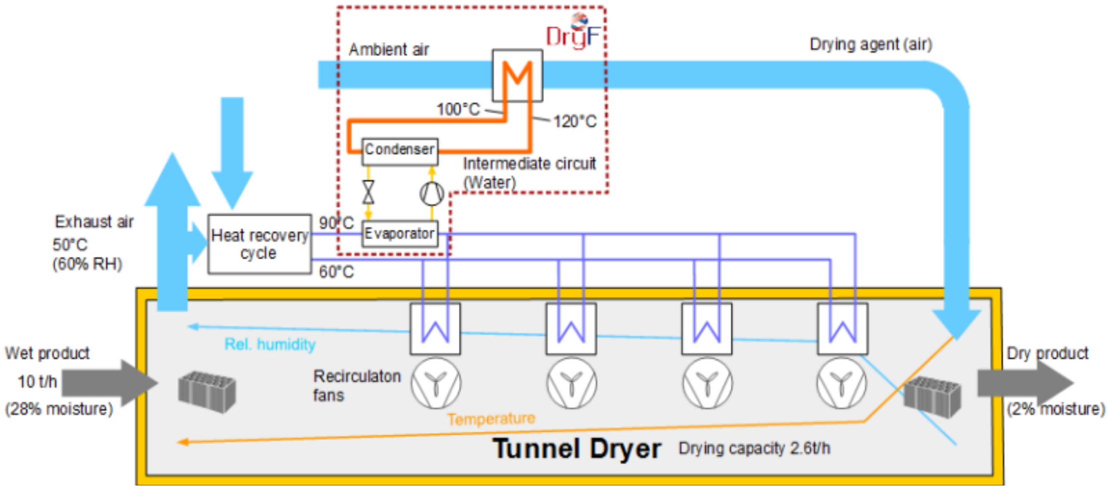
Refrigerant: R-1336mzz(Z) (GWP=2)

Heating source: Waste heat (water)

Max. temperature: 110 –160°C

Description

The Wienerberger Group is the world's largest manufacturer of clay blocks and facing bricks. The plant in Uttendorf, Upper Austria, uses a high-temperature heat pump in the brick drying process. The process uses the waste heat from the tunnel dryer in a closed-loop process to provide hot air for drying. In the drying process, the water content of the bricks is reduced from 30% to 2-4%. The demonstrator started operating in 2019 and achieved a heat utilization temperature of 160 °C. The installation of the demonstrator was implemented as part of the EU Horizon 2020 project DryFiciency and coordinated by AIT Austrian Institute of Technology GmbH.



Replacing the natural gas burner with a heat pump is expected to save up to 84% energy and achieve a reduction in CO_2 emissions of up to 80%.

Sources:

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Industrial waste heat for district heating

The project in short

Location: Skjern, Denmark

Industry: Pulp & Paper

Company: Skjern Paper Factory

Year: 2014

Saved CO_2-Emissions: 8200 t (in 2015)

Heating capacity: 5.3 MW

COP: 6.5 - 7

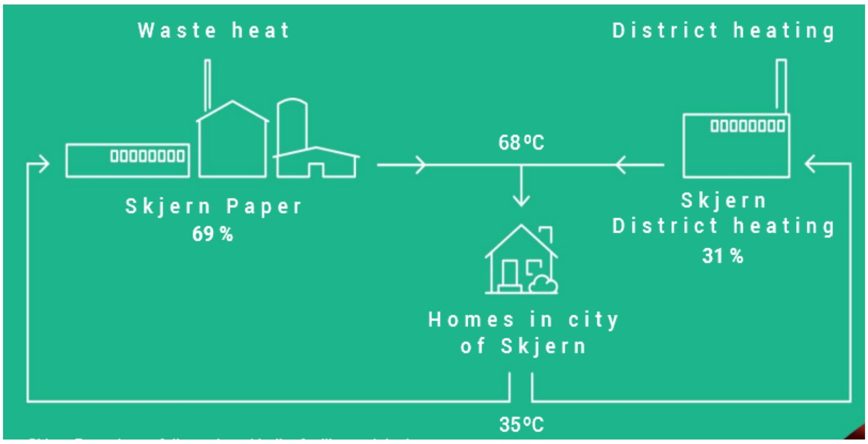
Refrigerant: R717 (ammonia)

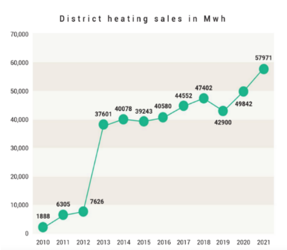
Heating source: Humid air 55°C –> 30°C

Max. temperature: 70°C

Description

The city of Skjern, Denmark, uses industrial waste heat in district heating. In 2012, the local paper mill Skjern Paper installed three industrial heat pumps, each with 1.33 MW, to utilize the waste heat from the paper drying process. Later, the plant added another heat pump, bringing the total capacity to 5.2 MW. Supplemented by a direct heat exchanger, the plant reaches a capacity of 8 MW and a plant COP of 6.5 - 7. In 2021, the Skjern paper mill could supply 69% of the households in Skjern with its waste heat.





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Large scale heat pumps in Europe 16 examples of realized and successful projects

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Snellman - pioneer user of industrial heat pumps

The project in short

Location: Pietarsaari, Finland

Industry: Food industry (Meat processing)

Company: Snellman

Year: 2019

Heating capacity: 1,090 kW

COP: 3.5

Refrigerant: R1234ze (GWP=1)

Heating source: 30°C

Max. temperature: 95°C

Description

The Snellman Group is a family business in the food industry with roots in Pietarsaari, Finland. The business areas are Meat Processing and Ready Meals. They are considered pioneers in the use of industrial heat pumps. They installed the first heat pump with a capacity of 1 MW at the Pietasaari site back in 2007. Using waste heat from the hot water of a washing process to reheat the washing water to 55 °C enabled saving around 450,000 kg of heating oil per year. In 2009, they installed additional heat pumps to use waste heat from the refrigeration machines to produce 75°C hot water for heating the plant. Then, in January 2019 they added another two high-temperature heat pumps from Oilon with a heating capacity of 1,090 kW. These generate temperatures of 95°C, which are required e.g. for the sterilization of knives and other tools. Previously, the high temperatures were generated using steam from a biogas boiler. Snellman switched from oil to biogas back in 2014. With the new heat pumps, Snellman now can significantly reduce the use of biogas.

Sources:

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Large scale heat pumps in Europe Vol. 2

"Qwark³" District heating central in Berlin, Potsdamer Platz

The project in short

Location: Berlin, Germany

Industry: District Heating

Company: Siemens

Year: 2022 (operation to start in November)

Generated heat: 55 GWh/a

Heating capacity: 8 MW

COP: >2.5

Refrigerant: R1233ZD(E) (GWP=4.5)

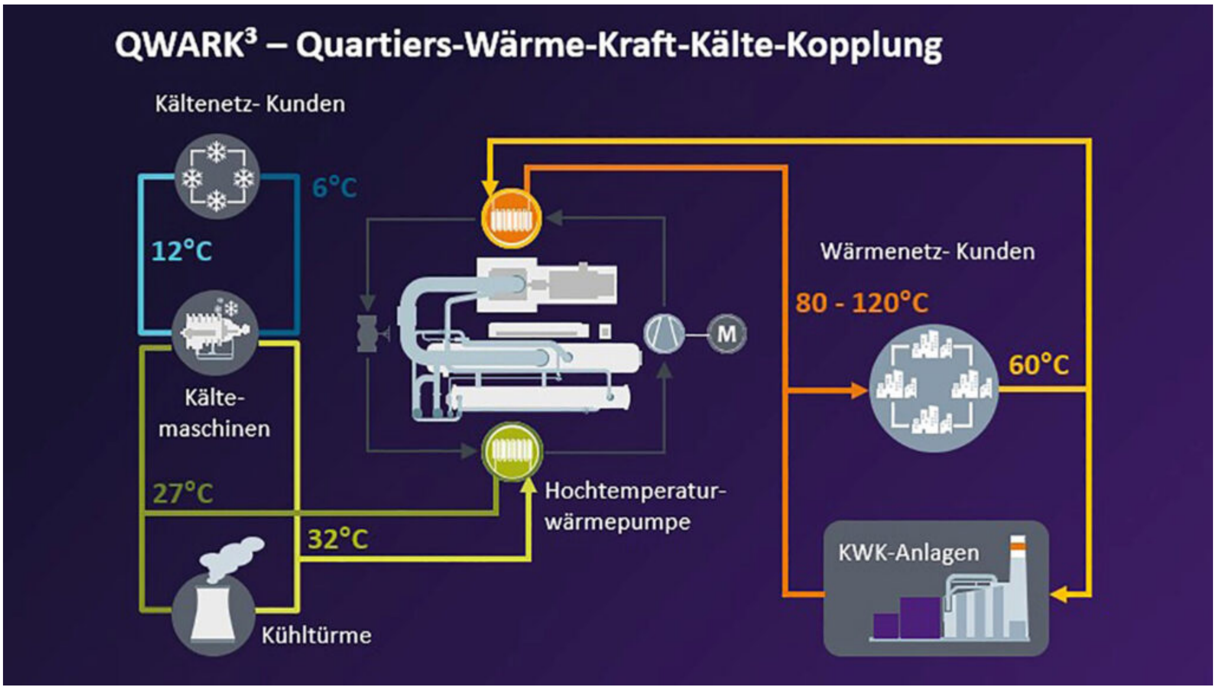
Heating source: 32°C

Max. temperature: 80-120°C

Description

The district cooling center in Potsdamer Platz, in the heart of Berlin, was built in 1997 to provide 12,000 offices, 1,000 apartments and various cultural institutions with cooling. Refrigerating units cool water down to 6°C and in the process generate waste heat at around 30°C, which was previously discarded. The new Siemens high temperature heat pump raises that waste heat to temperatures suitable to feed into the district heating network – around 80°C in summer (mainly for hot water) and up to 120°C in winter. The new heat pump system should be able to provide around 55 GWh of heat per year, enough to provide 30,000 households with hot water in summer and 3,000 households with heating in winter. By replacing natural gas it should reduce CO_2 emissions by 6,500 tons per year, in addition to saving cooling water and reducing local heat emissions.

The project also serves as a demonstration of novel high temperature heat pump technology at a significant scale under real-life conditions. The project cost € 7.8 million to plan and build, 40% of which was provided as a federal subsidy.



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6. Existing incentives to promote heat pumps in industry in Germany

In order to reduce amortisation times and incentivize heat pump installation by lowering upfront capital costs, many countries have implemented investment subsidies.

An example is the German program "*Energie- und Ressourceneffizienz in der Wirtschaft*" (Energy and Resource Efficiency in Industry), which the Ministry of Economic Affairs (BMWK) initiated in 2019 and last reformed in 2021.[23] The program has a budget of up to €1 billion per year, paid for by revenue from carbon pricing ("Energy and Climate Fund").

The program has five different modules for a wide variety of different efficiency projects

1. Efficient cross-sectional technologies
2. **Renewable Process Heat**
3. Digital technology and energy management systems
4. **Systemic energetic and resource optimisation**
5. Transformation concepts

Modules 2 and 5 cover heat pumps:

- Module 2 specifically aims at "Renewable process heat" and supports solar thermal, biomass, as well as heat pumps. It has specific technology requirements concerning installed heat pumps, including a COP > 2 and ν > 0.4. It also requires a renewable source of heat, making waste heat from fossil energy ineligible. The subsidy is 45 % of total capital costs (55 % for SME).

- Module 5 offers general support for all kinds of efficiency measures, which may also include heat pumps. It is completely technology-open: Any type of project that saves energy and carbon emissions can apply, as long as the main source of emissions savings is not a switch from one fossil fuel to another (e.g. coal to gas). In principle, it allows for more complex, "systemic" optimisation measures, including a combination of measures. The subsidy is 30 % of capital cost (40 % for SME).

Both programs also support integration and installation costs (planning, construction work, pipelines, heat storage, measuring equipment, etc.). The maximum subsidy available is €15 million per project.

Other subsidy programs exist in other European countries, such as the "**Fonds Chaleur**" in France.

In addition to investment support, other policy measures can be helpful for promoting feasibility of heat pumps or electrification in general. Some examples currently being implemented in Germany are:

Carbon pricing: Industrial carbon emissions are either covered by the European ETS or the German national ETS "BEHG" (the latter mostly applies to transportation, space heating, and smaller production facilities), which serve to drive up the cost of fossil fuels as well as incentivize energy efficiency measures and switching to alternatives. Both prices are expected to keep rising: EU ETS price has risen from €10 per ton of CO_2 equivalent in 2018 to almost €100 in 2021 and has consistently been above €60. The carbon price under the BEHG will rise from €30 in 2022 to €55 in 2025, after which it will fluctuate according to market demand.

Industrial electricity **tax exemptions**: Energy intensive industries are exempted from certain taxes and levies, which significantly lowers their electricity cost. While this measure is primarily aimed at preventing carbon leakage (i.e. industries with high carbon emissions relocating to jurisdictions with lower or no carbon prices), rather than electrification, some of these exemptions are contingent on companies introducing energy management systems or implementing efficiency measures. The "renewable energy levy" (EEG-Umlage), which previously contributed to making German electricity prices some of the highest in Europe[24], ended in 2022, lowering costs for all consumers. Subsidies for renewable energy are instead funded through the federal budget.

Carbon Contracts for Difference (CCfD): The German government is planning to introduce "Carbon Contracts for Difference" (CCfD), covering the additional costs of low-carbon production technologies compared to conventional, fossil, processes. As these contracts generally do not prescribe specific technologies, heat pump solutions are eligible.

Carbon Contracts for Difference (CCfDs) for the decarbonisation of industry are project-based contracts between companies and the government or a government-sponsored entity. They cover additional costs for low-emission or climate-neutral production technologies compared to conventional production methods.

As of present, climate-neutral products are often significantly more expensive, resulting in considerable specific carbon abatement costs, which are not expected to be covered by the CO_2 price level in the next years. By covering the difference between the actual abatement costs and the carbon price level, CCfD would offer security for companies to be able to produce competitively independent from the actual CO_2 price, and thus permit them to invest in these technologies.

The "strike price" of these contracts, i.e. the assumed abatement cost up to which companies receive payments, should be determined via product- or sector-specific tenders. These tenders should not restrict the deployed technology, except that solutions must be climate-neutral or compatible with long-term climate neutrality. The duration of a CCfD must be determined on a project-specific basis and can be based on depreciation periods or the actual operating life of a plant, taking into account the characteristics of each sector. In case the carbon price rises above the strike price, companies might have to pay back money to the financer.

In most cases, the most important cost factor for low-carbon production is the additional cost of renewable energy sources (mostly hydrogen or green electricity), which should be indexed in the contract design for CCfD as part of contractually agreed monitoring to avoid cost risk or over-subsidization.

7. Obstacles to wider adoption of heat pumps and policy recommendations for promoting them

Obstacles

The biggest obstacle to electrification projects, including the wide-spread deployment of industrial heat pumps, are current energy price regulations, especially the comparatively high taxes and levies on electricity compared to fossil fuels such as gas.[25] Until fairly recently, the electricity mix in many countries was quite polluting, with a high proportion of coal. Using gas was therefore often considered as the "cleaner" solution compared to electrification, especially with CHP (Combined Heat and Power). In countries such as Germany, the phase-out of gas for a long time had not been part of long-term energy strategies. This only changed with the increasing proportion of renewable energy, along with Germany introducing its ambitious climate neutrality target.

Furthermore, heat pumps are not typically a "drop in" solution to replace fossil fuel burners, but entail a higher complexity and require advanced know-how: To efficiently implement heat pumps, it is often necessary to fundamentally redesign factory processes, which leads to significantly higher installation costs.

Moreover, the availability of (high temperature) heat pump technology only improved quite recently. Until a few years ago, heat pumps were considered a "niche" technology, and installed numbers are still very low compared to gas boilers.[26] The small number of demonstrative applications as well as the lack of proven systems at large scale prevent scale effects from driving down costs and improving technology development through "learning curve effects". Policy support for electrification solutions can break this vicious circle by providing planning security to potential investors.

Policy recommendations

The basic requirement to enable large-scale heat pump adoption is enabling a positive business case for companies and other investors. As operation costs are the determining factor during the lifetime of a plant, enabling competitive energy prices for electricity compared to fossil fuels is the key. A positive example is Sweden, where electricity is cheap compared to gas, and industry is pushing ambitious electrification projects[27]. Some policy options for promoting high temperature heat pumps in industry and beyond include:

- Reliable **carbon pricing** that internalises the cost of emissions, with an ambitious and rising price path. "Free allocations" or other exemptions should be limited as much as possible.
- Creating a **level playing field** between electricity and gas. In many countries taxes and levies on electricity still are higher than those on fossil fuels.
- **Phasing out subsidies for fossil solutions**
- Enabling **cheap access to renewable electricity**, such as supporting the adaptation of Green PPAs
- Operation cost support such as **Carbon Contracts for Difference** (CCfD) can also help make heat pumps competitive or lower the risk for operators.
- Enabling flexibility measures such as industrial **Demand Side Management** to reduce electricity (system) costs and carbon emissions

Support for the development, scale-up and installation of heat pumps can help overcome the issue of higher initial capital costs, and long amortisation times (especially with currently lower adoption numbers):

- **R&D** support to enable higher efficiencies, higher temperature levels, low-GWP refrigerants, etc.
- **Support schemes for early adopters**, e.g. financial support for innovative pilot schemes such as "fossil-free factories", to promote technology demonstrators at scale
- **Capital cost subsidies** for the installation of heat pumps and other renewable energy in industrial plants
- Support for developing **standardized solutions** for certain industries, as well as consulting and

other services, in order to support SME in adapting heat pumps

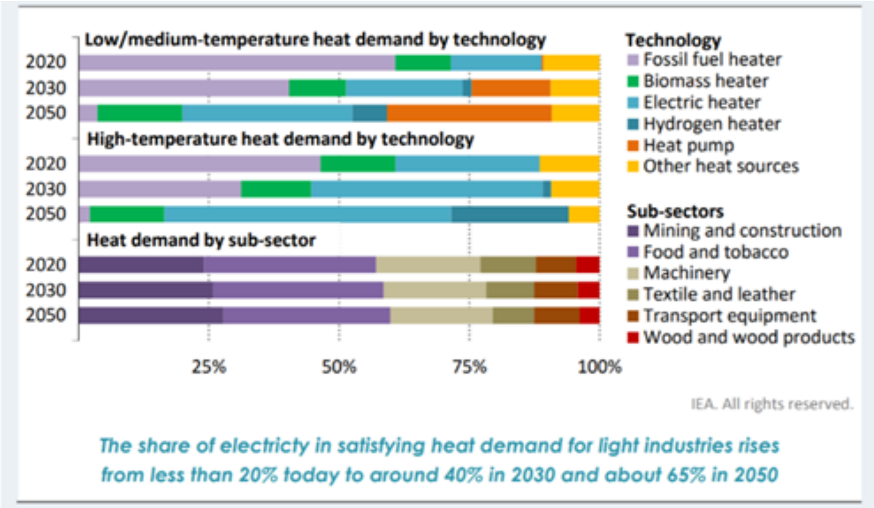
In some cases, establishing mandatory requirements can help spur investment by companies and incentivize industrial fossil fuel phase-out:

- Mandating **high efficiency** for industrial processes, e.g. minimal primary energy requirements or obligations to reduce waste heat
- Regulatory **facilitation** of using new energy sources such as geothermal in combination with heat pumps
- Prescribing a transparent **carbon footprint** on industrial products and preferential procurement of low-carbon products will incentivize deployment of efficiency measures and low-carbon production technologies

The expansion of **renewable and other low-carbon energy sources**, electricity grids, and storage will ensure a cheap and reliable power supply, which will allow replacing CHP, as well as lowering the carbon footprint of electrification solutions.

Public agents such as government institutions and state-owned companies should set an example by rapidly phasing out fossil fuels, thus allowing the scale-up of clean solutions. This can be supported by discouraging installation of new fossil burners and the promotion of heat pumps as a more sustainable alternative, including making knowledge and training available.

8. Conclusion



Share of heating technology by temperature level in light industries in IEA's Net-Zero Scenario

According to the IEA's "Net Zero by 2050" Scenario, the share of low/medium-temperature heat (<400°C) demand covered by heat pumps will increase from less than 1 % today to about 15 % by 2030, and to 30 % by 2050.

This will offer both unprecedented market growth for heat pump producers and installers of heat pump solutions, as well as significant cost and energy saving potential for heat-using industries. With its strong equipment manufacturing industry, as well as its enormous light industry sector, China is poised to strongly benefit from the roll out of heat pumps.

As heat pumps offer significant primary energy savings, and carbon emission reductions, even on the existing grid electricity mix, fast adoption is a "no-regret-move". It can be initiated immediately, faster than other electrification solutions, as a significant step towards a low-carbon future. In Germany, in recent decades, many industries have upgraded their heat generation systems from coal to gas, and from gas to gas CHP. Now, they will need to electrify their process energy demand. By adopting heat pumps for suitable applications now, China could be able to "**skip gas**" and move directly to low-carbon solutions.

Regulators should provide support to enable large-scale adoption of industrial heat pumps. Recommendations for China include:

1. Support early adopters of heat pumps with generous funding for pilot projects in order to accelerate market maturity of heat pump solutions and provide show-cases for "best-practices".
2. Make fossil fuels more expensive by ending subsidies and imposing emissions pricing or other levies, while at the same time ensure cheap access to renewable electricity.
3. Use regulations to spur adoption, such as emissions control or clean energy mandates.

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