



**Technology
overview waste
heat utilization**



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Renewable resources in thermal energy supply

The expansion of renewable energies continues to progress throughout Germany. While approximately one third of the electricity generation is already based on renewable energies, the share in both the heating and transport sectors is still far below this figure¹. With a share of 13 % of renewable energies, their expansion in the heating sector has stagnated for years. Moreover, in the transport sector it is even declining slightly. As a result, there is still an enormous backlog of work to be done to achieve the climate protection targets, particularly in the heating and transport sectors. In Germany, for example, the share of renewable energy in gross final energy con-

sumption is to amount to 60% across all sectors by 2050 (BMUB 2017). For a closer look at this goal, a small-scale analysis is carried out at the level of Lower Saxony. For example, the share of renewable energy in gross final energy consumption was 17.8 % in 2015. Due to its coastal location, Lower Saxony can score points mainly in power generation. For example, the share of renewable electricity in 2015 was already 86.3 % (preliminary figure). Whereas, in the heating (7.0 %) and mobility (4.7 %) sectors Lower Saxony is still lagging behind the German average, see Figure 1 (LAK 2018) (BMW 2017).

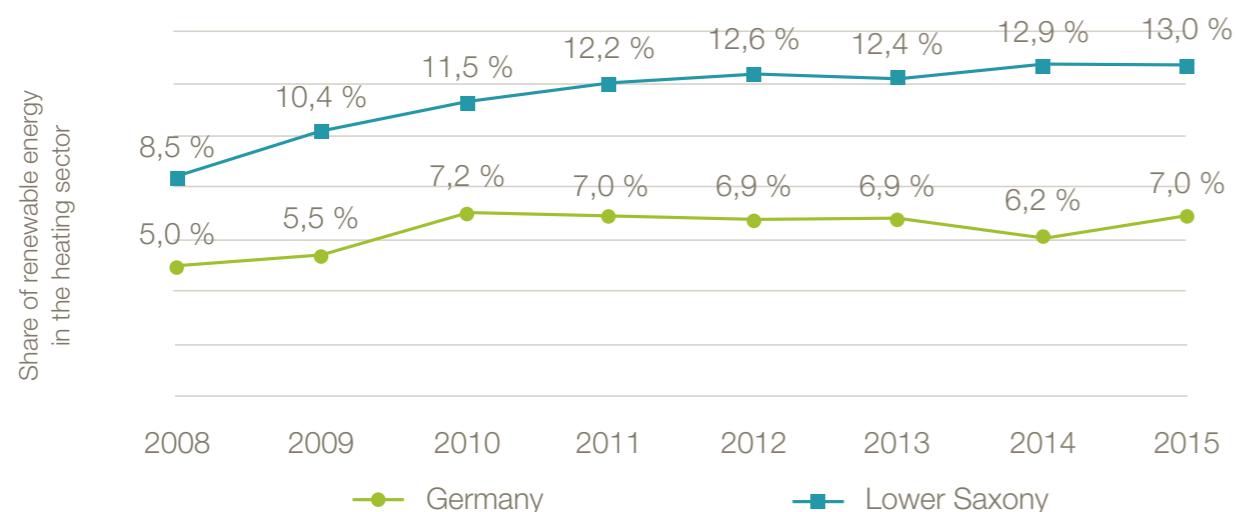


Figure 1: Share of renewable energy in gross final energy consumption in the heating sector (LAK 2018) (BMW 2017)

The future of decentralised heat utilization

A detailed look at the heating sector reveals why it is desirable to increase the share of renewable energy within this sector, see Figure 2. Currently, more than 80 % of conventionally produced heat is generated in the „household“ and „industry“ sectors. A closer look at the situation in the industry reveals that approx. 90% of industrial heat requirements is generated by process heat. About 70 % of the generated high temperature levels from 100 °C on (43 % are above 400 °C) make reuse of

the resulting waste heat interesting. This may be seen from both economic as well as ecological view angles (Handelsblatt 2011). Various contemporary studies take up this aspect of the use of industrial waste heat potentials. They all assume a waste heat share of industrially used heat between 15 and 30 % (EU-Consult 2008) (Schnitzer et al. 2012) (Waldhoff and Reckzügel 2014) (Brückner 2016).

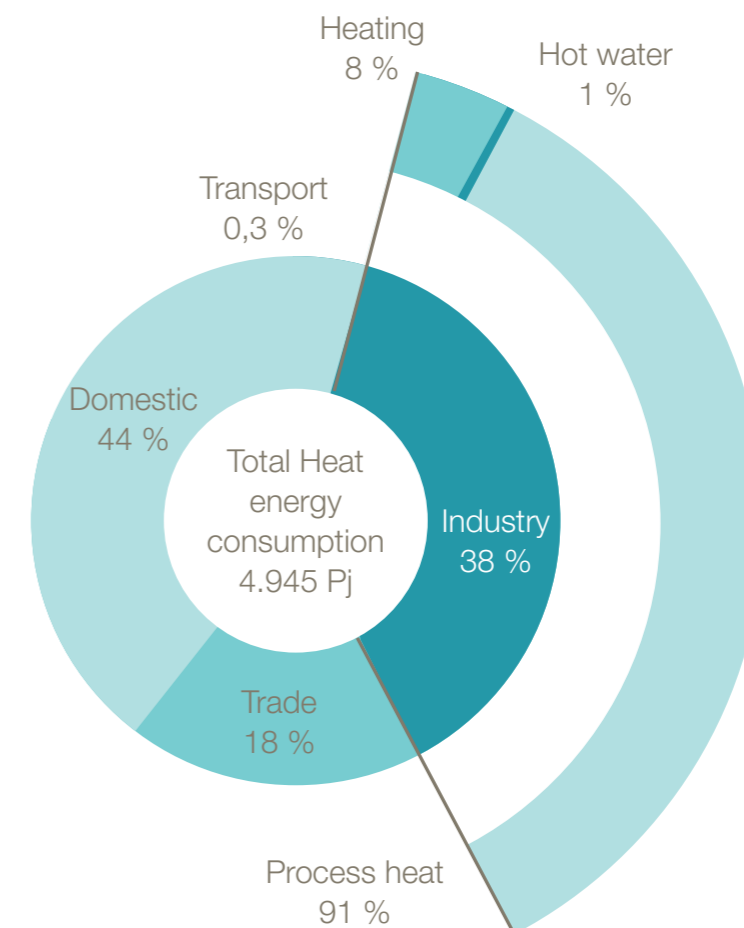


Figure 2: Share of heat demand of industry in Germany's total heat demand in 2016, data basis: (AGEB 2017)

¹ 31,3 % renewable energy in gross energy consumption, 13,0 % renewable energy in end energy use of heating and cooling as well as 5,3 % in end energy use of traffic, in total this is 14,7 % renewable energy in gross energy consumption within Germany in 2015 (BMW 2017)

As already demonstrated in Waldhoff and Reckzügel (2014), a strict distinction must be made among the different qualities and levels of terminology in the determination and discussion of waste heat potential. The potential which is derived from statistical data on energy consumption, is generally referred to as theoretical potential. However, the individual technologies and applications are not discussed in detail. The determination is carried out exclusively on the basis of the physical boundary conditions. As a consequence, this potential is not achievable. A more detailed look at the individual technologies reveals the technical potential. Typical technology-based data such as temperature levels, efficiency and performance ranges are taken into account. This potential can therefore be clearly influenced by the advancing development of technologies. An additional consideration of the economic feasibility of heat recovery measures results in economic potential. In addition to many other boundary conditions such as energy prices and interest rate developments, it is important to factor in whether the system is subject to a business or economic evaluation. According to Schnitzer et al. (2012), this potential is between 12 and 60 % of technical capabilities in general. A qualitative representation of the different potential definitions is displayed in Figure 3 (Waldhoff and Reckzügel 2014).

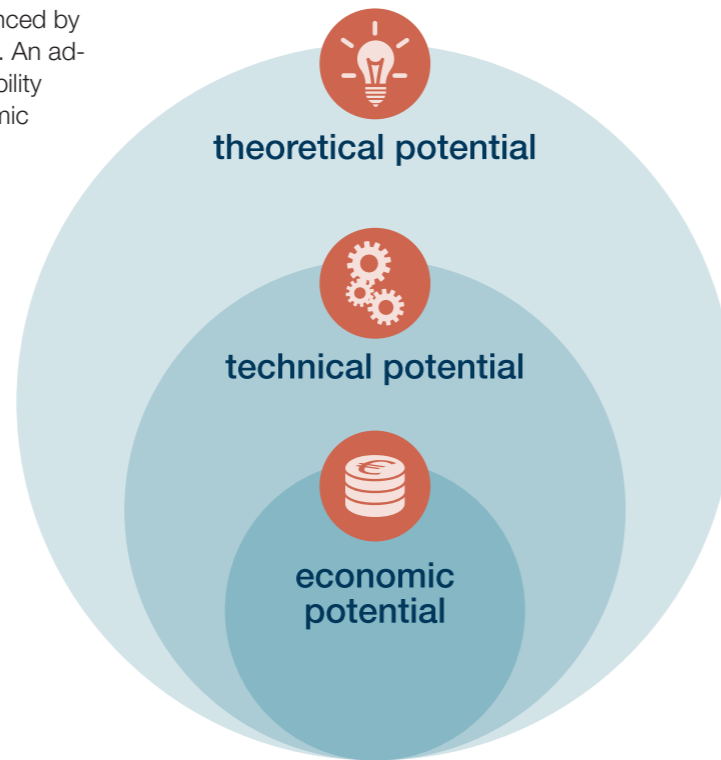


Figure 3: System sketch of the different potentials (Waldhoff and Reckzügel 2014)

Technologies for a decentralized use of thermal energy

If energy is used locally, it is generated in the vicinity of the local consumers. Typical examples are a common supply of residential areas, e.g. by means of CHP or the utilization of industrial heat supplying heat to residential buildings or other commercial and industrial enterprises. With the latter in particular, direct use of the waste heat as thermal energy is

not always economically and technically feasible. In contrast to direct use of waste heat, conversion to another form of energy or to a higher temperature level is possible. This is called indirect use of heat. In the following, the standard technologies including technical conditions and typical areas of application are briefly explained.

Use of (waste) heat by providing ...

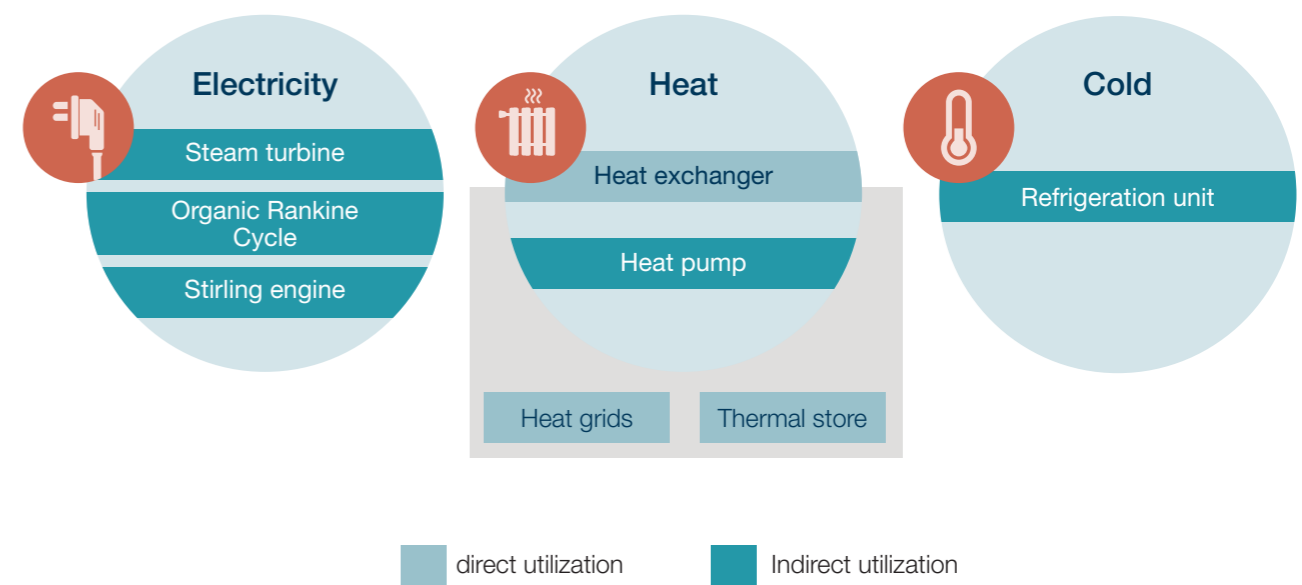


Figure 4 Technologies for direct and indirect use of thermal energy

Regardless of all technological opportunities for the use of thermal energy, the following sequence of avoidance/utilization possibilities is recommended, in particular on the basis of economic and technical efficiency (saena 2012):

1. Reduction of waste heat;
2. Reintegration into the process;
3. Internal use;
4. Internal transformation into other forms of useful energy;
5. Sale to third parties.

Identification of applicable technologies

A first classification of the technologies explained below can be made using the following decision trees.

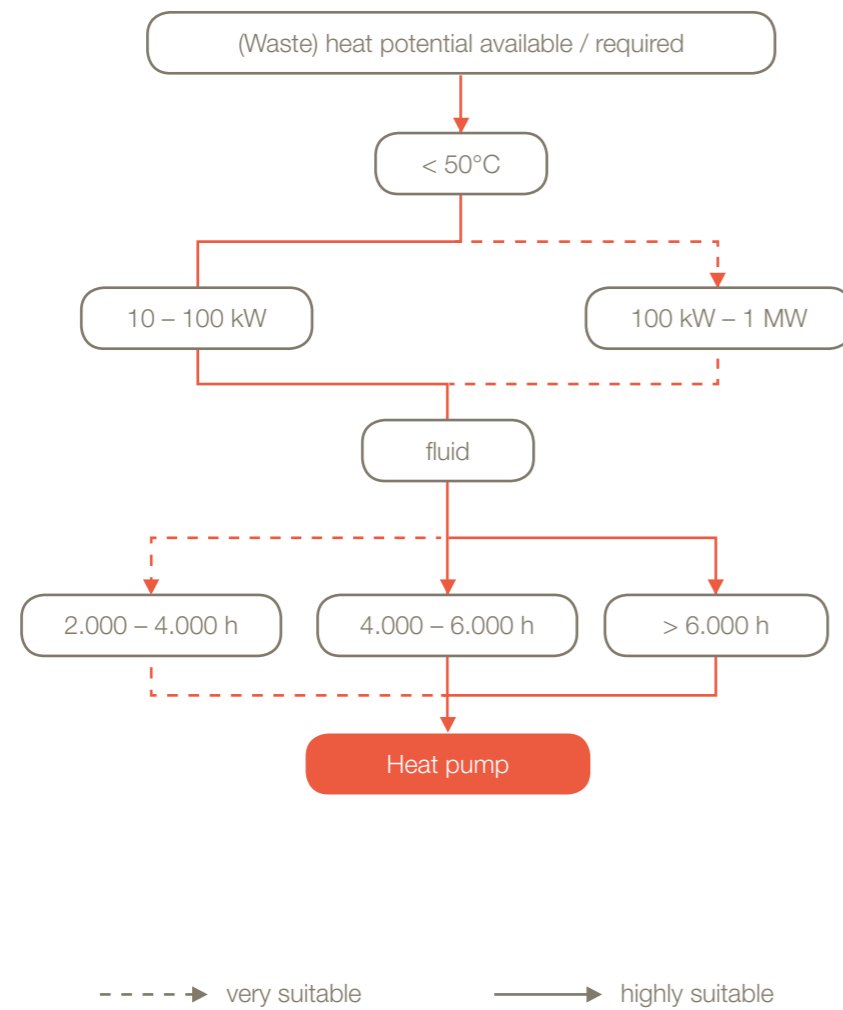


Figure 5: Decision tree for a temperature level of 50°C, data basis: (saena 2012)

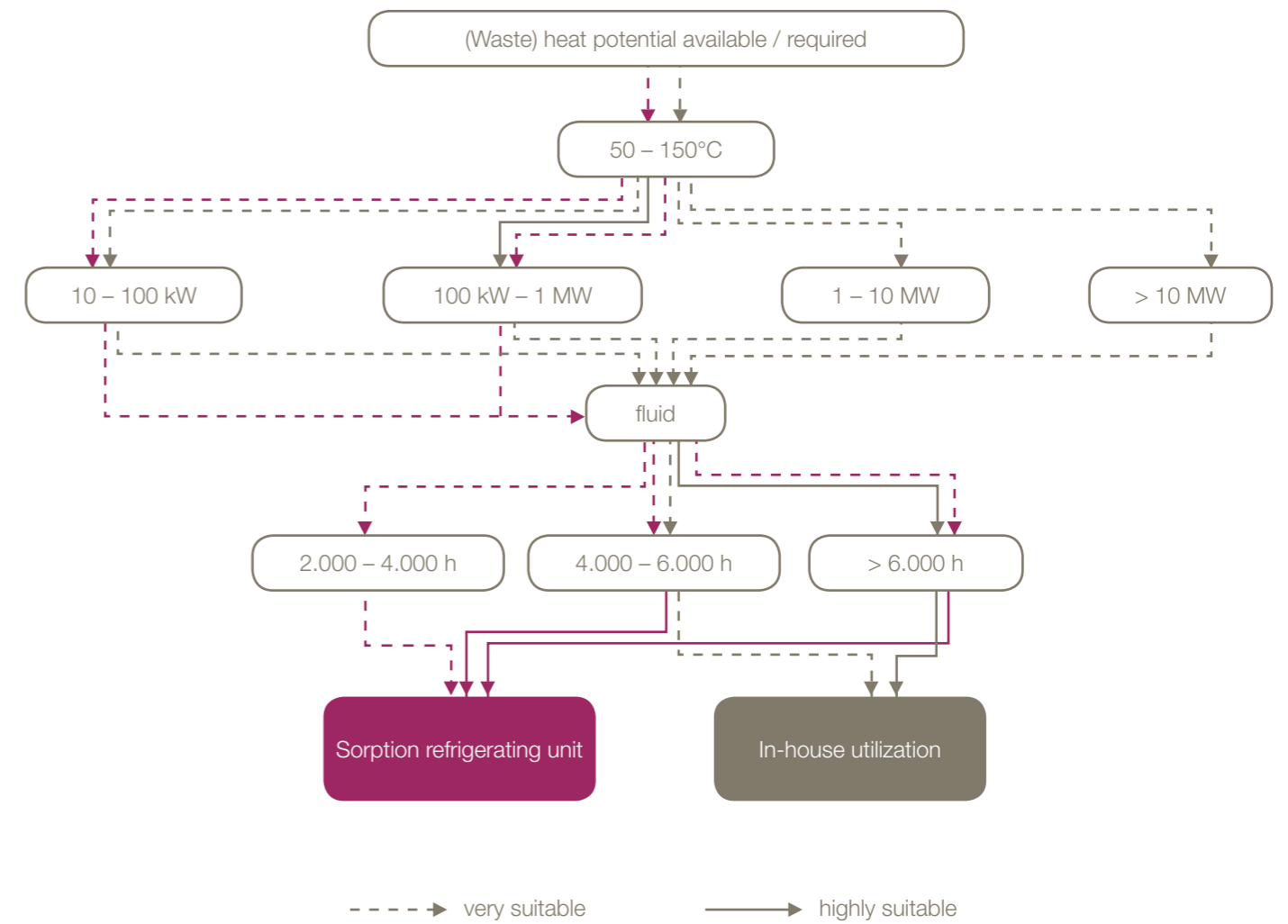


Figure 6: Decision tree for a temperature level of 50 to 150°C, data basis: (saena 2012)

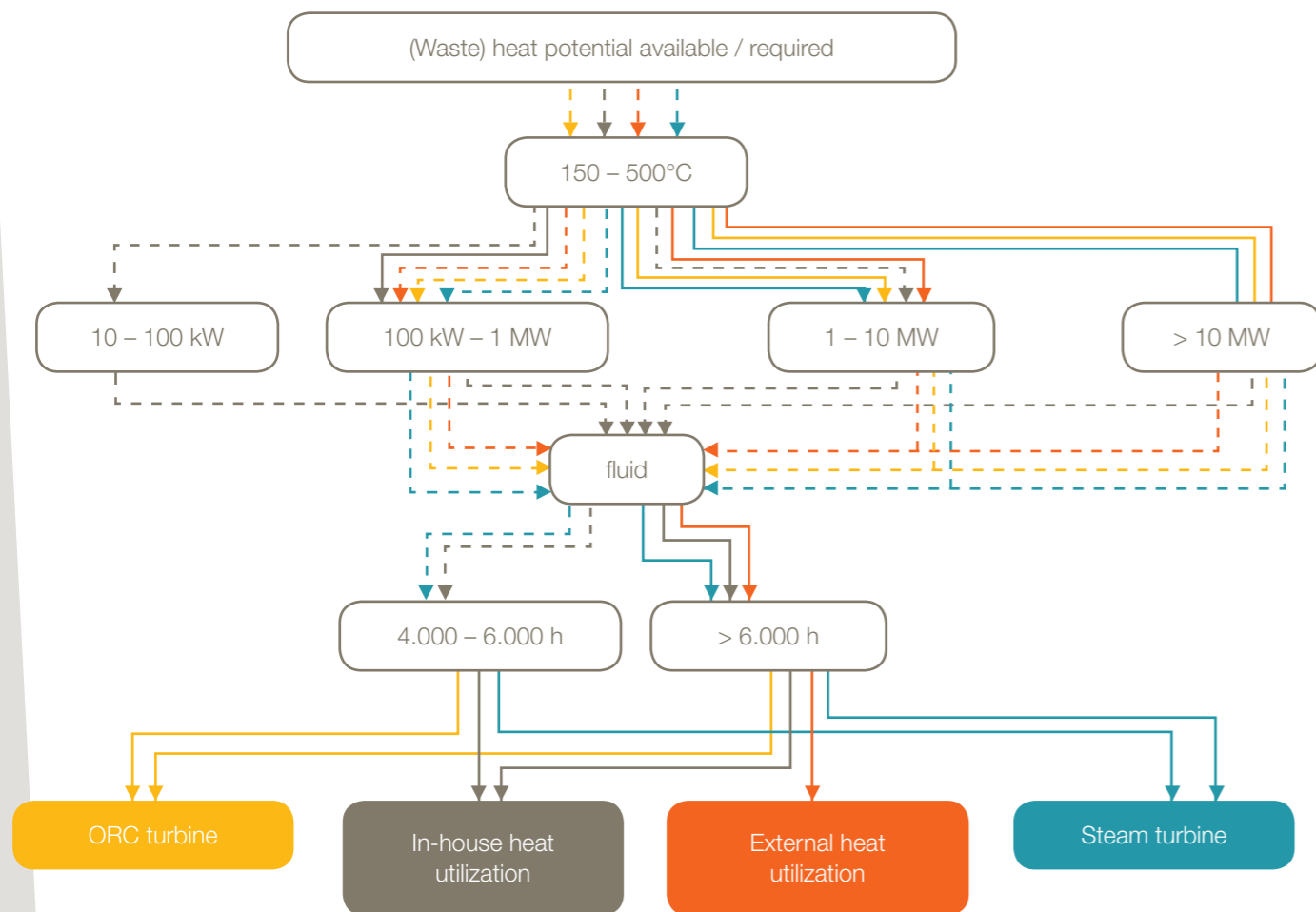


Figure 7: Decision tree for a temperature level of 150 to 500°C, data basis: (saena 2012)

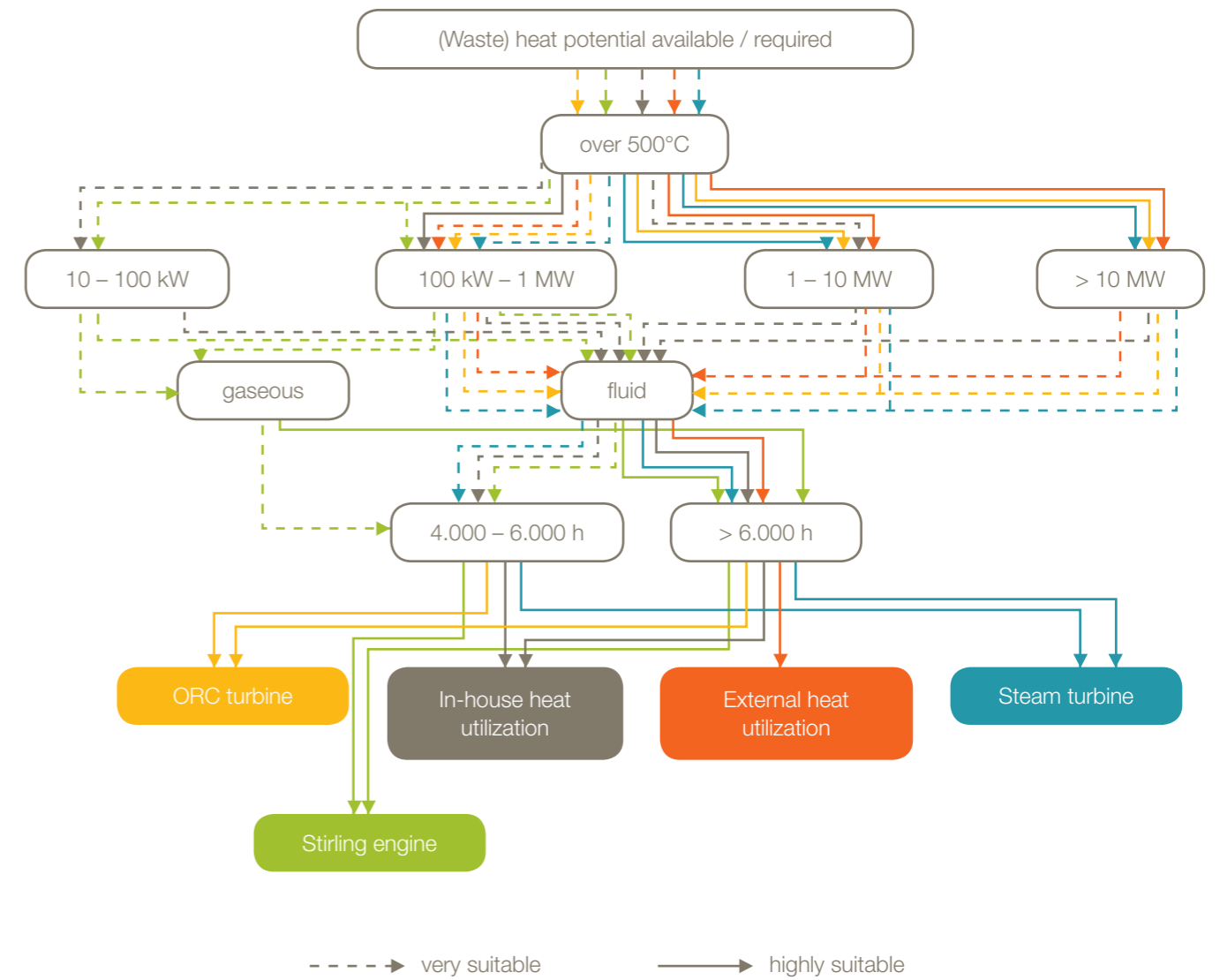


Figure 8: Decision tree for a temperature level above 500°C, data basis: (saena 2012)

Direct heat utilisation

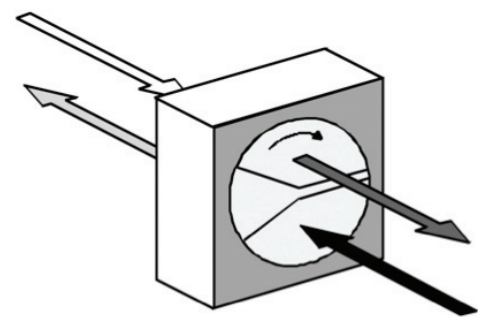
Heat exchangers

Heat exchangers are heat engineering systems in which at least two fluids with different temperatures flow through. Driven by an existing temperature difference between these two material flows, the material flow with a higher temperature level transfers part of its thermal energy to the colder fluid. Thus, the thermal energy is indirectly transferred from the exhaust air flow to the fresh air flow.

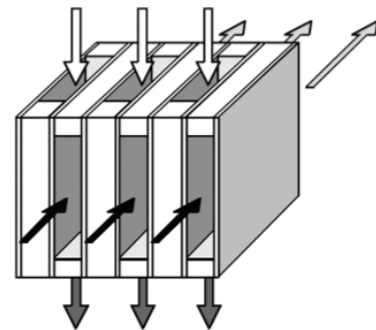
The two different construction methods depicted in Figure 9 demonstrate fundamental differences in heat exchange.

Regenerators lead two phased heat flows past an intermediate medium - usually a storage mass. Using this concept, the heat of the exhaust air flow is absorbed by the intermediate medium and then released into the fresh air flow (Hörner and Schmidt 2011).

The most frequently used system is the recuperator. That system leads both material flows simultaneously through a tube separated only by a fixed partition wall (Cerbe 2011).



a) Regenerator



b) Recuperator

Figure 9: Schematic representation of different heat exchanger types (Brunner 1993)



Table 1: Typical data of various heat exchangers (saena 2012)

Type	Temperature	Power	Media	Costs
Double-pipe heat exchanger	< 150 °C	< 3.500 MW	fluid/fluid	
Finned tube heat exchanger	< 300 °C	< 1.000 MW	gas/fluid	< 15 €/kW
Shell and tube heat exchanger	< 550 °C	< 20 MW	fluid/fluid	10 - 150 €/kW
Rotary wheel heat exchanger	< 650 °C	< 1,6 MW	gas/gas	
Heat pipe heat exchanger	< 650 °C	< 3 kW (je Rohr)	gas/gas	
Plate heat exchanger	< 750 °C	< 400 MW	fluid/fluid gas/gas	< 10 €/kW

Heat accumulators

Heat accumulators enable operators to decouple processes of heat supply and dissipation. In this way it is possible to deploy irregular or staggered heat sources for heat utilization. Heat accumulators are also differentiated on the basis of their functionality of heat storage. Currently, these devices are mainly used to store sensitive or latent heat. Both storage types require a higher temperature of the waste heat generated than the storage temperature. In addition, the storage temperature must be higher than the temperature available for applications.

Nowadays, sensible heat accumulators are the most common variant for storing thermal energy. For example, they are used as typical hot water accumulators often found in smaller designs in residential buildings or as intermediate accumulators in local heating networks.

Latent heat accumulators, on the other hand, make use of the enthalpy of reversible state changes (heat of transformation) for heat storage. Thus, heat is usually absorbed or released during the phase change between solid and liquid at a constant temperature level, see Figure 10 (saena 2016) (Schellong 2016).

To date, this type of storage technology is used, for example, in building architecture. Many people are familiar with this type of heat storage in the form of pocket heaters. Large facilities are currently still under development (energy2.0 2012) (Blesl et al. 2010).

Regardless of the storage type, the storage cycles should be kept as short as possible from an economic point of view. Theoretically, however, it would also be possible to store the waste heat during the summer and use it in winter, for example saena (2016).

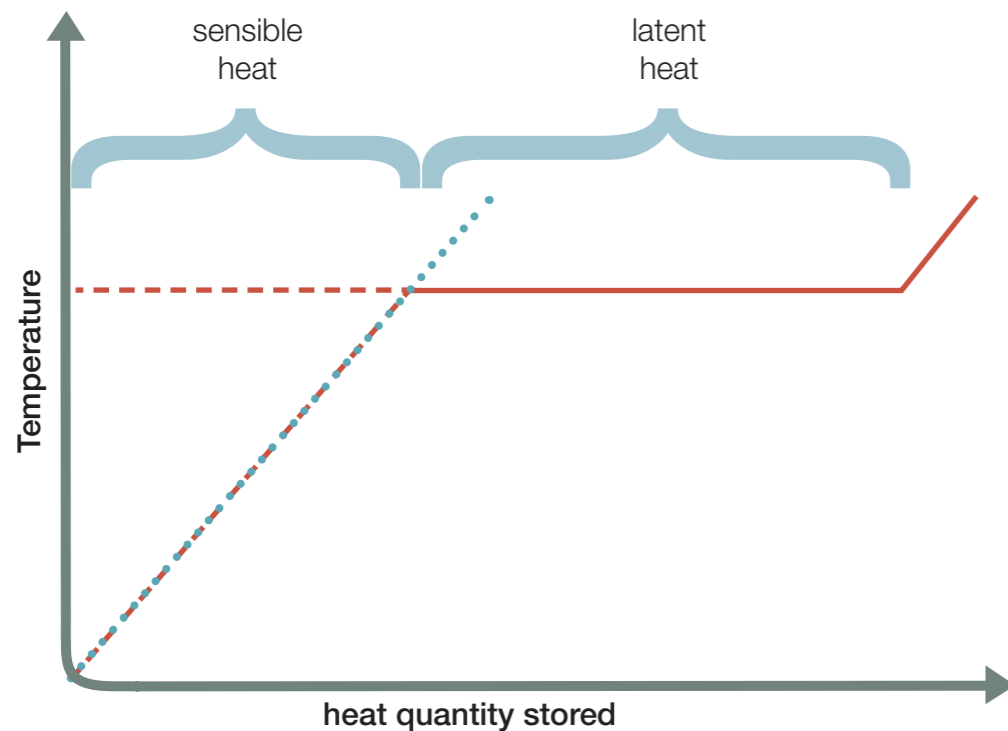


Figure 10: Functional principle of latent heat accumulators

Table 2: Typical data of different heat accumulators (saena 2012)

Type	Temperature	Power	Size	Storage capacity	Storage density	Costs
Sensible heat store	> 1.000 °C	> 100 MW	> 10.000 m ³	> 100 MWh	< 100 kWh/m ³	
Latent heat accumulator	< 0 - > 400 °C		< 17 m ³ (demonstrated)	< 2,5 MWh (demonstrated)	< 150 kWh/m ³ (demonstrated)	10-50 €/kWh
Sorption heat store	> 1.000 °C		< 50 m ³ (demonstrated)	< 4,5 MWh (demonstrated)	< 185 kWh/m ³ (demonstrated)	8-100 €/kWh

Heat transport

Heat networks are used to transport thermal energy from a heat source to a heat sink. Water is usually used as the transportation medium. Infrequently, it may be steam (approx. 3 % of the heating networks) (AGFW 2017). The heat that cannot be used internally at a source is transferred to the carrier medium flowing through the heat network by means of heat exchangers. There, the energy is again partially extracted from the carrier medium by means of additional heat exchangers and transferred to an

internal cycle of the heat sink. The cooled transfer medium then flows back through a return line, and the loop starts again.

In many places the use of mobile latent heat accumulators is planned. This may be compared to the shape of a tanker truck, see e.g. Wunder (2016) and Walter (2017). Already in 2011, this technology was applied economically within a radius of 30 km. (Petersen 2011).

Table 3: Overview of various types of heating networks (C.A.R.M.E.N. 2018)

Type	Temperature	Excess pressure
Hot water	< 100 °C	4-10 bar
Low-pressure hot water	70-120 °C	4-6 bar
High-pressure hot water	120-180 °C	6-20 bar
High pressure steam network	120-160 °C	2-15 bar

Indirect heat utilisation

Heat pump

Heat pumps offer an opportunity to increase the temperature level of the heat flows by means of additional electrical energy supply. Hence, they enable an upgrading of low-temperature heat. Basically, the smaller the temperature difference between waste heat and useful heat, the more effectively such a pump can work. The efficiency, which is referred to as the COP (Coefficient of Performance), indicates the ratio between the useful heat flux and the electrical power used (drive power). Based on their design, heat pumps can be divided into compression- and sorption-based heat pumps.

Compression heat pumps use supplied energy to drive a compressor, which in turn increases the pressure level of the working medium. These heat pumps can be operated with electrical energy as well as with natural gas or diesel fuel. This technique results in a temperature increase of approx. 40 to 50 K. As a result, a multiple of the power deployed is available as usable heat output. The gain emerges from extracted ambient heat (saena 2016).

Sorption heat pumps (absorption and adsorption heat pumps), unlike compression heat pumps, have a thermal drive rather than a mechanical one. Thus, these devices generate higher-temperature heat by

means of the available waste heat. Absorption heat pumps are usually driven by fossil fuels, biomass or waste heat. Whereas, adsorption heat pumps are powered by means of combinations of materials such as silica gel/ zeolites and water or ammonia and water. Due to their low maintenance requirements, absorption heat pumps are already used in industrial waste heat utilisation (saena 2016).

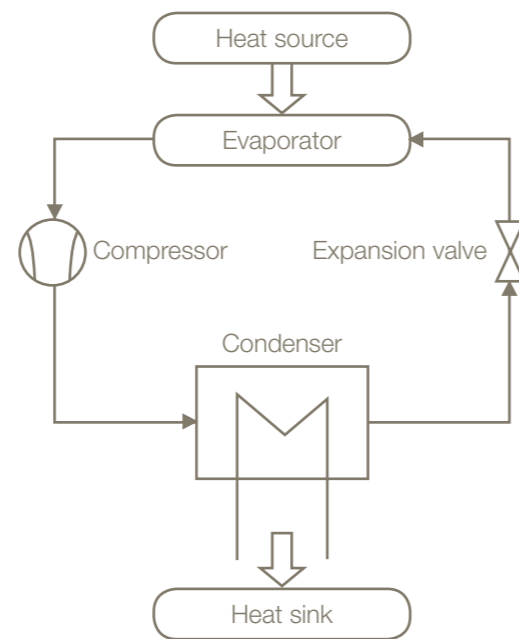


Figure 11: Schematic diagram of a heat pump

Table 4: Typical data of different heat accumulators (saena 2012)

Type	Temperature of heat medium	Power	Heat carrier	Performance coefficient	costs
Compression heat pump	< 50 °C	15 kW-20 MW	air, fluid	3,0-5,0	150-1.500 €/kW _{th}
Absorption heat pump	< 200 °C	15 kW-20 MW	fluid	1,4-2,2	500-1.200 €/kW _{th}
Adsorption heat pump	< 90 °C	7,5-500 kW	fluid	1,3-1,6	1.500 €/kW _{th}

Refrigerating units

The technologies for providing cooling by means of refrigeration machines and heat supply by means of heat pumps are based on an identical design. While in heat pumps the useful capacity of the condenser (heating capacity) is transferred to the consumer, in refrigerating machines, however, the useful capacity of the evaporator (cooling capacity) is transferred to the consumer.

A main distinction is made between ammonia water and water/lithium bromide plants in the work equipment used. Water/lithium bromide plants achieve cooling temperatures of up to +5 °C. Ammonia-water plants achieve a cooling temperature of up to -10 °C. (saena 2016) (Schmid et al. 2016).

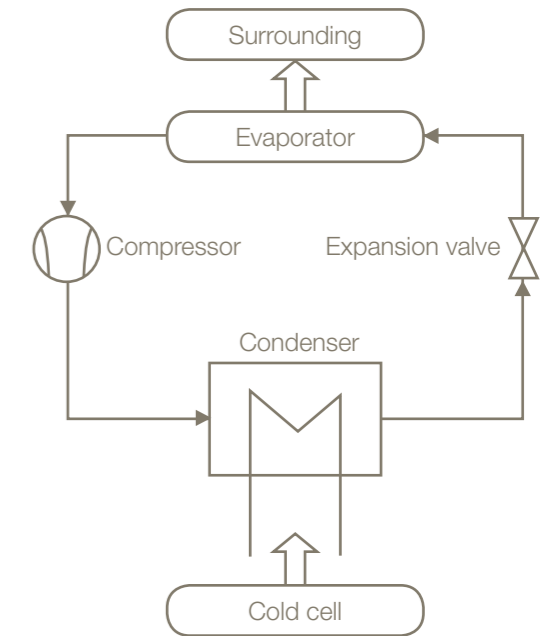


Figure 12: Schematic diagram of a refrigerating unit

Table 5: Typical data of various plants for temperature reduction of thermal energy

Type	Temperature of heat medium	Power	Heat carrier	Performance coefficient	Costs
Absorption refrigerating units	<70 °C	5 kW-12 MW	fluid, steam	0,5-0,8	200-1.250 €/kW _{th}
Adsorption refrigerating units	55-100 °C	5-350 kW	fluid	0,6-0,7	300-1.500 €/kW _{th}

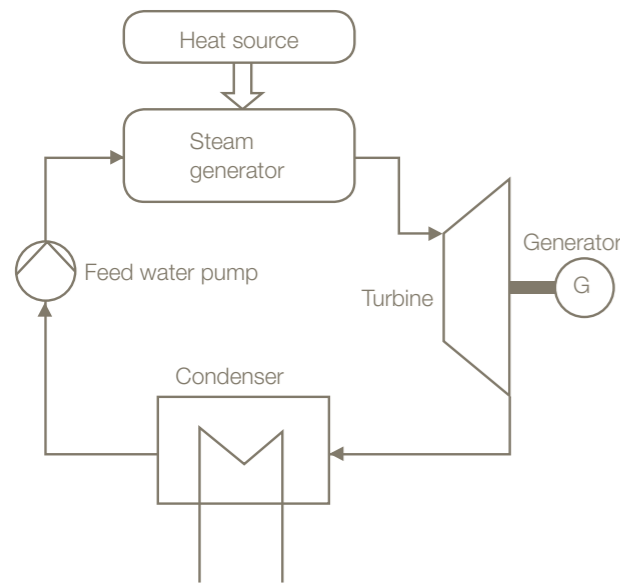
Electricity generation

Another way of using excess heat is to convert it into electricity. The use of electricity can be carried out both for own consumption and by feeding it into the power grid.

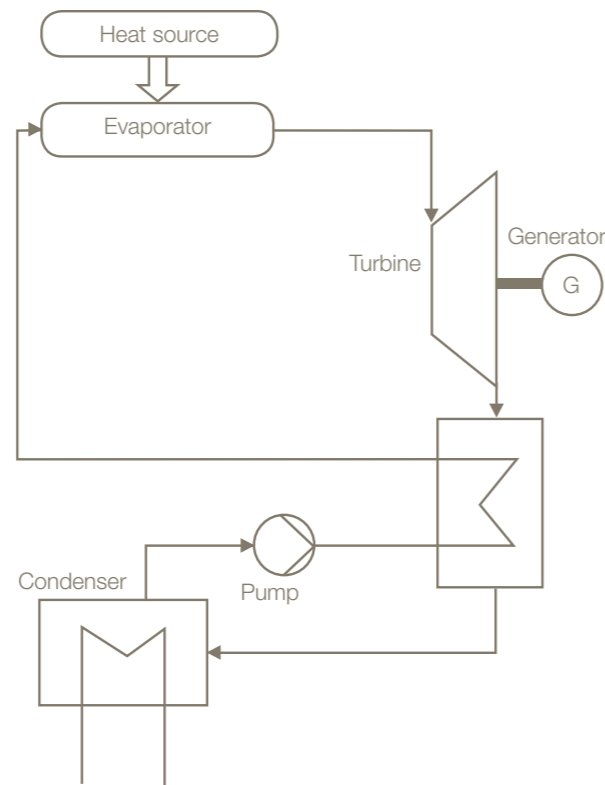
In the steam process (Clausius Rankine Cycle), a turbine is driven by water as the working medium. Since water as a working medium requires high temperatures and high thermal capacities, there are hardly any applications for this in industrial waste heat utilisation. The main area of application for this standardized process is in conventional thermal power plants (Grote, Hoffmann and Tänzer 2015).

In contrast to the Clausius Rankine cycle, the Organic Rankine Cycle (ORC) uses organic substances such as butane, pentane or silicone oils. These all have a lower boiling point than water and can therefore be deployed at a lower temperature level. (Grote, Hoffmann and Tänzer 2015) (Köhler 2005)

The principle of the Stirling engine is based on the properties of some working media to expand with heat. In an enclosed working area the working medium is alternately compressed or expanded within a cycle process of a piston. Typical areas of application for Stirling engines are solar thermal and biomass applications. (Waldhoff and Reckzügel 2014)



a) CRC process



b) ORC process

Table 6: Typical data of various plants for the conversion of thermal into electrical energy (Grote, Hoffmann and Tänzer 2015) (saena 2012)

Type	Temperature of heat medium	Power	Heat carrier	Efficiency	Costs
Steam process	> 150 °C	> 20 kW _{el}	fluid, steam, gas	< 10 %	< 5.000 €/kW _{el}
ORC	> 110 °C	30 kW _{el} -3 MW _{el}	fluid, steam, gas	5-15 %	3.000-7.500 €/kW _{el}
Stirling engine	650-1.100 °C	30kW _{el} -300 MW _{el}	exhaust gas	10-16 %	1.400-1.700 €/kW _{el}

Figure 13: Schematic representation of thermal energy into electrical energy

Activities in the district of Osnabrück

The district of Osnabrück recognised the potential of heat utilization, especially industrial waste heat utilisation, early on. In 2012, the district and neighbouring towns and districts became master plan municipalities in the federal „Master Plan 100% Climate Protection“ programme. In this way they opened up to the future-oriented field of climate protection. In this context, the use of waste heat has been defined as a key topic. Starting with a structural analysis of the district of Osnabrück and the development of a heat register for energy-intensive industries as part of the study „ReWIn - Regional Heat Register Industry“, the planning portal „PlnA - Planning Portal Industrial Waste Heat“ was developed on this basis. Building on this, one of the main objectives of „COBEN - Delivering Community Benefits of Civic Energy“ is the identification of hot spots as well as their development and implementation planning. In recent years a gradual process has advanced in the district. The respective projects have continuously received scientific supervision by the Hochschule Osnabrück and the Energy Competence Centre:

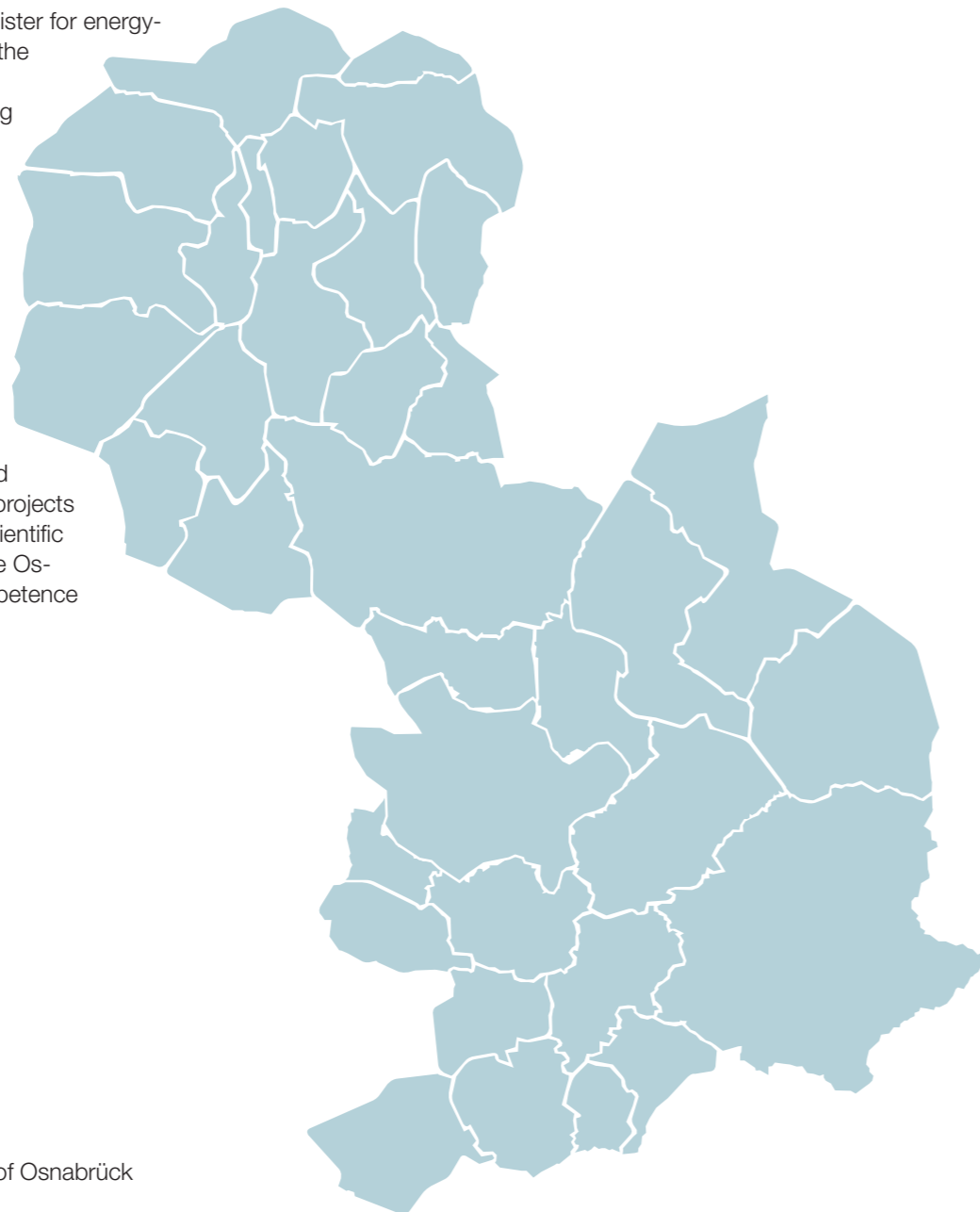


Figure 14: Map of the district of Osnabrück

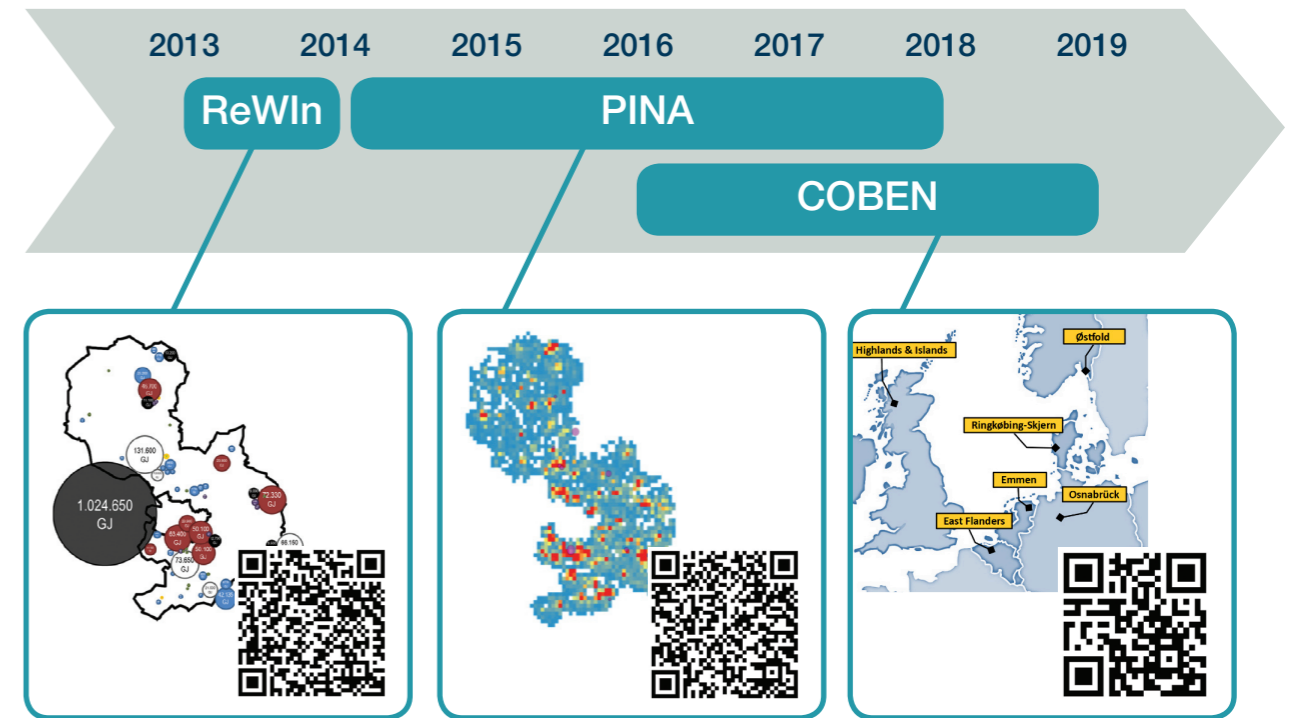


Figure 15: Activities in the main area of waste heat utilization (Waldhoff and Reckzügel 2014) (LK Osnabrück 2017) (McGovern 2018)



Partners in (waste) heat utilisation projects

Although every local energy situation including its framework conditions is special (e.g. waste heat or other forms of energy might be used externally) and must be seen as an individual case, the contacts are always similar. The implementation of such a project requires a structure from which all participants feel adequately represented. Usually, a small number of strong personalities initiate and bundle opinions and activities. The local government as an independent, central institution is always an important contact. The district of Osnabrück and its Climate Initiative Team are in an excellent strategic position. In this way, long-term strategies are developed and tangible, implementable projects are initiated. At the same time the involved enterprises themselves can pursue their core business undisturbed. For example, the expertise required for this endeavour is provided by energy suppliers, planning offices and the scientific community. Yet, they can be consulted for specific questions (Energie-Strategierat Weser-Ems (Hrsg.) 2017).

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