German-Japanese Energy Transition Council

Topical paper on the potential of waste heat usage in Germany and Japan

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List of Abbreviations, Units and Symbols

Abbreviations

#AGFW	Energieeffizienzverband für Wärme, Kälte und KWK (Energy Efficiency Association for heating, cooling and CHP)
#BMUV	Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz (German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection)
#BMWK	Bundesministerium für Wirtschaft und Klimaschutz (German Federal Ministry for Economic Affairs and Climate Action)
#CHP	Combined Heat & Power
#COP	Coefficient of Performance
#DENA	Deutsche Energie Agentur (German Federal Energy Agency)
#DOE	United States Department of Energy
#EU	European Union
#Fig.	Figure
#FY	Fiscal Year
#GWB	Gesetz gegen Wettbewerbsbeschränkungen (Act against Restraints of Competition)
#KWKK	Kraft-Wärme-Kälte Kopplung (Combined heat, power and cooling)
#LANUV	Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen (State Office for Nature, Environment and Consumer Protection North Rhine-Westphalia)
#LED	Light-emitting diode
#METI	Ministry of Economy, Trade, and Industry (Government of Japan)
#MOE	Ministry of the Environment (Government of Japan)
#NEDO	New Energy and Industrial Technology Development Organization (Japan)
#NRW	North Rhine-Westphalia
#ORC	Organic Rankine Cycle
#PCM	Phase Change Material
#PV	Photovoltaics
#R&D	Research and development
#RED	Renewable Energy Directive
#SMEs	Small and medium-sized companies
#SRC	Steam Rankine Cycle
#Tab.	Table
#TCES	Thermochemical energy storage
#TEG	Thermoelectric Generator
#TherMAT	Thermal Management Materials and Technology Research Association
#WI	Wuppertal Institut für Klima, Umwelt, Energie GmbH (Wuppertal Institute for Climate, Environment and Energy)

Units and Symbols

#%	Per cent
#°C	Degrees Celsius
#CO_2	Carbon dioxide
#g	Gram
#h	Hour
#K	Kelvin
#kW	Kilowatt
#t	Ton

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Executive Summary

When realizing the planned sustainable energy transition, it is crucial to minimize the consumption of finite resources and to move away from the dependence of fossil fuels. In this regard a wide variety of measures - such as energy efficiency, the expansion of renewable energies, or the increasing integration of energy storage systems - are being developed and promoted. Usually, little notice is taken of the **use of waste heat**, which **offers enormous advantages for many different users**. Even though waste heat is generated as a by-product in almost all technical processes, it is often lost without being utilized. This reduces the overall energy efficiency of technical processes, since a significant part of the thermal energy is wasted, leading to unsustainable processes. Thus, **an improved utilization of waste heat can lead to higher energy efficiency and can at the same time reduce energy costs**.

The use of waste heat is rather simple: Processes or machines generate heat through their operation. This heat is then released in the form of heated air or warm wastewater and can be used with the help of a heat exchanger. This technology is also used in heat pumps or ventilation systems for heat recovery. The heat energy can be extracted from the exhaust air or the wastewater via this heat exchanger and is transferred to a separate heat circuit. Such waste heat uses and sources as well as their potential are explained in more detail in Chapter 2 of the present study. **Identifying and utilizing the diverse waste heat potentials** will require a holistic analysis of all production processes as well as the building energy technology for utilization of waste heat from production processes in other processes or in buildings. More generally, waste heat potentials can be identified by examining all waste heat sources and each prospective heat consumer. In this regard, the following criteria must be kept in mind: Temperature level, available heat quantity, continuity of the waste heat stream, timing of heat supply and heat demand, heat transfer medium, and local conditions. Beyond the operational optimization of waste heat utilization in the own company or premise, existing surplus amounts of heat can also be transferred or sold to third parties. Feeding waste heat into local or district heating networks or to neighboring companies can make a **major contribution to** achieving the goal of **a climate-neutral building stock and industry.**

To fully exploit the identified potentials, several technologies can be utilized. The **state of the art as well as future technological trends** are explained in Chapter 3. Important components in waste heat utilization and distribution are among others heat storage technologies, heat pumps, absorption / adsorption chillers and thermal electric generators. Next to several options of those technological standards, Chapter 3 describes **crucial materials and components needed for waste heat utilization** as well as whole **system technologies**.

Furthermore, the present paper provides a condensed overview on the **usage of waste heat in Germany and Japan** (see Chapter 4) as well as its potentials, including technological developments and **policy measures** in both countries. It gives an outlook on the contribution of this energy source to a **sustainable energy supply** for industry, public institutions and communities. Regarding the existing infrastructure, for example for use of waste heat by third parties, Germany mainly holds **district heating grids**, which is only common in the very Northern part in Japan. On the other hand, Japan already has longer experience in the construction and operation of cooling systems, highly efficient heat pumps and Thermoelectric Generators, just to name a few.

In both countries, Germany as well as Japan, various **subsidy programs** to support the use of waste heat have been launched. An exchange of experiences on the effects of the subsidy programs would be desirable here. However, **large-scale "waste heat markets" do not yet exist in both countries**; in contrast to the electricity market, there is no free market for heat, including waste heat. **Political action is needed** on both sides to support the creation of a “waste heat market”, potentially as a part of a wider sustainable heat market.

Several **German-Japanese workshops and bilateral exchanges** such as the GJETC have identified a whole range of potential areas of cooperation that can subsequently be further developed in **collaborative projects**, for instance: Optimization of thermoelectric generators, increasing efficiency and demonstrating possible applications for industrial heat pumps such as in the food industry, use of waste heat from data centers, use of waste heat from waste water, concepts for (municipal) heat networks, or methods for developing waste heat registers and local heat planning. Learnings can be derived by looking at **best practice examples from both countries**. Japan for instance possesses a wide knowledge on municipal **waste incineration,** through which heat is generated and supplied for heating and hot water. Those incinerators can be found in municipalities such as Hikarigaoka or Shinagawa. An example for best practices in Germany can be found at the Neckarpark in Stuttgart, where **heat from a sewage system** is used for supplying heating and hot water for a quarter in Stuttgart. More best practice examples from Japan and Germany are listed in Chapter 4.4.

Regarding technologies, a cooperation between German and Japanese research institutes and heat pump manufacturers for the **further development and use of heat pumps** (also in the high-temperature range of 120°C and more) and users would make sense. One technological cooperation that has already started, taking thermoelectric generators into account. This **cooperation between a Japanese company and a German research institute has already been established** as a **follow-up to the German-Japanese workshop** "Industrial Waste Heat Usage - German-Japanese Expert Workshop 2021". This shows, that an **intensified bilateral** exchange regarding technologies and systemic concepts, but also policies, could **enable further synergy effects for industry, research and policy for both countries**.

1 Introduction

In order to realize a sustainable energy transition, energy efficiency is one important part of the puzzle. Energy efficiency makes the transition to renewables sustainable and affordable, and it makes economic sense. Most actions to reduce demand are cost effective and cheaper than investments in new energy supply.

The utilization of waste heat is a possibility of saving energy which had been neglected in the past. In Germany, heat demand for space and process heating is responsible for around one-third of CO_2 emissions in Germany (AGFW, 2020). To achieve the German government's climate protection targets and make the heating sector climate-neutral by 2045, the considerable waste heat potential in industry, commerce, services and trade must be harnessed. Even though waste heat is generated as a by-product in almost all technical processes, it is often lost without being utilized. This reduces the overall energy efficiency of technical processes. Thus, an improved utilization of waste heat can lead to higher energy efficiency and can at the same time reduce energy costs.

The usable potential is enormous. In Germany, for example, around 50 % of process heat in industry alone is still emitted as waste heat instead of being used for a secondary heating purpose (Deller, 2022). However, there is largely untapped potential not only in industry but also in other areas, such as waste heat from data centers or municipal sewage systems. Low-temperature sources, such as cooling circuits and exhaust air, are also increasingly becoming the focus of potential identification and development. Processes that currently generate waste heat are being converted with a view to increasing efficiency, changing energy sources from fossil fuels to renewables, and using waste heat within the company or between factories, either directly or, for example, by using heat pumps.

In order to find sustainable solutions, it is crucial to find out which waste heat sources are potentially useful and available in the long term. Therefore, when identifying and quantifying potential, the future perspective must always be considered.

The present paper provides a condensed overview on the potential and usage of waste heat in Germany and Japan, on technology developments, and on policy measures in both countries. Further, it gives an outlook on the contribution of this energy source to a sustainable energy supply for industry, public institutions and communities.

In Chapter 2, general overviews of potential waste heat uses, available heat sources/heat sinks and their temperature level, and methods for identification of potentials and examples are given.

Chapter 3 informs on the technology for using waste heat: state of the art and future trends for the main technologies and components for the use of waste heat, such as heat storage systems, heat pumps, chillers, electricity generators, and system technologies.

Afterwards an overview on waste heat usage in practice is given separately for Japan and Germany in Chapter 4. This includes the current state of usage and the potential for expanding it, policy measures to overcome barriers for waste heat utilisation, and finally best practice examples.

Finally in the conclusion (chapter 5), suggestions for priority research fields for German-Japanese cooperation are provided.

2 Waste heat sources and uses

Identifying and utilizing the diverse waste heat potentials usually requires a holistic analysis of all production processes as well as the energy technology for utilization of waste heat from production processes.

Beyond the operational optimization of waste heat utilization in the own company or premise, existing surplus amounts of heat can also be transferred or sold to third parties. Due to high transaction costs in project preparation and the coordination of involved actors, only a few projects of this type have been implemented in the past. However, feeding waste heat into local or district heating networks or to neighboring companies can make a major contribution to achieving the goal of a climate-neutral building stock and industry.

Basically, a distinction is made between internal and external waste heat utilization. Internal utilization is in the own company or premise, while external waste heat utilization refers to third parties.

Internal waste heat prevention and utilization:

a) Reduction of the occurrence of waste heat through e.g. thermal insulation, or process optimization.

b) Reintegration of waste heat into the same process (heat recovery, e.g., through combustion air preheating or preheating and/or drying of the starting materials)

c) Use of the waste heat outside of the process of its origin at the highest possible temperature level (integration into other processes or space heating/hot water or steam preparation)

d) Transformation into other useful energy forms (electrical energy, air conditioning/cooling)

External waste heat utilization:

Transfer of waste heat that cannot be used internally to third parties (e.g., to neighboring companies or for heating adjacent residential or business premises)

2.1 Heat sources/heat sinks and their temperature level

The following figure shows typical **sources of waste heat** in the manufacturing sector and typical temperature levels for these.

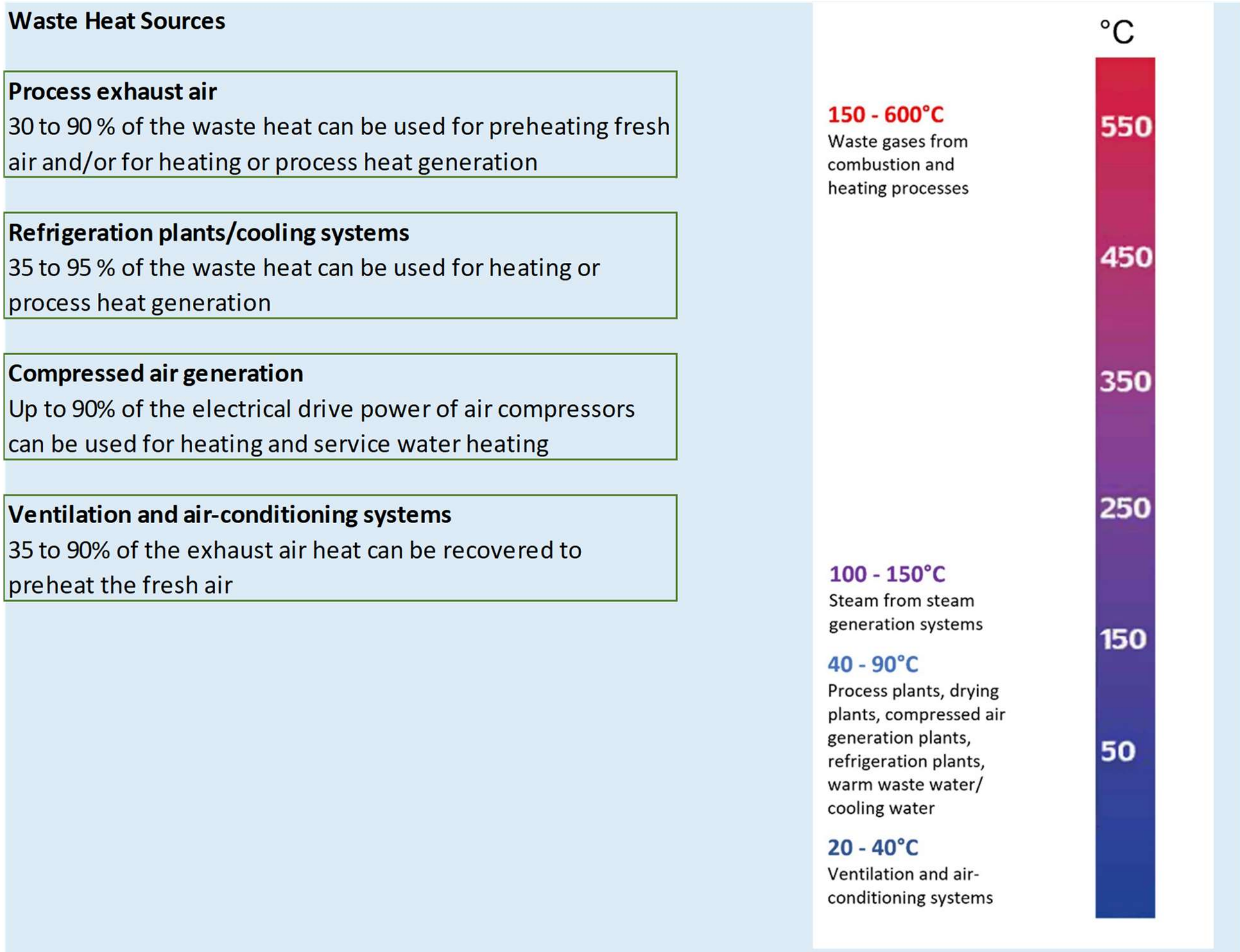


Fig. 1 Typification of waste heat sources (DENA, 2015)

A **heat sink** is the part of a system where it transfers energy to an adjacent system. In other words, heat is lost from the system at the heat sink, which is why heat sinks used to be generally referred to as "heat losses". It is initially irrelevant whether the release of heat is desired or undesired.

Desirable heat sinks are found in both heating and cooling systems. In the heating system, for example, the radiator is referred to as a heat sink because it is here that the heating system releases heat energy into the room air. However, the heat exchanger through which a heat pump is supplied with heat is also a heat sink, because the respective heat source (heat transfer medium/working medium) releases heat (to the downstream heat network) there.

In addition, the term heat sink is occasionally used with reference to a larger system that uses the heat, such as a heating network. In this context, the individual consumers of the heat provided can also be referred to as heat sinks.

The temperature level of heat sinks can be very different and can often be influenced. For example, in the heating sector, flow temperatures of around 35 °C are sufficient for low-temperature heating systems such as underfloor or wall heating, while systems with radiators typically require flow temperatures of between 50 °C and 60 °C at maximum heat demand on cold days. In conventional heating networks, the flow temperature is approximately between 60 and 90°C. In the industrial sector, much higher temperatures are also required.

2.2 Methods for identification of potentials and examples

The use of a waste heat register brings together suppliers and users of waste heat; if necessary, it can also be implemented in connection with a so-called "waste heat information exchange". Companies can report their waste heat potential there and potential users such as housing associations, energy suppliers or other commercial enterprises can research waste heat sources and sinks and obtain information on waste heat utilization.

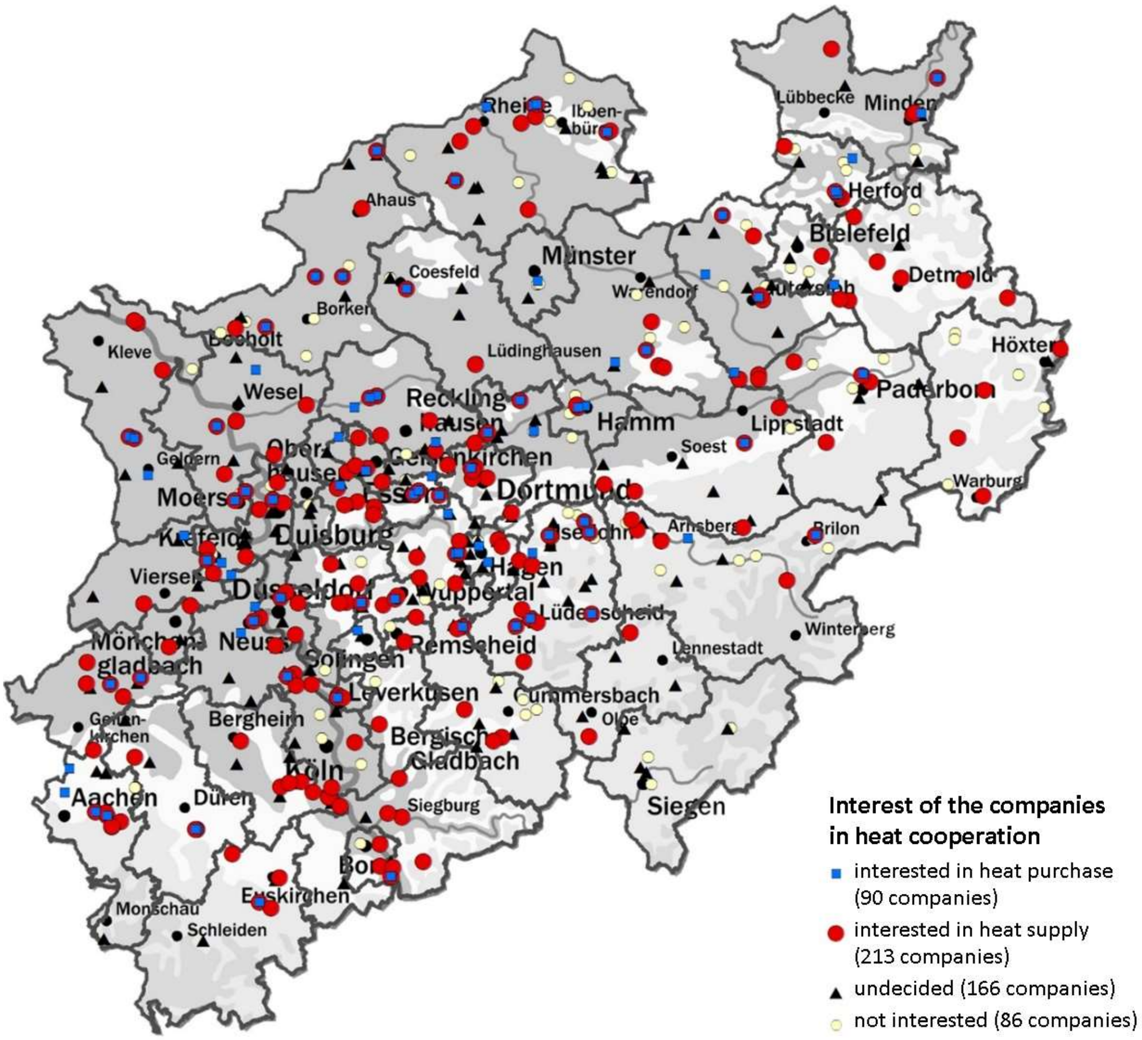


Fig. 2 Result of surveys of more than 1,850 companies (with a response rate of almost 30 percent) in the federal state of North Rhine-Westphalia on waste heat potential and interest in waste heat cooperation or external waste heat utilization. (Landesamt für Natur, Umwelt und Verbraucherschutz (LANUV) Nordrhein-Westfalen, 2019)

Methodology for the preparation of waste heat cadastres:

The **top-down** method uses available nationwide statistical data on energy consumption in industry to determine a theoretical amount of waste heat, which is then broken down to the county or municipality level. This breakdown can be based on employee or sales figures, for example. The sole use of statistical data eliminates the need to survey participating companies, thus enabling rapid processing.

The statistical basis for the waste heat potential in Germany can be the study "Abwärmenutzung - Potentiale, Hemmnisse und Umsetzungsvorschläge" (Waste Heat Utilization - Potentials, Barriers and Implementation Proposals), which was prepared by IZES gGmbH (Grote et al., 2015) on behalf of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety in 2015. In addition to an overview of the technologies, this study also provides the status of current publications in Germany and at the international level. In addition, an estimate of the potential can be made based on data from the Federal Statistical Office (energy consumption per industry and industry data).

This is opposed by the **bottom-up** method. For this variant, a significantly higher effort is required. Here, the specific data for each company must be recorded and processed by means of surveys, such as in the example in figure 2-2. The appointments required for this survey with subsequent visits to the companies mean that long-term planning is necessary. In addition, experts must be consulted for the data collection and, above all, the subsequent evaluation. Each company has different processes and, consequently, boundary conditions that need to be considered in a differentiated manner and can only be correctly assessed and evaluated with background knowledge.

Against the background of increasing energy efficiency, the data obtained can also be used to investigate whether and how individual companies in selected industrial and commercial areas can join forces. In addition to the focus on industrial waste heat utilization, this will also provide a basis for establishing a joint infrastructure (local heating networks) for the industrial and municipal sectors.

2.3 Criteria for assessing waste heat potentials

To identify waste heat potentials, an examination of each waste heat source and each potential heat consumer should be carried out regarding following criteria:

- Temperature level: the higher, the easier it is to utilize the waste heat.
- Available heat quantity: It will support cost-effectiveness, if the available quantity is in the same order of magnitude as the demand on the utilization side.
- Continuity of the waste heat stream: This has a positive effect on the economic efficiency of waste heat utilization.
- Timing of heat supply and heat demand: Simultaneous occurrence simplifies waste heat utilization.
- Heat transfer medium: Medium-bound waste heat, such as exhaust air streams or cooling liquids, can be used much more easily than diffuse waste heat, which must first be collected and removed for further use.
- Local conditions: If possible, avoid transport losses and check the space availability for the installation of storage technologies, for example.

3 Technology: state of the art and future trends

The use of waste heat is rather simple: Processes or machines generate heat through their operation. This heat is then released in the form of heated air or warm wastewater and can be used with the help of a heat exchanger. This technology is also used in heat pumps or ventilation systems for heat recovery. The heat energy can be extracted from the exhaust air or the wastewater via this heat exchanger and is transferred to a separate heat circuit.

Depending on the temperature range in which the waste heat occurs and the intended use, the following technologies (which are described in the following chapters) may be considered for waste heat utilization:

Temperature range	**Intended use**			
	Electricity generation	**Production at different temperatures**	**Space or water heating**	**Cooling**
High (> 350°C)	Steam turbine, Stirling engines, thermoelectric systems; heat storage systems	Extraction of higher temperature waste heat from power generation; heat storage systems		
Medium (80 to 350°C)	Organic Rankine Cycle (ORC), thermoelectric systems; heat storage systems	Extraction of medium temperature waste heat from power generation; heat storage systems	Local and district heating; Extraction of lower temperature waste heat from power generation; heat storage systems	Absorption chiller
Low (< 80°C)		Heat pumps; preheating; heat storage systems	Heat pumps; space heating, domestic water heating; return temperature boosting; heat storage systems	Adsorption refrigeration

Tab. 1 Waste heat – appropriate technologies depending on intended use and temperature range (based on C.A.R.M.E.N. eV, 2020)

3.1 Heat storage

Waste heat streams may vary with time, as may the demand for their utilization, and they may not directly match in time. Therefore, heat storage is an important component in waste heat utilization and distribution. While for the use of waste heat in internal processes, the necessary storage time is usually only hours or days, it is particularly interesting for heating buildings to use large storage tanks, which can provide the energy required for several days, weeks, or even months. Heat accumulators can be classified according to the time period over which the generated thermal energy is to be stored. These include, for example, buffer, short-term or long-term storage. On the other hand, heat accumulators are divided into sensible, latent or thermodynamic storage units according to their basic operating principle.

Buffer storage

In the form of large water tanks with varying capacities, they store heat on an hourly or daily basis. Especially in the industrial sector, buffer tanks are used to better match fluctuating waste heat supply and heat demand on the user side, e.g. in combination with heat recovery systems and/or heat pumps.

Short-term storage

With a storage period of up to two days, this type of heat storage is mainly used with wood boilers, solar or domestic hot water storage systems to balance heat supply and demand. It is also useful in industrial applications to use waste heat in cyclic processes and applications, and thereby to recover waste heat that would otherwise be lost.

Long-term storage

Long-term storage, also called seasonal storage, can store heat for weeks or months and is suitable, for example, to bridge the transition from the warm to the cold season. In addition to using heat from renewable energy sources, they are thus also well suited for storing waste heat. The imbalance between heat supply and demand is thus minimized.

Sensible heat storage

These storage systems use the so-called sensible or tangible heat of liquid or solid storage media such as water, magnesite, concrete, or earth. Energy is absorbed and released by changing the temperature of the storage medium. While heat is supplied to a storage medium during the layering process, which then increases its temperature, the medium releases the stored thermal energy again during discharge, which can then be used for heating, among other things. Examples of applications are hot water or steam storage as well as gravel water or geothermal probe heat storage.

Latent heat storage

This type of storage makes use of the change in aggregate state, from solid to liquid or vice versa. The storage units are filled with PCM (Phase Change Material). When a storage medium changes its aggregate state from solid to liquid, it absorbs heat. The latent heat remains bound in the material and can be released and made usable again at a later time by physical action. Latent heat storage entails a higher cost than sensible heat storage, but the corresponding benefits are a much higher storage capacity per volume and a stable temperature of the heat released. Salt hydrates or kerosenes are suitable for heat storage, while water or aqueous salt solutions are suitable for cold storage. An example of latent heat storage is ice storage, which uses crystallization energy - the energy released when water freezes. Latent heat storage systems are also attractive when mobile systems are to be used for heat transport because of too great distances to the user of the waste heat or too low heat flows, so that installation of a pipe connection is not cost-effective.

Thermodynamic storage

Thermodynamic reservoirs are reversible systems, which can be divided into sorption reservoirs and reservoirs with reversible chemical bonds. While the latter are still largely in the research and development stage, the former are mostly used in the form of adsorption storage systems with water as the working medium. Such a storage system works as follows: Air at a high temperature is supplied to the solid storage medium. This causes the water contained in the storage medium to vaporize, and the resulting steam is extracted. This vapor is liquefied again in a condenser, and the water remains there. During discharge (adsorption), the water evaporates again due to the supply of heat. This vapor accumulates on the sorption material (usually substances with large internal surface area and hygroscopic properties such as zeolites or silica gels), releasing energy and heating the air.

Thermochemical heat accumulators

At present, various research projects are being carried out on thermochemical heat accumulators (TCES). One example is a process in which boric acid is converted into boric oxide and water by adding heat. During the back reaction, the heat is released again. According to the Vienna University of Technology, this process, which has a high energy density, is ideally suited to the use of waste heat from industrial plants, which can be stored in an environmentally friendly manner for a virtually unlimited period of time (SAENA GmbH , 2016).

3.2 Heat pumps

3.2.1 General information

If the temperature level of the waste heat is not sufficient for direct use, heat pumps can be used. In this case, the waste heat is raised from a low to a higher temperature level with the aid of supplied drive energy and thus made usable for other purposes.

In a heat pump, heat is extracted from the waste heat source. In Germany, the achievable temperatures of compression and absorption heat pumps are specified as 65 °C, and up to 90 °C for special solutions of compression heat pumps.

The differences between heat pumps are primarily in the place of heat generation and the medium of heat transfer. In addition to the four "standard" heat pumps named below, a further distinction is made on the basis of the heat pump's drive. Each heat pump uses a coolant that is evaporated and recompressed in the cycle to generate heating energy (exception: air-to-air heat pump).

- Air-to-air heat pump: for example, waste heat from the ventilation system is used to heat the building.
- Air-to-water heat pump: for example, heat is extracted from the ambient air to heat a building via a water-based heating system.

- Brine-water heat pump: Heat from the ground is used to heat the building via a water-based heating system.
- Water-to-water heat pump: Heat is extracted from a water reservoir to heat a building or process.

Except for the brine-water system, the other three processes can also be used for waste heat utilization. The air or water source feeding the heat pump could carry the waste heat stream, and the higher temperature heat emerging from the heat pump could be used either in a production process or to heat buildings.

In sorption heat pumps, the drive energy is supplied in the form of heat (principle of thermal compression) - instead of electricity as in compression heat pumps.

Currently in R&D projects, a temperature range of up to 160 °C was achieved through the development of suitable refrigerants. For absorption heat pumps, on the other hand, a temperature of up to 300 °C is considered feasible. Absorption and adsorption heat pumps are mainly used for waste heat recovery in the industrial sector (DENA Broschüre Abwärmenutzung, 2015; DryFiciency, 2021).

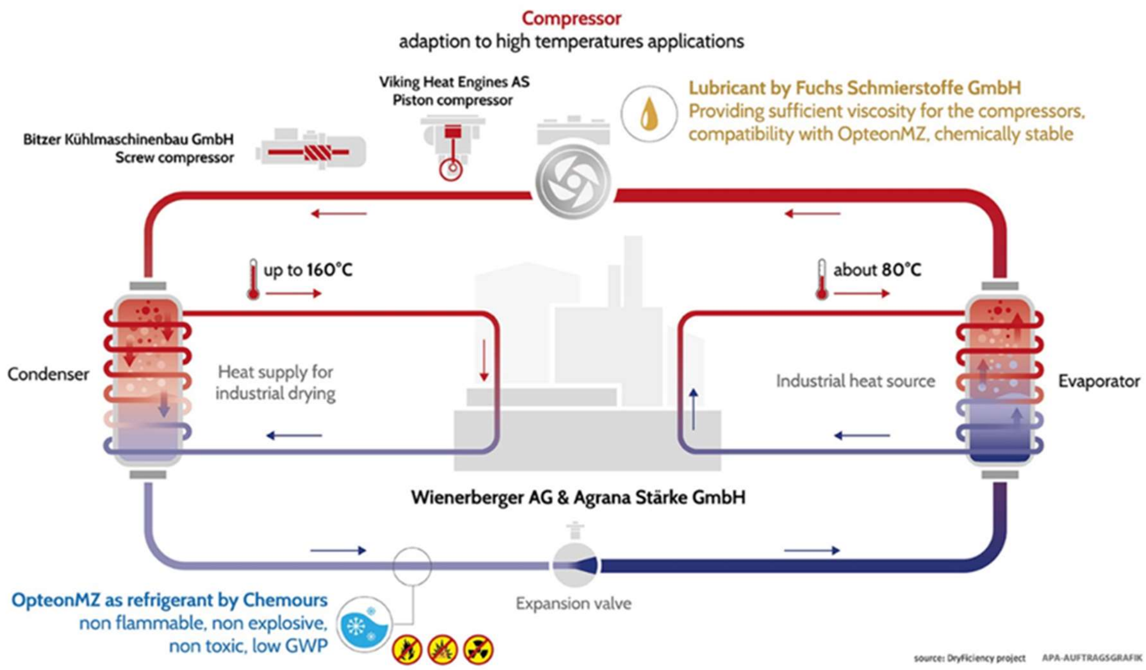


Fig. 3 Example of a high temperature heat pump. (Source: DryFiciency Project, 2021)

A heat pump heating system consists of three parts: the heat source system, which extracts the required energy from the environment; the actual heat pump, which harnesses the extracted environmental heat; and the heat distribution and storage system, which distributes or temporarily stores the thermal energy in the house or, as process heat, for industrial applications.

As a measure of the efficiency of a heat pump, the so-called COP value, or "coefficient of performance", indicates the ratio of the heat generated by the heat pump to the drive energy (electricity) required for this. Thus, the COP depends on several parameters in the heating system – the efficiency of the heat pump itself, the flow temperature of the heating system and the temperature of the environmental energy.

3.2.2 Industrial and domestic heat pumps

Today, more than 1 million heat pumps are already in use in Germany (even though only few of them are used for waste heat utilization), and the trend is rising thanks to extensive subsidies (Bundesverband Wärmepumpe, 2022). The classic application in Germany / Central Europe lies in the field of heating technology, but the use of heat pumps in industry is also showing an upward trend.

3.2.3 High temperature heat pumps

A high-temperature heat pump raises the temperatures of the environmental heat sources to a particularly high level. While conventional systems barely get above a flow temperature of 65°C, high-temperature systems achieve values of 80 to 100°C or even above.

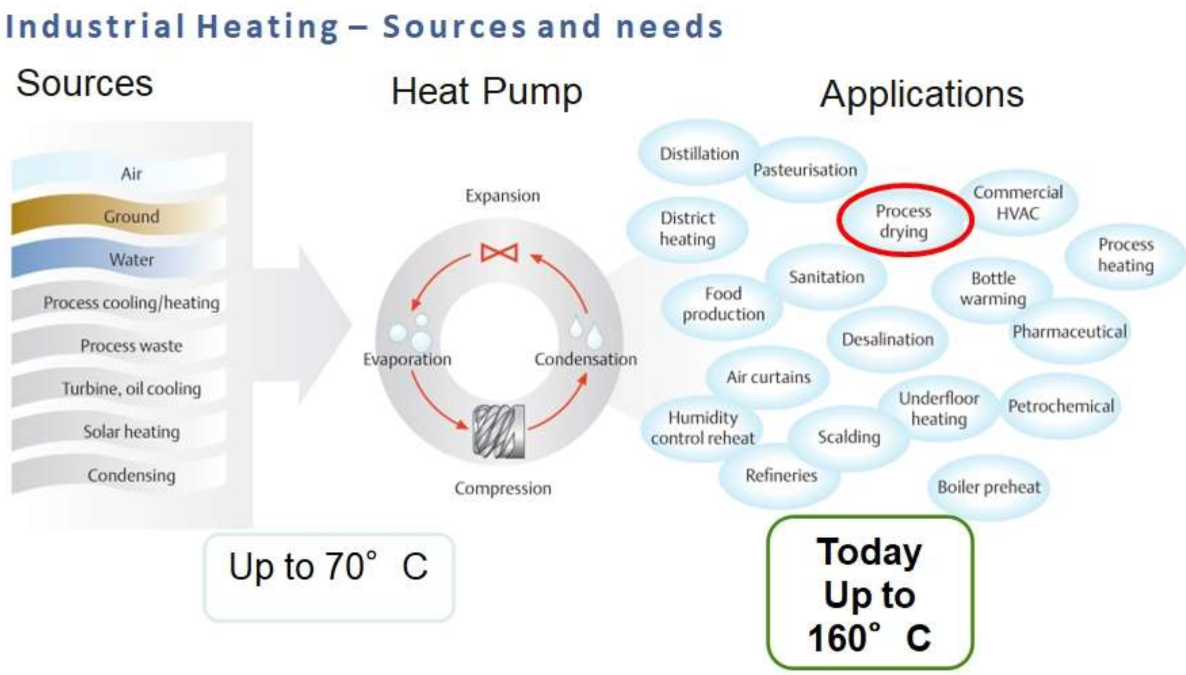


Fig. 4 Industrial heat pumps, heat sources and applications (Source: European Heat Pump Association EHPA, 2021)

While heat pumps provide temperatures of up to approx. 70°C in most cases to cover heating requirements, this temperature range is now being extended to up to 160°C. This results in a wide range of possible applications for the heat pump.

3.2.4 Different system variants for the utilization of heat pumps

Cascading

Cascading (interconnection) of heat pumps is nowadays often used for larger heat pump systems in order to match the output to the respective heating demand. This is because while today's heat pumps in the smaller output range have appropriate compressor technology (inverter compressors or modulating heat pumps) to adjust the heating output according to demand, the heat pump output can no longer be adjusted via the compressor alone in the case of larger fluctuations in demand. Cascade connection and extensive capacity modulation increase the annual performance factor and thus improve the economic efficiency of a cascade system compared to hybrid heat pumps.

The use of heat pump cascades is especially possible and sensible where

- large heating capacities are required,
- the heating, hot water and cooling requirements fluctuate greatly or have to be covered in parallel,
- even large heat pumps reach their performance limits.

Combining heat pumps with renewable energy systems

Another popular form of heat pump operation is the combination of renewable energy systems such as PV plants and heat pumps. This is especially used for providing heat for buildings.

Operating costs of heat pumps as well as CO_2 emissions can be significantly reduced by using the self-produced solar power. The use of solar electricity is all the more economical because it is now increasingly sensible to use the electrical energy produced by photovoltaics oneself instead of feeding it into the grid. At the same time, more self-use increases the economic efficiency of the photovoltaic system.

3.3 Absorption and Adsorption Chillers

An absorption chiller is a refrigeration system that uses thermal compression to raise thermal energy to a higher temperature level. It can be used for cooling or heating (heat pump) buildings as well as processes and is considered particularly energy-efficient. One reason for this is the fact that the electricity requirement is more than 90 percent lower than that of conventional systems. The energy required to increase the pressure and temperature of refrigerants can also be provided in part from renewable sources or from waste heat.

While the refrigerant is absorbed by a liquid solution during absorption, it attaches to a solid during adsorption. An example of this is the zeolite heat pump, an adsorption refrigeration machine in which vaporous refrigerant accumulates on the surface of a porous rock. The pressure and temperature increase here also takes place with heat that comes, for example, from a waste heat stream or a biomass heating system.

Like absorption chillers, also adsorption chillers are thermally driven refrigeration systems. They consist of two working chambers filled with sorbent as well as a condenser and an evaporator. Silica gel is used as the sorbent and water as the refrigerant.

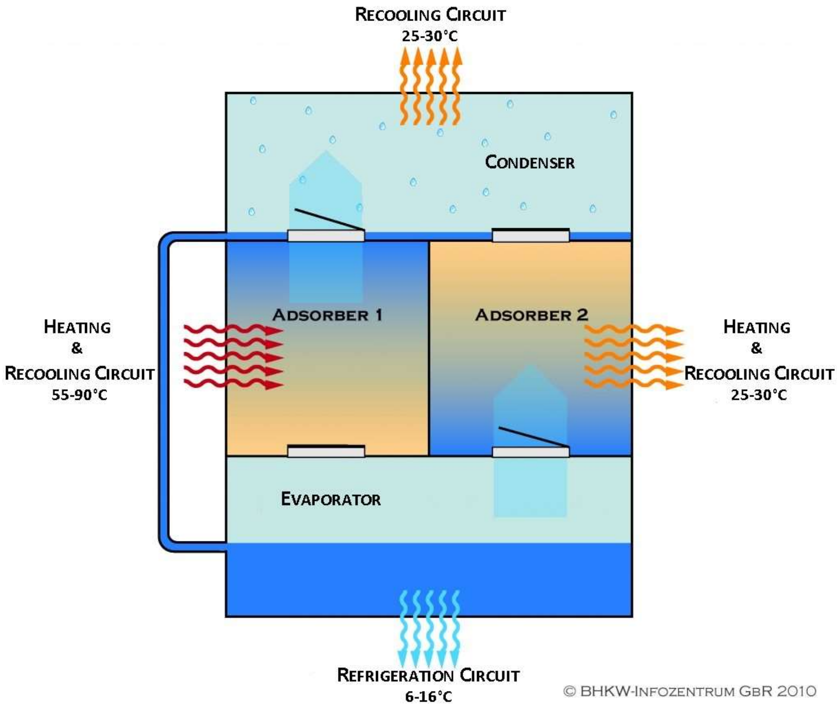


Fig. 5 Principle diagram adsorption chiller system. Source: "KWKK Informationsseite zu Kraft-Wärme-Kälte-Kopplung", (BHKW Infozentrum, 2022)

Two processes take place simultaneously. One is the evaporation of the refrigerant and adsorption of the resulting refrigerant vapor by the adsorbent. On the other hand, the desorption of the refrigerant bound in the adsorbent and subsequently the condensation of the resulting vapor. Since it is necessary to switch cyclically between two adsorber beds, only a quasi-continuous process can be realized with adsorption chillers. Water-silica gel adsorption chillers are particularly suitable for district heating and solar thermal applications, since they can still utilize drive temperatures of 60° C. The low COP (approx. 0.4), the high investment costs and the large weight and construction volume make it difficult to use adsorption chillers and usually make them uneconomical. In addition, the maximum permissible cooling of the heating water is a ΔT of 13 K, but only 5 - 6 K at low temperatures.

3.4 Thermal electric generators (TEGs)

Thermoelectric generators can convert waste heat into electricity. A TEG consists of heat exchangers for hot and cold media and thermoelectric modules in between. Despite the still comparatively low efficiency of TEMs, TEGs offer advantages over other power generation technologies. The passive components have no moving parts, are virtually maintenance-free and can be integrated into existing systems thanks to their compactness.

Currently, compared to other techniques (like ORC and SRC) the payback period of TE (Thermoelectric) technology is still one of the highest. Depending on the waste heat source, individual TEG waste heat recovery systems must be designed and thus the costs are increased. So in the future the production costs of TEG have to be significantly reduced by a couple of measures e.g.:

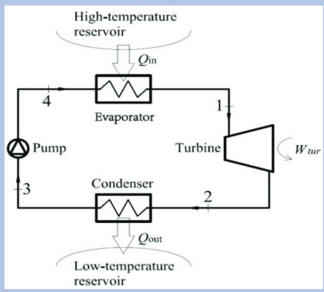
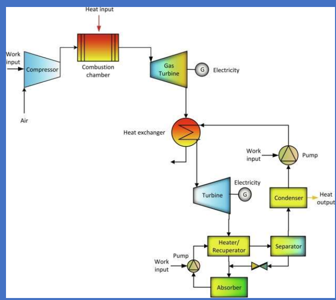
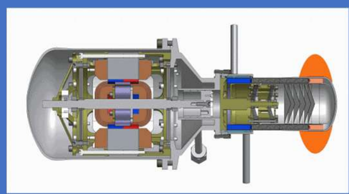
- Advanced TE materials
- New concepts for mass production of TE materials as well as lower-cost TEG manufacturing
- Automated fabrication techniques for mass production of complete TE systems

Under these conditions, TE systems currently may have better chances for producing electric power from smaller waste heat sources (lower temperatures or waste heat flows), which are not usable for ORC and SRC and for smaller applications like power supply of sensors at movable plants/processes.

In addition to power generation from waste heat, TEMs can also be used where cooling is required with little temperature difference or no requirements for economy.

3.5 Other technologies for producing electricity from waste heat: ORC-, Kalina- and Stirling-process

Thermal power engines: Other technologies available for generating electricity from waste heat are for example, the steam turbine, the Kalina process, the ORC process, and the Stirling engine. All these processes operate with an external heat source and therefore are suitable for the use of waste heat. Which technology can be used most advantageously is mainly determined by the temperature level of the waste heat.

Technology	Working media	Efficiency	Application temperature	
Organic Rankine Circle (ORC)	for each upper temperature level there is another optimal working medium: e.g. R600a (isobutene), R143a (trifluoro-1,1,1-ethane) (Fischer et al., 2007)	approx. 17-20% (Fischer et al., 2017)	approx 80-350°C (Grube et al., 2017)	 (Wang et al., 2017)
Kalina process	principally a modified Rankine cycle, which utilizes the mixture of two different working fluids (water and ammonia).	can improve power plant efficiency by 10% to 50% over the Rankine Cycle depending on the application (Kalina Power, 2015)	approx. 60-200°C (Elsayed et al., 2013)	 (Dinçer & Bicer 2019)
Steam turbine	Water (Steam)	Up to approx. 45%, depending on steam temperature and pressure (Paschotta, 2021)	up to approx. 600 °C	 (Energate Messenger, 2013)
Stirling process	Among others: Helium, Hydrogen, Nitrogen Air	Approx. 10 to 35%, depending on type, temperature and pressure of working medium (gas) (Infinia Corp, 2006)	up to approx. 800°C	 (Infinia Corp, 2006)

Tab. 2 Examples of thermal power processes available for generating electricity from waste heat

3.6 Heat exchangers

Heat exchangers have the task of transferring heat from a warm medium to a colder one. In the process, both media are directed past a heat transfer surface to and from which the heat is transferred.

There are many forms of heat exchangers for the utilization of waste heat:

Technology	application	Power class (thermal)	application temperature	
Rotary heat exchanger	air (gas) / air (gas)	up to 1,600 kW	up to 300 °C (650 °C in the high temperature range)	
Heat pipe heat exchanger	air (gas) / air (gas)	3 W - 3 kW (per heat pipe)	up to 700 °C	
cowper (recuperator)	air (gas) / air (gas)	< 140 MW	up to 1,300 °C	
Finned tube heat exchanger	air (gas) / fluid	5-1,000 kW	up to 400 °C	
Spiral heat exchanger	fluid/fluid; air (gas) / fluid	20-800 kW	100-450 °C	
Plate-fin heat exchanger	air (gas) / fluid	1-900 kW	up to 900 °C	
Plate heat exchanger	fluid/fluid	2-400,000 kW	up to 150 °C (900°C for welded plate heat exchangers)	
Shell and tube bundle heat exchanger	fluid/fluid	2-20,000 kW	up to 300 °C	
Double-tube heat exchanger (shell and tube heat exchanger)	fluid/fluid	1-3,500 kW	up to 200 °C	

Tab. 3 Overview: types of heat exchangers. (Source: brochure "Technologien der Abwärmenutzung" Sächsische Energieagentur - SAENA GmbH, 2016)

3.7 Materials and components

Heat storage system with Phase Change Materials (PCM):

Latent heat storage systems function by exploiting the enthalpy of thermodynamic changes in the state of a storage medium. The most commonly used principle is the utilization of the solid-liquid phase transition and vice versa (solidification-melting) (phase-change materials - PCM). When charging the contents of commercial latent heat storage systems, special salts or kerosenes are usually melted as the storage medium, absorbing a great deal of energy (heat of fusion) in the process, such as dipotassium hydrogen phosphate hexahydrate. Discharge takes place during solidification, with the storage medium releasing the previously absorbed large amount of heat back into the environment as solidification heat.

There are now many PCMs on the market in Germany in the temperature range -30 to 100°C. At temperatures up to 0 °C, water and aqueous salt solutions are used; in the range 5 to about 150°C, kerosenes, fatty acids, salt hydrates and their mixtures are mainly used, and for some years now sugar alcohols. Above about 150 °C, salts and their mixtures can be used (Sonne Wind & Wärme, 2008).

Materials for heat exchangers:

Corrosive components in the waste heat stream influence the lifetime and material selection for heat exchangers. To avoid the failure of aggressive condensate in gas heat exchangers, plants are designed so that the outlet temperatures are above the dew points of the corrosive components of the waste heat stream. As a result, the minimum exhaust gas temperatures vary with the composition of the fuels or due to process-related components in the exhaust gas. For example, the minimum exhaust gas temperature for the use of natural gas is given as 120°C, while temperatures of 150 to 175°C are given for the use of sulfur-containing oils and coal. As a result of process-related sulfur contents in the exhaust gas stream of glass melting furnaces, the minimum exhaust gas temperatures there reach 270 °C (cf. U.S. DOE, 2008). In addition, depending on the composition of a heat stream, deposits and biofilms can form that can degrade heat transfer in heat exchangers, reduce flow, and cause heat exchanger failure. (Hirzel et al., 2013)

3.8 System technologies

3.8.1 Heating networks

Feed-in of waste heat into existing heating networks:

Priority is given to avoidance and internal use. Feeding waste heat into a heating network can be an interesting option, but some conditions must be considered:

- A large part of the waste heat does not occur continuously.
- Waste heat can often only be used as an additional heat source. If the industrial process is changed over, the waste heat may no longer be available.
- A suitable contractual arrangement must be made between the industrial plant and the external heat user.
- The industrial plant and the heat user enter a long-term commitment to each other.

- The extraction and feed-in of heat is usually associated with high investments.
- The sale of heat may not be considered the core business of the heat supplier.
- Larger heat storage capacities may be required to couple supply and demand because of the difference of timing.

Low-temperature district heat network technology

The heat networks currently used for local or district heating generally require flow temperatures of 70 to more than 100°C. When waste heat is fed into these networks, the existing temperature level of the waste heat must of course be adapted to the flow temperature of the heat networks. This is made possible, for example, with the aid of heat pumps.

However, a heat supply can already succeed with low temperatures between 5 and 35 degrees Celsius; especially in densely built-up new construction areas or, for example, in energy-refurbished urban quarters. These buildings have a low heating requirement and need low flow temperatures. Suitable for cold local heating. The cold heat networks are - physically correct - called anergy networks. A mixture of water and glycol (brine) usually flows through the pipe system to protect against frost damage.

Due to the low temperatures in the network, the difference to the temperature in the ground is also only slight. This means that there are only minor losses in the pipe network and there is no need for often cost-intensive insulation of the network's piping, because ideally the network absorbs the ambient heat directly. However, due to the small temperature difference between the supply and return temperatures and the overall low temperature level, large flow rates, larger pipelines and a higher power requirement for the pumps are needed. In principle, reverse operation is also possible with these networks in order to realize the cooling of buildings. This will become more and more important as temperatures rise in the future.

In order to be supplied via these low temperature networks, the houses must have a decentralized heat pump, as the operating temperatures are not sufficient for the production of hot water and heating. In addition, the waste heat generated in this process can be fed back into the heating network. In this way, the users are not only customers, but can also act as prosumers. Depending on the circumstances, they can consume or produce heat or cold (Verbraucherzentrale Schleswig-Holstein, 2021).

3.8.2 Systems for heat recovery and storage for the industry

Waste heat, especially from industrial processes, offers great untapped potential for energy efficiency and is therefore increasingly becoming the focus of efficiency planning. For example, heat recovery from heated building air can save 20-30 percent in space heating costs, and waste heat recovery from industrial processes can even generate more heat than is needed for space heating.

3.8.3 Waste heat in trade and commerce:

Just as in service- or office buildings, it can be worthwhile to use the waste heat from a workshop or production hall: In summer, the heat that is lost can be used to heat water, and in winter it can additionally support the heating system. Depending on the building and the company, an investment in heat recovery can pay for itself within a few years.

The cost-effectiveness of waste heat recovery in industrial or commercial operations primarily depends on the following factors:

- Room size
- Processes in the company
- Heating system

4 Overview on Waste Heat Usage in Germany and Japan

This Chapter gives an overview on waste heat usage in practice, separately for Japan and Germany. This includes the current state of usage and the potential for expanding it, policy measures to overcome barriers for waste heat utilization, and finally best practice examples.

4.1 Current state of Waste Heat Usage

This chapter mainly covers information on external use of waste heat, as in most cases only data for external use of waste heat are available, since most of the Japanese and German companies do not publish data about their internal heat fluxes. Although internal use of waste is already common in many factories in Japan and Germany, it was not possible to obtain meaningful data for Japan and Germany.

4.1.1 Japan

Power plants

The power industry discharges a large amount of waste heat with relatively low-temperature. The latest gas turbine combined cycle power plants are able to utilize about 60% of the heat in the entire power plant through the reuse of waste heat from gas turbine and the use of high-efficiency equipment. However, the amount of the remaining 40% of waste heat, which is relatively low temperature, is enormous. On the other hand, the City Planning Act regulates to separate the residential area and industrial area. Therefore, it is difficult to locate non-factory heat consumers, which potentially have a demand for relatively low temperature heat, near power plants. Therefore, creation of heat demand in areas adjacent to the power plants and development of technologies to utilize low-temperature waste heat are needed.

Municipal waste incinerators

Since Japan has little potential landfill site for waste, the volume of waste has long been reduced by incineration and then disposed of in landfills. It is said that more than half of the world's incinerators are located in Japan. The status of the facilities as of FY2020 is as follows:

Total amount of municipal waste:	42 million tons (per person per day: 901 g)
Number of municipal waste incinerators:	1,056 facilities
Rate of facilities with power generation:	36.6%
Total electric power generated:	10,153 GWh

4.1.2 Germany

The use of industrial waste heat offers outstanding energy potential for companies in Germany. For example, German industry uses approx. 1,900 Petajoules of energy input for process heat, or approx. 530 Terawatt hours of energy to generate heat for production and manufacturing processes. However, about 50 % of this is lost as unused waste heat (BMWK, 2021).

At present, however, there are still no comprehensive statistical surveys on current waste heat utilization in Germany. One of the reasons for this is that the temperature levels of the waste heat sources and the types of use (internally in the company, externally e.g. via heat networks etc.) are very different.

More concrete data were available on the feed-in of waste heat into heat networks. In 2018, for example, the share of waste heat from industrial processes in the heat grid feed-in was 1.7%. A survey by the Federal Statistical Office shows that 2,383 GWh of the heat network input in Germany in 2018 was provided by external purchases from industry, which can be assumed to be the use of industrial waste heat in district heating (Steinbach et al., 2021).

In addition, around 5.5 % of district heat (ca. 7,000 GWh/yr) was produced by waste incineration plants in Germany in 2020 (BDEW, 2021); about half of this is counted as renewable energy, based on the composition of the waste. More than half of the district heat supply in Germany is provided by from cogeneration of heat and power, i.e., making use of waste heat from gas or coal power plants. There is also a lot of industrial cogeneration. On the other hand, most of the waste heat from thermal power plants in Germany remains unused (cf. chapter 4.2).

4.2 Potential for Waste Heat Usage

4.2.1 Japan

Waste heat sources

In Japan, about 60% of primary energy is discharged into the environment without being effectively utilized during conversion and utilization. Figure 4.-1 shows the results of a survey of 1,273 business sites in 15 types of energy intensive industries, in terms of the temperature range and amount of heat of exhaust gas, that is waste heat, per business site. Note that only the power industry has a second axis on the right-hand side in Figure 4.-1. Overall, the majority of the waste heat is in the 100-199°C range, and waste heat below 200°C accounts for 76% of the total.

From the power industry, there is a very large amount of waste heat of 1,200 TJ/factory in the 100-149°C range. It is estimated that approximately 260621 TJ/year of waste heat is generated by the power industry in Japan as a whole, of which 186851 TJ/year is waste heat at 100-149°C. Waste treatment industry produces relatively high temperature waste heat with a considerably high amount of heat. The oil/coal and nonferrous metals industries also produce a large amount of waste heat at temperatures of 500°C or higher. Waste heat from the Waste treatment, oil/coal, and nonferrous metals industries are estimated to be about 57942 TJ/year, 44889 TJ/year, and 16367 TJ/year, respectively in Japan as a whole.

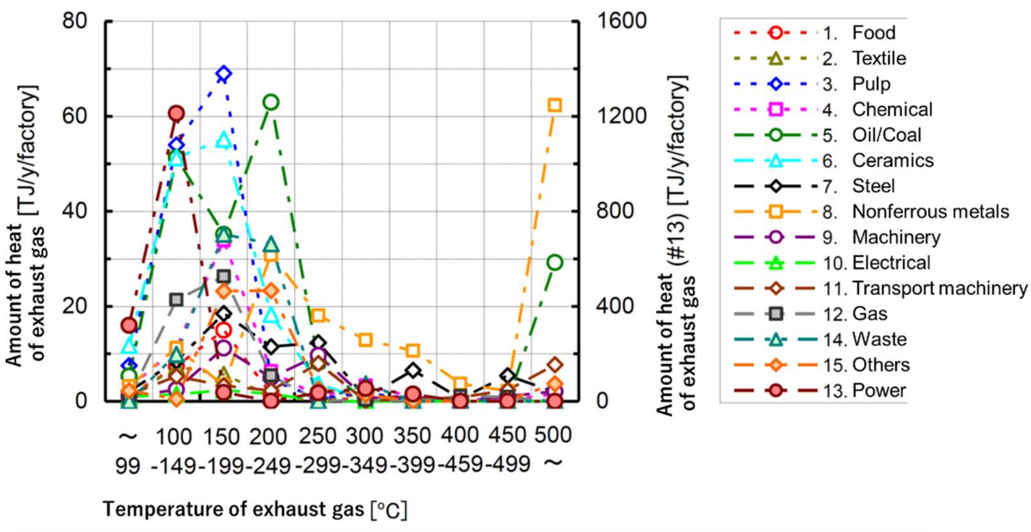


Fig. 6 Temperature and amount of heat of exhaust gas per factory by industry. (TherMAT, 2019)

Potentials for expanded waste heat utilization

Most of heat demand is in a range of above 200°C whereas the potential for waste heat is mainly in a range of below 200°C. Therefore, it would be important to develop technologies to utilize low-temperature waste heat, such as high-temperature heat pumps.

As for relatively high-temperature waste heat, waste heat use within a factory has been progressing, but heat transfer between factories and heat supply to residences has not yet.

For expanding waste heat utilization, it will be important to review regulations regarding factory locations and promote government support.

A promising application for expanded waste heat utilization is using waste heat from data centers. There are initial approaches to the use of waste heat in Japan, and NEDO is now also tendering projects. There are R&D measures and project ideas, e.g. in Hokkaido. Since the climate there is cool, there are many data centers there that use both, cooling power and heat pumps (source: discussion at the German-Japanese Expert Workshop on Industrial Waste Heat Usage (online) with NEDO on April 22nd, 2021).

Municipal waste incinerators

At present, each municipality in Japan is responsible for its own waste. In the meantime, municipalities are starting to join forces and share larger incinerators in order to have a more cost-efficient operation and also generation of electric power. (Source: discussion of ECOS with the Natural Energy Research Center – NERC in Hokkaido, 2023)

Since municipalities operate the incinerators, the main heat utilization is limited to heating and air conditioning in public facilities such as swimming pools, and there are few examples of supply to private sector. The problems with heat utilization are the distance between the incinerators and heat consumers and the fact that it is limited to public utilities. To solve these problems, both technology and municipal policies are needed (MOE, 2022-1).

Sewage treatment facilities

At the sewage treatment facility, the digestion gas (biogas) is generated as part of sewage treatment. Biogas is fed to a combined heat and power plant, which generates heat and electricity. The heat and electricity are mainly used for internal purposes, and it is difficult to generate excess heat in a stable manner except for large facilities. In addition, heat consumers are rarely located near the plant in the most cases, making heat transport difficult. In Japan, where the natural gas pipeline network is less developed than in Germany, there are limited ways to inject biogas into the pipeline. In recent years, in addition to the conversion of sludge into fuel, the heat in the sewage pipes, which is vastly abundant, is being focused on and effectively utilized.

4.2.2 Germany

Waste heat sources: Sector-specific and temperature-dependent averaged waste heat potentials

The following figure shows an overview of the waste heat potentials in Germany. It can be seen very clearly that there is great potential above all in the area of thermal power plants and CHP plants in particular. It should be mentioned here that the potentials of thermal power plants, CHP plants, waste incineration plants and renewable energies (mainly from biomass plants) are purely theoretical potentials. The potential for Industrial Waste Heat utilization is approx. 10 % of the total usable waste heat.

As part of an IREES study, a database from Fraunhofer ISI was expanded and supplemented to include industrial sites with their production volumes and technologies used. The potential amount of waste heat was then calculated from this database using the calculated energy source inputs and efficiencies. Accordingly, the total amount of waste heat from industry in Germany is approx. 51 TWh. A reference temperature of 25°C is used for the calculation. The waste heat from industrial plants that can be used in heat networks amounts to approx. 8 TWh. For this purpose, it was analyzed which waste heat sources are located within a radius of no more than 10 km from an existing heating network. The reference temperature here is 95°C, so that the waste heat can be used directly in the heat network. (Steinbach et al., 2021)

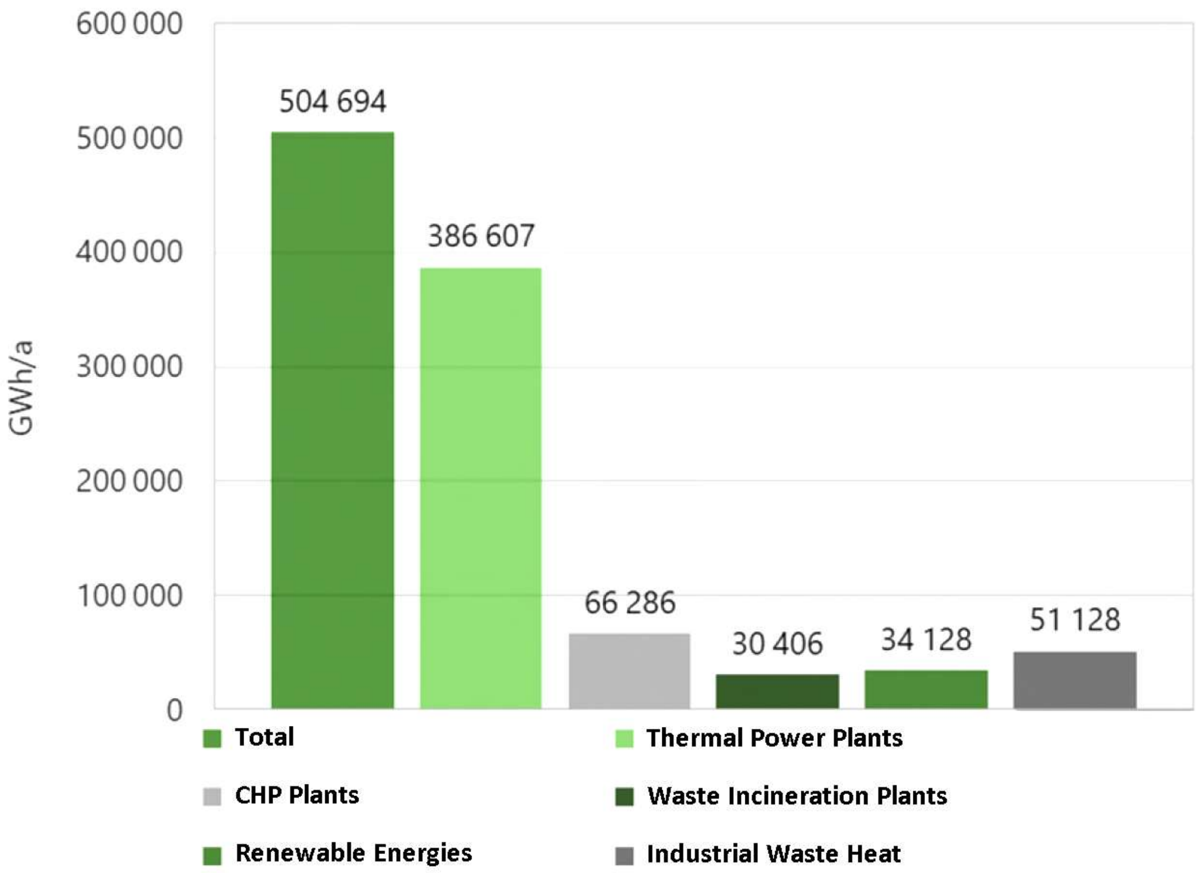


Fig. 7 Potentials of waste heat utilization in Germany (Steinbach et al., 2021)

Potentials for expanded waste heat utilization

The biggest potential for the utilization of industrial waste heat is seen in the iron and steel industry, the chemical industry, the aluminum industry and the mineral industry, especially in the temperature range between 100 and 500 °C. Currently this waste heat is used predominantly internally. However, there is also great potential for future external usage.

Conservative estimates indicate a usable waste heat potential for Germany of at least 12,000 GWh to 70,000 GWh (Steinbach et al., 2021) from various sources that can be harnessed for external use from a technical perspective.

The integration of 70,000 GWh/yr of waste heat for example in district heating networks alone would reduce CO_2 emissions by around 19 million tons per year (AGFW, 2020). This corresponds to around 36% of the reduction target set by the German government in the building sector of 53 million metric tons of CO_2 between 2020 and 2030 (Climate Protection Law 2021). The utilization of waste heat can therefore make a significant contribution to Germany achieving its climate protection targets in the building sector.

In addition, there is probably also substantial further potential for internal use in industry (e.g. power generation) or in industry clusters, by the use of high-temperature heat pumps that can replace other technologies using fossil fuels (e.g. gas boilers). Other promising waste heat sources are sewage water (an example is given in chapter 4.4.2., tab. 4-2) and the utilization of waste heat from data centers. An example is the city of Frankfurt/Main where, for example, the German

Commercial Internet Exchange (DE-CIX) and 60 data centers are located, which together consume 1.6 TWh of electricity. If all their waste heat were used, it would be possible to provide CO_2-neutral heating for all the residential and office space in the Frankfurt City by 2030. Various projects for the use of waste heat from data centers, such as the project in the Westville district with 1,300 apartments, most of which are supplied by data center waste heat, have already started (Datacenter Insider, 2021).

4.3 Policy Measures for Promotion of Waste Heat Usage

4.3.1 Japan

Energy consumption efficiency has improved by 40% since the oil crisis of the 1970s, due to the efforts of the public and private sectors in Japan. The Act on Rationalizing Energy Use was enacted in 1979, and it continues to be revised to the present. Japanese government aims to achieve a more rational energy supply-demand structure by integrating regulatory measures based on the law with budgetary measures and other effective support measures (Strategic Energy Plan, 2021):

Regulatory measures

In 2018, the Act on the Rational Use of Energy was revised to establish a cooperative energy conservation planning system that allows the government to certify and evaluate energy conservation efforts made by multiple businesses in cooperation. The Act on the Rational Use of Energy requires, as an effort target, a reduction in energy consumption intensity or electricity demand leveling assessment intensity (energy consumption intensity plus a factor of electricity purchases during electricity demand leveling hours which is from 8:00 to 22:00 in July to September and December to March) of 1% or more per year on average over the medium to long term. Internal waste heat utilization is one way for a company to achieve this target. In addition, the Benchmark Program is being introduced to set targets for energy consumption intensity by industry sector. This has been introduced in 6 industries and 10 sectors in the industrial sector (METI, 2022).

The Act on Promotion of Global Warming Countermeasures requires entities whose energy consumption or greenhouse gas emissions exceed a certain level to report their energy consumption and greenhouse gases (METI, 2022).

In addition, the Top Runner Program for energy-consuming equipment requires manufacturers to improve the energy consumption efficiency of the equipment they ship. Reducing waste heat that is released from the equipment is one way to achieve this for several types of equipment (METI, 2022).

Financial incentive measures

Financial incentive measures are being promoted in tandem with the aforementioned regulatory measures.

METI (The Ministry of Economy, Trade, and Industry) provides subsidies of 25 to100% of the investment to companies in the introduction of advanced energy-saving equipment, the introduction of various energy-saving facilities, and measures to reduce electricity consumption during peak periods. The budgeted amount is approximately 160 billion yen in 2022FY. Besides, 100 billion yen is contributed to improve the thermal insulation of homes, and 30 billion yen for the introduction of high-efficiency water heaters. In addition, subsidies are provided for Net Zero Energy Building / Net Zero Energy Home and energy-saving renovations, and support is provided for the development of innovative technologies (IEEJ, 2022).

MOE (The Ministry of the Environment) has budgeted more than 10 billion yen per year in total for promoting regional renewable energy and resilience. It includes the projects to support the introduction of facilities that utilize unused local heat, such as heat exchangers, heat pumps, heat pipes, pumps, heat conduits, and thermal storage systems (power generation facilities are not eligible) and subsidizes companies and organizations by 33 to 50% of the investment (MOE, 2022-2, MOE, 2022-3,).

Research and development

Over the past decade, METI and NEDO (New Energy and Industrial Technology Development Organization) have been developing technologies to reduce thermal energy losses, reuse and convert unused thermal energy, and develop thermal management technologies and basic technologies that address these technologies across the board. Reduction technologies include thermal insulation, heat shielding, and thermal storage. Reuse technologies include heat pumps. Conversion technologies include thermoelectric conversion and waste heat power generation. The total budget for FY2013 to FY2022 is approximately 10 billion yen (NEDO, 2022).

4.3.2 Germany

Regulatory measures

Internal use:

On the EU level, the product-specific regulations under the Ecodesign directive set legal requirements for products' circularity, energy performance and other environmental sustainability aspects and creates energy labels that, among others, also include standards for heating and cooling devices (European Commission, 2022).

In addition, the European DIRECTIVE (EU) 2018/2002 of 11 December 2018 on Energy Efficiency regulates, among other things e.g., the mandatory energy management or energy audits for companies that are defined to be larger than small and medium enterprises (European Union "Official Journal of the European Union", 2018), which is transposed in Germany in the energy services law. This helps to identify potential internal uses of waste heat to save energy.

On the national level, a variety of regulations for planning and installation of components are to be complied.

External use:

In general, all guidelines relevant to the transport and use of heat must also be observed for the use of waste heat.

On the national level, the access of third parties (e.g. for the supply of waste heat) to heating networks and infrastructure facilities is currently regulated in Germany in Section 19 of the Act against Restraints of Competition (GWB – "Gesetz gegen Wettbewerbsbeschränkungen"). In addition, guidelines are currently being planned at the EU level that guarantee the feed-in of waste heat:

In the current draft amendment to the Directive on the Promotion of Energy from Renewable Sources (RED II, Art. 24, Para. 4a), the EU Commission stipulates, among other things, that member states must ensure that operators of district heating and cooling systems with a capacity of more than 25 MWth are obliged to grant third-party suppliers of energy from renewable sources and waste heat and cooling access to the grid, or that they must offer third-party suppliers to purchase their heat or cooling from renewable sources or waste heat and cooling and feed it into the grid.

Financial incentive measures

Currently, various programs are in effect in Germany that provide subsidies for waste heat utilization, among other things:

a) Energy and resource efficiency in enterprises

This financial incentive program supports, among other things, measurement and control technology, sensor technology, energy management software, and measures for the use of waste heat in and outside the company. The funding rates are up to 40, 50, or 55 % depending on the subject, and they are higher for SMEs than for large companies (Deller, 2022).

b) Federal funding for efficient heat networks

In force since September 2022:

Module 1 funds up to 50 % of the costs of feasibility studies for the construction of heat grids with a minimum of 75% heat feed-in from RE and unavoidable waste heat, as well as transformation plans with the goal of converting existing heat grids to full supply from eligible renewable heat sources by 2045.

Module 2 supports investment costs for the implementation of new heat networks based on a feasibility study as well as packages of measures for the implementation of a transformation plan for existing networks. The rate of support is 40 %.

Module 3 offers 40% of the investment costs for, among other things, heat pumps, heat storage, pipelines for the connection of RE generators and the integration of waste heat, as well as for the expansion of heat grids and heat transfer stations (Deller, 2022).

c) Waste heat and municipal heat planning

Financial support (currently up to 80%) and technical advice to promote municipal heat planning. Central coordination instrument for the local heat transition to create investment security for the development of infrastructures, especially heat networks, but also gas and electricity networks. The government plans to make such planning mandatory for medium and large municipalities in a few years from now (Deller, 2022).

Barriers for the utilization of waste heat (technological, political and infrastructural)

The existing policy measures listed above already try to tackle the many barriers for the utilization of waste heat. However, further policies and measures may be needed to overcome the barriers discussed below. These are based on experiences and analyses in Germany, but the same, similar, or other barriers may also exist in Japan.

In addition to technological and physical barriers due to the often different temperature levels of waste heat sources and heat sinks, there are also energy and electricity tax barriers to the integration of industrial waste heat into the municipal heat supply.

In connection with industrial waste heat utilization, the following barriers are particularly noteworthy:

Payback periods: The investments for the plant technology for heat recovery sometimes lead to long payback periods. Investments increase especially when special requirements are made regarding temperature and corrosion resistance or when large heat exchangers are needed for low-temperature applications.

Heat partnerships: Further hurdles lie in the design of the heat partnerships between waste heat producing companies (heat source) and heat supply companies (heat sink). As a rule, waste heat projects have a long planning lead time because numerous technical, legal and contractual issues have to be considered and clarified. Due to high investments with long depreciation periods, the business models of district heating companies are usually designed for at least 10 to 20 years. Since industrial companies typically expect much shorter investment cycles and location decisions can be made within a short period of time, there is a potential for conflict and increased uncertainty for district heating suppliers.

Plant size: Larger plants for waste heat recovery tend to be economically more advantageous than smaller plants due to economies of scale.

Availability: If a third-party supplier wants to feed waste heat into heating grids, the amount of heat contractually guaranteed to customers must be secured with non-fluctuating generation capacities. Depending on the design, it may also be necessary for smaller renewable energy or waste heat capacities fed into the grid to be secured by the third-party suppliers in the grid itself (Source: Ortner et al., Umweltbundesamt (German Environmental Agency), 2022)

4.4 Good Practice Examples

This chapter presents a selection of good practice example for the external utilization of waste heat from different sources. There are of course many good practice examples for the internal utilization in industries, but we found it difficult to obtain concrete data on the internal use of waste heat, which may be due to commercial reasons.

4.4.1 Japan

Examples of multiple use of waste heat

Currently, in most cases, the waste heat from power plants, municipal waste incinerators, and sewage treatment facilities is used for on-site use or in nearby public facilities. However, there are also cases where heat is supplied from those waste heat sources to chemical plants and nearby residential areas. Typical examples are shown in Table 4-1.

Heat source	Name/Place	Description	Overview
Power plant	**Kawasaki Steam Net (Kanagawa)**	Steam from the Kawasaki Thermal Power Station is supplied to 10 nearby factories (chemical plants, etc.) located in the Keihin industrial area.	
Municipal waste incinerator	**Hikarigaoka Housing Complex (Tokyo)**	Heat is supplied for heating and hot water supply from the Hikarigaoka municipal waste disposal facility in conjunction with the construction of a large 12,000-unit residential complex.	
	Shinagawa Yashio Housing Complex (Tokyo)	Provides heat for heating and hot water supply to a large residential complex of 5268 units, using waste heat from the incineration plant of the Shinagawa municipal waste disposal facility.	
Sewage treatment facility	**Rokkou Island Housing Complex (Hyogo)**	Rokko Island Energy Service supplies waste heat from the incineration of sludge from the sewage sludge center to nearby housing complexes. Supply conditions are variable depending on the operation of the sludge center.	

Tab. 4 Best Practice Examples of waste heat usage in Japan (Source: ANRE, 2015)

Example of research and development outcomes

As an example of R&D outcomes, a new type of heat-driven chiller with increased thermal efficiency (COP) has been developed to generate cold heat from low-temperature waste heat that could not be used in the past; the chiller recovers heat from 95°C waste hot water to 55°C and generates cold water down to 0-3°C for cooling. It has been installed in buildings, factories, and hospitals in Germany, Poland, and Slovakia.

4.4.2 Germany

Examples of multiple use of waste heat

In most cases only examples for external use of waste heat have been available. Although internal use of waste is already common in many factories, most of them do not publish data about their internal processes and heat fluxes. In Germany there is a growing number of district heating networks using waste heat. Table 4-2 gives some examples for using waste heat from sewage water and industry for urban quarters.

Heat source	Name/Place	Description	Overview
chemical by-product of copper production	**Industrial heating eastern HafenCity in Hamburg***	Heat is supplied for an urban quarter. The heat supply comes from a chemical by-product of copper production at Aurubis (copper production). A 2.7-kilometer-long heat transport pipeline connects the eastern HafenCity with the Aurubis plant. There, it is fed into district heat supply network of the utility company “enercity” a municipal energy supply and service company. The pipeline for heat transport is designed for a capacity of up to 60 MW, which is the total potential of the Aurubis industrial waste heat.	 Area of copper factory Aurubis and HafenCity in Hamburg*
Waste heat from sewage	**'Neckarpark' quarter in Stuttgart****	Heat from a sewage system is supplied for heating and hot water supply for a quarter in Stuttgart. Since 2020, heat has been supplied to the first three connected buildings, In the following years, the number of heat consumers will gradually increase to around 850 residential units and commercial areas. The heat exchanger is developed for retrofitting of existing and new sewers in a modular design and can be positioned using the existing manhole structure. Due to the modular concept the heat exchanger can be extended any time. In addition, the heat supply system contains a heat pump with an output of approx. 2.9 MW and a COP of approx. 3.45, as well as a CHP unit and a peak load boiler to cover peak loads on particularly cold days. The energy demand of the heat pump is partly provided by a PV system installed on the buildings in the district. The entire plant went into operation in September 2020.	  Heat exchanger for sewage water**

Tab. 5 Best Practice Examples of waste heat usage in Germany

*(*Sources: Elbe Wochenblatt (2018); Aurubis (2022), Ch. Hein, presentation at the waste heat symposium “BMWK-Fachtagung „Klimaschutz durch Abwärmenutzung“ in Hamburg)*

*(**Sources: “Energie Wende Bauen “– Portal for energy-optimized buildings and neighborhoods, 2021; Stadt Stuttgart; “Neckarpark: Neuer Platz für Wohnen und Gewerbe“, 2021; Uhrig Energie GmbH, 2021)*

5 Conclusion: Suggested Priority Research Fields for German-Japanese Cooperation

Several German-Japanese workshops such as "Industrial Waste Heat Usage - German-Japanese Expert Workshop 2021" (online event from April 19-22, 2021) and bilateral exchanges such as the GJETC have identified a whole range of potential areas of cooperation that can subsequently be further developed in collaborative projects. These include, for example

- Optimization of thermoelectric generators (efficiency, materials, production costs, applications),
- Increasing efficiency and demonstrating possible applications for industrial heat pumps such as in the food industry,
- Use of waste heat in data centers
- Use of waste heat from waste water
- Concepts for (municipal) heat networks
- Methods for developing waste heat registers and local heat planning.

From the analysis of framework conditions, available waste heat sources and sinks, as well as the current state and trends of waste heat utilization, the following can be identified as priority research fields for a German-Japanese cooperation:

<u>**Framework conditions and policy**</u>

Promote analysis of waste heat utilization potential:

An important step is to identify existing usable waste heat potential and the opportunity to promote Energetic Neighborhoods. This includes identifying both the potential "providers" of waste heat, i.e. location/temperature/quantity and temporal availability of the waste heat, and the potential users and their requirements. In Germany, there are now numerous providers of waste heat mapping on the market whose services and know-how could also be used in Japan.

Based on these measures, waste heat producers could be encouraged to disclose their potentials and offer them for use to potential customers, especially district heating companies. This may be combined with an obligation on the part of district heating companies to feed in waste heat if this is economically viable. In addition, subsidies for various systemic measures and technologies such as heat networks, heat storage, heat pump technologies and potential studies would be desirable, like they are already available in Germany. Japan not only relies on the proven "Toprunner" program for equipment and components, but also obliges companies to submit regular reports and take measures to continuously increase energy efficiency in production, which also includes operational waste heat utilization.

Both countries, Germany and Japan, have already launched various subsidy programs to support the use of waste heat. An exchange of experience on the individual effects of the subsidy programs would be desirable here.

<u>**Market Design:**</u>

In both countries, Germany as well as Japan, large-scale "waste heat markets" do not yet exist; in contrast to the electricity market, there is no free market for heat, including waste heat. Political action is needed on both sides to support the creation of a “waste heat market”, potentially as a part of a wider sustainable heat market.

Infrastructure:

While in Germany mainly district heating grids exist or are also being expanded, this is only common in the very Northern part in Japan. On the other hand, Japan already has longer experience in the construction and operation of cooling systems. An intensified bilateral exchange with regard to technologies (e.g. chillers, heat pumps, energy storage, etc.) and systemic concepts (e.g. heating and cooling networks) could enable further synergy effects for industry, research and (funding) policy for both countries.

A positive example is currently the internal heat infrastructure in chemical parks or steel plants that generate waste heat internally and use it in other production areas. A joint waste heat project, e.g. involving industry (as a potential supplier of waste heat) and municipalities as users, could be beneficial for both sides (Japan e.g. as a supplier of heat pumps or chiller technology, Germany in the area of systemic technology of heat networks and heat storage).

An important challenge in Germany is the gradual decarbonization of existing district heating infrastructure. The injection of industrial waste heat, the use of deep geothermal energy or the conversion to "cold" heat networks (with temperatures of 30°C and less) in which the inclusion of low temperature waste heat sources (e.g. waste water or waste heat from data centers) is currently being discussed. Here, too, bilateral cooperation in research as well as in industrial or municipal applications would make sense.

Technologies

Industrial heat pumps:

Especially in Germany, certain industrial sectors are affected by high energy costs (e.g. natural gas). The substitution of fossil fuels with hydrogen will take a longer period of time in most cases, but many sectors, such as the food industry, need short- or medium-term solutions in order to continue to produce economically. Heat pump technology is capable of closing heat cycles and replacing fossil fuels in the medium term by using operational waste heat at different temperature levels. Here, cooperation between German and Japanese research institutes and heat pump manufacturers for the further development and use of heat pumps (also in the high-temperature range of 120°C and more) and users would make sense.

Heat storage

Heat storage is an important component in waste heat utilization and distribution.

Besides classical methods of heat storage via liquid storage media, solid media are also well suited to store waste heat without heat loss over a longer period of time or to reuse it in the short term. Especially in the field of phase change materials (PCM) for latent heat storage, Japan has numerous research and development results that could also be helpful for German industry or municipal waste heat utilization within the framework of a joint bilateral project.

Thermoelectric generators (TEG)

Here, both the German and Japanese sides are working on further development of the systems. A possible interface for installation here would be, for example, integration into an heat exchanger as an intermediate layer. In both countries, there is potential for the application of TEG, but the conversion efficiency of approx.. 5-7 % for electricity generation from heat is not very high. However, TEGs have the operational advantage over other methods of generating electricity from heat, such as ORC plants, in that they can be used for both continuous and discontinuous waste heat generation even with relatively small temperature differences. In addition, TEGs can also be used for cooling, as is the case with heat pumps. Japan has already made considerable progress in this area, for example in the cooling of LEDs in telecommunications equipment.

In Germany, there is still a need to catch up here, which means that cooperation in the research and application sectors is particularly recommended. In this field, a cooperation between a Japanese company and a German research institute has already been established as a follow-up to the German-Japanese workshop "Industrial Waste Heat Usage - German-Japanese Expert Workshop 2021".

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