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for Economic Affairs
and Energy

MITTELSTAND
GLOBAL
ENERGY SOLUTIONS
MADE IN GERMANY

Energy solutions made in Germany

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Abbreviations

AFC	Alkaline Fuel Cell
AHK	Deutsche Auslandshandelskammern (German Chambers of Commerce Abroad)
ASEAN	Association of Southeast Asian Nations
BMWi	Federal Ministry for Economic Affairs and Energy
BREEAM	Building Research Establishment Environmental Assessment Methodology
BtL	Biomass-to-Liquid
BTTP	Block-type Thermal Power Station
CCHP	Combined Cooling, Heat and Power
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CSP	Concentrated Solar Power
DAkkS	Deutsche Akkreditierungsstelle (National accreditation body for the Federal Republic of Germany)
dena-RES	dena Renewable Energy Solutions Programme
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council)
DMFC	Direct Methanol Fuel Cell
FLOX	Flameless Oxidation
GIZ	Gesellschaft für Internationale Zusammenarbeit GmbH (German Agency for International Cooperation)
GWh	Gigawatt hour
IEC	International Electrotechnical Commission
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
ICT	Information and Communication Technology
kW	Kilowatt
kWh	Kilowatt Hour
kWp	Kilowatt Peak
LEED	Leadership in Energy and Environmental Design
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MCFC	Molten Carbonate Fuel Cell
MW	Megawatt
MWp	Megawatt Peak
NOx	Nitrogen Oxides
ORC	Organic Rankine Cycle
PAFC	Phosphoric Acid Fuel Cell
PDP	Project Development Programme
PEFC	Polymer Electrolyte Fuel Cell
PV	Photovoltaics
SME	Small or Medium-sized Enterprise
SMES	Superconducting Magnetic Energy Storage
W	Watt
VPP	Virtual power plant

1 Introduction

To reduce greenhouse gas emissions and establish an affordable, secure, and reliable energy supply, we need to generate most of our future energy requirements from renewable sources and use these sources efficiently. Our energy systems can be transformed worldwide by using sustainable energy solutions. These solutions not only contribute to climate protection, they also further innovation, sustainable and dynamic economic growth and the creation of employment. More and more governments, and businesses in particular, are recognising the benefits: Switching to renewable energy and energy efficiency reduces our dependence on fossil fuels and aids climate protection, while helping to reduce costs, create sustainable jobs and boost overall competitiveness.

It is in this context that the present brochure of the German Energy Solutions Initiative of the Federal Ministry for Economic Affairs and Energy (BMWi) outlines the extensive range and potential of sustainable energy solutions – along the entire energy supply chain, from production and transport, through to consumption. In addition to energy production technologies (Chapter 2 of this brochure), these solutions include technical solutions for providing a stable energy infrastructure (Chapter 4 of this brochure), technologies and systemic solutions for implementing efficient energy consumption (Chapter 5 of this brochure) in the electricity, heat and mobility sectors and cross-sectoral services (Chapter 6 of this brochure). The benefits of sustainable energy solutions can be maximised by combining technologies in certain application fields, for example in the hybridisation of a diesel-powered plant with photovoltaic installations. Besides combining different technologies, another means of making the energy system more flexible is by linking the electricity, heat and transport sectors as part of an integrated energy transformation, a process often referred to as "sector coupling" (Chapter 3 of this brochure).

Energy production

Renewable sources can be used to generate energy in a CO_2-neutral and highly efficient manner thanks to energy efficiency. The various technologies implemented draw on solar energy, wind energy, bioenergy, geothermal energy and hydropower. Technological solutions for increasing energy efficiency in the production of energy include the use of fuel cells, combined heat and power (CHP), and modern burner and boiler technology. Energy production technologies can be differentiated according to their end product, depending on whether they deliver electricity, heat or refrigeration.

Energy infrastructure

Climate-friendly transformation of energy systems also requires modernisation of the existing energy infrastructure. The power and heat supply networks need to be adapted, in particular, while storage technologies, measurement and control technology also need to be incorporated. Furthermore, having a large proportion of decentralised generated energy from volatile renewable sources in the system means that smart grids comprising digital and automated communication and control technology are essential. Self-powered consumers and off-grid regions depend on special technology systems that enable off-grid energy supply.

Energy efficiency

Energy efficiency technologies have an important role to play in achieving the goal of a sustainable energy supply. From an economic and ecological view, saving energy has an even higher priority than generating additional energy from renewable sources. Therefore, every kilowatt hour (kWh) not generated represents an important achievement. The use of modern technology can substantially boost energy efficiency in the construction, industry, manufacturing, services, agriculture and transport sectors.

Cross-sectoral services

A climate-friendly energy supply requires cross-sectoral services that enable the use of sustainable technologies in the electricity, heating and transport sectors. These cross-sectoral services range from engineering services to activities in the area of planning and management through to measures such as energy contracting, certification and accreditation. They are based on applications of information and communication technology (ICT), measurement technology, open-loop and closed-loop control technology.

Energy solutions made in Germany

About twenty years ago, Germany laid the political, economic and social foundations for a fundamental restructuring of its energy system. The aim was to establish modern, dynamic and sustainable supply structures and processes. Today, German technologies are in demand internationally, while many German companies are global leaders in their industries. Germany is considered to be a pioneer in the area of smart and sustainable technology. While leading the way in the shift towards renewables *("Energiewende")*, Germany is driving change towards a climate-friendly and resource-efficient energy supply both at home and abroad. German suppliers of sustainable technologies, services and system solutions have many years of experience and vast expertise, and not just in the domestic market. International projects and solutions implemented globally have also relied on German expertise. German companies can draw on the experience acquired at home and make profitable use of their system expertise to contribute to the sustainable transformation of energy markets abroad.

The German Energy Solutions Initiative

The German Energy Solutions Initiative, which is coordinated and financed by the German Ministry for Economic Affairs and Energy (BMWi), promotes the international marketing and foreign trade of German technologies through various programmes. Examples are the dena Renewable Energy Solutions Programme (dena RES Programme) and the Project Development Programme (PDP). The dena RES Programme supports the implementation of flagship projects of German companies together with local project partners in the field of smart and sustainable energy solutions. The PDP builds on existing development aid measures and facilitates business partnerships as well as the exchange of experience and expertise between local and German companies. Thus, the PDP forms a vital basis for sustainable market development. The initiative targets small and medium-sized enterprises (SMEs), the German Mittelstand, which is mainly responsible for the transfer of know-how and technology that takes place as part of the international cooperation between Germany and partner countries. These companies' technological solutions and expertise in the area of sustainable energy solutions are in high demand internationally.

2 Energy generation, heating and cooling

Solar energy, wind and hydropower, bioenergy, and geothermal energy are increasingly being used as renewable energy sources for energy and heat generation, as well as for cooling.

As an introduction to the range of sustainable and efficient energy solutions available, the provision of electricity from renewable energy is described in this section. Thanks to their scalability, renewable energy technologies can be used not only to supply private households, but also power plant solutions with several megawatts of electric or thermal power. A vast range of energy technologies is available with different power categories for generating electricity and heat in private households, for commercial and agricultural use through to industrial power plants for utility companies or for supplying energy to industrial companies, cities and local authorities.

Energy efficiency technologies designed to provide a combination of electricity, heat and cooling play an especially important role in what is known as combined heat and power generation (CHP). Renewable energy is also integrated in hybrid power plants in order to save fossil fuels. Since hybrid power plants combine several different energy sources, fluctuations in the production of electricity from renewable energy can be balanced out in order to meet demand.

2.1 Industrial and private electricity supply

Solar power, wind power and hydropower are currently the three main sources of renewable energy generation globally.

Solar energy offers enormous potential to shift the conventional power mix in favour of renewable energy. The global availability of solar energy allows photovoltaics (PV), for example, to offer an attractive solution for generating grid-connected and off-grid electricity. Wind energy is also increasingly being used worldwide. Wind and solar energy are becoming economically viable in more and more countries due to the economies of scale resulting from decreasing system costs in production and project development and also due to the high natural potential. Hydropower has been used to generate electricity since the end of the nineteenth century. Today, it is the most widely used renewable energy source for electricity generation in the world. Advantages such as base load capability, storage capability, grid stabilisation and decentralisation are some of the strengths of hydropower. The following section presents technologies that utilise solar energy, wind energy and hydropower as solutions for generating electricity – either in small-scale or in large-scale applications.

2.1.1 Solar energy

Solar energy is an inexhaustible source of energy and harnessed in diverse forms for generating heat and electricity. In the area of electricity production, PV plants and solar-thermal plants both offer a sustainable technological solution. In the case of a photovoltaic plant, several solar modules are required, depending on the electrical plant output needed. These solar modules are connected together and within these solar modules, solar cells are in turn connected together. Direct electrical current is then produced in the solar cells by means of the photovoltaic effect. This current is converted by inverters so that the solar energy can be consumed directly or fed to a power grid. Thanks to their scalability, photovoltaic plants are operated in private households, in industry or as commercial power plants delivering megawatts of power.

In solar-thermal plants in contrast, solar energy is used to superheat water vapour. Depending on the technology used, this process either happens directly or is supported by upstream heating of special heat-transfer oil. The energy from the superheated water vapour is then converted into electrical energy by means of a turbine. These two technical options for using solar energy are explained in more detail in the following section.

Photovoltaics

PV systems are used to generate electricity and are among the most environmentally friendly and efficient energy supply systems. German PV research institutes and industry are further developing PV system components and production processes in order to further optimise applications and reduce costs. Over two decades of research and market development has positioned Germany as a location for reliable solutions and development of innovative and more efficient PV systems.

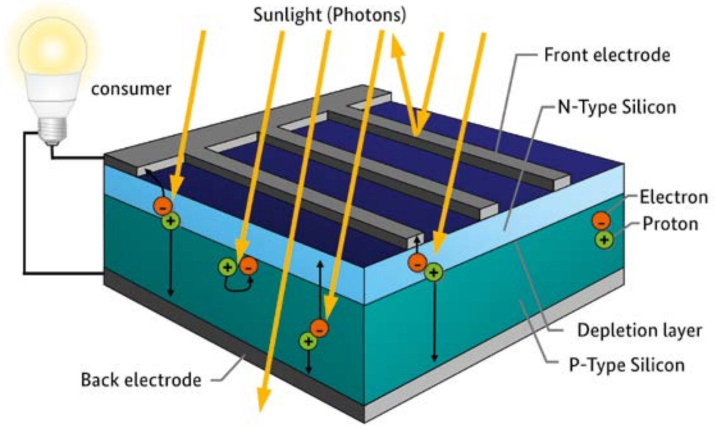


Figure 1: Operating principle of a PV cell
Source: Volker Quaschning/Hanser Verlag

How it works: Photovoltaics

First, it is generally differentiated between crystalline wafer-based technology, consisting of mono- and polycrystalline silicon cells, and thin-film technology, modules made of copper, indium, gallium and selenium or amorphous silicon. PV cells consist of one or more semiconductor materials and enable solar energy to be converted directly into electricity. Chemical elements are added to produce two layers, a p-conductive layer with a positive charge carrier surplus and an n-conductive layer with a negative charge carrier surplus. Due to this imbalance, an inner electric field is formed which acts as a barrier layer. Light incident on the cell then produces a charge separation. The charge carriers released in this process can be conducted through contact with metal and used as direct current by an electrical device or fed into the grid as alternating current via an interconnected inverter. To provide higher capacities, PV cells are interconnected in modules.

In many countries, the cost of electricity generation from solar energy is comparable to the consumer price for conventional electricity from the grid. This is also known as "grid parity". In countries with high solar radiation and no other natural or fossil resources, PV is often the cheapest source of electricity generation. Dominant business models are self-supply for small and medium applications and independent power production for the sale of electricity to supply large-scale applications.

Advantages of photovoltaics

- Reliable and cost-effective electricity generation, independent of an existing grid
- Easy to install, robust design with no moving parts
- Wide range of applications from very small systems to large-scale installations thanks to modular structure
- Quiet electricity generation
- Silicon as primary material is common, inexpensive and easily recyclable
- Low maintenance requirements

Most domestic systems are rooftop installations. However, there are new ways of integrating PV systems into the building itself, for example by embedding PV into the facade or windows. To meet the annual consumption of a four-person family in Germany, an average household needs a PV system with a peak output of 3.5 to 4 kW. Depending on the PV technology used, this corresponds to a solar panel surface area of about 35 to 40 m². In areas with higher solar radiation, less surface area is needed. The roofs of factory buildings, production facilities and commercial complexes provide enough space for larger on- or off-grid PV systems.

Hybrid systems allow PV systems to be combined with other renewable energy technologies or diesel generators and storage devices.

Typically, large grid-connected systems are designed as ground-mounted systems or as large rooftop installations. Systems of this type can be used to power municipalities or other large consumers or stand-alone power systems (mini-grids). In the case of mini-grids, several PV systems feed into a stand-alone power system, allowing it to provide electricity for several houses or even entire villages. Typically, hybrid systems are used in this case. In order to maximise the generation of solar electricity and the yield benefit, sun-tracking PV modules can be installed.

Figure 2: Photovoltaic installation in Jamaica
Source: IBC Solar AG

Concentrated solar power

Solar-thermal power plants are also known as concentrated solar power (CSP) plants. In sunny regions, they can use the heat of the sun to generate electricity, heating, cooling and drinking water. When combined with a heat store and the addition of other fuels, CSP plants can provide continuous baseload power, similar to a conventional power plant. Much of the technology used in solar-thermal power plants is developed and manufactured in Germany. After years of laying the groundwork in development and research in this area, German companies can claim a significant role in establishing CSP as a reliable, affordable and financially viable power plant technology.

In solar-thermal power plants, sunlight is captured and focused by means of mirror systems onto an absorber. The heat thus generated is then used to produce electricity with conventional power plant technology, e.g. with steam turbines. Depending on the type of concentrating mirror system used, the different solar-thermal plants are: parabolic-trough power plants, solar tower power plants and dish-Stirling solar power systems.

Solar-thermal plants need direct solar radiation for operation and can therefore only operate around the Earth's "sun belt". At annual radiation levels of between 1,700 and 3.000 kWh/m², this technology allows solar energy to be produced affordably.

Parabolic-trough power plants

In parabolic-trough power plants, sunlight is focused on an absorber with selective coating. With the heat thus produced, a heat transfer medium such as heat-transfer oil is used to generate steam at temperatures of 400° C and over. The concentrating mirror elements are curved in the shape of a parabola (parabolic trough concentrating collectors) or consist of individual segments of flat mirrors (Fresnel collectors).

Solar tower power plants

In solar tower power plants, sunlight is focused by means of an array of biaxial sun tracking flat mirrors, or heliostats, onto a relatively small absorber located on a solar tower. Temperatures of over 1,000° C are achieved as a result of the high concentration of solar radiation, thus enabling highly efficient two-stage energy conversion. Today, there are several different technological approaches based on various heat transfer mediums such as air, water, steam or molten salt and heat exchangers such as shell and tube heat exchangers, atmospheric or pressurised volumetric structures.

Figure 3: Solar tower power plant
Source: DLR

How it works: Heat exchangers

Heat exchangers are used in many ways to transfer heat between two mediums. In many heat exchangers, a hot and cold medium are streamed past a common heat transfer surface simultaneously. The heat flow transferred through these heat transfer surfaces varies according to the heat transfer coefficient of the heat exchanger, the size of the heat transfer surface and the mean temperature differential between the two mediums. There are various types of heat exchangers, depending on the design and mode of operation. These include 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 and rotation heat exchangers. Heat exchangers have a broad area of application. An important area is power plant technology such as CSP power plants. In this case, the heat exchanger transfers the heat from the cycle taking up the heat through sunlight, which could, for example, run on thermal oil, to another cycle running on water, which drives the electricity-generating turbine.

Dish Stirling systems

In Dish Stirling solar power systems, the working gas of a Stirling engine, such as hydrogen or helium, is heated to a temperature of up to 900° C by a biaxial sun-tracking reflector to allow high electric efficiencies of around 30 percent. Dish Stirling solar power systems with a power output of between 10 and 50 kW are especially suited to decentralised applications.

Use of heat stores and hybrid operation

The energy conversion process particular to all solar-thermal power plants allows the use of thermal stores or co-firing of fossil or biogenic fuels to make power plant operation more flexible. This variant is also known as hybrid operation. The electricity production thus enabled at peak load times or around the clock can greatly boost the profitability of the power plants.

Figure 4: Dish Stirling systems
Source: fotolia.com/jdoms

Solar hybrid gas-steam-turbine power plants

Solar gas-steam-turbine (combined cycle) power plants are considered to be efficient solar power plants. For a high level of efficiency when converting solar radiation into electricity, the radiation must be directly coupled into the gas turbine. In solar hybrid combined cycle plants, air is heated to drive the gas turbine, in part by solar radiation, in part by natural gas.

Solar gas-steam-turbine power plants comprise heliostats, a solar tower, receiver and a combined cycle power plant component. After being concentrated about 1,000 times by the array of heliostats, the solar radiation is absorbed in receivers. Here, the air is intensely heated. The higher the air temperature achieved, the less natural gas is required as fuel to further heat the air to the necessary turbine entry temperature.

2.1.2 Wind energy

In recent years, wind energy technology has become one of most widely used renewable energy technologies. Wind energy is basically differentiated as either onshore or offshore.

How it works: Transforming wind into energy

The kinetic energy of the wind is used to generate electricity from wind energy. This kinetic energy acts on the rotor blades, causing the rotor to rotate. The rotation energy is then fed to a generator, which generates electricity. A wind power plant can convert up to 59 percent of the kinetic energy contained in wind into mechanical energy. Aerodynamic losses also reduce efficiency. Wind speed is a decisive factor in a wind turbine's yield. The output therefore varies, depending on the weather.

Like PV plants, wind energy systems generate electricity only, which means they have a similar array of applications. However, there are important differences. Unlike PV systems, which comprise interconnected modules of application-defined sizes, the capacity of wind turbines cannot be adjusted in very small increments. Wind turbines are much more suitable for partially powering entire buildings, industrial complexes and communities. Using modern control engineering to interconnect wind farms enables smooth power transitions to be achieved in order to prevent fluctuations in the power grid.

Figure 5: Wind turbines
Source: Sowitec group GmbH

Wind power plants are either grouped together in wind farms or set up as single units, which normally feed their electricity directly into the local grid.

They consist of a 50 to 150 m high tower, a nacelle that contains the generator and other mechanical equipment, a rotor with a horizontal axis and rotor blades.

A closer look: Three-blade horizontal rotors

To develop modern wind turbines, engineers drew on experience from aircraft construction in order to exploit the upward lift produced by wind. The most widely used technology today is the three-blade horizontal rotor. It has proven to be mechanically reliable, visually pleasing and quiet. The design was developed to deliver optimum power generation at wind speeds of 12 to 16 m/s, while still operating efficiently at lower speeds. In strong winds, the output is reduced to ensure a constant amount of electricity is fed into the grid.

To translate the rotation speed of the rotor blades to the frequency required by the generator, two different concepts are applied. The first uses a gearbox, in which the gear changes depending on the current rotation speed, much like a bike gearing system. A more recently developed concept is the use of a ring generator, which can generate electricity at a higher frequency even though it rotates at the lower speed of the rotor blades. Although the ring generator saves on maintenance costs for the gearbox, it is still currently the more expensive option.

Onshore wind energy

Onshore wind power turbines can be categorised according to their output capacity. Small wind turbines have a capacity of up to 50 kW. Large-scale wind turbines can reach a capacity of up to around 7 MW with higher hub heights.

In domestic use, small wind turbines can be used to generate electricity for households. Depending on the prevailing wind conditions, these can support or even replace conventional electricity sources, e.g. diesel. When combined with other renewable energy technologies, such as photovoltaics and storage solutions, small wind turbines are ideal for providing the base electricity supply in off-grid regions (for more information on off-grid technology solutions, see Chapter 4.1.3 Micro-grids)

Large onshore wind turbines are commonly installed in wind farms with a grid connection. To reach their maximum capacity output, they require high wind speed and constant wind flow. Therefore, they are usually located close to the coast or on elevated positions such as the top of a mountain, since these areas offer the best wind conditions. In case of stand-alone single units, the wind energy can also be directly supplied to commercial, industrial or agricultural consumers in order to power factories, commercial complexes and agricultural equipment.

Offshore wind energy

Offshore wind farms with several hundred megawatts of installed capacity benefit from continuous and stronger wind speeds on the open sea. This allows them to deliver constant electricity and replace large-scale power plants. Establishing a connection to the power grid (including cables to the overland grid, control units and transformer substations) represents the biggest cost in setting up offshore wind farms.

Advantages of wind energy

- Provides electricity at competitive prices
- Wide range of applications, from a few kW to several MW
- Ideal basis for an energy mix including other renewable energy power plants

2.1.3 Hydropower

Today, hydro energy is the most widely used renewable energy source for generating electricity in the world. At the same time, it is also the oldest form of renewable energy generation.

Hydroelectric turbines can produce electricity on demand, which means hydro power plants are particularly suitable to complement PV and wind energy generation in hybrid systems. Furthermore, some hydroelectric plants provide higher flexibility due to their storage capability.

A closer look: Turbines for hydropower

Several types of turbines can be used to generate hydropower. Choosing the most suitable type of turbine depends on the rate of flow, the drop height and the pressure of the water driving the turbine.

Francis turbines: The Francis turbine is one of the oldest and most commonly used conventional turbines. It is suitable for a wide spectrum of flow rates and drop heights of 20 to 700 m. However, it operates best when water volumes are steady.

Kaplan and bulb turbines: Kaplan and bulb turbines are suitable for small drop heights and a wide range of fluctuating water volumes, which makes them ideal for large run-of-the-river hydropower plants.

Pelton turbine: Pelton turbines are impulse-type turbines used for drop heights of 100 up to 1,500 m and low water volumes. They are highly suitable for pumped storage power plants.

Hydrodynamic screws: Other types of turbines include hydrodynamic screws, which work on the principle of Archimedes' screw and are primarily used for low drop heights and low capacities.

Cross-flow turbines: Cross-flow turbines are used for low drop heights and low water volumes. They generally have a small capacity.

The construction of hydropower plants has a notable impact on the environment and landscape. Statutory regulations affecting water, nature and landscape protection must therefore be considered when planning a hydropower plant. Hydrological connectivity for fish and other water organisms must be guaranteed by means of fish ladders. Small hydropower plants are considered to have less impact on the environment than large plants. Besides the construction of new plants, existing plants are also being replaced, modernised and reactivated.

Figure 6: Francis turbine for the Guri hydroelectric power plant in Venezuela
Source: Andritz Hydro GmbH

Advantages of hydroelectric power

- Produces electricity on demand and can thus balance fluctuations of electricity
- Storage capacity, e.g. in pumped storage plants
- Long-established technology
- Run-of-river power stations with stable base load generation
- Wide-ranging capacity from small-scale to large-scale hydropower plants

Large-scale hydropower

Since the space and locations for large-scale hydropower plants are limited due to the geographical and environmental conditions required, growth rates for this technology lag behind solar or wind energy. There are three main types of large-scale hydro power plants: run-of-the-river plants, pumped storage plants and storage plants. Run-of-the-river plants are constructed in large rivers with high flow volumes, while pumped storage and storage plants require a height slope and are most often located in mountain ranges or river valleys.

Small-scale hydropower

Small hydropower plants are often situated on small rivers and can have water basins of different sizes and types of construction. Micro and mini hydropower plants can be differentiated based on their capacities as follows.

- Micro: 1 – 100 kW
- Mini: 100 – 1,000 kW
- Small: 1,000 – 10,000 kW

2.2 Combined heating, cooling and electricity generation

It is possible to generate multiple types of energy at once from one resource or within a single production process. When thermal and electrical or mechanical energy are generated through a chemical or physical process simultaneously, this is referred to as cogeneration or a combined heat and power (CHP) system. CHP systems thereby manage to recover the heat produced as a by-product of an electricity generation process and allow this thermal energy to be used in the form of heating or transformed into cooling agents (the latter usually with the help of an absorption refrigerator). In cases where the thermal energy generated in this manner is used for both heating and cooling, this process is called trigeneration or combined cooling, heat and power (CCHP).

Trigeneration is the most efficient way of producing and using energy, while a cogeneration system still outperforms any process in which excess heat is not used at all. The efficiency of the energy generation system is therefore maximised by minimising the amount of waste energy. Generally, these technology options can be applied anywhere, in factories, private housing or other buildings.

2.2.1 Bioenergy

Bioenergy is derived from solid or liquid biomass, biogas or biofuels. The most widely used form of biomass for energy generation is wood, for example in the form of firewood, wood chips and pellets. The practice of using bioenergy, especially in the form of burning wood, is a tradition dating back thousands of years.

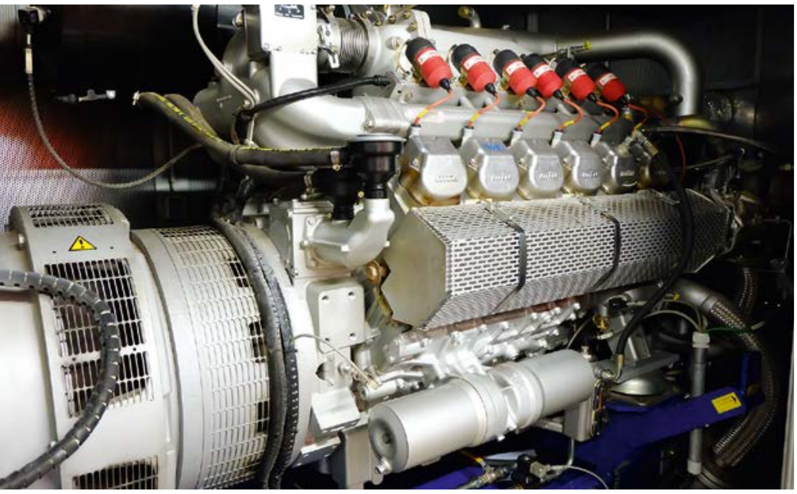


Figure 7: Detail view of a block heat and power plant
Source: Gerhard Hirn/Bine Information Service

Advantages of bioenergy

- Storable energy, versatile use
- Available in almost all countries
- Can be used to balance fluctuations in volatile electricity feed-in from renewable energy sources such as wind and solar energy
- Use of waste products e.g. animal waste, household waste, crops etc.

Since bioenergy can be used to generate electricity involving the combustion of biomass, biogas or bio fuels, it is ideally suited for applications in CHP and combined cooling, heat and power (CCHP) processes. Despite the combustion process at the heart of converting solid biomass, biogas and biofuels into usable energy, the conversion is virtually CO_2-neutral. Burning wood or other biomass agents only releases the amount of emissions absorbed by the organism during its growth phase. The same amount would be released if biomass was simply left to decay.

A closer look: Biogas and CHP

Biogas is the byproduct of the decomposition of organisms and can be used just like natural gas. It can be produced in biogas plants, and extracted from landfill sites, municipal waste water, industrial, domestic, commercial and agricultural waste materials and energy crops. Finally, biofuels are liquid energy sources most commonly used in the mobility sector.

Stationary use of biogas in CHP plants for generating power and heat achieves a very high degree of efficiency. The electricity produced can be fed into the grid or used as an independent power supply. The waste heat can be used for heating, drying, additional power generation downstream or, in a CCHP plant, for refrigeration.

2.2.2 Deep geothermal energy

Geothermal energy uses the heat originating from the earth's core. The deeper a geothermal well, the more heat that can be absorbed. Geothermal energy can be used either to provide heating or generate electricity. At temperatures typical for Germany, the heat output for geothermal power plants is approximately ten times greater than the electrical output. Technically the heat extraction can be either parallel or sequential, or alternate between both.

Figure 8: Drilling for deep geothermal energy
Source: BMWi

How it works: Closed and open systems

Geothermal systems can be designed either as open or closed systems. Closed systems are often used in near-surface areas, while open systems are commonly used for deep geothermal applications. At the surface the heated medium can be used for heating and for electricity generation.

In an open system, hot water is extracted from an underground aquifer and pumped to the surface, where the heat is transferred to a heat exchanger. The cooled water is then pumped back into the aquifer and the cycle starts over again. Other types of open systems, like the hot dry rock technique, pump a heat carrier under pressure into hot rock layers. The heat carrier absorbs the heat of the rock formation and is pumped back to the surface.

In closed systems the heat carrier medium circulates through a closed pipe system. The pipe has a high heat permeability to facilitate heat transfer between the subterranean earth layers to the heat carrier in the pipe system.

Geothermal power plants offer several ways of extracting heat:

- Separation in a power generating circuit with heat use downstream at 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

A closer look: Three forms of geothermal systems

Based on the availability of deep water, water permeability and the system concept, a distinction can be made between hydrothermal and petrothermal geothermal energy as well as deep borehole heat exchangers.

Petrothermal applications: Petrothermal geothermal energy comes from deep-lying heat reservoirs, which have no water flow or only negligible water flow, such as dry layers of rock with temperatures of more than 150°. Through an injection borehole, water is transferred under the earth for heating.

Hydrothermal applications: Hydrothermal applications tap into existing hot water reservoirs some 400 metres below the surface. In this case, the hot water is used for driving a steam turbine to produce electricity and heat simultaneously.

Borehole heat applications: Deep borehole heat exchange technology refers to a closed system of energy production comprising a single borehole at depths of 400 m to several thousand metres. Water circulates through double pipe exchangers in a closed circuit. The heat from the water heated at these depths is then extracted at the surface and delivered to a heat pump circuit. In the case of high temperatures, the recovered energy can be used, for example, as process heat for industrial applications or for agricultural applications in the case of low temperatures.

2.2.3 Fuel cell

Fuel cell technology has the potential to revolutionise the energy world. In a chemical process referred to as “cold burning”, a fuel cell transforms oxygen and hydrogen or other fuels (i.e. methanol, diesel, etc.) into energy, heat and water. Unlike most conventional technologies, the energy generation works directly, without the production of steam and the use of turbines. That is why the application of the fuel cell technology could significantly improve energy efficiency.

This innovative way of generating energy can be applied in a wide range of areas and cases: Some car manufacturers use fuel cells to power their vehicles. This technology could compete with both traditional combustion engines and electric vehicles. Many car manufacturers have already initiated programmes for realising fuel cell engine technologies. Stationary appliances, such as heating systems for homes and other buildings, are another promising area for fuel cell rollout. In addition, fuel cells could compete with rechargeable batteries when it comes to powering small mobile devices such as smart phones, tablets or laptop computers.

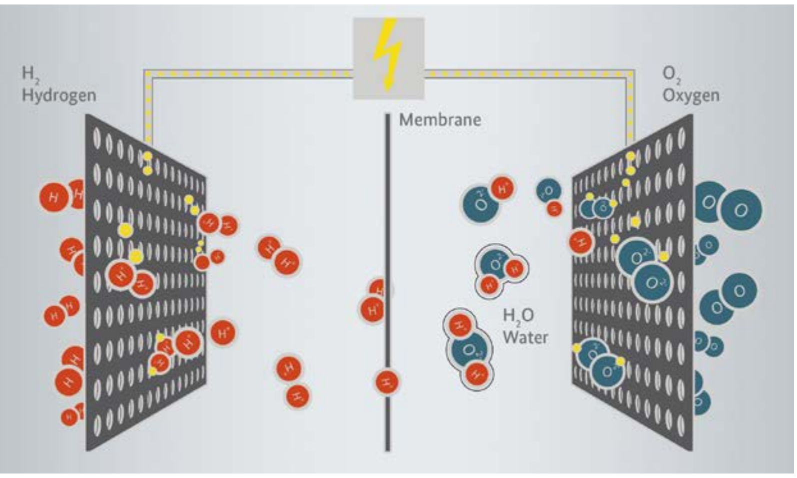


Figure 9: Operating principle of a fuel cell
Source: Viessmann

How it works: Fuel cell technology

In fuel cells, heat and electricity are generated from an electrochemical reaction. The core components of a cell are an anode, cathode and electrolyte membrane. Hydrogenous gas is delivered to the anode, while oxygen is delivered to the cathode. To prevent a direct oxyhydrogen reaction, the two gases are separated from each other by a membrane which is impermeable to gas. Free electrons and positively charged hydrogen ions are formed at the anode and diffused through the electrolyte membrane. Here they meet the negatively charged oxygen ions which are formed at the cathode. Both types of ions react chemically in an exothermic reaction to water while heat is released. The free negatively charged electrons formed on the anode side are discharged along an external conductor and used as active current in the form of direct current.

Fuel cells with membranes function at temperatures of 70 to 90° C. A polymerelectrolyte-membrane-fuel cell or low-temperature fuel cell is known as a “proton exchange membrane fuel cell“. In future, this type of fuel cell will be increasingly used to power vehicles or as a highly efficient source of power and heat in individual buildings.

High-temperature fuel cells, on the other hand, function at temperatures of 900 to 1,000° C and comprise solid oxide electrolytes to separate hydrogen and oxygen in the cell. At this temperature range, fuel cells can be operated as highly efficient heat and power stations for generating heat for local heating networks. High-temperature fuel cells are also known as “solid oxide fuel cells“.

Advantages of fuel cells

- Highly efficient
- Flexible installation
- Wide range of applications
- Minimal emission of noise and pollution
- Immense potential for further technological development

Different technology options with distinct characteristics are available to cover a broad spectrum of applications. Alkaline fuel cells are highly efficient and extremely reliable. However, since the chemical substances they employ must have high level of purity, they are mainly used for military and aerospace purposes. Polymer electrolyte fuel cells, in contrast, are less demanding and regularly used with mobile devices and vehicles. Similarly, direct methanol fuel cells are potentially useful for the automotive industry, while solid oxide fuel cells are a promising option for house heating.

Figure 10: Filling up a fuel cell vehicle
Source: Tetra Images

2.3 Industrial and private heating and cooling

There are many different ways of supplying heat. Oil or gas-firing of burners and boilers is an important heat source with a secure supply. High levels of efficiency can be achieved using efficient burner technology.

Renewable heat technologies are already helping to reduce our consumption of oil and gas in conventional heat production by means of the heat they contribute. In many cases, they cannot currently be relied on as the sole source of heat, but they will assume a greater share of the supply as the technologies continue to develop. Other renewable sources of heat, besides the burning of biomass in pellet heating systems, for example, include the sun in the form of solar heat and heat extracted from the air, earth and water using a heat pump.

In terms of temperature and heat requirements, private and commercial applications differ greatly. For household applications, the temperature is usually below 100° C and output between 2 – 2.200 kW; in industry, the corresponding values are up to and over 1.000° C and 120 MW. All of the heat sources listed can be used to supply different quantities of heat at various temperatures.

2.3.1 Heat conversion into cooling and air conditioning

The demand for heating often fluctuates seasonally, with lower demand in the summer. Meanwhile, the options for heat production are either relatively constant over the course of the year, as in the case of geothermal energy for example, or even greater as in the case of solar heat in the summer. However, in the summer cooling requirements for buildings and processes are also higher. By implementing the appropriate technology, it is possible to exploit heat surpluses to cover cooling requirements, rather than leaving this energy unused. Its use is also possible in year-round applications such as industrial cooling.

Sorption chillers use this technology. In terms of their operating principle, they work in the same way as a conventional compression refrigeration unit such as a refrigerator. However, instead of using electricity to drive a compressor, these machines use heat for thermal compression. They use reversible bonding of two working substances for this purpose. With the supplied heat, the coolant can be expelled or desorbed from the other working substance again after providing cooling. It is then available for a new cycle. In absorption chillers the coolant is mixed with a liquid sorbent, while adsorption chillers use a solid sorbent for mixing with the coolant. The operating temperature of adsorption chillers is generally lower than that of absorption chillers. Different cooling capacities can be provided, depending on the particular combination of coolant and receiving sorbent used.

2.3.2 Burner and boiler technology

The installation of energy-efficient burner and boiler technology offers energy-saving opportunities in heat supply systems. Burner and boiler applications are used both on a small scale in the private sector and on a very large scale in the industrial sector.

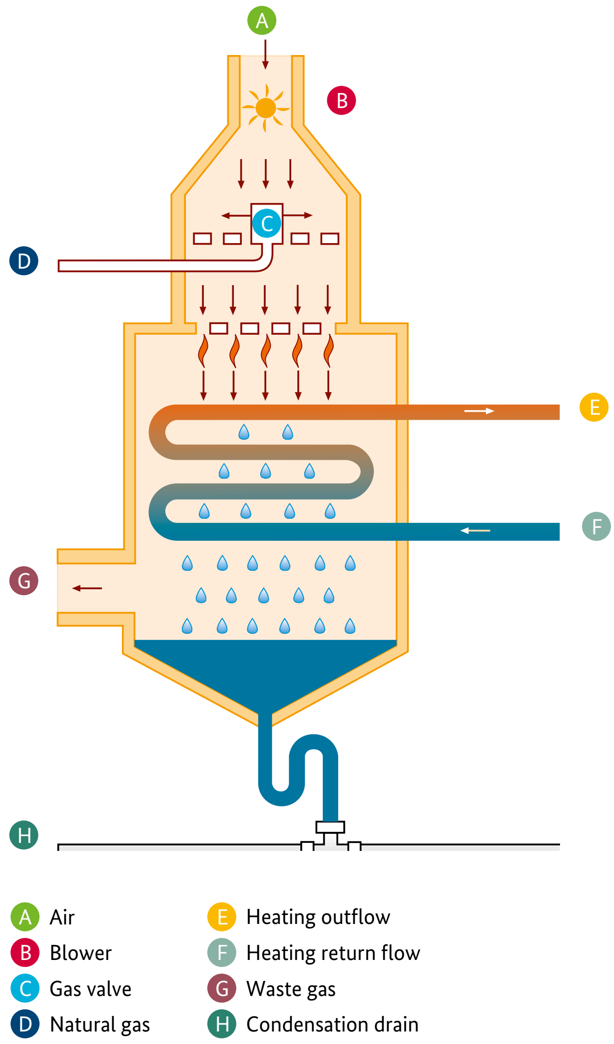


Figure 11: Principle of the condensing boiler
Source: Bundesverband der Deutschen Heizungsindustrie (BDH)

Unlike conventional boilers, condensing gas boilers recover the heat contained in waste gases using additional heat transfer surfaces. The hot water vapour contained in the exhaust gas after combustion of the gas-air mixture is used for this purpose. Cold feedwater is passed over the heat transfer surfaces through the hot water vapour. The feedwater is thus preheated, while the steam is cooled so that it condenses. Condensing boilers have a much lower exhaust gas temperature and energy content than conventional gas boilers, which accounts for their greater efficiency.

Waste heat recovery boilers use heat from waste gases, or exhaust gases as they are also known. The exhaust gases from combustion processes or hot exhaust air flows are used to generate hot water or steam. For this purpose, the hot exhaust gas is passed through a tube bundle which transfers its heat to the water in the boiler.

The following burners and processes are especially relevant for furnaces:

- Flameless oxidation (FLOX) is a highly efficient burner technology that allows compliance with strict nitrogen oxide (NOX) limits, even at high combustion air-preheating temperatures.
- Due to the high exhaust velocity of the combustion gases, these high-speed or high-momentum burners ensure that the combustion chamber gases are internally recirculated in the combustion chambers, thus achieving uniform distribution of temperature. These burners are therefore more efficient than conventional burners.
- Combustion with pure oxygen in furnaces offers some advantages over combustion with air: The combustion temperature and combustion efficiency are significantly higher using this process: combustion with pure oxygen reduces the waste gas volume flow and also results in a considerable decrease in exhaust gas losses.

2.3.3 Solar thermal energy for heating and cooling

Solar thermal energy is used for space and water heating, for cooling or dehumidifying air, for process heating, drying and desalination. It reduces energy costs for thermal energy, saving on fossil fuels for heating.

Advantages of solar thermal systems

- Secure heat supply in comparison to fireplaces or gas stoves
- Reduced fossil fuel use, emissions and costs
- Quiet electricity generation
- Tried-and-tested technology
- Low maintenance requirements

Solar thermal systems use different types of solar collectors with varying characteristics, especially in terms of the temperature level they can achieve and their cost intensity. These collectors can be categorised as unglazed absorbers, flat plate collectors, air heater solar collectors and evacuated tube collectors.

Unglazed absorbers are the simplest type of solar collector, in which water flows through pipe- or pad-shaped installations, slowly heating up over time by absorbing the heat of solar radiation. The main advantage of this technology is its modest price, which is lower than that of fossil fuel boilers. However, due to their simple design, unglazed absorbers achieve temperature levels of only 30–40° C and offer relatively low efficiency. They are frequently used for heating swimming pools or powering heat pumps.

Accounting for almost 90 percent of solar collectors installed, the flat plate collector is the most common type of collector in Germany. Beneath a robust glass pane, a metal solar absorber is used to absorb as much solar thermal energy as possible. These collectors operate within a temperature range of 60 – 90° C but are more expensive than unglazed absorbers.

Air heater solar collectors are similar to flat plate collectors. However, unlike other technologies, they use air instead of fluids as a heating agent. Air is heated and normally used to heat buildings immediately, without having to be stored in the interim. The heated air can also be used to dry agricultural products. The use of air-water heat exchangers enables the heating of water, e.g. tap water. Although relatively inexpensive in terms of purchase and maintenance, air collectors are less efficient than flat plate technology.

Evacuated tube collectors can be used to achieve high temperatures and efficiency levels. Isolated in a vacuum, the individual tubes form a closed system that transfers thermal energy through a frost-proof heat cycle to water or spaces to be heated. Tube collectors can achieve temperatures of 120° C. They are the most cost-intensive technology option.

To generate higher temperatures than 120° C, the sunlight needs to be concentrated (for more information, see chapter 2.1.1 Solar energy).

Figure 12: Solar thermal energy system for domestic water heating in a detached house
Source: Bundesverband der Deutschen Heizungsindustrie (BDH)

In domestic use, the most common application for solar thermal energy worldwide is that of heating water for detached houses. In Europe, these systems are designed to provide 100 percent of the warm water required in summer and 50 – 70 percent in winter. They consist of large collectors with a surface area of 3 to 6 m² and a hot water storage capacity of 200 to 400 litres. This capacity means that the average amount of heated water necessary for a household of four can be stored. In colder months, the hot water can be heated mainly via a heat generator, such as a boiler or a heat pump, which is supported by the solar thermal energy system on sunny days. The boiler is usually operated with gas, oil or wood.

Figure 13: Solar heating collector
Source: Fraunhofer ISE

Solar thermal energy also has a variety of industrial and commercial applications. The energy obtained through a collector can, for example, be used to operate an air-conditioning system. The advantage of this technology is that its energy supply is highest when the need for cooling is the greatest – when the sun's rays are most intense. In addition to the immediate savings in fossil fuels, this also reduces the peak period power loads in summer since less electricity-based cooling is needed. Furthermore, it can be used to heat buildings and fresh water, dehumidify the air, provide process heat for drying or washing purposes and for seawater desalination, or as direct steam production for processes up to 400° C.

2.3.4 Heating and cooling with heat pumps

Heat pumps are a key technology in the supply of renewable heat since they also allow the use of heat sources whose temperatures are not high enough for use in heat exchangers. They use the heat from low-temperature heat sources such as the ground, water and air and upgrade this heat to a higher temperature for heating purposes. Modern heat pumps operate very efficiently, even though they require additional energy to raise the temperature. The heating energy produced is significantly greater than the additional energy consumed. The additional energy is usually contributed in the form of electricity or gas. Heat can also be used for this purpose if the heat pump is used as a reverse sorption chiller (for more information on supplying heat, see 2.3 Industrial and private heating and cooling). Since electricity can also be obtained from renewable sources, heat pumps can also be used in hybrid systems.

If electricity or gas are used, compression heat pumps are necessary since the energy sources then drive a compressor. Different models of heat pump are available, depending on the medium that releases and receives the heat. Water is usually used as the receiving medium. In water-to-water heat pumps, the heat is collected through heat exchange with ground water. In other cases, the heat is transferred to the air in a ventilation system. An air-to-air system provides heat for the ventilation system through an exchange with the outside air. Other combinations with air, ground and water heat sources are possible, depending on the locally available heat.

Since it is technically easier to provide smaller heating output with low-temperature heat sources, this solution is currently mainly used for space heating in private households or small businesses. In these cases, heat pumps are usually combined with another technology based on oil, gas or biomass in order to cover periods of peak consumption. Larger-scale applications up to an output of 2,500 kW are also possible. If the heat pump is operated in reverse, it can act as a cooling unit and cover a cooling requirement. Depending on the technology, this is either a compression or sorption chiller (for more information on supplying heat, see 2.3 Industrial and private heating and cooling).

2.3.5 Near-surface geothermal energy

Near-surface geothermal energy (from depths less than 100 m) can be exploited to provide heating or cooling. It is used in combination with a heat pump. Especially during cold weather periods, the near-surface temperature is not sufficient for heating and must therefore be raised by the heat pump. The low-temperature heat used for the heat pump is provided by collectors installed at 80 – 160 cm below the surface, where the soil temperature usually does not fall below 5° C, and varies according to the size of the collectors. Alternatively, a borehole heat exchanger goes deeper into the ground (more than 50 m) and provides heat at a higher temperature, but is also more difficult to install.

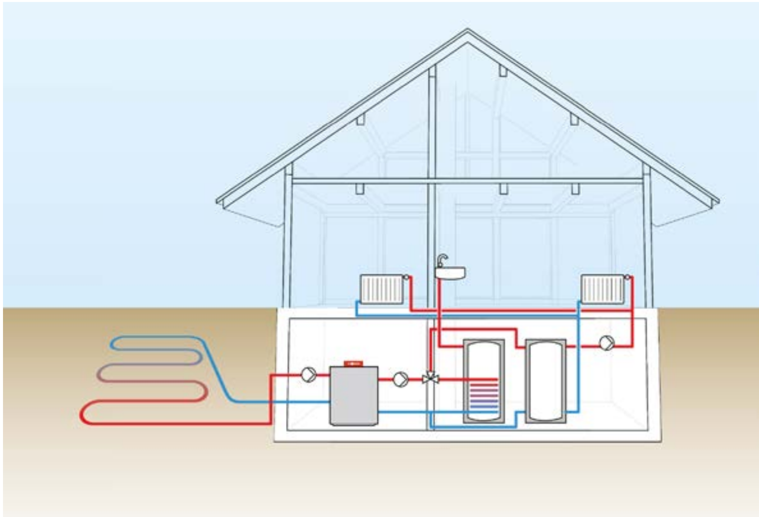


Figure 14: Near-surface geothermal energy use in a residential building
Source: Viessmann Werke

Advantages of near-surface geothermal energy

- Low maintenance requirements and user-friendly operation
- No extra above-ground space required, depending on installation
- Constant supply of energy, independent of climate, season and weather conditions
- Versatile: provides heating in the winter and cooling in the summer

Depending on the specific technology used, facilities of different sizes – from small residential units to larger complexes – can be supplied with the required heating or cooling energy. Near-surface geothermal energy installations are primarily used for residential applications since the obtained temperatures are usually not high enough to provide energy for industrial processes.

3 Sector coupling technologies

Sector coupling refers to the cross-sectoral supply and use of energy and the associated increasing integration of the electricity, heat and mobility sectors. The aim of sector coupling is to optimise energy supply in all sectors by combining the existing infrastructure and various technologies in order to use them efficiently and flexibly, thus minimising energy losses. In addition to improving energy efficiency and capacity utilisation of the energy grid, sector coupling can help better integrate energy from volatile renewable sources in the energy system. In this way, fluctuations in the power grid can be compensated for by distributing surplus electricity across all sectors at feed-in peaks and by providing additional electricity using gas or heat to generate electricity.

Typical examples of technological solutions for sector coupling include the use of electric motors as a drivetrain technology in the mobility sector, combined heat and power plants (CHP plants), which enable the simultaneous production of heat and electricity, and various Power-to-X technologies, which are used to recover or store surplus electricity in the form of heat or gas (for more information on electromobility and CHP systems see Chapter 5.4.1 Electromobility and charging infrastructure and Chapter 2.2 Combined heating, cooling and electricity generation). In addition, power-to-X technologies provide flexibility that can be used to relieve bottlenecks in the power grid. These technologies include:

- Power-to-heat
- Power-to-gas
- Power-to-liquid

Due to the growing share of renewables in electricity production, the electrification of sectors by Power-to-X technologies is becoming more important. In this way, electricity from renewable sources can also help reduce emissions that are harmful to the climate and ensure sustainable energy production in the heating and mobility sectors.

Power-to-heat

Using power-to-heat technologies, electricity is converted into heat and used to supply heat. This technological solution is applied in conventional electrical heat and in heat pumps (for more information on how heat pumps work, see Chapter 2.3.4 Heating and cooling with heat pumps). Many everyday household appliances such as electric kettles and hot water boilers are also based on the technological concept of power-to-heat. In addition, power-to-heat technologies are also used in commercial supplies of negative control energy, process heat and local and district heating for water heating and the operation of heating systems.

Conversely, the power-to-heat technological process can also take the form of conversion of heat to electricity, such as the use of waste heat in gas-steam power plants. In these cases, the waste heat from the gas power plant process is used to operate the steam power plant and thereby converted into electricity (for more information on waste heat utilisation, see Chapter 5.3.2 Waste heat utilisation).

Power-to-gas

With power-to-gas technology, electricity is converted to hydrogen or, in an additional step, to a synthetic gas.

How it works: Power-to-gas

With this technology, electrical energy is used to split water into hydrogen and oxygen by means of electrolysis. This one-step process is also known as power-to-hydrogen.

The hydrogen can then be used directly, stored, or converted into synthetic methane by the addition of carbon dioxide in a follow-up synthesis process. In contrast to hydrogen, synthetic methane has similar properties to natural gas and can thus be easily transported via the existing natural gas network to the consumer or stored in natural gas storage facilities.

The two gases can be used either in the energy or mobility sector. Hydrogen may be used as an alternative fuel to generate electricity and heat within a fuel cell and thus drive, for example, an electric motor in a fuel cell vehicle or a hydrogen heater (for more information on fuel cells, see Chapter 2.2.3 Fuel cell). Synthetic methane, on the other

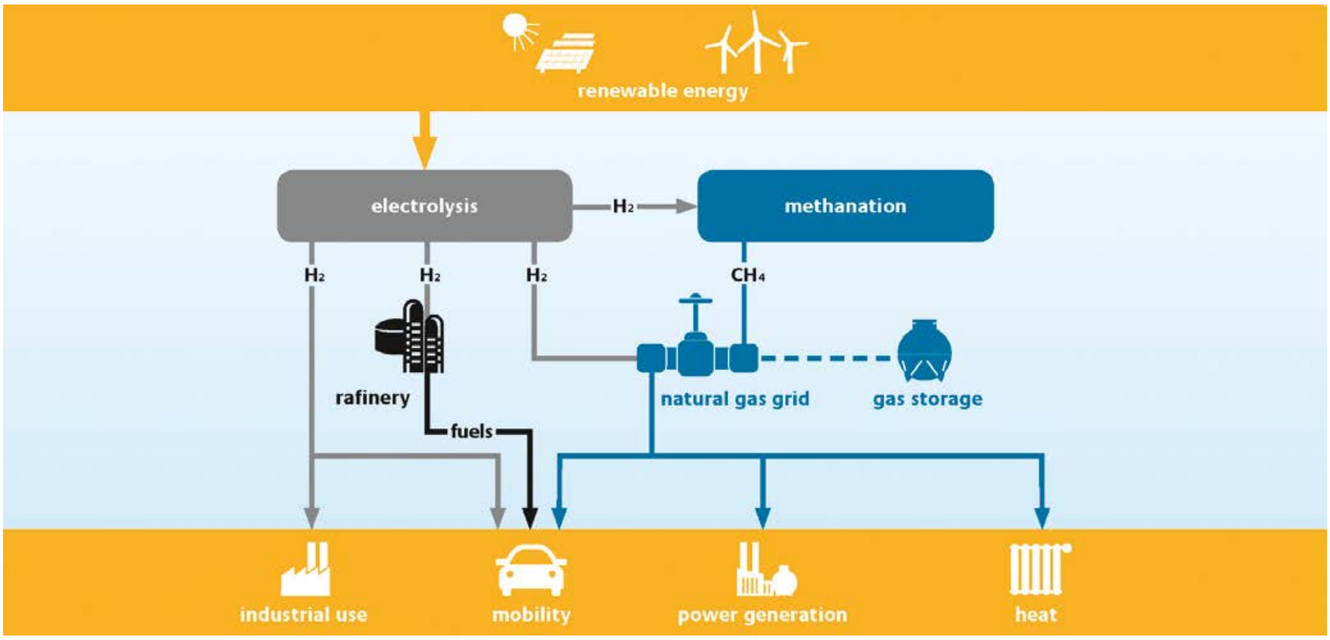


Figure 15: Application fields of Power-to-gas*
Source: Deutsche Energie-Agentur (dena) – German Energy Agency

hand, can be used as an alternative fuel for the propulsion of natural gas vehicles in the mobility sector and to operate CHP plants or block-type thermal power stations and gas heating systems.

Power-to-gas technology also enables hydrogen and synthetic methane to be used as a power storage medium and stored in gas storage tanks. At the end of the desired storage period, the hydrogen or synthetic methane is, for example, converted back into electricity by a block-type thermal power station.

Power-to-liquid

The production of liquid fuel from electricity is also known as power-to-liquid. The power-to-liquid process is based on the power-to-gas process, but with the addition of another conversion process. Power-to-liquid technology is used to liquefy the gases generated from the power-to-gas process, making them easier to transport far away from piping systems.

Various methods are available for the liquefaction of hydrogen or synthetic methane. Both gases can be liquefied by means of compression and cooling to extremely low temperatures. Alternatively, the recovered hydrogen can be mixed with carbon monoxide or carbon dioxide and converted in a synthesis process to liquid hydrocarbons. Synthetic gasoline can be obtained, for example, from the hydrocarbons in another processing step.

* For further information visit: www.powertogas.info/englisch

4 Energy infrastructure

The existing energy infrastructure faces new challenges as the share of renewables in the energy mix grows. To transport electricity and heat from the producer to the consumer, a modern energy infrastructure needs to able to connect both centralised and decentralised power plants, volatile renewable and base-load power plants with metropolitan areas as well as with individual off-grid consumers.

Figure 16: Overhead transmission lines in a power grid
Source: fotolia.com/thomaslerchphoto

This increasingly decentralised and volatile supply of energy means that energy systems need to be designed more flexible through the use of new technologies. The energy infrastructure can be adapted by using smart metering devices and grids and integrating energy stores and technologies to allow cross-sectoral use of the generated energy and expansion of the range of services. Another new field of expertise in energy infrastructure is the provision of alternative fuels, especially in the mobility sector.

4.1 Power grids

With the rising share of volatile and decentralised electricity feed-in as well as new types of consumers such as electric vehicles, the traditional power grid infrastructure is reaching its limits. In the past, power from conventional power plants previously flowed unidirectionally from the transmission system to the distribution grids. However, nowadays the power transfer is bidirectional. This is because of the electricity feed-in from renewable energy systems, which usually takes place at the low-voltage and medium-voltage level of the distribution network.

Distribution grids were not originally designed to feed in electricity. To avoid bottlenecks and maintain stability at all voltage levels, more and more measurement, control and communication technology is needed to support frequency and voltage control in the power grid. This in turn means that more and more interfaces are required between the grid and generators, consumers and power storage units. The flexibilisation, decentralisation and digitalisation of the power supply are also playing an increasingly important role as well as the associated IT security and system services these require.

A closer look: System services

Power grid operators access system services in order to ensure a trouble-free and efficient power supply with the fewest possible supply interruptions and transmission losses. These include various measures designed to stabilise the frequency, voltage and load in the electricity grid when balancing demand and supply.

Figure 17: Grid operator’s central control station
Source: TransnetBW

4.1.1 Power electronics and network control technology

The transmission of electricity is becoming more complex due to changes in electricity generation brought about by the shift towards renewables. More producers mean more flows of electrical energy, even at upstream voltage levels. As the number of producers increases, so does the coordination effort required between producers and consumers and between different network levels. Decentralised generation plants therefore increasingly have to contribute to system stability using power electronics. In addition, grid operators are required, due to the use of network control technology, to optimally utilize the transmission capacity of the grid and regulate the utilisation.

Power electronics

Power electronics are necessary in the power grid whenever the profile, amplitude or frequency of the voltage and the current intensity of current flows need to be adjusted, for example, when electricity is fed into the supply grid. The power electronics used here are converters. The converters convert the power in accordance with the technical connection rules with regard to the required frequency, voltage and phase position, for example, with direct current becoming alternating current.

A closer look: Application fields of power electronics

Power electronics play a key role in achieving a sustainable supply of power with a growing share of renewables, as these energy sources require a combination of AC and DC systems. While alternating current flows through most supply grids and domestic appliances are also powered by alternating current, direct current is generated or required during electricity generation. For this reason, an inverter nowadays acts as the standard interface between a photovoltaic system and the supply grid. However, in wind turbines, frequency converters are used to align the frequency of the variable-speed wind turbines with the grid frequency.

Modern power electronics, such as those used in high-voltage direct-current transmission, can significantly reduce transmission losses during network operation. Current research and development is focusing on optimising costs, efficiency, service life, weight and volume as well as the system efficiency of power electronic components.

Network control technology

The term "network control technology" refers to the technologies used for data acquisition, transmission and evaluation and the monitoring, control and regulation of networks enabled by these technologies. It is used both in power grids and other supply networks such as heat, gas and water networks. In the past, network control technology was mainly implemented at the highest voltage level, since this is where the feed-in took place. Now, with the integration of multiple decentralised power generators in the grid and feed-in of these generators at low-voltage and medium-voltage levels, the application of network control technology has expanded to include these levels and is increasingly important in the field of feed-in management.

4.1.2 Digitalisation of the electricity infrastructure

Digitalisation of the electricity infrastructure refers in particular to the development of smart grids. These smart grids enable better balancing of electricity generation with electricity consumption so that supply can be guaranteed at all times despite volatile sources. The modern information and communication technology (ICT) incorporated in smart grids enables real-time acquisition and transmission of network states. These data can then be used for the precise connection and disconnection of loads and generators. Digital technologies are also used in virtual power plants. Virtual power plants (VPPs) can help make the power grid more flexible by, for example, consuming excess power by increasing demand and reducing production within the virtual power plant.

A closer look: Virtual power plants

VPPs are not power plants in the traditional sense, but a virtual network of multiple generating plants, loads or storage. While the individual plants can be in different locations, the electricity they generate is balanced across all plants before being bundled into the power grid.

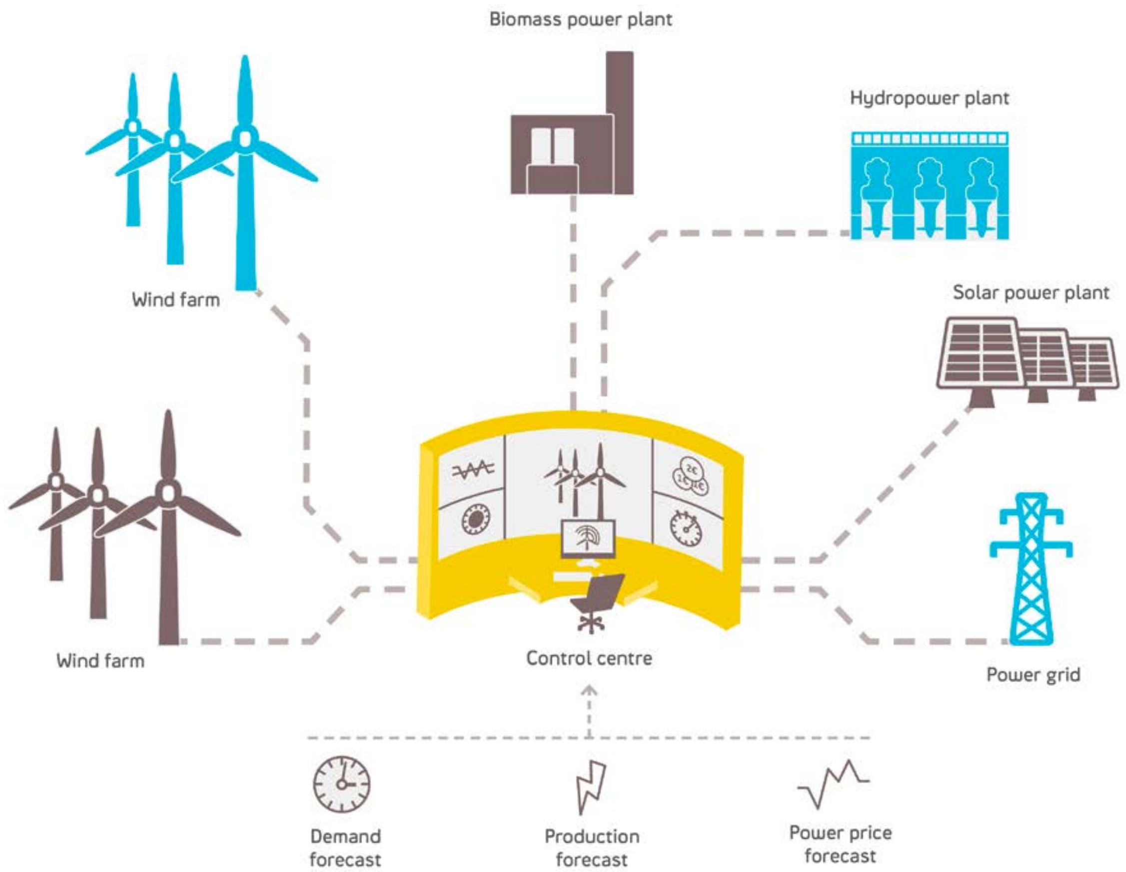


Figure 18: Central control station of a VPP
Source: BMWi

The operation of a virtual power plant requires a real-time monitoring system that allows producers to monitor their available power and operational readiness. If, for example, a virtual power plant comprises solar and wind power plants, weather data also needs to be considered within the monitoring system. The monitoring system determines how much power the VPP can feed into the power grid, since the amount of electricity that can be delivered by the plant varies depending on the weather.

4.1.3 Micro-grid systems

Micro-grid systems or mini-grids are self-sufficient power grids that cannot be connected to larger interconnected grids, or only connected with difficulty, due to geographical conditions or cost-benefit considerations. In the case of cost-benefit considerations, micro-grid systems are used in particular for rural, remote areas with low electricity consumption or in countries with weak infrastructure in general. The size of these micro-grid systems varies greatly: from the self-sufficient power supply of a single consumer, such as a remote hotel or remote mine, to the power supply of an entire village or island state.

A closer look: Micro-grids for rural electrification

Particularly in countries with an underdeveloped grid infrastructure, the development of individual micro-grid systems offers an economical and efficient way of providing rural electrification and ensuring greater security of supply to essential public facilities such as hospitals or schools. According to the International Agency for Renewable Energy (IRENA), around 26 million households in rural areas are already being supplied with electricity via micro-grid systems. About five million of these are supplied with electricity from renewable sources. The size of micro-grid systems generally ranges from one kilowatt to multi-megawatt.

Traditionally, diesel generators have been a core element of the power supply within a micro-grid system. They provide a flexible, demand-driven supply of electric power. However, diesel combustion is also associated with environmental and health downsides such as exhaust gases and noise, as well as high fuel costs and a dependence on

Figure 19: Micro-grid power supply
Source: SMA Solar Technology AG

energy imports. An environmentally friendly, cost-effective and reliable alternative is to substitute or supplement diesel generators with renewable energy systems in conjunction with storage technologies. Photovoltaic systems, small wind power plants and hydroelectric power plants used together with battery storage systems offer good potential for application in micro-grid systems.

Hybrid systems, in particular, are widely used internationally. These include one or more diesel generators which are used in addition to renewable energy systems for emergency power supply. In general, several generating units are required within a micro-grid system.

Another feature of micro-grid systems is that they have particular requirements for network management. Network capacity must be balanced in the event of an oversupply or undersupply of electricity, without the option of the micro-grid itself being able to exchange power with adjacent networks. Furthermore, the low number of power generators and consumers within the micro-grid can lead to high grid fluctuations as soon as there is a change in load or electricity generation. Due to the complicated network balancing, micro-grid systems require special inverters and charge controllers, which take over the entire energy management of the micro-grid system by controlling voltage and frequency with battery, generator and load management.

4.2 Storage technologies in the electricity sector

For a sustainable energy supply with a high share of renewable energy and alternative fuels to become reality, energy storage is an essential part of the energy infrastructure. These storages can generally help to make the energy system more flexible, compensate for peaks in demand and supply, and also enable off-grid or mobile energy supplies. In the electricity sector, energy storages can also be used for voltage and frequency control.

Advantages of storage technologies

- Enable energy consumption independent of the exact time of energy generation
- More profitable due to option of demand-based electricity marketing at times of high electricity prices
- Allow cross-sectoral and infrastructural use of fed-in electricity, in the form of power-to-gas for example

Power storage systems can generally be broken down into electrical, electromagnetic, electrochemical or mechanical storage systems. Within these various categories, the individual power storage systems vary in terms of their injection and withdrawal rate, storage capacity, depth of discharge, service life, self-discharge, reaction times and costs. With regard to their fields of application, power storage systems can be either short-term or long-term.

4.2.1 Short-term storage systems

Short-term storage systems, which can be used for frequent but only brief power storage of several seconds to minutes, include in particular capacitors, superconducting magnetic energy storage systems and flywheels. Batteries are also included under the heading of short-term storage systems, although they offer a much longer storage time of hours to days.

Batteries

Batteries store electrical energy in the form of chemical energy. The power storage process is carried out as electrolysis, which is triggered when a voltage source is connected. Electrolysis takes place in reverse when the battery is discharged. Batteries that can be recharged several times are also called accumulators.

The application fields of batteries cover a wide range: from storage modules in electric vehicles, **small storage units** in residential buildings, storage units for emergency power supply in micro-grid systems, to mass storage systems for the provision of primary control power in public power supply facilities. Since batteries have a modular structure, they can therefore be scaled to any size. Their use is independent of location so they are suitable for mobile use, given their high energy density (depending on the battery type). Batteries are used both in small-scale and large-scale solutions.

Figure 20: Lithium-ion storage batteries in standardised industrial racks
Source: Franz Meyer/BINE Information Service

A closer look: Types of batteries

The most common types of battery technologies in the electricity sector are lead-acid batteries or lead gel batteries, lithium-ion batteries and redox flow batteries.

Lead-acid batteries are the currently the most commonly used batteries worldwide. They are relatively safe, robust and cost-effective.

However, they are increasingly being replaced by more environmentally-friendly lithium-ion batteries. These are lighter and more compact, have a higher energy density and a lower self-discharge rate. However, since they are flammable at high heat, they must be kept cool.

Redox flow batteries have an energy storage capacity that can be scaled as desired, while their efficiency and storage time are high with a low self-discharge rate. Their disadvantages are their high cost and low energy density.

Capacitors

Capacitors are components in which electrical energy can be stored in an electric field. They generally consist of two electrodes, which are separated by an insulating layer. When both electrodes are charged with an applied voltage, an electric field is formed between them. This is where the electrical energy is stored. The electric field remains in place even when the power connection is interrupted.

Capacitors are highly efficient since there is no need to convert the energy for their storage process and their energy losses are thus low. They have a high cycle stability and therefore a long service life. Capacitors are chiefly used whenever a large number of short charging and discharging cycles are required. As storage systems, the limitations of capacitors are their low energy density and storage capacity. In both cases, these are significantly lower even with supercapacitors than with batteries. Due to their high rate of self-discharge, they are also only suitable as short-term storage systems for time scales of seconds. Moreover, their use has so far been associated with high investment costs.

A closer look: Supercapacitors

Many different types of capacitors are available. These differ mainly in their design as well as the materials used for the electrodes and insulating layer. One special type of capacitors are supercapacitors, or “supercaps” as they are also called. These supercaps have the highest energy density of all capacitors and feature comparatively high capacity.

Superconducting magnetic energy storage systems

Superconducting magnetic energy storage systems (SMES) store electrical energy in the form of an electromagnetic field. SMES consist of a coil inside which an electromagnetic field is formed as soon as a current flow within the coil is triggered by an applied voltage. When this current flow stops, the electromagnetic field remains and thus stores the electrical energy which can then, when necessary, be converted back into a current flow by means of a power conversion system.

Like capacitors, SMES have the distinct advantage of high efficiency compared to other power storage technologies. This efficiency is achieved by storing the power directly without conversion. The power can thus be stored in a very short period and also made available again. Compared to batteries, SMES have the advantage of a long service life due to their theoretically unlimited number of charging and discharging cycles. However, like capacitors, SMES can only be used for a short storage time span of a few seconds to minutes, have a low energy density and require high amounts of investment. Because of these characteristics, SMES (like capacitors) are suitable for applications in which current must be stored and made available again at short notice, for example for network balancing in the event of voltage dips or short outages.

Flywheel energy storage systems

Flywheel energy storage systems store electricity in the form of kinetic energy. The flywheel is a rotor driven by an electric motor, thus converting electrical energy into kinetic energy. If the kinetic energy is to be converted back into electricity, the electric motor is used as a generator. This brakes the rotor and generates electricity. Depending on the application, the charging and discharging time takes between a few seconds to about 20 minutes.

Flywheels can store and resupply a large volume of electricity in a short time span, have a long service life and relatively low operating costs. They are particularly suitable for use in stabilising networks with short-term load fluctuations, for example, small micro-grid systems, as well as for balancing the supply of wind power. However, flywheels have a high rate of self-discharge, a low energy density and comparatively high costs per stored kilowatt-hour.

4.2.2 Long-term storage systems

In contrast to short-term energy storage systems, long-term energy storage enables electricity to be stored over weeks to months. It is therefore used in the industrial and public energy supply sectors. Long-term storage solutions include pumped storage, compressed air energy storage and gas storage tanks.

Figure 21: View of the pipes on the power house of a pumped storage station
Source: alamy.de/Hans Blossey

Pumped storage systems

Pumped storage systems store electrical energy in the form of kinetic energy. They do so by using electrical energy via an electric motor to drive a pump that transports water from a lower reservoir to a higher upper reservoir.

The kinetic energy of the water which is generated by the difference in elevation of the two reservoirs can then be converted back into electricity when the water flows down from the upper reservoir into the lower reservoir, thereby driving a turbine. Combined with a generator, this turbine converts the mechanical energy back into electricity.

Although their operating costs are low, pumped storage stations require high investment at the building stage. In addition to the high costs, the construction of pumped storage stations often has a considerable impact on the landscape, which makes them a less socially acceptable option in some cases. Furthermore, the option of using pumped storage in areas with specific geographical conditions is limited. For the required elevation difference between the two reservoirs, pumped storage stations require either mountainous topographies or caverns such as underground former mine tunnels, opencast mines or man-made water reservoirs.

A closer look: Application fields of pumped storage stations

Pumped storage stations can provide large storage capacities in the gigawatt range, whereby the storage capacity can be scaled using the capacity of the reservoirs and the difference between their elevations. They are highly suited to long-term storage because they can store electricity for hours to weeks. In addition, they offer a long service life, high energy density and, compared to other long-term storage systems, high efficiency. Pumped storage stations are especially suited to provide control energy and reactive power, since they only require a short lead time to supply the stored electricity. In addition, pumped storage stations have black start capability. This means they do not need an external power source to power up and can be used to restore the power grid after a shutdown.

Compressed air energy storage

Compressed air energy storage is a type of mechanical energy storage system. Electrical energy is stored in this case in the form of the pressure energy of compressed air. During the storage process, excess injected power is used to drive a compressor that compresses the ambient air. This air is then cooled and stored in an underground cavity or compressed air tank. When the stored electricity is needed again, the compressed air is directed into a gas turbine where it expands. The gas turbine is powered by the expanding air and thus produces electricity in conjunction with a generator.

In terms of advantages and disadvantages, compressed air storage systems are largely comparable with pumped storage stations.

Figure 22: x Process gas expander of a compressed air energy storage system

Source: MAN Diesel & Turbo S.E.

Gas storage

Electricity can also be stored in the form of gas using power-to-gas technology (for more information on Power-to-gas, see Chapter 3 Sector coupling technologies). Power-to-gas technology converts electrical energy into either hydrogen or synthetic methane. When the electricity is needed again, the hydrogen or synthetic methane can be converted by means of internal combustion engines, generators or fuel cells.

Hydrogen and synthetic methane can be stored both in gaseous and liquid form. For gas storage in liquid form, the gas must be cooled down to extremely low temperatures. Additional energy must be expended for this purpose.

To store gaseous hydrogen and synthetic methane, which have lower volumetric energy density, large-volume storage tanks or containers are required. These are difficult to transport. The volumetric energy density of synthetic methane is three times higher than that of hydrogen. Compression can be used to increase the energy density or storage density, but in this case the gas storage tanks must be able to withstand the increased internal pressure with their mass. This has a negative effect on the weight and thus on the transportability of the storage tanks.

Gas storage tanks are very well suited as large-scale long-term electricity stores, since electricity in the form of gas can theoretically be stored for an indefinite period. However, the process of converting electricity into hydrogen or synthetic methane leads to high energy losses. This approach therefore offers low efficiency compared to other storage technologies. Energy losses that occur when electricity is stored in the form of synthetic methane are particularly high, due to the additional conversion process incorporated in the synthesis. However, if hydrogen and synthetic methane are considered as something other than power storage mediums only (direct reuse in other sectors is possible without reconversion), a much higher level of efficiency can be achieved.

Figure 23: Hydrogen tank for intermediate storage of hydrogen generated
Source: The Linde Group

A closer look: Liquid gas storage

Liquid gas storage tanks are particularly well suited to mobile storage. Liquefied gas storage tanks are mainly used to transport hydrogen: pure hydrogen, unlike synthetic methane, cannot be transported via an existing natural gas network because of its special chemical properties. Vacuum-insulated tanks are generally used for liquefied gas storage, as they are better for cold storage.

4.3 Heating and cooling networks

To ensure an efficient heat supply, local and district heating networks as well as heat stores are needed, especially for applications and processes with high temperatures for industrial sites. This also applies to the supply of densely populated metropolitan areas. Heating networks can help boost efficiency in the energy supply, in particular by using combined heat and power plants or by using unavoidable industrial waste heat as heat sources. In addition, sector coupling technologies such as power-to-heat can be used to maximise the use of existing infrastructure and energy from renewable sources for an efficient and climate-friendly energy supply (for more information on sector coupling and power-to-heat, see Chapter 3 Sector coupling technologies).

Heating networks are therefore a vital infrastructure element of a future heat supply. These networks offer the systemic advantage of spatial and temporal balancing of heat sources and heat demand within a technically and economically optimised system using adapted flow and return temperatures and heat stores. Heating networks are not a viable option for all applications or locations. Any planning of heating networks should therefore always be preceded by careful weighing up of the pros and cons of a heat network-based supply.

A closer look: Heat sources of heating networks

As a direct heat source, for example, conventional heating plants can be used, as well as heat stations, cogeneration plants or block-type thermal power stations that are operated using waste or biomass. Other sources are biogas plants, thermal solar energy, geothermal or waste heat from industrial processes or from combined heat and power plants (CHP). In addition to the use of direct renewable heat sources to reduce fuel costs and emissions, using power-to-heat technologies to couple heat networks with electricity from renewable sources offers another option for sustainable heat supply.

4.3.1 Local and district heating networks

Heating networks are used to transport and supply heat, cold or steam. Depending on their reach, they are categorised either as local or district heating networks. They usually connect several heat sources with several consumers via underground pipelines or overhead lines. Using the heat sources or heat generator, a heat transfer medium is heated to a certain temperature and transported to the consumer via the pipeline system by means of pumps. The heat transfer medium is usually water or steam. At the consumer site, the heat transfer medium is either used directly via heaters or transferred via a heat exchanger to a second heat transfer medium, which can then be circulated and used for various heating purposes within an object like a building, for example. In both cases, the heat transfer medium cools down and is returned to the heat source in the heating network, where the cycle is repeated.

Heating networks can also be used to provide cooling, referred to as cooling networks. Cooling can be produced by using absorption chillers, using heat energy. In this process, the absorption chiller can either be used once heat is transported through the pipe system to the consumer site or it can be connected directly to the heat source (for more information on absorption chillers, see Chapter 2.3.1 Heat conversion into cooling and air conditioning).

Depending on the field of application, type and number of consumers connected to the heating network and their distance from one another, the heating network must be able to meet a certain demand for heat and also guarantee a particular temperature level for heat transport. Especially high temperatures are achieved, for example, during heat generation in fossil-fuel heat stations or cogeneration plants and are needed for process heat supply in industry. Low-temperature sources that are used within bidirectional heating and cooling networks are, for example, the waste heat from industrial processes and the heat generated from renewable energy systems such as solar collectors, biogas plants or near-surface geothermal collectors.

Figure 24: District heating tunnel
Source: gettyimages.de/Ralf Müller/EyeEm

A closer look: Local heating networks and district heating networks

The fields of application of the transported heat and cold range from room heating or air conditioning, through heating of drinking water to process heat supply. With their small spatial reach, local heating networks provide a decentralised heat supply to smaller areas such as housing estates, business parks and small communities. District heating networks are used for centralised, nationwide heat supply over long distances.

4.3.2 Low-temperature bidirectional thermal networks

In low-temperature bidirectional thermal networks, unlike high-temperature heat networks, less heat is lost to the environment since the temperature of the transported heat corresponds to the ambient temperature of the pipes. Bidirectional thermal networks require flow temperatures of only 40° C. In contrast, conventional heat networks in the high temperature range require flow temperatures of around 110° C in winter. In the pipe system of the bidirectional thermal networks no insulating layer is used, since the water draws on the temperature of the environment, for example in the soil, to maintain its own temperature.

Since the insulating layer is not needed, cheaper materials can be used for the pipe system. To heat the heat transfer medium to the required higher temperatures for various fields of application, bidirectional thermal systems need to use local, decentralised heat generators at the consumer site. Heat pumps, renewable energy systems such as solar collectors and waste heat from industrial processes or CHP plants are especially suitable for this purpose. The operation of bidirectional thermal systems relies on large volume flows: pipes with a larger pipe internal diameter are therefore necessary.

4.3.3 Solar heating networks

Thermal solar systems are suitable for supplying heat from renewable energy via local heating networks. These solar systems can be connected to a heat network in combination with a peak load boiler, biomass cogeneration plant or a heat pump as heat sources. Well-insulated underground water pits, geothermal heat pumps or aquifer storage fields are used to store solar heat seasonally. Solar thermal systems also need large solar collector panels for heat generation: large free open spaces or extensive roof surfaces must be available on site for the installation of these panels.

4.4 Storage technologies in the heating sector

Thermal energy storage systems (also referred to as heat or cold storage systems, depending on the application) are used to make the heating and cooling supply more flexible and thus allow the deferred or off-grid provision of heat and cooling. They offer great potential for a steady supply of heat or cooling, especially when renewable energy is used, since the energy supply then varies over the course of the day and year and depends on the given external conditions. Thermal storage systems are also suitable for the use of waste heat in industry, which is flexible timewise and demand-driven. For example, the waste heat generated during industrial processes can be stored and used at a later stage for room heating and air conditioning or to supply process heat and cold. During cooling, the stored waste heat is converted into cold via absorption chillers or conventional compression refrigeration units (for more information on the provision of cooling, see Chapter 2.3.1 Heat conversion into cooling and air conditioning).

Figure 25: Industrial heat storage
Source: istockphoto.com/IP Galanternik D.U.

A closer look: Temperature level of heat stores

Like heating networks, heat storage systems are differentiated into low-temperature and high-temperature systems. In the low-temperature range, hot water tanks are the most commonly used systems. For high-temperature storage systems, fluid storage based on liquid salt, solid storage, steam storage or latent heat storage is used.

As the share of electricity generated from renewable energy grows, it makes increasing environmental and economic sense to use thermal storage also for storing excess electricity in the form of heat or cold. In this process, the electricity is first converted into heat by means of power-to-heat technologies and then stored as thermal energy (for more information on Power-to-heat see Chapter 3 Sector coupling technologies). Based on the current state of technological development, storing heat or cold is cheaper than storing electricity.

Thermal storage can be split into three subcategories: sensible heat storage, latent heat storage and thermochemical storage.

4.4.1 Sensible heat storage

In sensible heat storage, thermal energy is stored when a transfer of thermal energy increases the temperature of a storage medium such as water or stone, without causing a change in the physical state of the medium. The most widely used sensible heat storage methods are water storage and hot blast heating. Water storage tanks are used, for example, to supply heat to buildings. Hot blast heaters are filled with refractory rock and used as high-temperature storage for preheating the air blown into blast furnaces. Sensible heat storage systems can also be used as sensible cold storage systems, for example in the form of water storage tanks.

In the field of renewable energy, sensible heat storage systems are used, for example, in the form of molten salt stores in solar thermal power plants. Here, surplus solar-generated heat is used to heat salt from about 200° C to 400° C to a liquid state, which is stored in storage tanks with a capacity of several tens of thousands of cubic metres. The stored energy can provide heat, cold or electrical energy. The liquid salt storage tanks can be used not only for short-term balancing of fluctuations in the energy supply, but also to extend the energy supply of the solar thermal power plant beyond the daytime limit of solar radiation.

4.4.2 Latent heat storage

In latent heat storage, excess thermal energy is stored when it is used to cause a change in the phase state of a material, for example by changing its physical state. The thermal energy absorbed or emitted during this process is referred to as latent because the supply or release of the thermal energy does not lead to a temperature change and thus remains “hidden”. Depending on the type of material, the phase changes occur at a different level of pressure, temperature etc. The materials used in latent heat storage systems include paraffins, salts and salt hydrates. Latent heat storage systems can also be used as latent heat cold energy storage systems, for example in the form of ice storage devices.

Other applications include latent heat storage systems used in connection with building materials in construction, where they are installed for air conditioning and heat storage in facades.

Figure 26: Private heat store as latent heat storage system for water
Source: istockphoto.com/zazamaza

4.4.3 Thermochemical energy storage

In thermochemical heat and cold storage methods, thermal energy is absorbed by the use of reversible chemical reactions or released again when the opposite reaction occurs. The chemical reactions are triggered by the separation or combination of at least two substances. In this process, the absorbed heat is bound in a chemical form and can thus be stored indefinitely without any losses.

Thermochemical heat and cold storages are therefore particularly suitable as long-term storage methods, for example, for the year-round provision of solar heat and cooling, for heating and air conditioning of residential buildings or for load balancing in district heating networks. In the case of sensible or latent heat storage, however, long-term storage is only possible under limited circumstances, whereby very good insulation of the storage facilities and large storage volumes are necessary.

5 Efficient energy consumption

Increasing energy efficiency and generating energy from renewable sources are essentially two sides of a coin. They are key to sustainably restructuring the entire energy system. Less energy needs to be consumed and generated wherever opportunities for energy efficiency can be exploited. The available technologies and planning approaches differ fundamentally depending on which sector, building or industrial or commercial process consumes energy.

5.1 Energy efficiency in buildings

The best way of increasing energy efficiency is to reduce general energy consumption. At a global level, energy consumption in buildings accounts for approximately 30 percent of total final energy consumption. In the European Union and Germany the figure is as high as 40 percent. Buildings therefore offer great potential for energy savings and for the associated positive effects such as reduced heating and electricity procurement costs. Energy efficiency measures, such as improving thermal insulation in the building envelope, modernising building services equipment or implementing construction strategies that are based on holistically planned, sustainable building and energy supply systems can exploit this potential. It is important to view building systems holistically, as structural solutions must be balanced with the use of building services engineering to attain a high level of energy efficiency, climatic comfort and indoor hygiene at minimum cost is essential.

5.1.1 Building envelope

The main influencing factors in improving energy efficiency in the building envelope include the quality of insulation, construction with minimum thermal bridging, airtightness and windows or glass facades. The most energy-efficient construction method depends on the immediate local climatic conditions and thermal conditions in the building environment as well as the current and planned use of the building. Generally speaking, buildings can be divided into residential buildings and non-residential buildings, the latter category comprising very different building types that fulfil a diverse range of functions. These include office buildings, schools and creches, shopping centres, industrial buildings, sports facilities and swimming pools. Depending on what they are used for, buildings are constantly exposed to certain processes and stresses from inside and outside, temperature fluctuations, airflows, air humidity ratios and even pressure ratios. These factors must be taken into consideration when choosing the construction method used for a building and the building services equipment.

Insulation

Insulation options can be differentiated according to various insulation levels and insulation materials. The insulation levels can be classified as exterior, interior and core insulation.

A closer look: Insulation

Among the various options for insulating buildings, exterior insulation is the easiest and least problematic from a structural perspective. Interior insulation, on the other hand, is exposed to various stresses and can lead to the formation of mould if not installed properly. It also restricts the use of the living or utility space. Interior insulation is used primarily when insulation measures cannot be used on the exterior facade, for example in the case of listed facades. Core insulation is suitable for renovating double exterior walls, which have a layer of air between the interior and exterior wall. The potential insulation strength is dictated by the width of this layer of air, but in practice it is often significantly constrained, for example by residual mortar.

Figure 27: Installing interior insulation
Source: istockphoto.com/Highwaystarz-Photography

Insulation materials are mainly distinguished between organic and inorganic insulation materials. Examples of inorganic insulation materials are mineral wool or expanded granules. Organic insulation materials can be broken down further into fossil-based insulation materials, such as polystyrene, and renewable insulation materials, such as those based on wood fibre, hemp or seaweed. The ability of an insulation material to transfer heat is specified by its thermal conductivity: excellent insulation is obtained from materials with low thermal conductivity. In insulation materials, the range extends from approx. 0.025 watts per metre and Kelvin (W/(m·K)) for PUR insulation materials up to 0.045 W/(m·K) for wood fibre panels. Mineral wool and polystyrene have a heat conductivity of approx. 0.035 W/(m·K). In addition to heat conductivity, other properties play a role in the selection of a particular insulation material, e.g. protection against overheating in the summer months, fire protection and even permeability to water vapour.

A closer look: Heat loss through thermal bridges

Thermal bridges are areas in the thermal building envelope in which increased or additional heat flows occur during the heating period due to component geometry, a change in the material in the component level or construction constraints. As a result, the local surface temperature drops sharply on the inside of the exterior components. An increased heat flow can be identified on thermal bridges. Additional heat is required to counter the resulting cooling on the inside of the components. This can also produce condensation and, in a worst-case scenario, lead to the formation of mould or structural damage caused by damp. These risks must be avoided by implementing targeted, professional measures.

Airtightness

The best thermal insulation is futile if the building envelope is permeable, causing increased ventilation heat loss. The airtightness of the building envelope is therefore another important factor in the energy-efficient heating or cooling of a building. Uncontrolled ventilation losses through doors and windows that are not properly sealed or through incorrectly sealed penetrations in the building envelope (e.g. through cables or pipes) must therefore be avoided as much as possible. To achieve a high level of airtightness, attention must be paid to the use of suitable structural components. Alternatively, a separate airtight layer must be installed on the inside of the building envelope. This can be achieved with the use of films or by taping the joints in the wood frame construction. Another option is to carefully apply a layer of plaster on the inside of the exterior walls in the masonry.

The internationally established blower door test, a method to measure pressure differentials, is usually used to detect the presence of any leaks.

Windows and glass facades

While heat losses should be avoided and solar gains should be increased primarily in moderate and cooler regions, the focus in warmer regions is on avoiding overheating. This can be achieved through effective sun protection in transparent structural parts or – and this has a more effective impact – by means of climatically adapted building concepts, which facilitate a high degree of shade or natural ventilation and cooling. These passive systems and strategies help to save valuable energy.

Figure 28: Thermogram of a building facade
Source: Verband Privater Bauherren, Regionalbüro Emsland, Dipl.-Ing. Johannes Deeters

The airtight installation of modern windows can significantly reduce heat loss within the building envelope. Modern windows generally consist of two to three panes of glass, with the spaces in between filled with inert gases such as argon, krypton or xenon. This layer of gas acts as thermal insulation. Barely visible coatings on the glass, which allow only radiation with certain wavelengths to penetrate, provide another layer of thermal insulation. This means, for example, that visible light can pass through during the summer, while long-wave heat radiation is reflected.

Modern window frames are very well insulated and are fitted with a multi-chamber profile to optimise a building's energy efficiency. The material in the glass spacers also has a strong influence on the transfer of heat through the windows. Plastic spacers with low thermal conductivity have an advantage over the traditional aluminium spacers.

Figure 29: LED lamps
Source: istockphoto.com/DKsamco

5.1.2 Technical building equipment

Technical building equipment covers mainly lighting, ventilation, heating and air-conditioning systems within a building. The use of building equipment can be optimised by coordinating the equipment with the structure and use of the building.

Lighting

The energy consumed by lighting in buildings can be reduced in two ways: energy-efficient lighting systems and needs-based lighting control. Total energy savings of up to 80 percent in the area of lighting can be obtained in this way.

The use of incandescent lamps should be avoided. Halogen lamps are a particular type of incandescent lamp that can achieve energy savings of around 30 percent compared to conventional incandescent light bulbs. Compact fluorescent lamps, commonly known as energy-saving lamps, can achieve electricity savings of up to 80 percent. However, the technology used in these lamps means that they have a longer warm-up time before they reach full brightness. This does not happen with light-emitting diode (LED) technology. Due to significant improvements in their brightness in recent years, LED lighting is now widely used. As a result, the compact fluorescent lamp is being phased out.

A closer look: Efficient lighting systems

The use of efficient light sources in electronic ballasts is vital in exploiting potential energy efficiency. In addition, efficient lamps with good light control should be used and the available daylight optimised using daylight-responsive lighting control. Presence detectors can also help to save energy. Excessive additional power should be avoided when planning new facilities. The use of lamps with a high protection class is advisable to avoid contamination indoors, particularly in the case of high pollution levels, water or dust.

In addition to the use of energy-efficient lighting systems, needs-based lighting control can help to make considerable energy savings, for example by aligning window facades to face south when designing and constructing buildings. Automated lighting control using sensors is another technical solution that can be implemented in building stock undergoing modernisation. Energy saving, needs-based lighting control can also be achieved through the deflection of light. With a light deflection system, mirrors, for example, are used to direct daylight from the window surfaces into areas where there is less natural light inside the building. The use of demand-driven lighting control, combined with energy-efficient lamps, is particularly beneficial in business and industry. In Germany, lighting accounts for up to 20 percent of electricity consumption in business.

A closer look: Lighting automation

Presence sensors can automate lighting in such a way that a room is only illuminated when occupied by people. In addition, daylight sensors can independently adapt the artificial light in a building to the intensity and direction of the natural light. This means that the artificial light can be automatically switched on and off or dimmed as required.

The implementation or replacement of lighting systems is determined by the individual stages of a professional modernisation project. In addition to an initial survey, it encompasses the planning, financing, procurement as well as the maintenance and operation of the new system. The potential energy savings that can actually be realised when refurbishing a lighting system depend largely on the current state of the system.

An analysis of life cycle costs is necessary to enable a comparison of the various measures with one another. In addition to investment costs, life cycle costs also factor in the costs incurred for energy, maintenance, cleaning and disposal.

Ventilation systems

Ventilation systems can ensure a high quality of indoor air and indoor hygiene by means of the automated, regular exchange of air in buildings. Such systems are especially suitable for well-insulated buildings with a largely airtight building envelope, as a controlled exchange of air is particularly important here, thus establishing the conditions for the efficient operation of the ventilation system. Modern ventilation systems with installed heat recovery and filter technology can deliver potential energy savings of up to 20 percent.

Heating and air-conditioning systems

Heating systems deploy various technologies and methods. In principle, for example, a distinction can be made between centralised systems, e.g. local and district heating systems, heat transfer, distribution and storage, and decentralised heating systems, which consist of a heat generating plant used for one building or even one residential unit. (For more information on heating and air-conditioning systems, see Chapter 4.2 Storage technologies in the electricity sector).

Both renewable energy and conventional heating systems can be used as local heating systems. These include, for example, micro and mini CHP units , condensing boilers or even heat pumps (For more information on heat supply, see 2.2 Combined heating, cooling and electricity generation and 2.3 Industrial and private heating and cooling). Solar thermal systems can also be installed to supplement virtually all of these types of heating. These solar thermal systems can be used to heat drinking water or, if larger solar collector panels are installed, to support the heating system in combination with a gas condensing boiler (for more information on solar heating and air-conditioning systems, see 2.3.3 Solar thermal energy for heating and cooling). The most suitable heating system for a building is determined by the construction method and the resulting heat requirements of the building.

Figure 30: Section of wall with radiant or wall heating
Source: aquatherm

Heat pumps are an example of an efficient way to supply heat to well-insulated buildings. The integration of thermal storage systems, known as buffer tanks in the heating system, is another important component of an efficient heating system. The phase change of the heat potential at times of higher consumption means that peak loads can be sufficiently covered and “buffered”, which facilitates consistent and efficient heating (for information on thermal storage systems see 4.4 Storage technologies in the heating sector).

Energy can also be saved when heat is distributed in the building through pump systems. By switching off the distribution of heat at times of low demand, e.g. at night, unnecessary energy losses are avoided. In order to do so, pumps with a standby mode are needed. The installation of modern thermostat valves, which can record and regulate the temperature precisely, can also be helpful in achieving the required room temperature.

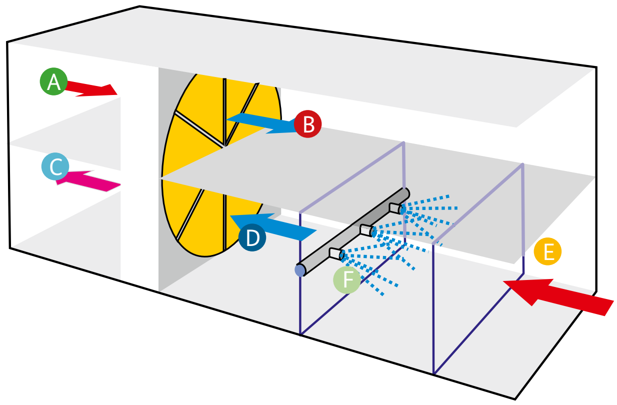
Air-conditioning measures are needed to obtain a room temperature below the outdoor temperature. The most energy can be saved through external sun protection, which reduces the absorption of heat through radiation and prevents the generation of thermal loads in the first place (these must be otherwise regulated with the use of energy). If it is not possible to use sun protection or if it is not sufficient to meet cooling requirements, the use of electrically operated air-conditioning systems may be necessary.

A closer look: Air-conditioning systems

Vapour compression refrigeration is the most widely used technology. More efficient alternatives with a similar operating principle are sorption chillers. (For more information on how this works, using the example of "solar cooling", see Chapter 2.3.3 Solar thermal energy for heating and cooling).

Another alternative is adiabatic cooling, in which water is evaporated and the evaporation process leads to cooling. In addition, special gas sensors, which record the condition of the air in the room, regulate the exchange of air in air-conditioning systems and thus their energy requirements.

In individual cases, or in more moderate climate zones, air-conditioning systems can also be used to heat buildings in certain circumstances. However, very little efficiency can generally be achieved here due to the high conversion losses. From the point of view of energy efficiency and climate protection, therefore, the use of air-conditioning systems for heating purposes should be avoided as much as possible in countries with a low proportion of renewable energy in the overall energy mix.



A Warm external air · C Heated outgoing air · E Warm exhaust air
B Cooled inflow air · D Cooled exhaust air · F Air washer

Figure 31: Principle of adiabatic cooling
Source: Solarpraxis

5.1.3 Sustainable building systems

A distinction must always be drawn between the energy efficiency and the sustainability of a building, whereby energy efficiency is an element of sustainability. Simply put, energy efficiency covers the efficient operation of buildings and thus of "continuous systems", such as heating, cooling, warm water, lighting or other power supply.

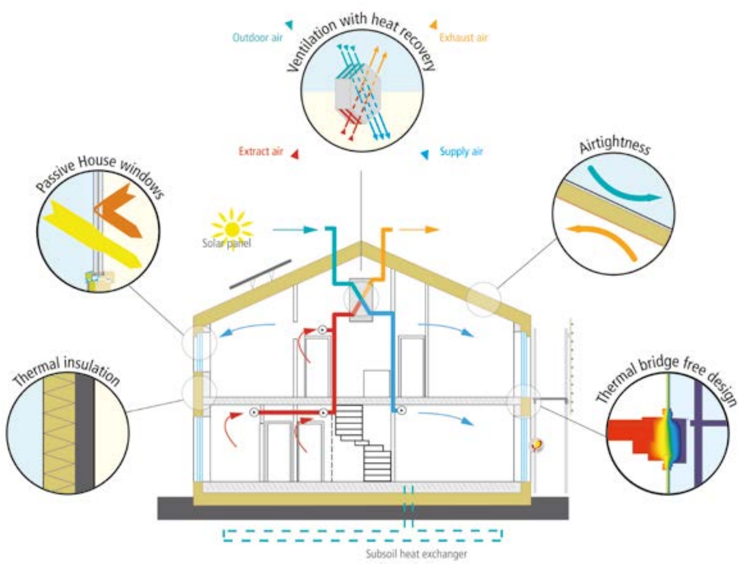


Figure 32: Principle of a sustainable building system using the example of a passive house
Source: Passive House Institute

Evaluating the sustainability of a building, on the other hand, covers not only its operational phase but also its construction. It may also encompass the demolition, continued or changed use of a building after its first "life cycle". The recycling of building materials also plays an important role.

Sustainability systems work on the principle of "Cradle to Cradle", i.e. from the manufacture of the materials used and the corresponding energy required to the manufacture of building materials and their recycling.

Various certification systems prove the sustainable construction of buildings. In Germany, the system offered by the German Sustainable Building Council (DGNB) is very widely used; internationally, the American Leadership in Energy and Environmental Design (LEED) or the British Building Research Establishment Environmental Assessment Method (BREEAM) is widely recognised. Criteria, requirements and necessary proof may differ, depending on the certificate.

Various aspects of technical building equipment are interdependent and must therefore be specially coordinated, such as the proportion and alignment of window facades with the lighting systems and the thermal insulation of the building envelope with the ventilation, heating and air-conditioning systems. Building automation technology can also be used to increase energy efficiency and comfort. The energy consumption of a building can be optimised significantly by taking a holistic view of the building system and using building automation technology.

A closer look: Sustainable building systems

In discussions of sustainable building systems, reference is made to a number of concepts. They are known variously as passive house, low-energy house, nearly zero-energy house, zero-energy house or energy-plus house. These building systems all have very effective thermal insulation and deploy a construction method that minimises thermal bridges. They are also largely airtight. Their systems technology is efficient, particularly in the areas of heating, warm water and ventilation.

The use of renewable energy sources to supply energy and the generation of electricity within the building can supplement a sustainable building concept. A sustainable approach to a building system entails the integrative planning of the building both within the framework of new constructions and in renovation measures used for existing buildings.

Building automation technology is based on the use of sensors and actuators, which measure movement, light, temperature and room humidity, and on the measurements obtained to regulate the shading of window facades, the lighting, heating, air-conditioning and ventilation systems in a building. Options like motion sensors, video intercoms and control technology for blinds also increase comfort for residents and users. The actual values of the sensors are displayed and visualised via a user interface and the desired target values are set.

5.2 Energy efficiency in industry

There are considerable opportunities for energy efficiency in the technologies used in industry, business and agriculture. The following pages will focus on a selection of cross-sectoral technologies, which can help to improve energy efficiency in energy-consuming applications used in industry, business and agriculture. The technologies are divided according to potential efficiency in terms of electricity and heat even if there is also some overlap between them.

Figure 33: Factory building with multiple uses of electricity and optimisation options
Source: gettyimages.de/Monty Rakusen

5.2.1 Pump systems

Pump systems offer great potential for energy-saving: the use of various measures can reduce the energy requirements of pumps in a company by up to 90 percent. Measures for optimising energy must be individually developed and assessed in economic terms for each pump system.

In order to evaluate the economic viability of planned investments to improve energy efficiency, the various cost items of a pump system over its entire life cycle must be considered. There is also a huge potential for energy-saving if the entire system and its components are optimised. The components of a pump system include, for example, a frequency converter, electric motor, transmission, pump and pipelines as well as the measurement and control system.

Layout of pipelines

To determine the layout of pipelines, the technical process and the need for the resulting process engineering equipment and tanks must be determined. During the actual implementation phase and planning of the pipelines, the focus is on the detailed planning of system sections, the performance of transportation and pressure boosting tasks and the determination of a control strategy for the building.

Selecting the pump and the motor

The direct interfaces between the motor and the pump system are the coupling on the motor shaft and the connection to the power electronics or the power grid. Both the coupling and the power electronics can be used to control the speed of the pump. Frequency converters can be used in this case to continuously modify the speed of the motor and thus control pumping capacity. A frequency converter converts the fixed mains voltage into a motor voltage that varies in frequency and voltage level.

A closer look: Selecting and controlling pumps

Pumps and their motors have an optimum operating point, which should be determined as accurately as possible when selecting the pump. The size of the motor is crucial – if it is too small, it cannot perform the task it is supposed to do. On the other hand, if the motor is too big, it leads to higher energy consumption as well as additional investment costs.

To minimise energy costs and wear, the pump model and size must be tailored to the process requirements and selected control strategy in such a way that the various operating points are within the range of the highest degree of efficiency. An average of 35 percent of the energy consumed by pump systems can be saved by optimising pump operation to achieve the optimum operating point.

Safety, reliability and availability

In addition to the direct cost of operating a pump, indirect costs can also be incurred if the pump cannot fulfil the function required of it and as a result can cause production failures. Added to this are the repair costs if a fault occurs, and possible consequential damage to other parts of the system.

Installation and operation

Significant additional costs for energy input can arise in the business or plant if a pump is installed incorrectly or if operating conditions are unfavourable. In addition to having a serious effect on energy efficiency, these factors can also lead to increased wear. On the suction side of the pump, at the pump inlet, uniformly smooth and non-rotating suction via straight sections of pipe with a sufficient diameter must be ensured. Problems can also arise with operating conditions that lead to overheating of the goods being transported, to the mechanical overloading of wheels, bearings, shaft seals and valves or to material abrasion.

Maintenance and upkeep

A number of technical and administrative measures are needed to maintain pumps and pump systems in good working order. Systematic maintenance of the machinery and a predictive maintenance strategy for the company are recommended. While maintenance is understood as a combination of all measures, the terms servicing, inspecting, repairing and improving describe separate work processes. Preventive maintenance based on the actual condition of the equipment requires systematic monitoring of the pump – either at sufficiently frequent intervals or even continuously.

The efficiency of pumps, motors and pipeline components is also reduced as a result of ageing. Conductor resistance in pipelines increases as a result of corrosion and deposits. Fittings become loose, which can lead to pressure losses in the system. In addition, a system may often no longer have an optimum design if components have been replaced. As the correct balance of components is key to low total costs, the entire system should be optimised when any improvements are envisaged.

Measurement technology

To monitor pump operation, the manometer remains the most important and most cost-effective tool for operators. Integrated pressure sensors can also be used as measuring instruments. Unfortunately, many businesses or plants fail to use manometers. If a pump system does not have a manometer, installing one is a basic, relatively cost-effective method of obtaining information about how the pump is operating. A variety of measuring instruments, based on different methods, are available to measure flow. The decision about which measuring instrument can be used depends on the properties of the material to be transported and the operating conditions.

5.2.2 Conveyor technology

Conveyor (material handling) systems are a key element of industrial production workflows and is used in all aspects of production, assembly and handling technology, sorting and distribution systems, packaging technology, transport, storage and handling processes as well as in other logistics areas.

A variety of different measures can be implemented in this area to save energy and costs. Almost all conveyor systems require electricity to operate. In the case of electromotive drives in particular, electricity consumption can be reduced significantly by using appropriate energy efficiency measures such as demand-based operation and braking energy.

Figure 34: Industrial conveyor belt
Source: istockphoto.com/Dusko Jovic

A closer look: Optimisation and modernisation

The modernisation of material handling components extends the lifetime of conveyor systems. Since the average lifetime of the functional units differs considerably, replacing individual components can make economic sense. A long-term strategic plan is necessary for this purpose. It should include all energy-related aspects.

Drive control, automation and electrical installation

During material handling, the speed can be varied for controlled drives depending on the drive task. Operating at a variable speed requires a controlled drive and an actuator, e.g. a variable-speed transmission or inverter to adjust motor frequency and control.

In addition to the electric motor, the drive system usually requires a transmission, additional mechanical and electrical components and the control and power unit. The electrical and electromechanical components include control and protective functions, communications interfaces, rotary encoders and sensors.

Safety, reliability and availability

In the face of increasing competitive pressure and tight delivery deadlines, the availability and reliability of conveyor and production equipment are becoming a key economic factor. Very little redundancy is available in the electric drives used in conveyor technology. The operation and availability of conveyor systems can be guaranteed using special monitoring and maintenance methods and by implementing troubleshooting measures.

5.2.3 Compressed air systems

When optimising energy efficiency in compressed air systems, the entire system – from consumer to generator – should first be considered as the consumer determines the pressure level, quantity and quality of the required compressed air. All available system components, such as generation, processing, control, storage, distribution and, if applicable, heat recovery, should function without adversely affecting these parameters.

A closer look: Compressed air requirements

To optimise electricity requirements for the operation of a compressed air system, all options for reducing the compressed air requirements must be taken into consideration. For example, the system pressure must be adjusted in such a way that pressure losses are minimised. Actual requirements can be best met either through individual compressors with a speed-controlled drive or through several smaller compressors to cover standard, average and peak load consumption.

Storage and control

In addition to the use of several flexible, small compressors, a sufficiently large buffer tank can help to prevent frequent load changes on the compressors. The maximum output of the compressed air system can be reduced using storage tanks, and the entire system can be operated more cost-effectively.

Distribution

To minimise losses, pipes with narrow cross-sections and certain pipe fittings should be avoided. To optimise the system, it is recommended that pressure losses are documented. Leakages should also be actively prevented or repaired immediately.

Consumers

The structure of a compressed air system is largely determined by the integrated consumers, such as compressed air tools. These have different compressed air requirements, which influence the design of the overall system.

5.2.4 Ventilation technology

Ventilation technology is an integral component of modern manufacturing facilities in industry, agriculture and commerce. Ventilation and air-conditioning technology supports or replaces natural ventilation, is responsible for removing impurities from the air and guarantees the operation of sterile spaces, for example. Process air technology allows the required levels of air quality to be provided in the production process. Huge efficiencies can thus be gained by using the right technologies.

Figure 35: Conveying pipe with drive in ventilation system
Source: istockphoto.com/seraficus

A closer look: Ventilation technology

Systems for transporting and processing air are part of the numerous areas of application of ventilation technology systems. In a broader sense, systems for gases, such as combustion gases, exhaust air and protective atmospheres can also be included, as can systems in which gases, and in particular air, can be used as a means of transport for other substances.

Fans and blowers

The fan or blower is a key element of any ventilation technology system. These transfer air from a lower initial pressure to a higher discharge pressure. The main types of fans used in ventilation technology systems are radial and axial fans; cross-flow fans are used less frequently.

A closer look: Types of fans

In axial fans, the air enters and exits in the direction of the axis of rotation. They are between 40 and 90 percent efficient, depending on size and model.

Centrifugal fans draw in the air axially and expel it radially.

In cross-flow fans, the air enters and exits transversely to the axis of rotation. The impellers are long rollers with small diameters. Cross-flow fans have low levels of efficiency of approx. 60 percent.

The following approaches can contribute significantly to the energy efficiency of ventilation equipment and systems:

- Optimising fan running times
- Approximating the fan speed to the actual current air requirement
- Maximising overall efficiency
- Optimising electric motors and drives
- Optimising control systems

Recording, processing and distributing

The role of a ventilation technology system is, for example, to comply with pollution limits or to ensure the necessary temperatures and air humidity levels. There are essentially three options for removing pollutants, thermal loads and moisture:

- Extracting highly polluted air that is in direct contact with the pollutant, heat or moisture source
- Removing contaminated room air while simultaneously supplying fresh or treated air
- Removing contaminants using cooling walls, local dehumidifiers or by washing out pollutants without the need to transport air across multiple rooms

Extensive duct systems are often used for distribution and targeted extraction. The duct system must be carefully planned and constructed in order to minimise pressure loss in the ducts. Excessive flow speeds or restriction of individual subducts should be avoided in this process.

Air filters are used in the supply air and the exhaust air. Regular maintenance and replacement of relevant parts reduces pressure loss in the system. This is also necessary for hygiene reasons.

Control technology

Control systems have a major influence on energy consumption and the life cycle costs. Very few applications require constant output. In general, a certain output must be delivered only during a few operating hours, depending on where the equipment is used. Cost-optimised operation and capacity utilisation can be achieved with higher-level control systems and well-adjusted regulators. For example, open-loop control and management systems determine which fans are switched on or whether and when the switch is made from forced to natural ventilation. Closed-loop control systems ensure that the specified volume flows, pressures, room temperatures, pollutant limits, moisture levels, etc. are observed.

Safety, reliability and availability

The requirements for safety, reliability and availability are as diverse as the ventilation devices themselves. In ordinary ventilation and air-conditioning systems, a temporary shutdown usually does not pose a serious problem. However, these systems are subject to particularly stringent requirements in terms of fire protection, especially in buildings frequented by the public. Particular attention must be paid to ensure explosion suppression in systems that extract dust or inflammatory gases and vapours.

5.2.5 Green Information and Communication Technologies (ICT)

A sustainable ICT strategy can help companies and public institutions to cut their electricity costs and CO2 emissions significantly. There are five key areas to be prioritised when implementing a sustainable IT strategy for efficient office organisation.

- **Needs assessment**: With hardware and software often being replaced constantly these days, IT workstations can be optimally equipped to meet their specific needs. A distinction should be made between stationary workstations with high processing power and graphics power requirements and mobile workstations. The workstations should then be set up according to actual needs.

- **Technology**: Users can choose from a selection of computer technologies when installing technical equipment for office workstations. Depending on electricity costs, higher purchase prices for more efficient equipment may make more sense financially over the productive life of the equipment.

- **Procurement**: Efficiency is a vital criterion in assessing equipment over the long term. It should be considered in invitations to tender and in purchasing decisions.

- **Configuration**: In many cases, the equipment must be configured appropriately to work efficiently. Appropriate steps should be taken to ensure this.

- **Raising awareness**: For the best results, all employees should be involved in implementing efficiency measures.

5.3 Energy efficiency in industry and commerce within the heating and cooling sectors

The high demand for energy in industry and manufacturing industries is attributable to the generation of heating and cooling for technical processes and air conditioning. Process heat is an increasingly important cost factor, especially for energy-intensive companies. First, potential energy savings can be achieved during the production and transmission stages, for example, by using modern burners and boilers, and by insulating industrial installations. Second, processes very often generate unavoidable waste heat. This offers many opportunities for reuse. For reuse options, the remaining temperature level is usually a decisive factor. In addition, heat can be used in its raw state or increased in value as an energy source by conversion into electricity. Either process is possible at the various temperature levels. They differ however in their technological implementation.

Measures to improve the use of heat should be considered as part of optimising the energy management of the overall system. Large energy efficiency gains can only be achieved if all components and their interactions, e.g. between heat and electricity consumption, can be combined to form an efficient overall system.

Figure 36: Industrial heat recovery plant: Conveying pipe with drive in ventilation system
Source: hdt Anlagenbau GmbH

5.3.1 Optimising the heat supply

Optimisation of the heat supply can start at the heat generation or distribution stage, or can be achieved by increasing efficiency through the use of unavoidable waste heat (for more information on specific technologies used in energy-efficient heat generators and heat supply systems and their operating principles, see Chapter 2.3 Industrial and private heating and cooling).

Selecting optimisation measures

Optimising the energy management of the heat supply and the waste heat utilisation can be achieved in many cases. First, the heat requirement during operation should be minimised by optimising production processes as well as insulating pipelines, fittings and pumps. This also includes optimal balancing of heat demand and heat generation. Second, systems such as burner and boilers should be replaced, retrofitted or newly purchased to ensure efficiency. The use of variable-speed burners and CO_2 or O_2 emission control is recommended, in addition to monitoring of the set control parameters. Further efficiency gains can be achieved by using heat recovery systems such as exhaust heat exchangers or burner air preheaters. The use of additional conversion or alternative generation technologies should also be explored. These include above all the use of combined heat and power (refrigeration) coupling systems, heat accumulators, heat pumps or renewable energy sources.

Burners and boilers

Just replacing existing heat generators with modern and energy-efficient burners and boilers can deliver high savings for year-round plants. Further measures such as **optimised piping** can enhance this effect (for more information on Burner and boiler technology, see Chapter 2.3.2 Burner and boiler technology).

Applying an insulation layer of economical thickness on the pipelines enables heat losses to be reduced in a simple manner and operation to be optimised. Storage technologies can reduce peak load while increasing the base load share. Waste heat can often be avoided or better used in this way (for more information on thermal storage systems, see Chapter 4.4 Storage technologies in the heating sector).

5.3.2 Waste heat utilisation

During industrial processes and industrial heat generation and use, an average of about 40 percent of the energy produced is waste heat. This is released into the environment unused. Its huge potential can be exploited by heat recovery systems. By implementing a systematic approach in combination with suitable technologies, waste heat can be significantly reduced or put to use, if not completely avoided.

Heat recovery or heat displacement are the most efficient and simplest technological approaches to use waste heat in order to increase overall energy efficiency and cost efficiency. When the waste heat from a process or the environment is recovered, it can be used again in the same process and in the same plant.

A closer look: Waste heat displacement

Waste heat can be 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.

Figure 37: Waste heat use through heat pumps
Source: Roth Werke GmbH

Heat exchangers are often used for this purpose. Heat exchangers transfer the waste heat to a transport medium, which then forwards the heat to other units. Examples of direct use are combustion air preheating, or preheating and drying of the source materials, or preheating of water and evaporation.

If waste heat cannot be used directly, consideration should be given to using waste heat within the organisation at the highest possible temperature level in other processes, such as heating water or providing room heating. If the temperatures in the waste heat sink are too low, heat pumps can be used to increase the temperature level.

Another possibility is the sale of non-usable waste heat to third parties, such as neighbouring companies or a local or district heating network or to meet the heat requirements of public buildings and households. However, losses occur when this happens. Furthermore, transferring waste heat to third parties requires additional transport infrastructure such as local and district heating pipes, buffer storage etc.

For power generation from waste heat, several technically advanced and economical technologies comprising different steam processes are available.

A closer look: Different types of conversion processes

Different conversion processes are available to convert heat into electricity with a mechanical intermediate stage:

Steam processes: In steam processes, water vapour is used to drive a steam turbine that is coupled to an electricity generator. The electric efficiency of steam processes is specified at approximately 25 to 42 percent at a temperature level of 250 to 540° C.

Organic Rankine Cycle (ORC) processes: ORC processes have the same functional structure as steam processes. The main difference is that in ORC processes, organic liquids are used. These boil at lower temperatures or pressures than water. Due to the lower operating temperatures, the efficiency of the ORC processes is lower than the efficiency of steam processes. The efficiency of ORC processes at temperature levels of 70 to 350° C is estimated to be 10 to 20 percent.

Kalina processes: Kalina processes use a mixture of ammonia and water rather than a single work medium. With the evaporation of a single work medium, the temperature would remain constant. However, due to the mixture of work mediums, the temperature can increase during evaporation and thus better adapt to the temperature level of heat flows and return cooling flows. Because of larger heat exchanger surfaces and the necessary material separation of ammonia and water, Kalina processes are considered to be more complex than ORC processes.

Stirling processes: Stirling processes use the expansion and contraction of a working gas during the application or withdrawal of heat to drive a mechanical shaft. The shaft in turn is connected to an electricity generator. Stirling motors are considered to be quiet, low-maintenance machines for waste heat use.

Cooling units can also convert waste heat into cold. The cold thus generated is then used, for example, for air conditioning or for a cooling process.

Using waste heat in the form of electricity and cold makes it possible to use the waste heat of a process even without a heat sink. (for more information on using waste heat, see Chapter 5.3.2 Waste heat utilisation).

5.3.3 Refrigeration technology

Refrigeration technology is a technology that has been established in numerous industrial, commercial and agricultural processes. It is an integral part of modern production and logistics chains.

Applications

Refrigeration plants are used in industrial, commercial and agricultural areas. The various designs and sizes of these plants are as diverse as their applications. However, a feature they all share is that they all generate cold at a particular point and this must be introduced elsewhere into the product or process.

Refrigeration can be carried out centrally or decentrally. Waste heat is produced during either process. Decentralised systems that generate cold at the location where refrigeration is required discharge this waste heat into the room air, for example. Central plants provide the cooling capacity by transporting the dissipated heat via cooling water or special cooling liquids to the central refrigeration system. The waste heat is then released to the outside environment via cooling towers.

Planning and optimisation

Numerous factors affecting efficiency are crucial in planning and optimising a refrigeration system. A systematic approach should therefore be applied. The following seven planning and optimisation steps are suitable for evaluating investments in both new and replacement plants:

- Minimisation of refrigeration requirements
- Fundamental decisions on process design
- Optimisation of performance, pressure and temperature levels
- Planning of control technology
- Detailed layout and selection of the individual components
- Commissioning and optimisation of operation
- Efficiency-oriented maintenance incl. monitoring

5.4 Energy efficiency in transport

Vehicle traffic is still dominated by internal combustion engines that deliver everyday operating efficiencies of 30 to 40 percent. A large part of the energy from the fuel remains unused and is lost as waste heat. Measures such as a reducing air and rolling resistance or the use of automatic start/stop can help to reduce overall consumption. However, waste heat is another area that offers further potential for reduction.

Regenerative braking is another way of reducing the energy consumption of vehicles and recovering energy that would normally be wasted as heat. Braking energy is recovered in this process. Energy produced by a generator is stored in a battery. Up to 80 percent of braking energy can be recovered in this way.

5.4.1 Electromobility and charging infrastructure

A complete transition to electric drives could potentially boost efficiency in the transport sector. A variety of electric motors can be used for this purpose. These electric motors are characterised by much higher efficiency than internal combustion engines. Electric motor efficiencies of over 90 percent and vehicle efficiencies of around 85 percent can thus be achieved. With regard to CO_2 emissions, the increased use of electric vehicles offers a particular advantage when the electricity used is largely from renewable energies.

In the area of mobility, three-phase motors are commonly used. Due to their contactless power transmission and mechanically simple construction, wear on these motors is low and their efficiency constantly high. Energy recovery can also occur here thanks to the motor's generator operation.

Figure 38: Charging station for electric vehicles
Source: istockphoto.com/kasto80

A closer look: Hybrid vehicles

Hybrid vehicles that use both a combustion engine and electric motor can achieve greater efficiency thanks to the combination of different drive types. In the lower performance range, the combustion engine can be operated far more efficiently in conjunction with the electric motor. Plug-in hybrids are a possible alternative to the self-contained hybrid vehicle model, in which battery charging only takes place internally. These plug-in hybrids can be charged from external sources. This is also usually associated with a higher storage capacity and therefore the internal combustion engine needs to be used even less frequently.

For efficient use of electric mobility, the first priority is reducing the weight and space requirements of the installed batteries. At the moment, however, batteries still have a low energy density compared to conventional fuels. This energy density is steadily growing as a result of technological developments, while the battery weight is being reduced. In addition, vehicle weights are decreasing, thanks to greater use of lightweight construction. Composite materials such as carbon fibre composites are used in this construction. In addition to reducing the weight and the energy requirements of the vehicle, these composites also improve the vehicle dynamics.

An important question in the field of electromobility is: how is the necessary energy fed into the vehicle and which charging technology is used? At present, most charging systems are cable-based. Depending on the capacity of the connected power source, charging capacities of 10 to 22 kW are currently achieved in Germany. Newer alternatives are also available besides this classic charging model. Inductive charging, in particular, which requires no cable connection, is becoming increasingly important. In this method, electricity is transferred between the battery and charging device wirelessly, by means of a magnetic field. This enhances user convenience and also solves the problem of compatibility with charging systems. Charging at up to 7.2 kW is already possible with this method. Further developments in technology that allow charging facilities to be installed under roads also offer huge opportunities for increasing vehicle range. Successful implementation of electromobility will also require expansion of the charging infrastructure.

A closer look: Private and public charging infrastructure

Two types of facilities are available for charging electric cars: public or private. Private connections can be set up to detached and multi-family houses and also to company offices. However, these connections are often not technically equipped to carry high power over longer periods of time. In these situations, a charging infrastructure that relies on moderate energy transfer with longer charging times is used. In public areas, mains connections can be at higher voltage levels. This allows the use of technologies with higher charging capacities. Fast charging can thus be offered, particularly at points with short turnarounds such as motorway service stations.

Charging infrastructures that provide access to a higher number of users can generate high demand. In this case, the use of a load management system for the charging point is advantageous. Such a system can alleviate the problem of peak charging loads and make the charging process more efficient.

In future, electromobility will also be integrated into the power grid infrastructure on the basis of smart grid concepts. With smart grid services, the vehicle batteries provide electronic storage capacity for excess electricity and, in the event of a supply shortage, return this electricity to the grid, a process also referred to as “vehicle to grid”. The charging stations required to feed the electricity back to the public grid are currently in development. The same applies to the power electronics required to coordinate the flow of electrical energy.

5.4.2 Alternative fuels

In addition to conventional fuels and electricity, alternative fuels exist with underdeveloped potential due to their limited distribution.

Natural gas and liquefied petroleum gas

Gaseous fuels are compressed for use in order to raise their energy density, which is essential for the transport sector, to an economic level. As a drivetrain technology, gas engines are basically similar to conventional petrol engines. Following the principle of the gasoline-powered engine, the fuel-air mixture is added to the cylinder and ignited. Savings of 15 percent on CO_2 emissions are possible with LPG and natural gas (CNG/LNG), compared to using a petrol engine. Due to the high degree of technical complexity, natural gas refuelling can only be carried out at specially equipped refuelling facilities.

A closer look: Different gas types

Compressed natural gas (CNG) is methane (CH_4) compressed to 200 bar.

Liquefied petroleum gas (LPG) consists predominantly of long-chain hydrocarbons, such as butane and propane, obtained as a by-product of crude oil production.

Liquified natural gas (LNG) also consists of methane (CH4), which has been cooled down to approx. -163° C and liquefied.

Biofuels

First-generation biofuels, such as vegetable oils, are relatively inefficient in terms of using raw materials. Nowadays second-generation biofuels such as biogas, biomass-to-liquid (BtL) and lignocellulosic bioethanol are used. These have a more positive energy balance and climate footprint compared to first-generation biofuels. The use of biomethane is particularly advantageous (for more information on biofuels, see Chapter 2.2.1 Bioenergy).

Biogas upgraded to biomethane can be used in natural gas vehicles and access the existing infrastructure. BtL and bioethanol are liquid fuels and can be used instead of gasoline or diesel (for more information on electricity generation using biogas, see 2.2.1 Bioenergy).

Hydrogen

When used in a fuel cell, hydrogen can be a low-carbon alternative fuel for the transport sector (for more information on fuel cells, see Chapter 2.2.3 Fuel cell). The hydrogen in this case is obtained from electrolysis. A problem here is that hydrogen cannot be integrated into the existing charging infrastructure.

Synthetic fuels

Other synthetic fuels can be obtained in subsequent steps after an electrolysis process. These are similar in their application to the known liquid and gaseous fuels (for more information on synthetic fuels, see Chapter 4 Sector coupling technologies).

6 Cross-sectoral services

A multitude of tools are available to exploit the potential for energy efficiency. In addition to the technical options described in Chapter 5, cross-sectoral services offer another option for increasing energy efficiency. Because these services are integrated, they often form the basis for sustainably developing such potential. Cross-sectoral services cover consulting, planning and management activities in the energy sector. The use of communications, information, measurement and control technology is key to these services. These technologies, which capture and process data, form the interface between customers and service providers in the form of smart meters or apps, for example.

A closer look: Examples of cross-sectoral services

Cross-sectoral services include the following:

- Scheduling and project planning of energy plant construction, financing services
- Installation and maintenance of technical and structural works and components
- Performance of energy audits
- Energy consultation and energy management
- IT-based controlling and monitoring services to monitor, control and regulate energy consumption, energy contracting
- Research services
- Initial and further training of skilled staff
- Certification of technical equipment and building materials and accreditation of expertise

Energy audits

Energy audits are used to identify opportunities for saving energy in order to optimise the provision and consumption of electricity and heat. At EU level, an energy audit is defined as “a systematic procedure with the purpose of obtaining adequate knowledge of the energy consumption profile of a building or group of buildings, an industrial or commercial operation or installation or a private or public service, identifying and quantifying cost-effective energy saving opportunities, and reporting the findings”.

Figure 39: Engineers conducting an energy audit
Source: istockphoto.com/ShadowDesigns

In EU Member States, it is mandatory for large-scale enterprises to conduct energy audits at least every four years, unless the company has implemented an international or EU-wide certified energy or environmental management system. In 2012, European Standard EN 16247 was introduced throughout the EU to cover the workflow and scope of an energy audit.

Based on the results of the energy audit, appropriate measures can be identified and implemented to improve energy efficiency and also reduce energy costs. Such measures include, in particular, building renovation measures, the replacement or modernisation of technical equipment and devices to use energy-efficient technologies, for example to heat buildings, heat water, provide cooling, manufacture goods, operate lighting and drivetrain technology or implement a company energy or environmental management system.

A closer look: Initial and further education

Initial and further education measures can indirectly help to increase the use of renewable energies and to improve energy efficiency. One of the ways in which skilled staff can obtain international initial and further training is by participating in international project work. The German Energy Solutions Initiative of the Federal Ministry for Economic Affairs offers capacity building activities and promotes know-how transfer. For more information visit www.german-energy-solutions.de/en.

International standards, certification and accreditation

To guarantee quality assurance in the international trade of products and services and in the application of procedures, standards have been implemented at a global level that define minimum requirements and properties. Standards in the energy supply sector cover generating installations and their components, building materials, energy services, energy and environmental management systems and production processes, to name just a few.

A closer look: Standards

The general recognition and requirements of standards can vary enormously. They may apply at the national level of individual states or entire communities of states such as the EU or ASEAN or even at international level. International standards in the energy sector include ISO 50001 for energy management systems and ISO 14001 for environmental management systems. At EU level, ISO 50001 has replaced the European Standard EN 16001. However, the EU standard for environmental management systems, known as the Eco-Management and Audit Scheme (EMAS), specifies more stringent requirements than ISO 14001 and is therefore only partly based on the international standard.

Companies, organisations and individuals can obtain certification as proof of their compliance with the minimum requirements demanded by the standards. The term accreditation is used, on the other hand, when confirming and recognising professional expertise. The “seal of quality” issued by certification or accreditation helps companies and organisations to gain the trust of potential customers in relation to the efficiency and quality of their products and services as well as the relevant expertise of the company and its employees. This can increase sales, particularly in the export market, and improve competitiveness. Certification is generally granted by certification companies, which operate independently of the standardisation organisations and usually specialise in examining certain individual standards. In Germany, several companies specialise in the area of certification. Deutsche Akkreditierungsstelle GmbH (DAkkS) is responsible for accreditation.

Energy contracting

Energy contracting is based on a contractual agreement between a service provider, also known as a contractor and a principal or client, for example a company or a private household. The services provided by the contractor differ, depending on the type of contracting, and a distinction can be made between energy supply contracting and energy performance contracting.

Figure 40: Business partners during energy contracting by a power consumption meter

Source: gettyimages.de/Daniel Ingold

In energy supply contracting, also known as plant contracting, useful energy in the form of electricity, heat or cooling is provided to the client. The contractor provides the plant and energy source for energy generation and is responsible for a reliable energy supply and the associated services, such as the installation and maintenance of the relevant technical equipment. This service is financed by means of the remuneration paid for the useful energy provided within a defined contract period. Energy supply contracting can be used by the clients, for example, to procure electricity or heat from renewable energy installations or combined heat and power plants without having to make a long-term investment in or commit to such facilities.

In contrast to energy supply contracting, energy performance contracting is based on the implementation of energy savings measures, the costs of which are financed in full or in part by the saved energy costs. The contractor is responsible for analysing the potential, planning and implementing the energy efficiency measures. The contractor also devises a strategy for how the energy savings targets can be achieved. For example, the energy efficiency measures can cover renovation measures, the replacement or upgrading of old technical equipment or the optimisation of energy management. In this case, the contractor invests in and maintains the systems technology. This entails assuming the technological and financial risk of providing the agreed quantity of useful energy or energy savings.

7 Conclusion

Over the last decades, the emergence of renewable energy solutions, technologies that increase energy efficiency and other energy-related breakthroughs has transformed the energy sector and related areas. However, if an emission-free economy is to become a reality, further major technological development in all areas is still required.

In some instances, new energy technologies have already solidified their position in the energy landscape, with mature markets and widespread diffusion. Some technologies are at the threshold of ground-breaking progress and rapid proliferation. In the case of others, more research and development are required before they are ready for efficient and ubiquitous use. Of course, the future will also hold a number of unforeseen technological developments and innovations.

This ongoing process of transformation is generating opportunities for all those involved. New, innovative business models can create jobs and wealth. Renewable energy and efficiency options empower consumers and citizens and provide a more reliable energy supply. Fossil fuels are being abandoned in favour of clean, sustainable energy sources.

This brochure provides a comprehensive overview of the technologies and applications available, their advantages and shortcomings as well as recommendations of how to apply them most effectively. Proven technologies for the use of wind, solar and hydropower promise a cleaner power system. Solar thermal installations, geothermal energy and waste heat options will do the same for the heating sector. Biomass, biogas and geothermal energy heating, cooling and electricity generation can be combined, via cutting-edge fuel cell technology, to maximize efficiency. Transforming renewable electricity into heat, gas or liquid fuel is another way to innovatively integrate multiple sectors of the energy system. Digitalisation and technological progress is actively improving the many different storage technologies for electricity and heat in terms of infrastructure. However, new methods of energy generation, transformation and distribution are only one element of change. The other major element is efficiency. Buildings, industrial, commercial and agrarian processes, technical devices and mobility can all be made more efficient with the appropriate technological fixes and services. The use of an enormous amount of transport fuel, electricity and heating fuels could thus be avoided.

All of these solutions are individual and ostensibly unrelated possibilities for change. To maximise their effect and move towards decarbonisation in all sectors, they all need to be integrated in a meaningful fashion. A coordinated approach to developing renewable heat and electricity sources, grid and storage solutions, cogeneration and a wide range of efficiency technologies is vital if these are to play a part in the big picture.

Over the last years and decades, Germany has proven that it is quick to set trends, identify options for progress and lead the way into a future based on renewable sources for power, heat and mobility, efficient technologies and innovative energy systems. German industries, products and services are synonymous with sustainability. Thanks to their unique technological insights and extensive international project experience, German technology suppliers are ideally placed to help implement sustainable and climate-friendly energy systems that are tailor-made to customers' specific needs.

8 German Energy Solutions Initiative

Thanks to the promotion of smart and sustainable energy solutions in Germany, the country now boasts an industry offering 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 systems, energy efficiency solutions, smart grids and storage technologies. New energy technologies such as power-to-gas and fuel cells also provide the basis for cutting-edge energy solutions. The transfer of energy expertise, promotion of foreign trade and facilitation of international development cooperation are part of the German Energy Solutions Initiative.

The initiative creates benefits for Germany and participating countries by:

- Boosting global interest in sustainable energy solutions
- Encouraging the use of renewables, energy efficiency technologies, smart grids and storage technologies
- Improving economic, technical and political cooperation between Germany and partner countries
- Generating jobs in Germany and abroad

Advantages of smart and sustainable energy solutions

- Contribution to innovation, growth and employment
- Independence from fossil fuel imports
- Reduction of greenhouse gas emissions and contribution to climate change mitigation

The German Energy Solutions Initiative, coordinated and financed by the German Federal Ministry for Economic Affairs and Energy (BMWi), is implemented in cooperation with its partners, including the German Chambers of Commerce Abroad (the AHKs), the German Energy Agency (dena) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

A closer look: Scope of services under the German Energy Solutions Initiative

- **Networking and business opportunities in your country and in Germany**
  The German Energy Solutions Initiative offers first-hand information about German smart and sustainable energy technologies and solutions and face-to-face meetings with German companies.
- **Showcasing of reference projects:**
  Participants gain first-hand experience of the application of German energy solutions by visiting reference projects in Germany and in various countries, e.g. the installations realised within the dena-Renewable Energy Solutions- Programme (RES-Programme) or through technology showcases.
- **Know-how exchange:**
  The German Energy Solutions Initiative aims to share know-how about smart and sustainable energy solutions via training events in selected countries, targeting decision-makers in the political, industrial and commercial sectors.

For more information about the initiative, visit www.german-energy-solutions.de/en or send an email to office@german-energy-solutions.de.

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