Process heat in industry and commerce

Technology solutions for waste heat utilisation and renewable provision

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1 Preface

Germany has succeeded in making renewable energies a main pillar of the energy supply: In the last ten years its share of total electricity consumption has increased from 8 percent to approximately 32 percent in the first half of 2015. Thus the goal of the Federal Government to extend the share of renewables to 40 to 45 percent by the year 2025 is within reach.

However, the energy transition is not just about extending renewable energy within the power supply. First and foremost, energy transition also means a more efficient handling of energy and the networking of different sectors, such as power, heat, or also traffic. In short: We must think of the energy transition and climate protection holistically.

German industry annually expends 1,670 petajoules of energy to generate heat for necessary production and processing operations. A high proportion of this energy is lost as unused waste heat. The priority is to increase this energy efficiency potential in support of international competitive capacity, and as a contribution to the energy transition. Thus the utilisation of industrial waste holds excellent energy efficiency potential for companies in the industrial waste heat location of Germany.

A variety of energy efficiency technologies available today offer excellent possibilities of sustainably reducing operational energy requirements through use of waste heat. Moreover, practical experience in Germany shows that a majority of the energy efficiency measures offer returns in double-digit rates.

The fact that the industrial sector was responsible for approximately one third (128,000 petajoules) of worldwide energy consumption in 2009, of which a good two thirds (87,000 petajoules) was expended for direct provision of heat alone, indicates the incredible potential, as well as the international relevance of energy-efficient utilisation of process heat.

In a scenario recently published by the United Nations concerning the expansion of renewable energies in industry, the projection is that by the year 2050, approximately 21 percent (50,000 petajoules per year) of the needed industrial supply could then be covered through renewables. Therefore, in the future, the use of renewable energies will also play a significant role internationally in the area of process heat provision. According to this scenario, the shares of the renewables could continuously increase, primarily through the biomass to be used.

German companies are esteemed internationally for developed energy technologies and can make a crucial contribution towards a sustainable and future-oriented energy supply. Overall German firms are characterised by their years of experience and great innovative power, they offer a broad range of products and services and set new quality standards. While this is good and important, it is certainly no reason to rest on our laurels. In this brochure we would like to share with you part of the extensive experience that the German economy can show in the areas of energy efficiency and renewable energies.

Today, German companies with international experience are already represented along the entire value chain. Projects and plants „Made in Germany“ support end users, business, agriculture, municipalities and industry in national economies throughout the entire world with a sustainable and reliable energy supply, with energy and cost savings, and ultimately in the reduction of emissions.

This positive development must be continued – for the sake of the energy transition, for the sake of international climate protection and a sustainable economic development.

To provide support in developing energy efficiency potential and through this support to intensify the dialogue is a fundamental concern of dena, as an agency for applied energy transition – also beyond the borders of Germany.

Consequently, I am pleased to introduce this process heat brochure of the German Energy Solutions Initiative, which is coordinated and financed by the German Federal Ministry for Economic Affairs and Energy.

Regards

Andreas Kuhlmann, Chairman of the Management Board
Deutsche Energie-Agentur GmbH (dena)

2 Introduction

The industry sector is responsible for approx. 30 % of the energy demand of the Federal Republic of Germany. Approximately three quarters of these requirements are for provision of process heat, as room heat, as hot water, for steam generation, for heating of input materials and other materials or for drying and cleaning processes.

For provision of process heat, in addition to conventional combustion processes, various technologies for utilisation of waste heat or renewable sources are ready. Waste heat can be used to provide heat for thermal processes, but also to generate power or refrigeration. Technologies for the use of renewable heat sources extend over a broad spectrum, for example, biomass and geothermal heat and power plants, as well as solar thermal energy systems and heat pumps. In this regard, the selection of suitable energy sources or heat sources is based on the temperature load profile of individual processes and the energy intensity of a company in general, as well as the environmental conditions and site conditions in particular.

The possibilities for utilisation of waste heat or integration of renewable heat sources differ significantly for companies from different industry sectors. This is particularly evident based on the temperature levels required by specific branches of industry. For example, heat at temperature levels above 1,000 °C is required to produce cement, glass or metal. On the other hand, the textile industry and food industry predominantly require heat at temperature levels up to 100 °C.

The fact that the industrial sector was responsible for approximately one third (128 EJ) of worldwide energy consumption in 2009, of which a good two thirds (87 EJ) was expended for direct provision of heat alone, indicates the incredible potential, as well as the international relevance of energy-efficient utilisation of process heat and intensified integration of renewable energy sources.[1]

Thus, a more efficient use of unavoidable waste heat and an increasing provision of renewable industrial process heat are essential, in achieving pioneering global improvements in the area of energy efficiency in line with targeted increased use of renewable energy sources, and not least, it can significantly reduce industry-related CO_2 emissions worldwide.[2]

In a scenario published by the United Nations concerning the expansion of renewable energies in industry, the projection is that by the year 2050, approximately 21 percent (50 EJ/a) of the energy supply in the producing industry sector can then be covered through renewable energies. Among other things, these renewable energies are comprised of the use of biomass at 74 percent (37 EJ/a), and approximately 20 % (10.5 EJ/a) of process heat through solar thermal energy (5.6 EJ/a) and heat pumps[3] (4.9 EJ/a).

These orders of magnitude indicate not only the great potential for expanding renewable energies in the industrial sector overall, they also indicate the special role that bio-energy can play as a substitute for conventional energy sources within the industrial production of the future. However, the projections cited are based on continuously advancing technological development, as well as functioning markets with established standards and the resulting cost-reducing effects and scale effects. Likewise, the political will to promote renewable energies, particularly for the provision of process heat must go hand in hand with the phasing-out of subsidies for conventional energy sources, to achieve a comparative cost advantage in all areas. Under the conditions cited above, the United Nations Industrial Development Organization (UNIDO) specifies a reduction of approximately 10 percent of worldwide greenhouse gas emissions or 25 percent of the industrial sector in 2050 that would occur from the forecast market development. In addition to short-term economic advantages through increased energy efficiency, this also emphasises a significant climate protection effect through more intensive use of renewable energies as part of the provision of process heat.

Under the impression of these emerging developments, this brochure provides examples of existing energy efficiency potential in Germany, information concerning technical and economic aspects in the selection of waste heat utilisation technologies, and information concerning integration of renewable energy technologies. Technical, economic, and ecological aspects are shown for companies that use these technologies – application examples, as well as the object of current research initiatives are provided to enable supplemental impressions in this regard.

Germany plays a key role, particularly in the area of energy research and development, such as the high-temperature solar technology, in contributing to the breakdown of worldwide technological and economic obstacles and in actively driving the establishment of international market standards.

1 IRENA, 2015
2 UNIDO, 2015
3 Heat quantities from heat pumps can only be considered as renewable if the power to operate the heat pump has been generated from EE power generating plants.

3 Location, industry sector and temperature level

Heat losses occur in many processes in industry and commerce. These losses are generally referred to as waste heat and they occur in almost every thermal or mechanical process. Accordingly, the bandwidth of possible waste heat sources is large. It extends from production equipment and motors to process heat and waste water, in which waste heat occurs, to compressed air, cooling systems and air conditioning equipment. Generally, waste heat is bound on specific carrier media, such as water or air, or it is diffused via the surface of a waste heat source. Although heat losses cannot be completely avoided through energy-efficient components, as well as economically optimal insulation and mode of operation, they can be considerably reduced through these measures.

The use of unavoidable waste heat from industrial processes in companies has extremely high potential for saving energy; after it is developed, this high potential not only has positive economic effects, it also has ecological effects as a result.

Waste heat is differentiated according to the temperature level present. In this regard distribution occurs in low temperature waste heat (< 150 °C); medium temperature waste heat (150–500 °C), as well as high-temperature waste heat (> 500 °C). To this point in time the greatest unused waste heat potential in Germany, is in the industrial area. Particularly for extremely heat-intensive production processes, frequently waste heat occurs where useful energy generated through use of energy is given off to the environment as energy loss in the form of industrial waste heat.

In Table 1 several industry sectors are listed, as well as the levels of waste heat temperature that are present in these sectors.

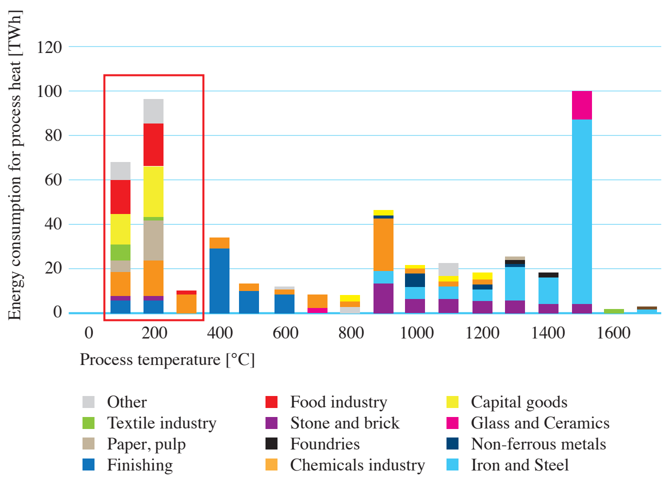
Table 1
Waste heat temperature level based on industry sector

Temperature level	Industry sector
High temperature (> 500 °C)	Pig iron industry, metal industry, glass industry, ceramic industry, stone industry
Mean temperature (150–500 °C)	Publishing and printing industry, paper industry, cement industry, plastics industry, textile industry, tobacco industry, food industry
Low temperature (< 150 °C)	In all industry sectors

Unavoidable waste heat quantities can be integrated in an economically effective manner in processes that require heat, directly or indirectly. Typical waste heat sinks in industrial areas and commercial operations for which heat is required, and in which waste heat can be used, are for example plants for room heating and hot water generation or for generating process heat. But even outside of an industrial operation, there are utilisation possibilities – such as the injection into local heating networks and district heating networks or the supply of a neighbouring company. Furthermore, excess waste heat can also be converted into other forms of useful energy, such as refrigeration or electricity. Thus numerous waste heat utilisation technologies are offered (see chapter 4 in this regard) to significantly increase the efficiency of the processes.[4]

As an example, Fig.1 below shows the demand for industrial process heat distributed over the process temperature levels and industry sectors in the Federal Republic of Germany for the year 1994. In Fig. 1 those industry sectors in Germany are marked in red that can be considered for a provision of heat with the aid of renewable energies, due to the low process temperature.

Fig. 1
Industrial process heat requirements in the Federal Republic of Germany, our own presentation based on[5]



The process heat demand for industry and business, as stated in the introduction makes up a considerable share of the energy consumption in industrialised countries. In Germany in this area just under 2,000 PJ are used every year, which is the approximate equivalent of 20 percent of the total energy requirement.

4 Source: dena, Waste Heat in Companies
5 Forschungsstelle für Energiewirtschaft, Munich, 1994

Approximately 30 percent of this requirement is in the temperature range below 200 °C, where suitable solar collectors are available on the market for provision of solar process heat.

There is a significant use potential for solar heat worldwide, particularly in the temperature range from 80 to 250 °C, but also above this level. An efficiency improvement on the consumption side should always be sought in the preliminary stage – non-concentrating solar collectors with minimised heat losses as well as concentrating, tracking solar collectors can provide the heat at these operating temperatures.

The question of integration of a solar collector system with accumulation in a heat or steam network is always linked to questions of regulation and process optimisation. For plants with thermal desalination, refrigeration, as well as solar power-heat(-cold) cogeneration a variety of optimisation possibilities are available. As a research institute in Germany, the Fraunhofer Institute for Solar Energy Systems ISE provides support in developing innovative collectors, plant configuration and process optimisation with system simulations and for monitoring installed plants.

In the Federal Republic of Germany the implementation area of **solar thermal energy plants** is restricted to low temperature processes, due to capacity of the collectors tied to the location conditions and also the use of highly efficient **heat pumps.** In some industries only minimal requirements are imposed on low-temperature applications, or high-temperature processes dominate, where use of waste heat is the more economically sensible alternative. Such processes are for example iron and steel production, production of glass, stone and soils, metal production and processing, pulp and paper industry and mechanical engineering (Müller 2004, page 147). With **biomass,** temperatures exceeding 800 °C can be reached, which enable implementation in the medium to high temperature range.

Several basic process engineering operations that require process heat in the low temperature range are used in different branches of industry (see Fig. 1) and they are particularly suited for the use of solar thermal energy or heat pumps. Table 2 below provides a summarizing overview of the respective industry sectors, processes and the temperature ranges necessary in this regard.

Table 2:
Industrial process heat based on temperature requirement[6]

Industry	Process
General	Washing
	Preheating
Food/beverage	Washing
	Boiling
	Pasteurising
	Sterilising
	Thickening
	Baking
	Heat-treatment
Metal	Paint stripping
	Galvanising
Textile industry	Washing
	Dyeing
	Bleaching
Wood	Drying
	Pressing
	Pickling
Chemicals	Var. processes
	Distilling
	Pressing
	Boiling
	Thickening
Paper industry	Bleaching
	Deinking
	Boiling
	Drying

Consumption of low-temperature heat is focused in the following industries and processes: Food and beverage industry (e.g. boiling and steaming processes), chemical industry, pulp and paper industry (boiling and drying processes), textile industry (dying, washing out, drying), capital goods industry (e.g. cleaning baths, paint booths, paint dryers) as well as services (laundry facilities).

6 Research based on AEE INTEC, 2005

4 Technologies, application areas and practical examples

4.1 Technologies for provision of process heat

A more energy-efficient provision of process heat, or even a provision of process heat based on renewable energies tends to become more difficult the higher the required process temperature. For efficiency reasons and cost reasons it is important to not select this temperature level higher than necessary.

For provision of process heat, worldwide predominantly fossil primary energy sources are combusted (natural gas or heating oil). High-temperature process heat is frequently generated with electrical energy. Other technical approaches for waste heat utilisation, as well as technologies for provision of renewable process heat at different temperature levels are briefly explained below.

4.1.1 Electric heat

High-temperature process heat is frequently generated with electrical energy (electric heat). For example, this can be systematically considered as less energy efficient than other processes in the preliminary stage, but for high temperatures often few practical alternatives are available (melting furnaces). Frequently electric heat is considered safer, compared with heat generation through combustion systems, since in this case, for example, flames do not occur and openings are not required for air supply and exhaust gas dissipation.

4.1.2 Energy-efficient burner and boiler technology

Savings potential can be achieved for heat supply systems in companies just by installing energy-efficient burner and boiler technology. The energy efficiency of an installation can be increased with the following burner or boiler types:

The principle of air-staged and fuel-staged mixed systems is used in **modern multi-fuel burner systems with internal exhaust gas circulation** for hot water and steam generation systems. By increasing the mix pressure, in addition the exit pulse of the air or air mixture flow escaping in the outlet zone, is increased in such a manner that an internal flue gas or combustion gas recirculation occurs in the combustion chamber. This results in an optimised and enlarged flame geometry that offers better thermal transmission to the surrounding combustion chamber and simultaneously reduces the flame temperature. Thus a significant reduction in nitrogen emissions (NO_x) is effected. Use of biogenic fuels is also possible in these systems. With the aid of speed-regulated operation power consumption for the burner motors can be lowered.

In **steam and hot water systems** in addition to classic boilers with high exhaust gas temperatures, today **condensing boilers** are increasingly used. Unlike traditional heating boilers, these boilers recover the heat contained in the exhaust gas via additional heat transfer surfaces. For example, the heat can be used for preheating service water or boiler feed water. For the condensing boilers the exhaust gas temperature is significantly lower. Condensing boilers are primarily interesting for installations with larger capacity and for retrofitting existing installations.

Waste heat boilers use the heat from exhaust gases (often also referred to as flue gases) from combustion processes or from hot exhaust air flows to generate hot water or steam. In this regard, the hot exhaust gas is routed through a pipe bundle in which it transfers its heat to the water in the body of the boiler.

The following **burners or processes** are particularly relevant for furnaces:

Recuperative and regenerative burners are highly efficient burners that use the exhaust gas heat directly for preheating the combustion air (heat recovery).

Flameless oxidation (FLOX®) is a highly-efficient burner technology that enables compliance with strict NO_x limit values even at high combustion air preheating temperatures.

Due to the high outflow speed of combustion gases for the **high speed or high pulse burners** internal return of the combustion chamber gases into the combustors or combustion chambers is ensured, and thus a uniform temperature distribution is ensured; these burners show better efficiency than conventional burners.

A **combustion with pure oxygen** offers several advantages over combustion with air: Combustion temperature and firing efficiency are clearly higher, because through combustion with pure oxygen the exhaust gas volume flow is reduced and thus the exhaust gas losses are also considerably lower.

4.1.3 Combined heat and power generation (CHP)

In the case of power generating plants with cogeneration, process heat can be provided as a by-product. In this regard however, the temperatures that can be achieved are more limited – frequently to under 100 °C. But there are exceptions, for example high-temperature fuel cells. Cogeneration is the simultaneous obtaining of power and heat that can be used for heating purposes (district heating or local heating) or for production processes (process heat) in a common thermodynamic process, usually in a cogeneration plant. Thus it is the extraction of useful energy, particularly for power generation. In most cases CHPs make heat available for the heating of public and private buildings, or they supply companies with process heat as industrial power plants (e.g. in the chemical industry).

Biogenic cogeneration (CHP) Example – Rittal International GmbH & Co. KG

At Rittal International GmbH & Co. KG, in the Rittershausen plant, a block heat and power plant fuelled by bio-oil with a capacity of 420 kW is operated for the basic heat load of the plant. Moreover, two catalytic exhaust gas cleaning system (KNVs) from the production are available as heat suppliers. The main heat customer is the painting unit; its pre-treatment basins must be kept at a constant temperature in summer and in winter. In winter heating the buildings is added as the biggest energy consumer. To optimise the system, in 2007 a multiple-boiler control was implemented at the location. In the course of implementation the primary and secondary circuit pumps were replaced with speed-regulated pumps. The volumetric flow measurement required for multiple boiler regulation was used in the primary circuit (heating system), the secondary circuit (secondary consumer) was decoupled through a hydraulic shunt. All energy efficiency measures together effect a lowering of energy consumption by approx. 1.3 m kWh and reduction of energy costs by approx € 270,000 per year. The measures package is very profitable with a return on investment of 44 percent.

- Reduction in gas consumption 8,056 MWh/year
- Bio-oil consumption for heat 6,720 MWh/year
- Absolute energy-savings 1,336 MWh/year
- Percentage of energy savings 9 %
- CO_2 reduction* 1,095 t/year
- Investments € 620,000
- Cost reduction € 270,670/year
- Return on investment 44%

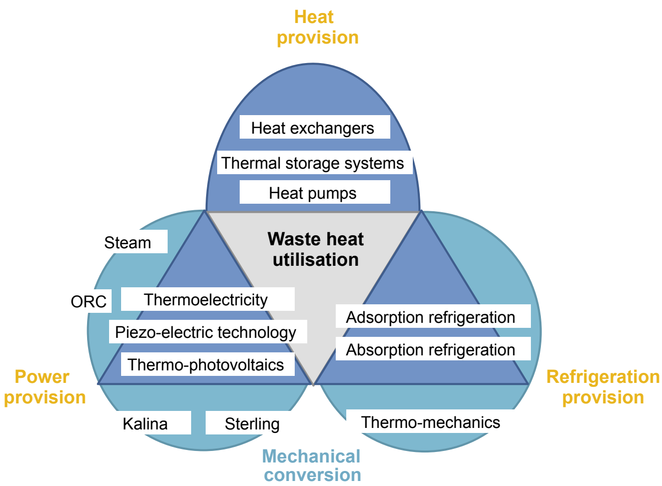
*According to Gemis, the following equivalence values serve as the basis for all examples: Natural gas 244 g CO_2/kWh, rapeseed oil 129.6 g CO_2/kWh (BioSt-NachV).

4.2 Waste heat utilisation technologies

Waste heat can be used to provide heat for thermal processes or to generate power or refrigeration. Two possibilities are present for provision of power and refrigeration: Waste heat is either converted directly, or mechanical energy is first generated via an intermediate step, which then drives an electric generator or a chiller (see the illustration below).[7]

The particular technologies are presented in more detail below.

Fig. 2
Technological approaches to waste heat use[8]



The thermal storage systems play an important role if waste heat accumulation and heat requirements are temporally uncoupled from each other. The technological approaches shown in the graphic will be explained in more detail in the following sections.

7 Frauenhofer ISI, 2012
8 Frauenhofer ISI, 2012

4.2.1 Heat recovery/heat displacement

Heat recovery or displacement is the most efficient and at the same time the simplest technological approach to waste heat use. For example, waste heat is extracted from an exhaust gas flow via a heat exchanger and transferred to a different medium. The heat transfer medium can be hot water, thermal oil, steam or a gaseous fluid. The transferred heat is transported via the heat transfer medium to available heat sinks, where it is further used. The heat transfer medium that is possible and the parameters (pressure, temperature, etc.) that are required depend on the available heat sources and heat sinks. Thus waste heat can be used to generate process heat in the form of steam or thermal oil, which substitutes for energy use. An additional application area can be the provision of heating energy. With use of firing devices in the production process the uncoupled waste heat can be used for example to preheat the combustion air, which results in savings of primary energy sources. As mentioned, waste heat use through direct heat recovery and heat displacement is characterised by extremely high efficiency. Losses are restricted solely to losses in thermal transmission.

Heat exchangers (heat transferrers) are used in many ways in industry. For many heat exchangers a hot and cold medium are fed past a common heat transmission surface simultaneously. The heat flow transferred through these heat transfer surfaces varies with the heat transfer coefficient of the heat exchanger, the size of the heat transmission surface, and the mean temperature differential between the two media. Based on design and mode of operation distinctions are made between different designs of heat exchangers (pipe bundle heat exchangers, plate heat exchangers, double-pipe heat exchangers, lamella heat exchangers, fin-tube heat exchangers, heat pipe heat exchangers, spiral heat exchangers, rotation heat exchangers, etc.). Combustion air preheaters are a special type of heat exchanger. They are implemented for use of waste heat in combustion exhaust gases to pre-heat the supplied combustion air. Since exhaust gas flows, in particular, often contain components, cleaning measures can be necessary to protect the heat exchanges from adhesions and clogs.

Heat recovery: Example – Textilveredlung an der Wiese GmbH

In 2007, the company Textilveredlung an der Wiese GmbH energetically modernised a steam generator in the textile finishing industry. Since energy efficiency of the heat generation had already been increased through implementation of O_2 regulation, it was possible to again significantly increase system efficiency by installing an economiser. In optimised operation with feed water preheating through the economiser, from this point on a waste gas temperature of merely 130 °C is achieved (formerly 230 °C). Exhaust gas losses can be reduced through this measure by 20 % at minimum load, and by approximately 45 % at full load. By retrofitting the steam boiler with an economiser, it was possible to lower annual fuel consumption by 3 %. Through this measure 850,000 kWh energy and € 34,000 operating costs per year can be saved at a high return on investment of 44 percent.

- Reduction in energy consumption 850,000 kWh/year
- Percentage of energy savings 3%
- CO_2 reduction* 207 t/year
- Investments €78,000
- Cost reduction €34,000/year
- Return on investment 44%

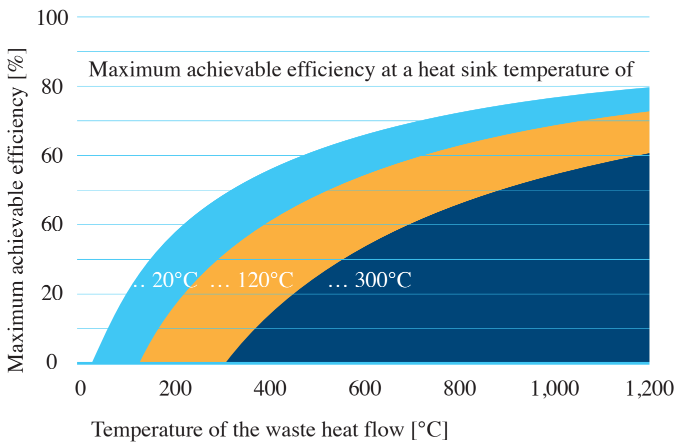
*According to Gemis, the following equivalent values are the basis for all examples: Natural gas 244 g CO_2/kWh.

4.2.2 Waste heat conversion into electricity

The conversion of waste heat into electricity in principle occurs in accordance with the concept of heat recovery introduced above. If heat sinks that can be covered with the useful energy generated from waste heat are not available in the company, waste heat can be used for conversion into electrical energy. Consequently, utilisation of waste heat should be considered below as an additional variant of waste heat use.

The thermodynamic maximum achievable efficiency of power generation for a closed cycle process depends on the temperature level of the waste heat sources and the heat sink. This is described through the Carnot efficiency value (Fig. 3 below). At a heat sink temperature of 20 °C for example, from a waste heat flow with a temperature of 70 °C, theoretically approximately 15 % of the energy carried in the heat flow can be converted into mechanical energy and then into electricity. On the other hand, if the temperature of the waste heat flow is 520 °C at the same temperature of the heat sink, this share increases to approximately 63 %. This shows that the theoretical efficiency for power generation is relatively minimal, particularly at low temperatures due to the thermodynamic conditions.

Fig. 3
Maximum efficiency of the conversion of waste heat into electricity depending on its temperature and the temperature of the heat sink[9]



Steam processes, organic Rankine cycle processes, Kalina processes, as well as Stirling processes can be cited as essential processes for conversion into electricity with a mechanical intermediate stage. The particular use of these processes depends on various factors, which particularly include the temperature level of the waste heat source.

1. **Steam processes** on the basis of the classic steam process (Clausius Rankine cycle process) are most frequently used to generate power from waste heat. In steam processes, water vapour is used to drive a steam turbine that is coupled to an electric generator. At temperatures in the range starting at approx. 350 °C, steam processes are considered to be the most efficient solution for conversion of waste heat into electricity. At lower temperatures the spatial requirements of the installations and overheating of the steam become more difficult. Consequently at lower temperatures, the ORC process and the Kalina process tend to be better suited for waste heat utilisation. The electrical efficiency of steam processes is specified at approx. 25 to 42 % at a temperature level of 250 to 540 °C.[10]

2. **ORC processes** (Organic Rankine Cycle processes) have the same functional structure as steam processes. However in ORC processes, organic liquids are used that boil at lower temperatures or pressures than water. Due to the lower operating temperatures efficiency of the ORC processes is lower as compared to that of the steam processes. The efficiency of ORC processes at temperatures from 70 to 350 °C is estimated at 10 to 20 %.[11]

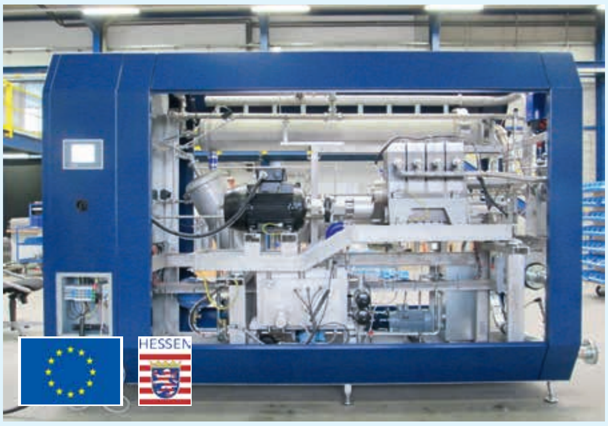
3. Unlike classic steam processes and ORC processes **Kalina processes** do not use a single work medium, but rather they use a mixture of ammonia and water. With evaporation of a single work medium the temperature remains constant, due to the mixture the temperature can increase during evaporation and can better adapt to the temperature level of heat flows and return cooling flows. Thus with Kalina processes higher efficiencies can be achieved. However, among other things, due to larger heat exchanger surfaces and a necessary material separation of ammonia and water Kalina processes are considered to be more complex than ORC processes.

4. **Stirling processes** use the expansion and contraction of a working gas under heat supply or heat withdrawal to drive a mechanical shaft. This shaft in turn is connected with an electric generator. Stirling motors are considered to be quiet and low-maintenance machines for waste heat use that can generate high torque even at low rotational speeds. In conjunction with temperatures between 650 and 1,000 °C an efficiency of 13 to 23 % is specified.[12]

9 Fraunhofer ISI, 2012

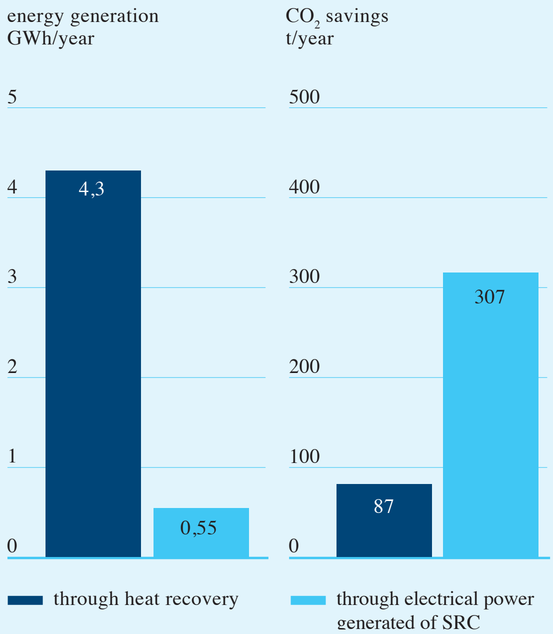
10 SAENA 2012
11 SAENA 2012
12 SAENA 2012

Waste heat conversion (steam process) and heat recovery in one process: Example – Volkswagen AG



At its Kassel location Volkswagen AG has approximately 16,000 employees and manufacturers a broad range of vehicle components. As part of the energy optimisation measures, high-temperature waste heat conversion installations have been integrated in the process of the roller hearth furnaces. A specially developed Steam Rankine Cycle plant (SRC plant) works with water as the medium, to exploit a specific use of the waste heat potential in the heat treatment process on a high temperature level. The up to 400 °C water vapour is expanded via a piston expansion motor in order to then produce power with a generator. In addition, the residual heat is used for room heating or as technical heat. Through the use of SRC technology 5 GWh waste heat per year can be converted into 0.5 GWh of electricity. Simultaneously 4.3 GWh heat can be recovered for thermal use.

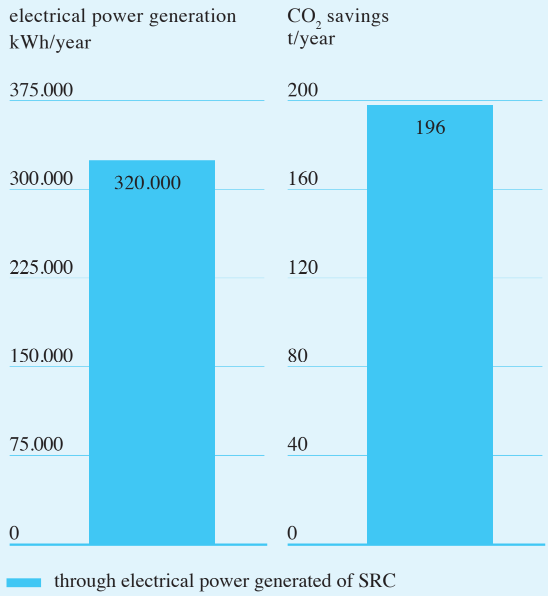
- Cost savings* € 230,000/a
- Investments € 768,000
- Internal rate of return 30 %/a



Modular Organic Rankine Cycle use at an SME: Example – Conrad Liphard & Söhne GmbH

Conrad Liphard & Söhne GmbH is a company in the ceramics industry; with approximately 80 employees the firm manufactures tiles for industrial ovens and tiled stoves and technical ceramics for high-performance turbines. In the company a lot of waste heat accumulates particularly for the ceramic ovens. To use this, on one waste heat source, two ORC modules (ePacks) with electrical power of 40 kW are installed. The ePacks (ePack stacks) can be operated individually or they can be interconnected modularly. The ORC modules make it possible to generate at least 320,000 kWh of power annually from the waste heat of one ceramic oven. This results in cost savings of more than € 50,000 a year for procurement of electricity.

- Cost savings* € 238,000/a
- Investments € 790,000
- Internal rate of return 30 %/a



*Assumed power price: 0.15 €/kWh, assumed gas price: 0.04 €/kWh.

4.2.3 Waste heat conversion into cooling and air conditioning

The cooling or the air conditioning of buildings or processes can also be realised with waste heat. To do this, waste heat is extracted to transfer low-temperature heat on a heat transfer medium. The low-temperature heat that is made usable can then be used in a sorption refrigeration unit to generate cold water. In the sorption refrigeration units cold water is generated through absorption or adsorption processes that is available for other useful purposes. Thus refrigeration from conventional compression refrigeration units and their power requirement can be substituted.

If, for example, there is no heat requirement in the company or if the existing heat requirement cannot be practically covered from waste heat, in addition to provision of heat, provision of refrigeration from waste heat can also be considered. Thermally driven methods of refrigeration provision can be differentiated as thermal mechanical methods and sorption methods:

Sorption-based refrigeration: The sorption-based methods of refrigeration generation are based on a reversible agglomeration of a working material on a sorbent. Absorption refrigerating machines and adsorption refrigerating machines are differentiated depending on whether the agglomeration occurs on a liquid medium or solid medium.

Absorption refrigerating machines work with waste heat temperatures in the range of approximately 80 to 160 °C, and depending on the waste heat temperature, tages of the refrigeration unit and coolant/sorbent used, typically achieve refrigeration temperatures of 5 °C (material pair: Water-lithium bromide) down to temperatures under 0 % (material pair: Ammonia and water). The COP as ratio of refrigeration and drive heat capacity is in a typical range of 0.30 to 1.2.

Thermo-mechanical refrigeration: The methods of thermo-mechanical provision of refrigeration are based on conversion of thermal energy into mechanical energy. Mechanical energy is either provided separately by the refrigeration unit and used to operate a classic refrigeration compressor, or conversion is integrated, e.g. in the steam jet ejector chiller. In the case of steam jet refrigeration, a jet compressor replaces the classic compression refrigeration unit to increase the pressure level of the refrigerant in the circulation process.

In adsorption refrigeration units water is frequently used as the refrigerant; the water is reversibly bound on a solid, such as silica gel or zeolite. The typical drive temperatures of adsorption refrigeration units is lower than the minimum drive temperatures for absorption refrigeration units and is specified at 60 to 95 °C. The COP of the adsorption refrigeration units is in the range between 0.4 and 0.7.

Generating refrigeration from the exhaust gas of a block heat and power plant (CHP): Example – Gropper Dairy

The Gropper Dairy is an owner-managed company headquartered in Bissingen that produces milk and dairy products, as well as fruit juice beverages and employs approximately 500 people. Since 2012/2013 the dairy has operated two natural gas block heat and power plants (CHPs). These make power as well as heat available for thermal processes in production. The exhaust gas heat of the CHPs is used to preheat the feed water and to generate steam. The remaining exhaust gas heat and the motor cooling heat of the CHPs are additionally used to operate two ammonia/water absorption refrigeration units. Depending on the season, these generate between 500 and 800 kW of refrigeration; annually this corresponds to 9.6 GWh. With this process the company saves € 515,000 a year. Overall the CHPs generate 34 GWh of power, 19 GWh steam and 9.6 GWh of refrigeration from 86 GWh of natural gas.

- CO_2 reduction 930 t/year
- Cost savings € 515,000/a
- Investments € 1,700,000
- Internal rate of return 30 %/a

4.2.4 Waste heat utilisation via heat pumps

With a supply of energy, heat pumps allow a change (increase) in the temperature level of industrial waste heat flows. Compression heat pumps and sorption-based heat pumps are differentiated based on their design:

Compression heat pumps use mechanical energy as drive energy for a mechanical compressor that changes the pressure level of a refrigerant. Pressure-dependency of the boiling temperature of the refrigerant can be used for a temperature increase of the available waste heat. The temperatures that these heat pumps can reach are specified at approximately 65 °C, for special solutions at up to 90 °C. The efficiency of compression heat pumps is referred to as the coefficient of performance (COP) and is described as the ratio of the usable thermal output based on the electrical energy used. The coefficient of performance of typical compression heat pumps is in the area between 3.5 and 6 (see SAENA 2012).

Sorption heat pumps have a thermally operated compressor instead of a mechanically operated compressor, which is driven through thermal energy of a high-temperature heat source (e.g. gas burner, high-temperature waste heat). These heat pumps use a solvent or an adsorption medium for the absorption or adsorption process of a refrigerant, to increase the temperature level of the supplied waste heat.

For absorption-based heat pumps the maximum temperature level for the generated hot water is specified at approx. 65 %. For adsorption-based heat pumps a temperature of up to 300 °C is considered as realisable. The efficiency of sorption heat pumps is described through the primary energy ratio. It reflects the ratio of drive heat used to useful heat. For sorption heat pumps, as orientation value a primary energy ratio in the range of 1.3 to 1.6 is specified (see SAENA 2012).

Waste heat use with the aid of a temperature boost through heat pumps: Example – Roth Werke GmbH

Roth Werke GmbH is a manufacturer of energy systems and sanitary systems with subsidiaries around the world and approx. 1100 employees. In 2010, as part of energy optimisation of the heating for tank manufacturing, one of two oil boilers was shut down and replaced with three brine/water heat pumps (compression heat pumps). With the aid of these heat pumps process waste heat can be increased to a temperature level of approx. 50 °C and used for heating purposes. The heat pumps heat the manufacturing facility during production time. The oil boiler that is still available is only used now as peak load boiler. Through use of process waste heat with the aid of heat pumps it was possible to reduce energy consumption of the heating system by approx. 1.7 GWh a year. Through operation of the heat pumps with cooling water from the production process the refrigeration unit was additionally offloaded by 21 percent.

- Cost savings €150,350/a
- Investments €250,000
- Internal rate of return 60 %/a

4.3 Renewable energy technologies

4.3.1 Biomass plants

With **biomass plants,** temperatures exceeding 800 °C can be reached, which enables implementation in the medium to high temperature range. Consequently, for the future, the provision of process heat, particularly through use of biomass, is projected to offer the greatest potential among the renewable energies by the 2050 (37 EJ/a); this corresponds to 74 percent of the total potential of 50 EJ/a.

Load profile and temperature level of the consumer have a crucial influence on the expected heat requirement for a process. The planning of a biomass plant is critical for the efficiency of the entire process. This also includes selection of the required storage tank capacity. Depending on the required temperature level and the heat quantity, other heat generators can be effective (e.g. a solar thermal energy system) or the biomass plant is used in an existing process to cover a specific temperature range in the overall process. If heat generated by the biomass plant is used directly for one or more consumers, it should be checked in advance whether in the near future, changes in the mode of operation, the operating times, or the plant technology used (of the process as well as the conventional heat supply) are likely. Good indicators in this regard are the efficiency standard, technical status, and the age of the plant technology used. If these indicators lag significantly behind the state of the technology, this can strongly increase the likelihood that the plant technology must be replaced within the next few years. Since under some circumstances temperature profile and load profile can change, these changes can have significant effects. Before commencing the project planning of a biomass plant, it should always be checked whether improvements in the efficiency and of the final energy consumption of a process are possible through alternative or supplemental measures.

4.3.2 Geothermal cogeneration plants

Geothermal power plants in Germany are always cogeneration plants; the customer structure decides if and to what extent the heat can be used. Here industrial processes represent a suitable form of use. At the temperatures that are usual for Germany, the heat output for geothermal power plants is approx. ten times greater than the electrical output. Technically the heat extraction can be either parallel or sequential, or it can also be a mixed form. Heat extraction means additional heat production as a second product of a power plant. In general this technology is referred to as cogeneration. For geothermal power plants there are several possibilities for extracting heat that can also be used mixed or demand-driven:

- Separation in a power generating circuit and a heat use downstream of the first heat exchanger (parallel operation)
- Use of the water cooled downstream of the evaporator as heat source (cascading use)
- Use of the heat dissipation of the condenser (heat extraction in the narrower sense)

Through heat decoupling, the overall efficiency of the installation can be significantly increased relative to pure efficiency of conversion to electricity. Efficiencies greater than 90% are possible here.

4.3.3 Heat pumps

Large heat pumps can be used in industry and commerce to generate room heat and process heat, to provide district heating and local heating, and as already described, heat pumps can be used to exploit low-temperature waste heat from processes. Unlike small heat pumps, large heat pumps must be planned and configured individually for their particular implemenation area. Several manufacturers already offer standardised plants, however connection to an existing process or heat cycle in a company must in each case be executed individually by a planner.

Possible usable heat sources for the provision of process heat are:

- Geothermal energy (in this regard, also see the **following digression – geothermal probes)**
- Groundwater
- Industrial waste heat (air and liquids – also see in this regard **4.2.4 Waste heat use via heat pumps)**
- Wastewater.

Suitable areas of application are:

- Heat pumps for heating and heat recovery as a component of large air conditioning systems in office buildings and department stores.
- Heat pumps for simultaneous heating and cooling of rooms
- Heat pumps for exploitation of the low-temperature waste heat of processes
- Heat pump distillation apparatus for partial reuse of the evaporation energy employed
- Heat pumps as replacement of cooling towers with simultaneous provision of hot water

Currently the main applications of heat pumps in the industrial area are waste heat use for provision of hot service water and room heat. Sectors that have been identified as particularly suitable are metal processing, the food industry (e.g. dairies, breweries), chemicals industry, paper, wood and textile processing (Lambauer, 2008).

Digression – geothermal probes

Geothermal probes are closed pipe systems that are introduced into the ground in stakes of several meters in length or boreholes several hundred meters in depth. A circulating liquid withdraws the geothermal energy from the surrounding soil. With a heat pump the heat is withdrawn from the probe circuit, brought up to a higher temperature level and used to heat buildings. In the summer geothermal probes can be used to cool buildings by driving the geothermal probe circuit without use of the heat pump. Thus power-consuming air conditioners for cooling rooms can be dispensed with. Geothermal probes are primarily used for exploitation of the near-surface geothermal energy (to 400 m). Use of geothermal probes is also possible for exploitation of deep geothermal energy. These function in the same manner as described above. However in this case the boreholes can be as much as several thousand meters deep. Temperatures that can be achieved are thus higher than they are for exploitation of near-surface geothermal energy. To ensure that heat loss at upward transport of the water remains minimal, the rising conveyor pipe run is thermally insulated. Through heat pumps the thermal energy obtained can be boosted to an even higher temperature level. Deep geothermal probes are primarily used for provision of heating energy that is injected into local heating networks or is used as process heat.

4.3.4 Solar thermal plants/solar process heat

An additional heat source for process temperatures that are not too high (80 to 250 °C) are solar collectors. Due to non-continuous availability of solar energy, solar collectors are frequently used in combination with other heat sources (such as burners). However, it is also possible to execute certain drying processes in sunny weather only (e.g. in the agriculture sector). Moreover, there are solar installations with concentrating mirror fields that bundle sunlight and can generate extremely high temperatures of 400°C and above. Concentrating solar collector systems are particularly well-suited for generation of process heat and for power generation in climate zones of the earth where there is high direct sunlight potential – in this case as well the combination with other heat sources (such as burners) or large heat accumulators is used. The Earth's so-called sunbelt extends north and south of the equator and includes Southern Europe, North Africa and the great deserts of our planet.[13]

One example of a solar heat, refrigeration and steam supply is given by a system from the German company SOLITEM installed at a Turkish Hotel in Dalaman. The award-winning plant concept (R.I.O. Innovation Award, Energy Globe Award, Global 100 Eco-Tech Award and Solar Prize 2005 from EUROSOLAR) with 20 parabolic trough collectors makes thermal capacities up to 100 kW available in pure steam supply operation or refrigeration capacities up to 130 kW. Both supply ranges are also possible in partial load operation. Through bivalent operation of the installation, in summer the process heat consumers or the two-stage absorption refrigeration unit that feeds the cooling circuit are supplied with steam. In winter the collectors heat the rooms and thus support fossile steam generation with the aid of solar energy.[14]

Due to high basic loads, at least a portion of the heat requirements can be covered with the aid of solar collectors for industrial processes, in particular in the low voltage temperature range. By 2008, worldwide approx. 90 projects with a total of 25 MWth were in operation for industrial applications.

For a temperature range to 80 °C there are a number of flat tube and vacuum tube collectors available on the market that can be used for direct heating of low-temperature processes. On the other hand, collectors that are optimised for the temperature range of 100–250 °C are required for injection into a heating circuit or for the heating of processes with higher temperatures. These are vacuum tube and high-performance flat collectors, CPC collectors, small parabolic trough or Fresnel collectors.

Only a small proportion of 0.02 % of the solar capacity installed worldwide is used to provide process heat (Lauterbach 2009, page 4).

13 FVEE, 2005
14 FVEE, 2005

Note:
Detailed information concerning process heat collectors for the temperature range from 80-250°C is provided in the brochure „Process Heat Collectors", which was prepared as part of IES-SHC Task 33/IV (Weiss 2008).

Integration of solar thermal systems

When configuring solar-thermal systems the temporal course of the heat requirements is the key factor. Heat requirements should always exist when the collector field delivers heat, or if the heat can be buffered for a short time. Stagnation should be avoided because the heat transfer medium and the components in the collector circuit are exposed to significant stress due to the high standstill temperatures.

In industrial processes air, water, or steam can be used as heat transfer media. There are different possibilities of coupling solar heat into a process. A coupling of heat generated with flat collectors at a low or medium temperature level is possible for preheating the cold water inflow of the boiler. For coupling directly into the hot water system, usually higher temperatures corresponding to the process are required, which can only be achieved with concentrating solar energy systems. Frequently solar energy systems can only be used to reduce the energy requirement of a process, because a conventional system must be present for heat generation.

The type of heat exchange is important for technically effective and economically effective integration. The device and regulating complexity increases with the number of heat exchanger circuits. With the simplest system the process medium flows directly through the collector and is heated there. However, this is only possible if the medium is non-corrosive and there is no danger of freezing. An additional possibility is a two circuit system in which the heat from the solar circuit is dissipated to the process medium via a heat exchanger. For example, this is used to heat galvanic basins. These two methods can be used for continuous process control, where a part of the base load is covered by the solar energy system and the rest is covered through conventional systems. The greatest technical complexity occurs for systems with heat accumulators. Through storage of excess energy (e.g. in the case of discontinuous processes) the degree of solar coverage can be increased. However system costs increase and the system losses are higher. The decisions associated with dimensioning of a solar energy system – i.e. if the highest possible degree of solar coverage should be achieved, and any over-capacities should be accepted, or if the system is configured smaller so that all energy can be used - must be made on the basis of a profitability calculation.

Case Study for beverage industry – Solarlite CSP Technology GmbH)

A beverage plant in Southern Europe manufactures on average 6,000,000 hectolitres of drinks every year. Due to the constantly fluctuating and rising price of gas, the issue of energy costs is a priority for the company.

How energy is supplied
The annual energy requirement of around 92 GWh thermal is provided by using two steam boilers with a total capacity of 22.6 t/h. The boilers are fired using gas and supply saturated steam at 170 °C (8 bar). With 6,000 operating hours per year, gas consumption amounts to approximately 10.6 m m³. The cost for the annual gas requirement amounts to 4.98 m Euro which equates to almost 15 % of the beverage plant's total cost.

The requirements of the company
Due to the continued increase in energy costs despite of a number of energy efficiency measures, the beverage plant wants to adapt its energy supply in the long term. As direct solar radiation at the beverage production plant location is very high, solar energy is at the top of the list. The beverage plant is aiming to achieve a share of up to 50 %.

A simple solar steam solution lowers the costs substantially
In order to be able to supply full steam output at any given time, the solar proportion should amount to up to 50 % of the boiler capacity. 42 CSP collectors will be used to provide the required solar steam output of around 16 t/h.

The investment in solar energy pays for itself

Energy costs/year	Energy consumption/year
Without solar heat 4,982,102 €	Without solar heat 10,600,217 m³
With solar heat 4,198,984 €	With solar heat 8,934,009 m³
Savings 783,118 €	Savings 1,666,208 m³
Savings in total with a lifetime of 25 years 31,674,118 €	Percentage energy saving (gas) 15%

Investment:	7,638,132 €	Return on investment 16,5%
Savings:	31,674,118 €	with a lifetime of 25 years
Capital value:	4,572,538 €	Levelized cost of energy (LCOE): 3,1 Cent/kWh$_{th}$

CO_2 saving per year: 3,202 t

CO_2 saving after 25 years of operation: 80,050 t

Project plan: Construction of a solar thermal energy system (solar boiler) for generating industrial process steam for a hotel laundry facility in El Gouna, Egypt

PROTARGET AG of Cologne specializes in the development, manufacturing and construction of modular solar thermal energy plants to supply industrial operations with process heat and steam.

Together with an Egyptian hotel operator, PROTARGET wants to build a solar boiler system in the seaside resort El Gouna, to supply the hotel's central laundry facility with steam. With a capacity of 15 tons of hotel laundry per day – this corresponds to 20,000 towels and 17,000 sets of bed linen a day – the laundry facility requires 2 tons of steam an hour. To this point in time this is generated in a conventional steam boiler, which for this purpose is fired with approximately 700 tons of heavy oil (HFO) per year.

Through operation of the solar thermal energy system in parallel with the existing boiler system, fuel consumption of the laundry facility drops by 80%; this results in a reduction of the CO_2 emissions of 1,700 tons a year. Furthermore, avoidance of the heavy oil with high sulphur content results in an annual 34 ton reduction in sulphur dioxide emissions.

Since heavy oil is still highly subsidised in Egypt at an actual fuel price of only € 0.20 per litre, the investment is amortised in 10 years. However, the Egyptian government has announced that they will massively reduce the subsidies in years to come. Thus this project would be a highly visible example for a number of possible applications within the tourism sector that is so important for Egypt.

The hotel operator will participate in the project with € 360,000 of his own capital (30 %). A suitable financing possibility is sought for the remaining € 840,000 (70 %).

Project description:
- Construction of a solar thermal energy system (solar boiler) for generating industrial process steam

Project parameters:
- Total project costs: € 1.2 m
- Capacity: 1.5 MW_{th}
- Financing: 30 % equity / 70 % debt
- Financing requirements: 70 %
- Participating companies: protarget AG, hotel operator

Advantages:
- CO_2 savings: 1,700 tons p.a.
- Fuel savings: 560 tons p.a.

Solar potential:
- 40 % of the entire energy requirement in the MENA region is used for generation of steam. This corresponds to 113 TWh/ p.a. (Source DLR 2012)

5 Economic aspects

5.1 Systematic investigation of existing waste heat sources

A systematic investigation of existing waste heat sources is the foundation of successful integration. Knowledge of waste heat sources improves the overview of the energy flows in a company and permits selection of a suitable utilisation technology.

Appraising the situation in the company

If the intent is to make waste heat usable for the company, an analysis of energy consumption and processes is necessary. To do this, all energy consumers are identified and characterised, and the processes that are relevant for energy consumption are evaluated. The result shows what waste heat in the firm is avoidable, where waste heat that cannot be avoided accumulates, and at what points this waste heat can be used to cover energy requirements.

Avoidance of waste heat

The principle is: First avoid, then use! Often waste heat quantities can be reduced or completely avoided through optimisation of the underlying processes and methods. The following questions offer starting points for effective optimisation:

- **Dimensioning:** Is the underlying process correctly dimensioned or are there unnecessary overcapacities? Can unnecessary heat-up or cool-down phases be avoided?
- **Control:** Is the plant or process controlled correctly? Are inefficient operating points or idle-running present and avoidable?
- **Temperature level:** Is the currently selected temperature level really necessary? Or can the process also be run at lower temperatures?
- **Insulation:** Can better insulation reduce heat loss of the equipment and reduce the waste heat quantity? Likewise, is a greater insulating layer thickness also economical?
- **Maintenance:** Is the plant adequately maintained?
- **Alternatives:** Are there alternative processes that are energetically more advantageous that can achieve the same result?

Identifying unavoidable waste heat

After successful minimisation of waste heat quantity the focus of possible measures is placed on the non-avoidable waste heat sources in the firm. Non-avoidable waste heat sources should be uniquely identified and intensively investigated, in order to allocate appropriate characteristic values to each individual waste heat source. Characteristic values are: Temperature level, capacity, medium of the waste heat, (e.g. exhaust gas, cooling water), temporal availabilities (continuously or fluctuating, seasonal, number of full-load hours per year), available energy quantities and position.

Examination of waste heat sinks

In the next step available waste heat sinks in the firm are identified, investigated and likewise categorised. Thus it is possible to assess which waste heat sink can be assigned to which waste heat source. The following characteristic values should be determined for waste heat sinks: Temperature level, capacity, medium of the waste heat, (e.g. exhaust gas, heating water), temporal requirements (continuous or fluctuating, seasonal, number of full-load hours per year), available energy quantities and position.

5.2 Waste heat utilisation factors

Waste heat utilisation as a measure for improvement of industrial energy efficiency takes on somewhat of a special role, because it should only be considered after the causes of a waste heat development have been reduced to a minimum. The reason for this is that accumulating quantities of waste heat can only be incompletely used in practice, and thus a portion of the energy originally used will always be lost unused. On the other hand, if energy requirements of the underlying processes are reduced at the outset, the corresponding energy quantity will be completely saved. Waste heat utilisation can easily result in the situation that inefficiencies in existing processes are hidden and losses are stabilised, since each later improvement also reduces the available waste heat capacity (see Pehnt et al. 2010).

For preliminary considerations in the decision-making process to determine the technical measure that can be used for a possible waste heat utilisation, there are different criteria to restrict the selection.

- The **temperature level** of the available waste heat source is one of the most important factors in selecting the appropriate technology for industrial utilisation of waste heat. In general it can be stated that conversion into electricity is usually only practical at medium temperature and high-temperature waste heat. Low temperature waste heat can be used for heat pumps, refrigeration units and heat transformation. Heat recovery and heat displacement are also possible at low temperature levels.
- **Waste heat capacity** is authoritative for the size of the apparatus and the economic practicality of waste heat utilisation. The higher the available waste heat capacity, the higher the useful energy that will be obtained. The waste heat capacity to be selected mainly depends on the following factors: Volumetric flow (exhaust gas, fluid) temperature upstream of

the heat exchanger, possible temperature downstream from the heat exchanger, as well as material composition of the exhaust gas/fluid. The waste heat capacity can be determined from the temperature differential upstream and downstream of the heat exchanger, in conjunction with the volumetric flow. Composition of the exhaust gas/fluid also decides on the energy content of the exhaust gas/fluid and thus also on the heat capacity that can be extracted. In addition, the composition can contain corrosive substances that must be considered when selecting the material of the heat exchanger, and that can have an effect on investment costs.

- **Simultaneity of potential and requirements:** For optimal and easy industrial waste heat use it is advantageous if the provision of heat through waste heat is in harmony with the requirements for process heat. Otherwise storage media must be used as buffer. For waste heat conversion into electricity buffering does not make economic sense. Consequently, if there is insufficient withdrawal of the electrical power, the excess power is injected into the public grid. Generally partial load operation of the waste heat utilisation system is also possible.
- The **useful life** of the waste heat utilisation system depends directly on the availability of the waste heat source. A continuous useful life that is as long as possible is important for economical operation of the waste heat utilisation system. The financial expenditures for the waste heat utilisation system are refinanced through the quantity of useful energy obtained. This means, the longer the useful life the shorter the amortisation period of the system. Because of discontinuous availability of the waste heat, there are increased start-up and ramp-down procedures. Thus the material is exposed to increased thermal stress. Accordingly this can result in increased expenses for maintenance and repair of the waste heat utilisation system.
- **Other factors:** In addition to the factors cited above there are other factors that influence the energy efficiency and economic selection of technology. These factors include the spatial conditions on site. The waste heat source preferably should be close to the heat sink, to keep investment costs as low as possible. Bundling is an additional factor. Bundled waste heat can be obtained as useful energy much more easily and more cost effectively than energy that is given off through diffusion.

5.3 Advantages of waste heat utilisation

Ecologically considered, useful energy provided from waste heat is useful energy obtained in a manner that is CO_2-neutral. For conversion into useful energy, additional primary energy sources are not required (with the exception of heat pumps). Another ecological aspect is the fact that the useful energy obtained substitutes for energy from other energy sources that require primary energy sources for conversion. Through this substitution, primary energy use decreases for generation of process heat, power or heating energy, for example. This substitution of useful energy also has economic effects. Through the savings in thermal or electrical energy, that would otherwise have to be provided through alternative generation, it is possible to save the costs for fuel or electrical power. Frequently energy costs constitute an important cost factor and significantly influence the competitive ability of producing companies on the world market. As opposed to energy procurement from public sources, costs for conversion of waste heat into useful energy can be calculated over the long term. This reduces dependency on the energy market at the particular production site and the risk of price increases that cannot be calculated. Furthermore, provision of process heat through waste heat utilisation can result in a reduced number of required CO_2 certificates, and this in turn results in cost savings.

Waste heat utilisation involves various advantages and disadvantages for companies. The points below (also see U.S. DOE 2008; Arzbaecher et al. 2007) speak in favour of waste heat utilisation:

- A reduction in energy requirements, i.e. energy costs
- An accompanying improvement in productivity
- A reduction in environmental pollution
- A greater independence from the external energy supply and
- Lower expenses for heating and recooling systems, if waste heat can be used continuously and reliably.

Furthermore, waste heat utilisation can contribute to the public image of an enterprise as a particularly environmental-friendly company, and it promotes a better understanding in the company of the existing energy flows.

However, there are also several disadvantages associated with waste heat utilisation that must be cited (for example, also see SAENA 2012):

- Waste heat utilisation requires additional costs and competencies for the procurement, maintenance, and operation of the appropriate system technology

- By coupling systems and processes in a waste-heat composite, reciprocal dependences are created, which can be problematic in the event of failures or restructuring
- Reserve infrastructure must possibly be kept ready if parts of the waste heat composite fail (reserve heat sink, reserve heat source)
- The required install space and increasing competence requirements for the additional plant technology must be taken into account and
- Additional approvals and verifications of the system technology may be necessary.

Consequently these points must be taken into account when considering the use of waste heat.

5.4 Challenges associated with solar process heat

Because heat cannot be transported over long distances with low losses, only those locations are suitable for provision of solar process heat where favourable irradiation conditions, as well sufficient areas for set-up of collectors are available (e.g. in the MENA region). For configuration and system integration of a solar collector field as heat generator, as described above in the brochure, necessary process temperatures have a significantly stronger influence than they do in conventional generation plants.

- Basically, generated solar heat can be coupled into a heat supply system of an industrial user or it can be coupled directly into an industrial process. However, because the efficiency of solar collectors decreases with increasing temperature, for the integration of solar process heat a **temperature level** that is as low as possible is advantageous. **Particularly in this case, as described, frequently waste heat from other processes or cogeneration can be used.**
- Therefore, to determine the optimal temperature level for utilisation of solar heat, **process integration methods** are recommended.
- Fluctuating daytime and seasonal, as well as weather-dependent **availability of solar radiation** is a challenge for provision of solar process heat. To avoid production deficiencies or failures, radiation fluctuations must be buffered though appropriate heat accumulation systems. As a rule, to bridge longer periods of low radiation, a one-hundred percent, conventional reserve capacity must be on hand. Consequently, investment in the solar energy plant does not bring about a reduction of the conventional section of the plant, and the solar energy plant must be amortised solely through the achieved fuel savings. At today‘s fuel prices this represents a hurdle for the profitability of such investments.
- **Simultaneity of potential and requirement:** To achieve a high level of fuel savings the objective is to reach degrees of solar coverage that are as high as possible. Preferably heat requirements and solar supply should temporally correlate. Frequently this is the case for cooling or air conditioning, and for users with pure daytime operations.
- These brief considerations make it clear that there is no „typical“ process heat application. But rather custom-solutions are sought that are matched to the **plant size, requirements profile, heat transfer medium and temperature level** of the particular processes. The **associated consulting and planning effort** poses a considerable challenge for widespread market development[15].

5.5 Advantages of a renewable provision of process heat

With the aid of renewables, use of conventional primary energy sources is reduced, and in the ideal case completely replaced. Through this substitution, primary energy use decreases for generation of process heat, power or heating energy, for example. This substitution also has economic effects. Through alternative generation, as shown, fuel costs can be saved. Frequently energy costs constitute an important cost factor and significantly influence the competitive ability of producing companies on the world market. As opposed to energy procurement from public sources, costs for process heat provision with the aid of renewable energies can be calculated over the long term. This reduces dependency on the energy market at the particular production site and the risk of price increases that cannot be calculated. Furthermore, (partial) provision of process heat through renewable energies can result in a reduced number of required CO_2 certificates, which in turn results in cost savings. Ecologically considered, process heat provided from renewable heat sources is useful energy obtained in a manner that is CO_2-neutral.

15 To accept and meet this challenge, an IEA Task (33/IV) was established in the International Energy Agency as early as 2003. Experts from many countries work together in this ongoing cooperation. Additional information is provided at http://www.iea-ship.org.

6 Research initiatives

The German government promotes the expansion of process heat utilisation in industry through several research programs.

The research initiative „Energy efficiency in industry, the trades, retail and for services (EnEff:Industrie)“[16] is part of the „6th energy research program „Research for an environmentally-friendly, reliable and affordable energy supply“ sponsored by the Federal Ministry for Economic Affairs and Energy (BMWi). The objective is not simply to drive the energy transition in the core of the German economy by promoting energy-efficient and resource-saving technologies, components and processes, but also to establish new technologies on the market. For this, explicit pilot and demonstration installations are supported for provision of research and development results. Research areas include more efficient technologies for use of industrial waste heat, innovative developments for thermal processes, optimisation of heat/refrigeration generation with electricity, energy-side and demand-side management, as well as new technologies for provision of refrigeration and heat on the basis of systems that are CFC-free and particularly energy-efficient.

EnEff:Industrie is accompanied by two additional research initiatives, „EnEff:Stadt“ and „EnEff:Wärme“ in the area of energy efficiency where applications can be found for process heat utilisation. For municipal development of districts and communities, these initiatives are focussed on the integration of holistic heat and refrigeration concepts. In this regard, the emphasis is on intelligent and future-safe solutions, such as cogeneration (CHP) and also the increased expansion of local heating and district heating networks.

In addition, there are a number of programs and initiatives that have specialised on specific industry segments or technologies and the associated issues for generation of process heat.
The International Energy Agency (IEA) has been pursuing Solar Heating and Cooling program (SHC) since 1977. Since 2012, under Task 49, „Solar Heat Integration in Industrial Processes (IEA-SHC Task 49)“ various approaches, such as research projects for collector development, process integration and intensification and monitoring, extending to pilot projects on the large industrial scale, to help provision of solar process heat reach a level of market maturity. In terms of content, Task 49 is directly connected to Task 33 „Solar Heat for Industrial Processes (SHIP)“ that many European countries had already participated in.

Likewise the Institut dezentrale Energietechnologien gemeinnützige GmbH (IdE) for solar process heat, in cooperation with the respective industry associations, promotes applications in the food industry via the program „SOLFOOD“. The program is subsidised by the Federal Ministry for Economic Affairs and Energy (BMWi) and has the goal of increasing awareness of the technology and developing its potential through case studies and preparation of planning manuals.

On the European level, the initiative „GREENFOODS“ among others is dealing with the same subject matter, which with the aid of energy audits and training programs for specialists is setting up a virtual European research network with best practice examples.

In the „SoProW“ project, the Fraunhofer Institute for Solar Energy systems (ISE) is involved with optimised generation and integration of solar process heat in laundry facilities, which likewise is subsidised by the Federal Ministry for Economic Affairs and Energy (BWMi). The project focuses on working out software-supported system simulations for industry concepts, in order to particularly improve forecasts concerning profitability with regard to investment security.

High-temperature thermal storage is also an object of current research in Germany as the following example illustrates:

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High-temperature thermal energy storage systems (HTTES)

STORASOL GmbH, located in Baden-Württemberg in the South-West of Germany, is designing, manufacturing and supplying high-temperature thermal energy storage systems (HTTES). If required STORASOL and its partners are providing the engineering and construction of the whole energy facility, including the parts for the conversion into thermal energy and/or electrical energy.

The energy storage technology of STORASOL is based on storage modules, which are using silica sand or small gravel as heat storage medium. The unique and novel solid bed arrangement of the storage material inside the modules is allowing lowest pressure loss with smallest energy own consumption, but at the same time highest thermal charging- and discharging-capacity. As heat carrier medium ambient air or flue gas is used. Of course other mediums can be used as well, adjustments of the system are easy to implement. Due to the modularity of the HTTES an up-scaling can be easily realized.

Recently a STORASOL-energy storage technology was commissioned in large scale at MW-level at the University of Bayreuth, Germany. In this HTTES-application high-temperature heat is stored at a level of up to 600 °C. With the heat recovered when discharging the energy storage modules, electricity is produced via an ORC-process (Organic Rankine Cycle). The amount of thermal energy to be stored in the two modules is up to 1,5 MWh_{th}, the charging/discharging capacity is up to 1,85 MW_{th}.

Picture: Photo of the HTTES-storage modules at University Bayreuth, Germany

Typical markets and applications for the STORASOL-HTTES are:

- Re-use/electricity production from industrial waste heat (ceramics, cement, glass, steel etc.)
- Process optimization via the re-use of anti-cyclic available heat
- Energy storage for solar thermal power plants
- Heat storage for compressed air storage systems (e.g. CAES)
- Intermediate storage for heat from difficult gases
- Energy efficiency optimization (e.g. CHP-plants)

STORASOL-HTTES-economics (examples):

- Industrial waste heat from a brick manufacturing facility in the amount of 6 MWh per day is stored in a STORASOL-HTTES and re-used in the dryer and replacing/saving natural gas.
  Financial figures example A: Investment 250.000 €, payback period 3 years, ROIC > 25 %.
- Industrial waste heat which is available for 6 hours per day with a thermal power of 10 MW is stored in a STORASOL-HTTES (60 MWh). The heat is re-used in a steam turbine with an electrical capacity of 750 kW_{el}, the steam turbine is approx. 20 hours per day in operation.
  Financial figures example B: Investment 3.300.000 €, Payback period 4 years, ROIC > 25 %.

7 Energy solutions – made in Germany

7.1. The Initiative

With energy prices on the rise and fossil fuel resources becoming scarce, both economic prosperity and competitiveness increasingly depend on our ability to use new energy sources and energy efficiency solutions.

This applies to all countries worldwide. The use of innovative energy solutions offers enormous potential for energy conservation in all fields.

The promotion of renewable energies and energy efficiency in Germany has resulted in the establishment of an industry which offers some of the world's leading technologies.

This industry encompasses several thousand small and medium-sized enterprises specialised in the development, design and production of renewable energy technologies, energy efficiency solutions, grids and storage. This is the basis for smart energy solutions.

Benefits of using renewable energies and energy efficiency
- Reduction of greenhouse gas emissions and contribution to climate change mitigation
- Contribution to innovation, growth and employment
- Independence from fossil fuel imports

The transfer of energy expertise, the promotion of foreign trade and the facilitation of international development cooperation are part of the German Energy Solutions Initiative.

The initiative creates benefits for Germany and the participating countries by:
- boosting global interest in renewable and smart energy efficiency technologies
- encouraging the use of renewables and energy efficiency technologies
- improving economic, techni- cal and political cooperation between Germany and partner countries
- generating jobs in Germany and abroad

Coordinated and financed by the German Federal Ministry for Economic Affairs and Energy (BMWi), the initiative is implemented in cooperation with partners such as German bilateral chambers of commerce (the AHKs), the German Energy Agency (dena) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

7.2 Renewable Energy Solutions Programme (RES)

Projects of the dena RES Programme are carried out worldwide and serve as flagship projects for renewable energy expertise in the fields of solar, wind, water, geothermal and biotechnology

All of the systems designed and implemented under this programme demonstrate the flexibility of German renewable energy technology and know-how while working under local conditions and meeting discerning user-specific requirements.

The programme, coordinated by dena, brings together growing international demand for German renewable energy technology and German companies with an interest in and the capacity to access attractive international markets. The close coordination of dena ensures the installation of unique, customised systems.

Furthermore, dena initiates and oversees the transfer of the specific technology and application know-how. Since 2004, 54 dena projects, in the area of solar technology, have been realised worldwide.

dena Solar Roofs Programme 2012/2013: Installation of Fresnel collector in Johannesburg

Together with its South-African partner REACH Renewable Pty Ltd., Industrial Solar GmbH has equipped the multinational telecom company Mobile Telecom Networks (MTN) with a solar thermal cooling system. A Fresnel collector with a thermal peak capacity of 272 kW_{th} was installed on the roof of the company's head office in Johannesburg. The collector powers a two-phase absorption cooling machine with a cooling capacity of 330 kW. The generated refrigeration is fed into the data centre's local district cooling system and used, among other purposes, for air conditioning or processor coolers. This reduces the use of fossil fuels, CO_2 emissions and electricity costs, especially in the hot summer months.

Installation of the system in Johannesburg

Solar thermal system data:	
Installed capacity:	272 kW_{th} (heat)
Module type:	Linear Fresnel LF 11
Absorber pipe:	SCHOTT PTR 70
Fresnel collectors:	2 lines of 11 modules each
Aperture surface:	484 m^2
Annual yield:	390 MW_{th} (heat)
Reduction in CO_2 emissions:	47,000 kg/year

The inauguration ceremony took place on 9 July 2014 in the presence of local politicians and media representatives, the German Embassy, the Deutsche Energie-Agentur (dena) – the German Energy Agency – and Industrial Solar GmbH.

Inauguration ceremony for the solar thermal cooling system: first row, from left to right: Brandon Gombert (MTN), Gabriele Eichner (dena), Andreas Kuenne (German Embassy SA), Frank Major (REACH Renewable); back row: Cristian Cernat (Voltas Technologies), Tobias Schwind (Industrial Solar), Willem Weber (MTN), Olu Soluade (AOS).

8 Addresses of institutions/associations

8.1 Energy Efficiency

AGFW – Der Energieeffizienzverband für Wärme, Kälte und KWK e.V.
(District Heating and Cooling and Combined Heat and Power (CHP) Association)
Stresemannallee 30, 60596 Frankfurt am Main, Germany
phone: +49 (0)69 6304-1

BDEW – Bundesverband der Energie- und Wasserwirtschaft e.V.
(German Association of Energy and Water Industries)
Reinhardtstraße 32, 10117 Berlin, Germany
phone +49 (0)30 72300199-0
fax +49 (0)30 300199-3900
E-Mail info@bdew.de
www.bdew.de/internet.nsf/id/EN_Home

BDH – Bundesverband der deutschen Heizungsindustrie
(Federation of German Heating Industry)
Frankfurter Straße 720-726, 51145 Cologne, Germany
phone: +49 (0)2203 93593-0
fax: +49 (0)2203 93593-22
E-Mail: info@bdh-koeln.de
www.bdh-koeln.de

BDI – Bundesverband der Deutschen Industrie e.V.
(Federation of German Industries)
Breite Straße 29, 10178 Berlin, Germany
phone: +49 (0)30 2028-0
fax: +49 (0)30 2028-2450
E-Mail: info@bdi.eu
www.bdi.eu

BWP – Bundesverband Wärmepumpe e.V.
(German Heat Pump Association)
Französische Straße 47,10117 Berlin, Germany
phone: +49 (0)30 208799711
fax: +49 (0)30 208799712
E-Mail: info@waermepumpe.de
www.waermepumpe.de

DENEFF – Deutsche Unternehmensinitiative Energieeffizienz e.V.
(German Industry Initiative for Energy Efficiency)
Kirchstraße 21, 10557 Berlin, Germany
phone: +49 (0)30 364097-01
fax: +49 (0)30 364097-42
E-Mail: info(at)deneff.org
www.deneff.org

HDB – Hauptverband der Deutschen Bauindustrie, Fachverband Wärme-, Kälte-, Schall- & Brandschutz
(German Construction Industry Federation, Professional Association for Thermal Insulation, Low Temperature Protection, Soundproofing and Fire Safety)
Kurfürstenstraße 129, 10785 Berlin, Germany
phone: +49 (0)30 21286-0
fax: +49 (0)30 21286-240
E-Mail: info@bauindustrie.de
www.bauindustrie.de

VBI – Verband Beratender Ingenieure
(German Association of Consulting Engineers)
Budapester Straße 31,10787 Berlin, Germany
phone: +49 (0)30 26062-0
fax: +49 (0) 3026062-100
E-Mail: vbi@vbi.de
www.vbi.de

VDE – Verband der Elektrotechnik, Elektronik, Informationstechnik e.V.
(Association for Electrical, Electronic & Information Technologies)
Stresemannallee 15, 60596 Frankfurt am Main, Germany
phone: +49 (0)69 6308-0
fax: +49 (0)69 6312925
E-Mail: service@vde.com
www.vde.com

VDMA – Verband Deutscher Maschinen- und Anlagenbau e.V.
(German Engineering Federation)
Lyoner Straße 18, 60528 Frankfurt am Main, Germany
phone: +49 (0)69 6603-0
fax: +49 (0)69 6603-1511
E-Mail: kommunikation@vdma.org
www.vdma.org/

VDZ – Spitzenverband der Gebäudetechnik
(Umbrella Association for Building Services Engineering)
Oranienburger Straße 3, 10178 Berlin, Germany
phone: +49 (0)30 27874408-0
fax: +49 (0)30 27874408-9
E-Mail: info@vdzev.de
www.vdzev.de

ZVEI – Zentralverband Elektrotechnik- und Elektronik-industrie e. V.
(Association of German Electronics Enterprises)
Lyoner Straße 9, 60528 Frankfurt am Main, Germany
phone: +49 (0) 69 6302-0
fax: +49 (0) 69 6302-317
E-Mail: zvei@zvei.org
www.zvei.org

8.2 Renewable energy

BEE – Bundesverband Erneuerbare Energie e. V.
(German Renewable Energy Federation, BEE)
Invalidenstraße 91, 10115 Berlin, Germany
phone: +49 (0) 30 - 275 81 70-0
fax: +49 (0) 30 - 275 81 70-20
www.bee-ev.de

FEE – Fördergesellschaft Erneuerbare Energien e. V.
(Association for the Promotion of Renewable Energy, FEE)
Invalidenstraße 91, 10115 Berlin, Germany
phone: +49 (0)30 84710697-0
fax: +49 (0)30 84710697-9
Internet: www.fee-ev.de

8.3 Geothermal energy

Bundesverband Geothermie e. V.
(German Geothermal Association)
Albrechtstraße 22, 10117 Berlin, Germany
phone: +49 (0)30 20095495-0
fax: +49 (0)30 20095495-9
www.geothermie.de

8.4 Solar energy

BDH – Bundesindustrieverband Deutschland Haus-, Energie und Umwelttechnik e. V.
(Federal Industrial Association of Germany House, Energy and Environmental Technology)
Frankfurter Straße 720–726, 51145 Cologne, Germany
phone: +49 (0)2203 93593-0
fax: +49 (0)2203 93593-22
www.bdh-koeln.de

BSW – Bundesverband Solarwirtschaft e. V.
(German Solar Industry Association)
Quartier 207, Friedrichstraße 78, 10117 Berlin, Germany
phone: +49 (0)30 2977788-0
fax: +49 (0)30 2977788-99
E-Mail: info@bsw-solar.de
www.solarwirtschaft.de

Deutsche CSP
(German Association for Concentrated Solar Power)
Clausewitzstraße 7, 10629 Berlin, Germany
phone: +49 (0)30 609839438
E-Mail: office@deutsche-csp.com
www.deutsche-csp.com

DLR – Deutsches Zentrum für Luft- und Raumfahrt e. V.
(German Aerospace Center)
Linder Höhe, 51147 Cologne, Germany
phone: + 49 (0)2203 601-0
fax: +49 (0)2203 673-10
www.dlr.de

8.5 Bioenergy

BBE – Bundesverband BioEnergie e. V.
(German Bioenergy Association)
Godesberger Allee 142 –148, 53175 Bonn, Germany
phone: +49 (0)228 81002-22
fax: +49 (0)228 81002-58
www.bioenergie.de

BDBe – Bundesverband der deutschen Bioethanol-wirtschaft e. V.
(German Bioethanol Association)
Reinhardtstraße 16, 10117 Berlin, Germany
phone: +49 (0)30 3012953-0
fax: +49 (0)30 3012953-10
www.bdbe.de

C.A.R.M.E.N. – Centrales Agrar-Rohstoff Marketing- und Energie-Netzwerk e. V.
(Central Marketing and Development Network)
Schulgasse 18, 94315 Straubing, Germany
phone: +49 (0)9421 9603-00
fax: +49 (0)9421 9603-33
www.carmen-ev.de

DEPV – Deutscher Energieholz- und Pellet-Verband e.V.
(German Energy Pellet Association)
Neustädtische Kirchstraße 8, 10117 Berlin, Germany
phone: +49 (0)30 6881599-66
fax: +49 (0)30 6881599-77
www.depv.de

FNR – Fachagentur Nachwachsende Rohstoffe e.V.
(Agency for Renewable Resources)
Hofplatz 1, 18276 Gülzow-Prüzen, Germany
phone: +49 (0)3843 6930-0
fax: +49 (0)3843 6930-102
www.fnr.de

FvB – Fachverband Biogas e.V.
(German Biogas Association)
Angerbrunnenstraße 12, 85356 Freising, Germany
phone: +49 (0)8161 9846-60
fax: +49 (0)8161 9846-70
www.biogas.org

Fachverband Holzenergie im BBE
(German Association for Wood Energy)
Godesberger Allee 142–148, 53175 Bonn, Germany
phone: +49 (0)228 81002-23
fax: +49 (0)228 81002-58
www.fachverband-holzenergie.de

FnBB – Fördergesellschaft für nachhaltige Biogas- und Bioenergienutzung e.V.
(German Biogas and Bioenergy Society)
Am Feuersee 8, 74592 Kirchberg/Jagst, Germany
phone: +49 (0)7954 921969
fax: +49 (0)7954 926-204
www.fnbb.org

IBBK-Fachgruppe Biogas GmbH
(International Biogas & Bioenergy Center of Competence, IBBK)
Am Feuersee 6, 74592 Kirchberg/Jagst, Germany
phone: +49 (0)7954 926-203
fax: +49 (0)7954 926-204
www.ibbk.fachgruppe-biogas.de

UFOP – Union zur Förderung von Oel- und Proteinpflanzen e.V.
(Union for the Promotion of Oil and Protein Plants)
Claire-Waldoff-Straße 7, 10117 Berlin, Germany
phone: +49 (0)30 319 04-202
fax: +49 (0)30 319 04-485
www.ufop.de

VDB – Verband der Deutschen Biokraftstoffindustrie e.V.
(German Biofuels Industry Association)
Am Weidendamm 1 A, 10117 Berlin, Germany
phone: +49 (0)30 726259-11
fax: +49 (0)30 726259-19
www.biokraftstoffverband.de

8.6 Other institutions and partners

B2B Renewable Energies – Multilingual online business platform for renewable energies
www.renewablesb2b.com

DEG – Deutsche Investitions- und Entwicklungsgesellschaft mbH
(German Investment and Development Company)

Deutsche Auslandshandelskammern
(German Chambers of Commerce)
Directory of German Chambers of Commerce abroad:
www.ahk.de/en

DIHK – Deutscher Industrie- und Handelskammertag
(The German Chambers of Industry and Commerce)
Breite Straße 29, 10178 Berlin, Germany
phone: +49 (0)30 203080
fax: +49 (0)30 203081000
www.dihk.de

Germany Trade and Invest – Gesellschaft für Außenwirtschaft und Standortmarketing mbH
(The economic development agency of the Federal Republic of Germany)
Friedrichstraße 60, 10117 Berlin, Germany
phone: +49 (0)30 200099-0
fax: +49 (0)30 200099-812
www.gtai.com

GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
(German Agency for International Cooperation)
Friedrich-Ebert-Allee 36 + 40, 53113 Bonn, Gremany
phone: +49 (0)228 4460-0
fax: +49 (0)228 4460-1766
www.giz.de

iXPOS – The German Business Portal
www.ixpos.de

8.7 German authorities and ministries

Auswärtiges Amt (AA)
(Federal Foreign Office)
Werderscher Markt 1, 10117 Berlin, Germany
phone: +49 (0)3018 17-2000
fax: +49 (0)3018 17-3402
www.auswaertiges-amt.de

Bundesministerium für Ernährung und Landwirtschaft (BMEL)
(Federal Ministry of Food and Agriculture)
Wilhelmstraße 54, 10117 Berlin, Germany
phone: +49 (0)30 18529-0
fax: +49 (0)30 18529-4262
www.bmel.de

Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB)
(Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety)
Stresemannstraße 128–130, 10117 Berlin, Germany
phone: +49 (0)30 18305-0
fax: +49 (0)30 18305-2044
www.bmub.bund.de

Bundesministerium für Wirtschaft und Energie (BMWi)
(Federal Ministry for Economic Affairs and Energy)
Scharnhorststraße 34–37, 10115 Berlin, Germany
phone: +49 (0)30 18615-0
fax: +49 (0)30 18615-7010
www.bmwi.de

Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (BMZ)
(Federal Ministry for Economic Cooperation and Development)
Stresemannstraße 94, 10963 Berlin, Germany
phone: +49 (0)30 18535-0
fax: +49 (0)30 18535-2595
www.bmz.de

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