LowTEMP

Combined heat and power (CHP)

Background Material

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Introduction to this module

In the course of the common European efforts to fight climate change and reduce CO_2-emissions, also district heating (DH) systems are undergoing basic restructurings in order to bring temperatures down and enable an increased use of renewable energies within heat production. This development is also making the increasing implementation of high efficient technologies within the process of heat production necessary such as combined heat and power (CHP).

Regarding the complex challenges the transformation of the energy sector towards carbon neutral energy sources is causing, CHP-technology offers a promising solution to provide reliability of energy and heat supply. Especially in countries that gradually transform their heat supply and distributing systems towards smaller and more flexible power and heat plants, CHP will help to shut down huge power plants operated with fossil fuels within the coming decade.

Moreover, due to the high efficiency of the technology, CHP has enormous potential to lower CO2-emssions by integrating renewable energies into the heating sector, reduce the amount of primary energy and by this can help European countries to meet their climate goals in future.

Against this background, in this seminar module we will have a look on different ways of integrating CHP-technology into DH-systems as well as discussing associated technical and infrastructural aspects CHP-heat generation requires. In order to give a brief overview about the technology, this module is structures as following. First of all, a short introduction and general facts to CHP will be given, before the general principle of different co-generation plants is exemplified. Moreover, this module focuses on several questions of a technical and economical efficient operation of CHP-plants, before different feed-in scenarios into DH-systems will be discussed. In the end of this module, different possibilities to upgrade CHP-technology by using renewable energies or synthetic gas instead of fossil fuels will be introduced.

The above described module content was cooperatively developed by AGFW-Project GmbH in the course of the Interreg Project „Low Temperature District Heating for the Baltic Sea Region" (LowTEMP). The accompanying PowerPoint slides follow the same structure as the here outlined explanatory notes.

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1 Introduction / General Facts of combined heat and power

1.1 Efficiency requirements

Until recently the production of the electricity was made in power plants where huge amounts of heat energy were lost in the environment. Also the electrical efficiency of conventional and mostly fossil fuel power plants is only in the range of about 30% to 40%. On the contrary, the principal idea of CHP is to take advantage of the thermal energy from the production of electricity. Utilizing the heat by connecting a huge power plant to a district heating system (DH), could be a measure to increase the overall efficiency. However, the utilized heat amount to increase the overall efficiency depends also on the distance to the potential heating network, the heat demand of the prospected heat sink as well as on the location of the plant. Especially coal power plants are often installed in vicinity to coal or lignite mines and are therefore often far away from possible consumers. Furthermore, the seasonal change of heat demand during summer, also decreases the efficiency of the waste heat utilization of these conventional power plants.

In future energy systems that are tending to use more and more decentral energy supply, CHP-technology is seen as one of the key ways in which Europe and its member states can meet their environmental goals, by increasing the overall efficiency of the power and heating sector and save primary energy. Therefore, extending the usage of applications such as CHP-plants/units of different seize could help to meet the climate goals until 2050 as well as to reduce carbon dioxide emissions for a given amount of energy produced, when compared to conventional or separate electricity and heat production methods.

1.2 Basic principles of CHP

The basic idea of combined heat and power (CHP) is the cogeneration of electricity and heat by using the remaining exergy and all anergy for heat delieveries to buildings that are connected to a District Heating (DH) system. In this regard, CHP-plants offer several ways of recycling heat that would otherwise be wasted. The technology offers a primary energy saving potential of up to 34% in contrast to the separate generation of electricity and DH [ASUE20].

Conventional power stations have an overall efficiency of only 35—60 % of the primary energy that is utilized, while the other 40 – 65 % are emitted through the cooling tower. The CHP-technology enables energy suppliers to reach an efficiency level of 80 to over 95 %, depending on the amount of heat that is recycled for DH-systems [Zah19].

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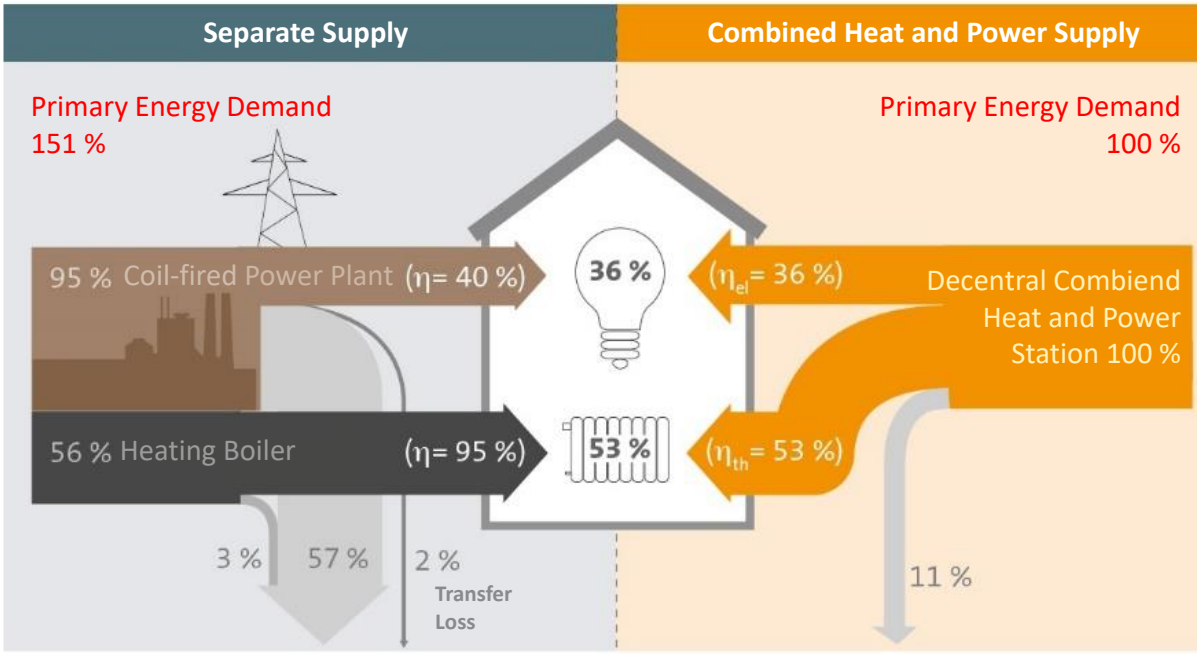

Figure 1: Benefit of CHP - Comparison of conventional energy supply and CHP regarding primary energy consumption [ASUE20].

Considering the heating market, it is even a saving potential up to 70 %. Due to this high efficiency level CHP can significantly reduce the dependence on fossil fuels, which mostly have to be imported in European countries and are thus strongly influenced by economic and political factors. Furthermore, CHP does not contradict to the use of renewable energy and therefore offers a future replacement of yet mostly used fossil fuels by biogas, synthetic gas or other solid fuels from biomass (cf. chapter 3). Regarding the overall amount of fuel required for the production of power and heat, CHP-technology is yet the most efficient way of using any fuels, regardless if fossil or renewable energy sources are used. Therefore CHP is advantageous for several actors within the energy market and the industrial production. Especially there, where at the same time a high amount of electricity and heat or cold is required, e.g. for process heat or hot water or cooling, small or medium sized cogeneration plants could be a practicable solution for supplying power and heat. Therefore, communities, companies or large industrial parks could benefit from CHP, especially there, where high annual thermal baseloads are needed. Moreover, the cogenerated electricity can be used on site, which makes CHP economically attractive – especially when the costs of electricity are on a high level.

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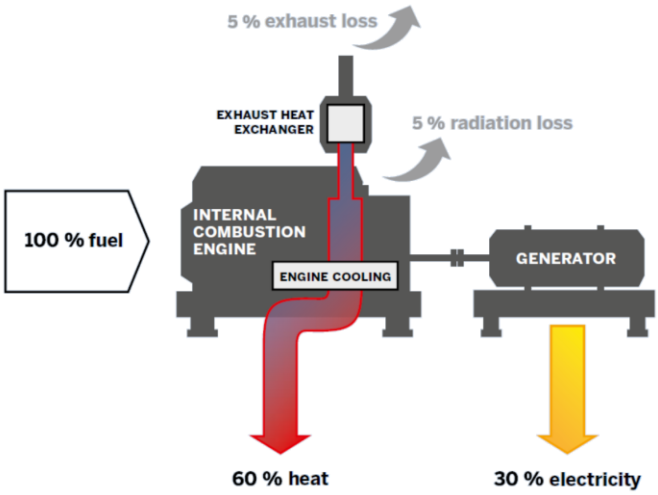

Figure 2: „The illustration above shows a cogeneration unit exemplary with a combustion engine. This drives a generator, which produces the electricity. The heat from the engine's cooling system and from the exhaust in the cogeneration unit. This means that the available heating potential is optimally exploited. Around 30 percent of the fuel is used for the generation of electrical energy." (Source: EnergieAgentur.NRW GmbH: 2016)[1].

For the production of cogenerated heat and electricity various technologies are useable, which are separate into CHP-units by using different fuels (Figure). Electricity -units are a combination of a generator and a combustion process for generate rotary motion directly or indirectly by using an internal combustion engine. Reciprocating Engines and gas turbines are convert primarily energy directly into combustion energy. Steam turbines are working indirectly by using steam which is produced by a combustion process. For a high efficiency of the CHP-units, the waste heat of the combustion is supplied by a DH-system to deliver heating water for space heating or domestic hot water preparation and sometimes also superheated steam for industrial process.

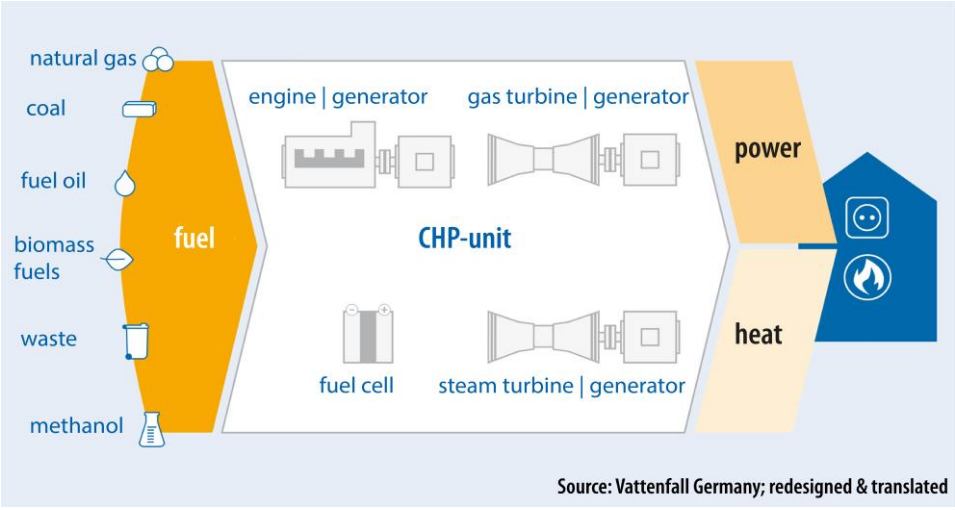

Figure 3: Supply chain of different incoming fuels to electricity and heat by utilize diverse CHP-devices (Source: Vattenfall Germany)

[1] https://broschueren.nordrheinwestfalendirekt.de/broschuerenservice/energieagentur/combined-heat-and-power-in-practice/2336

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Furthermore, (considering) CHP-units, various fuels are utilizable to realize combustion processes. Usual natural gases, liquid gas, coal, fuel oil, biomass fuels, but also sewage gas, landfill gas, residual production gases or different combination of it can be used for combustion[2]. Moreover, other heat generating processes (geothermal heat or solar heat) can be used for CHP-applications.

2 Operating principle

With CHP generation, 100 % fuel energy input can be converted into more than 90 % effective energy. In contrast, the utilization of conventional power plants is only about 35-59% (see figure 3). Between the production of heat and electricity is a fixed ratio, so that major or minor heat or electricity demand is only realizable by electricity from grid or heat by a peak boiler.

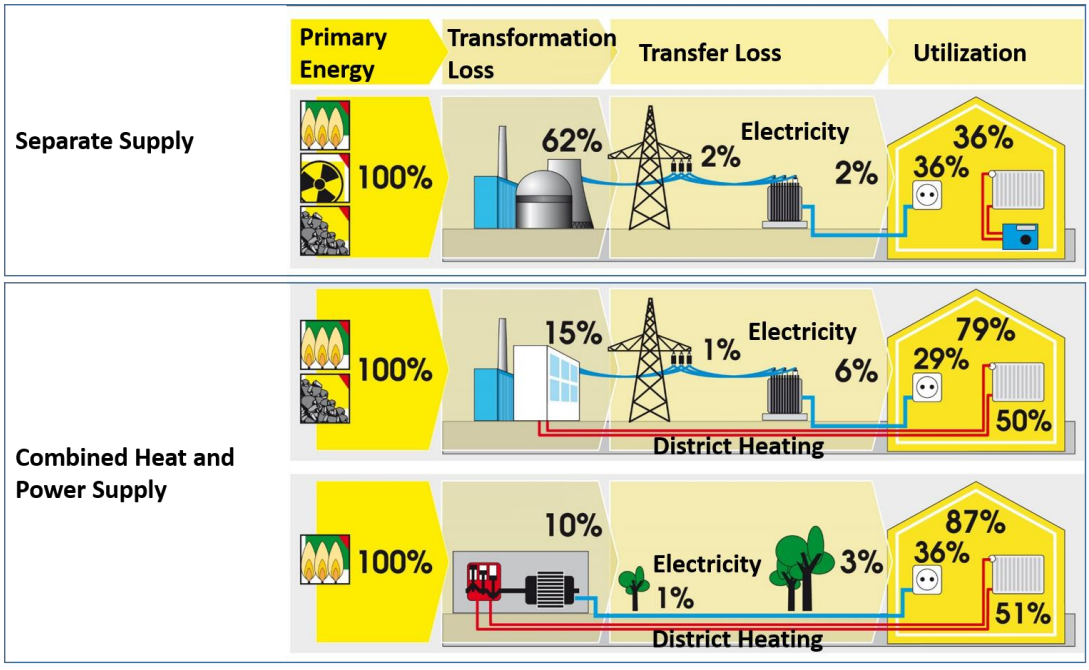

Figure 4: The energy flow in the pure energy supply as well as in the central and decentral CHP-generation [ASUE99].

In general, a distinction between a **power and heat-led control** of a CHP unit can be made. The right design depends mainly on the priority assigned to one of the two forms of energy. The highest efficiency-levels can be reached with a heat-led control design. The operating principle of CHP can divided in the following three different types [SS10]:

- Power-led controlled,
- Heat-led controlled,
- line-commutated controlled

A **power-led control** operation is necessary, if the control of the CHP system is determined by the

[2] https://www.getec-energyservices.com/Home/Technologies/CHP-units/

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general energy requirements of the customer or system, in which the CHP pant is integrated. This mode of operation of CHP systems is implemented less often, because the plant has rather a low utilization rate compared to other operation designs

Heat-led control means that an operating CHP-unit is generally used for heat supply. Simultaneously produced electricity can be used by the consumer, if there is demand, or feed into the grid by getting a refund. For various heat demand either several small CHP-units / aggregates are installed, which can be activate on demand, or a heat storage system, which can be used for peak loads or terms where the CHP-unit does not operate.

In case of a **line-commutated control**, the CHP operation design is producing power in dependence on the grid requirements. It is a new kind of operation. Here, different CHP-plants are interconnected and by this support the grid frequency, because such a virtual power station of different plants together, has a higher impact on the power-grid stability. Especially with regard to a continuous increase of renewable energies within the power sector, such an interconnection could gain high relevance for network stability in times of energy transformation. By a control centre the operation of CHP-units is controlled and the global grid load observed. The optimum efficiencies are only achieved with a heat-controlled operation designs [ASUE10].

Control	Principle	Advantages	Disadvantages
Heat-led	Determined by the demand for heat	Highest degree of fuel utilisation	Lower power generation
Power-led	Determined by the demand for power	Highest degree of power generation	Lower degree of utilisation
Line-commutated	Determined by the grid requirements	Contribution to the stability of the power grid Marketing of balancing energy	

Table 1: Overview of different CHP-control designs (Source: Getec[3])

For an increased efficiency of an operation design, heat storage systems can be implemented in the heating system. Heat storage systems are allowing a decoupling of supply and demand. Therefore, waste heat of the power generation can be stored for future heat demand. By that, heat storages could enable an increase of operation terms for the CHP-unit and make it more economic viable due to the significantly higher price for one kWh of electricity in comparison to the same amount of heat.

[3] https://www.getec-energyservices.com/Home/Technologies/CHP-units/

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2.1 Classification of power ranges

The electrical and thermal output of CHP-technology ranges from micro plants with a few kilowatts to big CHP-plants with a few megawatts. This makes CHP-technology suitable for almost every specific energy demand (heat & electricity). The size of CHP-units depends on several aspects like the dimension of the heating network, consumer behaviour (demand / requirement), or on the utilization of other in the DH-system integrated heat generating technologies.

Therefore Figure 2 shows an overview of typical CHP categories. For power and heat supply of single-family houses, small CHP-units are used with electrical power smaller than 2,5 KW and thermal output of 4 – 7 KW. Units with an electrical power of 2,5 KW - 15 KW are common to supply multi-family houses, apartment buildings and small commerce. These CHP-units provide a range of 40 – 58 KW thermal output. For the supply of hospitals and major buildings small CHP-units with electrical power of 15 KW – 50 KW and thermal out of 110 KW – 130 KW are used. This plant size could also provide electricity and heat to industries. Waste heat of such plants, could also distribute surplus heat to a district heating system which for example supplies a nearby housing area (heat sink). Cogeneration plants with electrical power major than 5 MW are placed in urban areas. Usually municipal utilities are the providers of such huge plants and distribute electricity and heat, whereby the heat is usually supplying an own district heating system [PAS19].

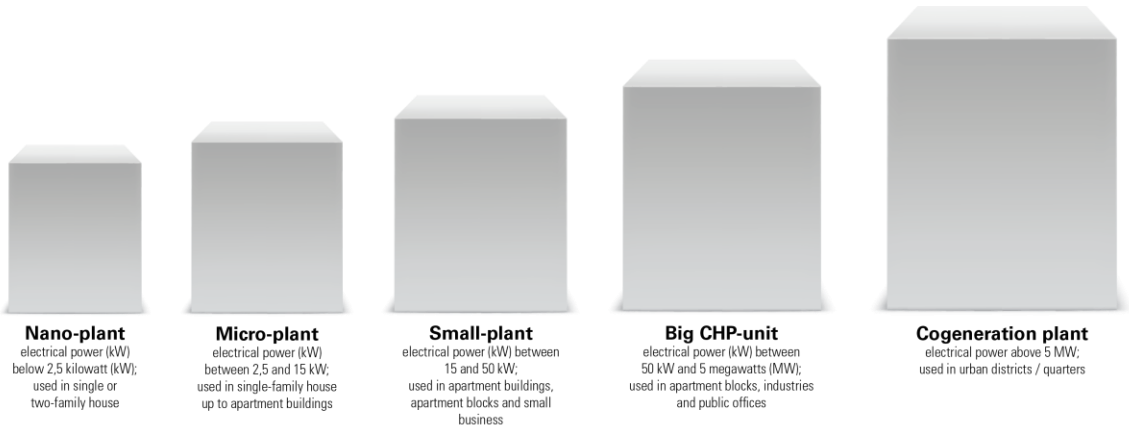

Figure 2: classes of electrical power. Plants up to 5MW represent cogeneration units. Higher power is available by cogeneration plants (Source: Vattenfall Germany)

For an effective utilization of a small or medium seized CHP-unit, it is important find the right dimensioning in order to ensure long durations and a high amount of full utilization hours per annum. Therefore, only 20 % of the thermal nominal capacity of the CHP-unit should be taken as a basis for calculation and planning and not the maximum heating capacity (see figure 6). By this, over 5000 hours with nominal capacity of the CHP-unit can be reached as well as about 50 % of the required annual heat demand covered. For covering the remaining heat demand usually other heat sources, especially boilers can be used, which could also be implemented as a back-up system in case the CHP-unit faces some technical issues. Longer durations of CHP-utilization can be also reached, if the plant is also supplying thermal energy for hot water heating and not only space heating.

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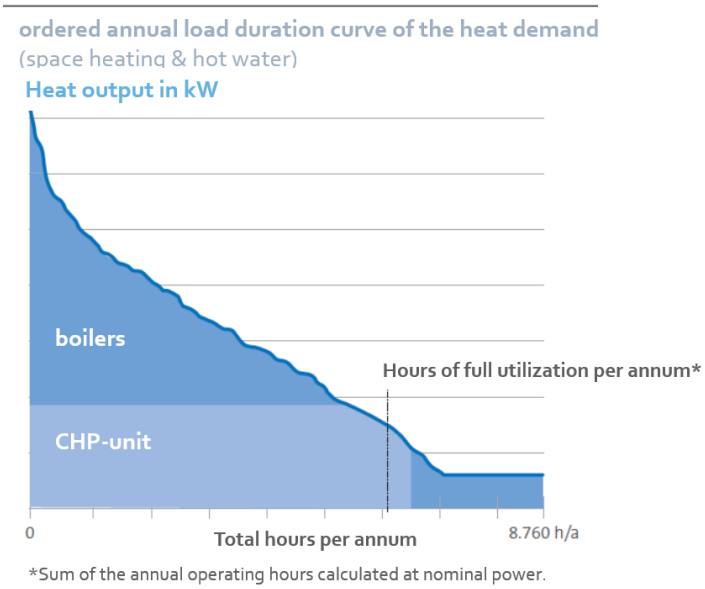

Figure 6: Exemplified operation hours and dimensioning of a CHP-unit [Source: ASUE, 2015 - translated][4].

2.2 Explanation of several CHP-units

By the reason, that several kinds of CHP-units are available for cogeneration of electricity and heat in the chapters 2.2.1 to 2.2.5 operations of typical CHP-units are explained. The choice on a CHP-unit depends on flexibility of customer behaviour, obtainable fuel and the quantity of heat and / or power. For example, CHP-units can divide at the following by regarding electricity power:

	POWER RANGE	FUELS
Steam or condensing turbine	500 MW < P_{el} < 1100 MW Nuclear power plant: P_{el} < 1600 MW	Coal (oil, gas, bio mass, waste nuclear power)
Gas turbine	1 MW < P_{el} < 545 MW Micro turbines: P_{el} < 100 kW	(natural) Gas, fuel oil
Combustion / recipro-cating engine	1 KW < P_{el} < 10 MW	(natural, biomass) Gas, (bio-mass) fuels
Fuel cells	125 KW < P_{el} < 1,4 MW (59 MW prototype)	Methanol, natural gas, hydro-gen, synthetic gas (coal gas)

Table 2: Classification of several CHP-units [Zah19, US20]

[4] https://asue.de/sites/default/files/asue/themen/blockheizkraftwerke/2015/broschueren/asue_050315_bhkw_fibel.pdf

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Also, diverse CHP-units are distinguishable in specific performance and efficiency ranges (Figure). The figure exhibit diverse CHP-technologies of the current state of the art. It is noted that future situation present another situation of performance and efficiency. Considering fuel cells, this technology is virgin in present, but in future it could be a well-engineered technology with an increased performance range.

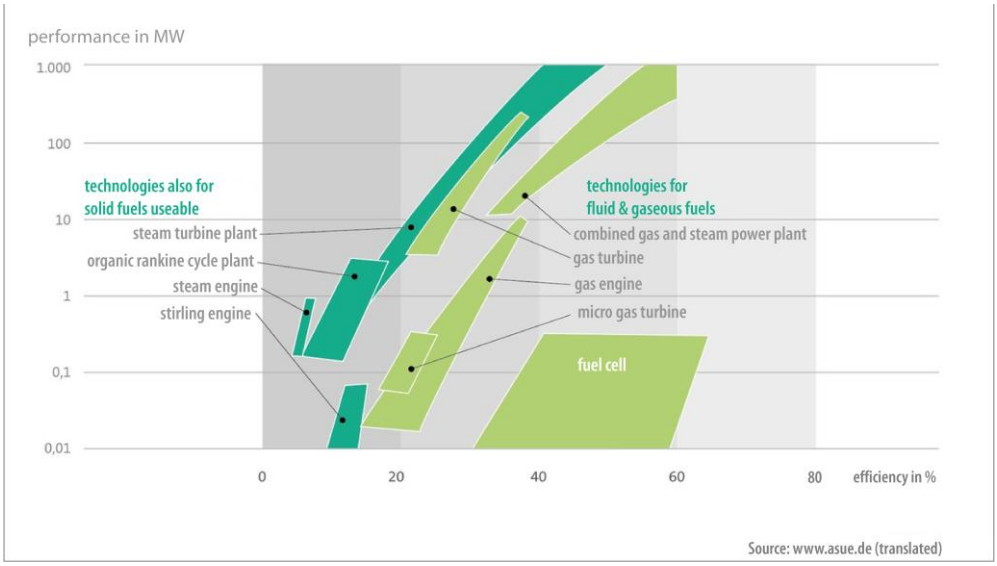

Figure 7: Divers CHP-device technologies. Performance subject to efficiency. [ASUE16].

2.2.1 Reciprocating / combustion engines and generators,

These systems are equipped with standard combustion engines and generate electricity and heat simultaneously (CHP). Usually, a boiler supplements the system to cover peak loads. To operate the system in CHP mode with a high utilization period, both plant components are predominantly used modularly in several units. The generated heat of the cooling water and oil have temperature levels of 80-90°C. Although, the temperature level of the exhaust gases would be high enough for steam generation, the required technical effort has to be considered.

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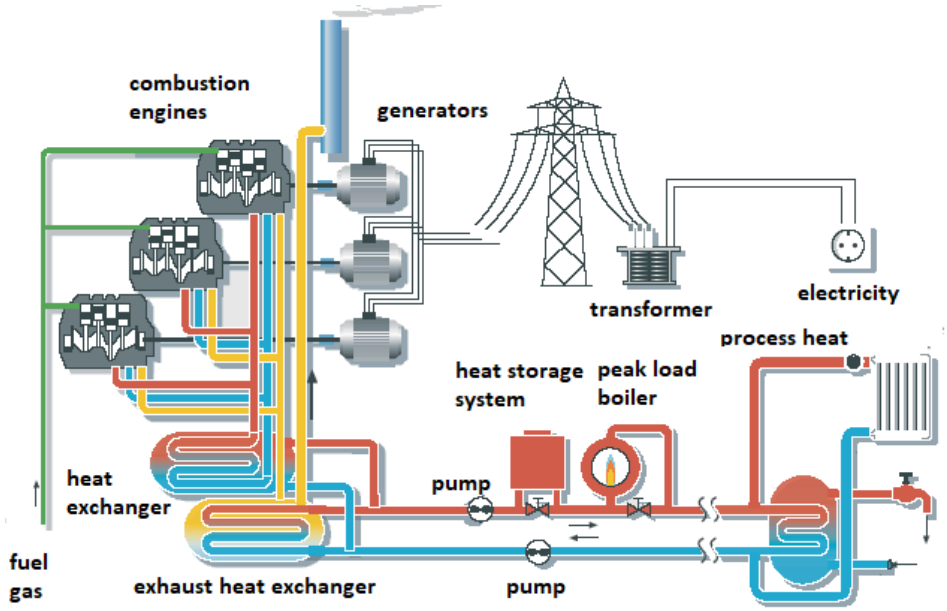

Figure 8: Common scheme of CHP-units working in a power plant. Several engines operates coupled for generation electricity and heat in case of huge demand [AGFW11].

Operational characteristics:

- Mostly rigid coupling between electricity and heat generation, unless additional equipment is provided
- The engine modules are generally operated at nominal load
    - alternating power demands are handled through switch on or off
- In terms of control engineering – systems are mostly used in on-off operations
    - modern control systems offer a performance range of 50-100%
    - Heat storages can avoid on-off operations
- Operation without constant monitoring is possible up to 72 hours

2.2.2 Gas turbines and generators,

Gas turbines use the enthalpy of exhaust gases with a temperature between 400-600°C. The today very sophisticated technology consists of the following components: compressor, combustion chamber and the turbine (cf. figure 8). The latter are available with electrical outputs up to approximately 240 MW. Gas turbines can be fed with gaseous fuels of different heat value as well as liquid fuels [AGFW11].

Essential characteristics are:

- Cheap operating conditions (start-up behaviour, automation)
- Depending on the design of the waste heat recovery system – decoupling of the electrical power from the heat output possible
- Compact design: relatively small space and room requirement

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- Relatively low investments
- Low personnel requirements due to high degree of automation

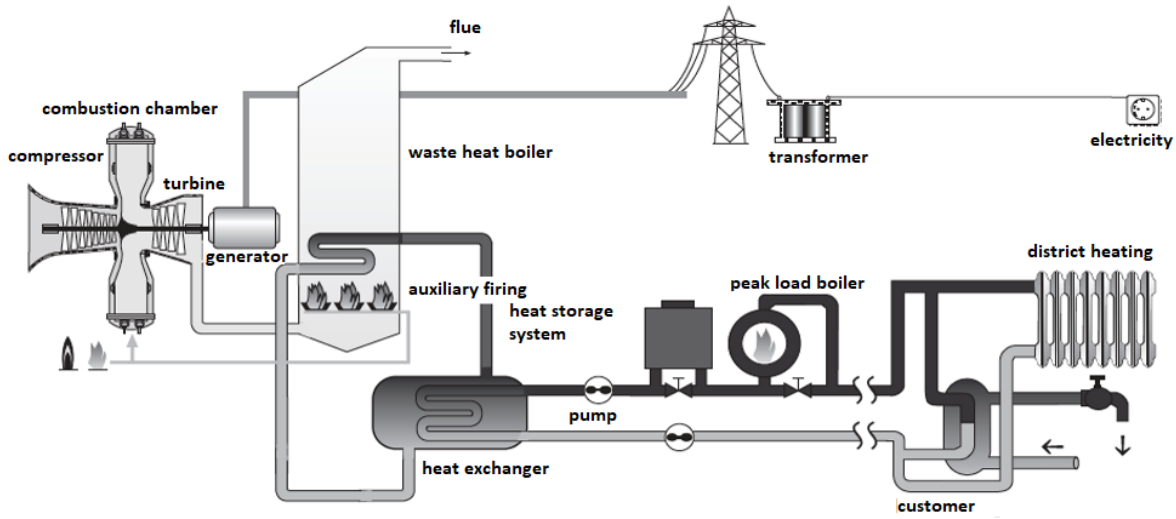

Figure 9: Example for decoupling District Heat from a gas turbine power plant [AGFW11].

In practice, the system consists of one or more gas turbines with waste or excess heat utilization in a waste heat boiler without or with auxiliary firing (cf. figure 8).

Work related electricity values of 0,5 – 0,8 kWh_{el}/kWh_{th} are reachable at a maximum possible DH heating power. Only the slightly higher pressure loss due to the waste heat boiler leads to a low electrical power loss of the gas turbine (approx. 0,5%) [AGFW11].

2.2.3 Steam / condensing turbines and generators

The main mechanism of a condensing power plant can be described as follows: Water is heated and transferred into steam within a boiler system. The steam is delivered to the turbine. The rotary motion, generated by the expansion of the steam in the turbine, is converted into electrical energy with a generator. The expanded steam condenses. Mostly, the condensation heat is discharged to the environment without being utilized and the condensed steam returns as feed water back into the boiler. However, it is also possible to extract and utilize the produced heat of the described power plant process [AGFW11].

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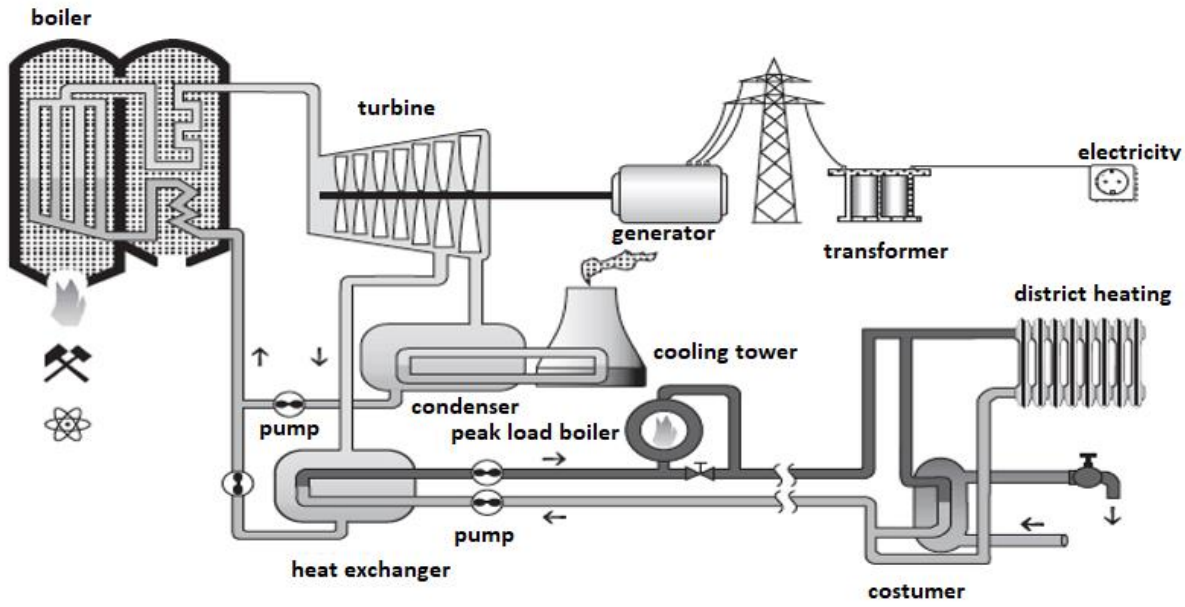

Figure 10: Main principle of a condensing power plant [AGFW11].

Decoupling heat from the power plant process

For this purpose, a part of the steam is fed into a steam network or a heating condenser, where it transfers its thermal energy to a heating water network instead of discharging it via a cooling tower to the environment. The steam, used for this purpose, is not available for electricity production in the turbine and leads to a so-called "electricity loss" [AGFW11].

Using the excess heat of the condensation process

A significant energetically and economical advantage of CHP generation can be reached by the utilization of the condensation heat. By using the heat of the exhaust steam for DH, the overall energetically and economic efficiency of a thermal power plant can be improved. However, the electricity generation always depends on the heat consumption, although for instance auxiliary condensers could help to run the plant also when the heat consumption is low. This general disadvantage of dependencies between power and heat generation can be reduced, if the system is operating for base load supply and is being supplemented by peak heat load generators or heat storages [AGFW11].

2.2.4 Combined-cycle gas turbine (CCGT) plant

The combination of one (or more) gas turbine(s) with one (or more) steam turbine(s) defines a gas and steam turbine plant, whereby the exhaust gas of 400-600°C are used for the production of live steam of 40-80bar/ 350 – 540°C within a waste heat boiler (with or without additional firing) that is then used for the steam turbine. The steam turbine is connected to several heat exchangers and a downstream DH network (cf. figure 9). Auxiliary firing in the heating boiler increases the electrical power of the steam turbine and/or the district heating power [AGFW11].

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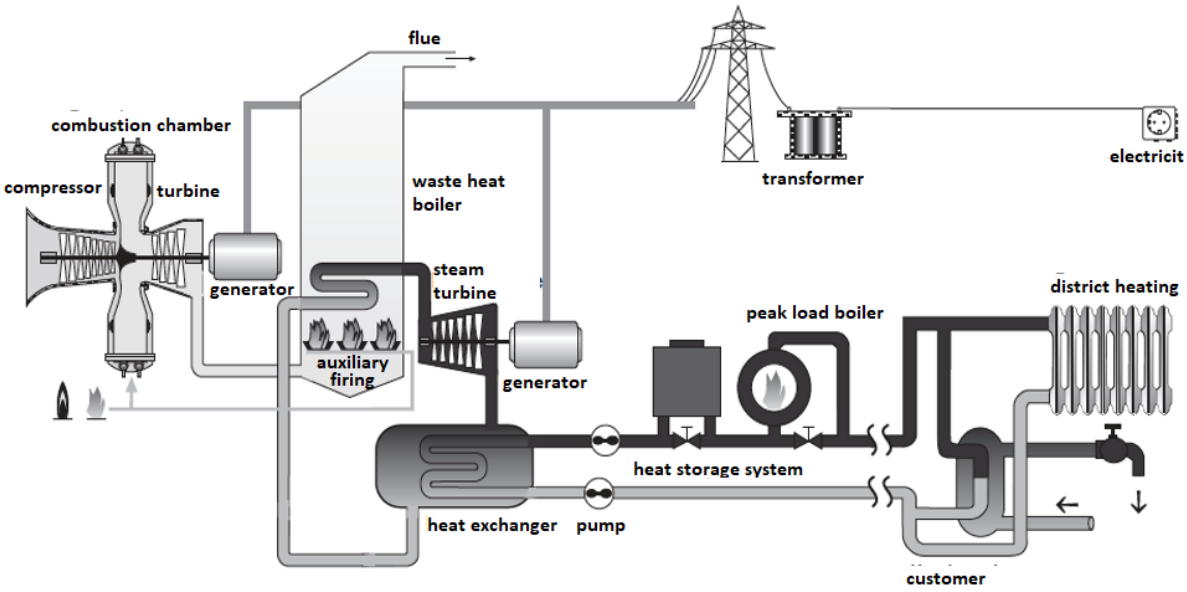

Figure 31: Decoupling District Heat from a gas and steam power plant [AGFW11].

In the showed system in figure 11, the major part of electricity generation is delivered by the gas turbine, which provides 65-80% of the electrical power. The utilization of the exhaust gas heat can be proceeded at low temperatures (80°C), which are mainly limited due to the corrosion and dew point values of the flue gas. In the waste heat process the CCGT shows following characteristics [AGFW11]:

- No additional heat source is required for the steam turbine process → high energy utilization
- Low personnel requirements due to a high degree of automation
- Relatively low investments
- Flat curve progression of the specific heat consumption in the electrical partial load area

CCGT reaches work related electricity values of 0,8 – 1,2 kWh_{el}/kWh_{th} at a maximum possible DH heating power. An optimal operation offers an efficiency level of almost 40 %.

Detailed explanation of the coupled gas turbine- and steam turbine processes

Compare to figure 10 for detailed explanation of the following processes as well:

- Gas is burned under high pressure within the combustion chamber (as in figure 10 visible: mostly the compressor, gas turbine and generator are installed on one drive shaft)
- The waste gas of the gas turbine is forwarded into a waste heat boiler for steam production
- The waste heat boiler is connected to a normal steam power plant process, which is equipped with a back pressure- or extraction condensation turbine
- Depending on the size of such a plant, water, gas- or air can be included in the power generation

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process in case of intermediate superheating

- By utilizing heat the whole power plant process can reach overall efficiency of over 60 %

2.2.5 Fuel cells

The coupled generation of electricity and heat can be achieved directly, without the need of mechanical energy, for example with fuel cells. Here, a controlled reaction of hydrogen and oxygen to water takes place. Fuel cells are mechanically simple as they do not need any moving parts, but the technological process is very demanding.

The electricity is generated highly efficient with an electrochemical process. The power output is well controllable and partly allows quick load changes. During the operation, waste heat is generated which could be utilized, e.g. by a heat pump (see here module 22, chapter 6: power to gas). The temperature level depends on the fuel cell technology. In general, fuel cells have very low pollutant emissions. In the ideal case, it is only water steam. Since hydrogen can only be produced with energy input, there are alternatively fuel cells powered by methane. In that case, CO_2 emissions would occur.

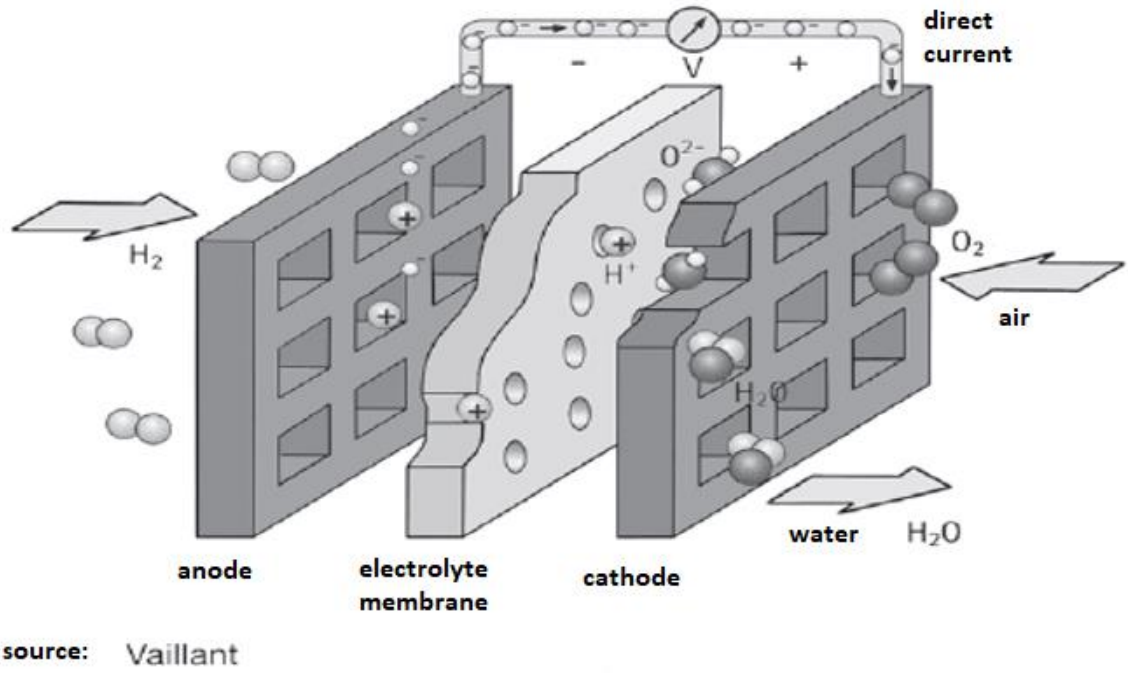

Figure 42: Principle operation of a hydrogen-based fuel cell [AGFW11].(Source:Vaillant)

Fuel cells are differentiated in regard to their technology and/or operating temperature (low, medium and high temperature systems). The technology is available in the market, but has higher investment costs compared to gas engines. "Most commonly used are proton electrolyte membrane (PEM) and solid oxide (SO) fuel cell technologies. Both types of cells in CHP can be either heat- or power-driven and can be deployed as mini or micro CHPs due to their compact sizes. They can either be fuelled with

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hydrogen directly or with natural gas or biogas where conversion into hydrogen takes place inside the unit. If the heat produced is of sufficiently high temperature, such a system can also provide cooling via adsorption (tri-generation)" (Adelphi et al. 2019: p. 4)[5]. In fact, this technology is not yet suitable for general use. There is still a need for further development as well as to test it more in daily practice. Yet, there are still possibilities of improvement regarding the use of the optimized material, cell life-time, investment costs and peripheral costs [AGFW11].

3 Future Prospects for CHP

Combined heat and power (CHP) plants have experienced rapid development in recent years for achieving high energy efficiency. In times of efficient use of limited resources and the targeted reduction of CO_2-emissions, CHP-applications contribute to energy and heat transformation. Moreover, with an increasing integration of renewable energies in the heating sector, CHP plants could to a great extend provide a promising opportunity for integration. In general, following potentials and advantages of the technology can be summarized[6]:

ECOLOGICAL

- Efficiency-boosting
- CO2-reducing
- Sustainable
- Environmentally friendly
- Resource-conserving

ECONOMICAL

- Dynamic
- Independent
- Cost-reducing
- Pro-competitive
- Reliable in terms of supply

Due to their ability to integrate also renewable energies CHP-applications have several ecological and economic advantages in comparison to the, in the beginning of this module mentioned conventional separated heat and power generation.

[5] https://www.adelphi.de/de/system/files/mediathek/bilder/The%20role%20of%20clean%20hydrogen%20in%20the%20future%20energy%20systems%20of%20Japan%20and%20Germany%20-%20Study.pdfhttps://www.adelphi.de/de/system/files/mediathek/bilder/The%20role%20of%20clean%20hydrogen%20in%20the%20future%20energy%20systems%20of%20Japan%20and%20Germany%20-%20Study.pdf

[6] https://www.getec-energyservices.com/Home/Technologies/CHP-units/

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CHP-applications are giving higher flexibilities to future heat and power supply systems. Hence, big applications will still be mainly used for supplying agglomeration or metropolitan areas, because piping effort and heat losses would make an efficient heat transport on long distances not possible. However, small or medium seized decentral CHP-applications could be a highly efficient solution for smaller DH-networks supplying housing areas, hospitals, industrial or commercial areas. Supplemented by heat storage and power-to-heat modules, CHP systems become multiple flexible interfaces between different forms of energy and infrastructures (see here module 22: Power-2-Heat & Power-2-X).
However, the general transformation towards renewable energies is also affecting CHP-technologies. Yet, most CHP systems are still using fossil fuels, however alternatives are being discussed and partly already test-wise implemented into pilot projects. Alternative and most importantly renewable energy sources for CHP will be presented in the following sections.

3.1 Changes in fuels / energy sources for CHP units

Besides efficiency measures, CO_2-emissions can be mainly reduced by the substitution of fossil fuels with renewable energies. If the entire heating sector will be upgraded in future, renewable energy sources can be easier integrated. The integration can either lead to primary energy savings by reducing the consumption of fossil fuels, or it can build new capacities for the system. An important key factor for this development is the diversity of heat generation technologies. With a well-designed heat generation structure and a well-planned upgrading, all available energy sources and available technologies can be used in an optimal way. This mixture of heat sources allows to reduce the use of fossil energy sources and to save primary energy. In addition to the inclusion of renewable energy sources, also the inclusion of surplus or excess heat can improve the environmental performance of the DH system.

Future vision of CHP-application operating with renewable fuels or climate neutral-fuels without CO_2-emission. Furthermore, the future of CHP will be more flexible and grid-interactive than nowadays. That means, small CHP-units or cogeneration plants are combined virtual to a huge cogeneration plant. Whose Operation is controlled by a central control centre **(line-commutated controlled design**). In Comparison to the present situation, these virtual CHP-plants do not ensure base load. It is rather a technology to supply peak loads dynamically. For instance, such an operation design goes along with the vision of industry 4.0 that contains the idea of a smart grid, maybe also a smart district heating system with smart devices that are working similar to the idea of IOT. Moreover, the energy generation with CHP-applications will also mostly depend on efficient sector coupling of heating, power, gas and also mobility, which will be elaborated in the last section.

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3.2 Possible renewable fuels & energy sources for CHP-technology

Using biomass-based fuels: Two different sorts of bio-based fuels exist, which are gaseous or liquid. Gaseous fuels are usually produced by biogas plants or also in sewage treatment plants. For the production within a biogas plant is produced by fermenting biodegradable waste, maize, crops, silage in a biogas plant. It consists of methane, carbon dioxide, nitrogen, oxygen, hydrogen sulphide and hydrogen and ammonia. Common CHP-units like gas turbines and combustion engines are yet unable to operate a combustion process with a gas of so many different components. Therefore, it is important to develop an efficient process, that only pure methane and pure hydrogen is passed into the gas grid [KSW14].

Using Hydrogen or methane produced by renewable energy:

Beside biogas also hydrogen or so called synthetic methane can be used for combustion in a CHP-application. This process is called Power-to-Gas and will be more detailed exemplified in the module 22, chapter 6. In a first step, the gas produced is hydrogen. By applying an additional process, this hydrogen can be converted to methane. Usually, the idea of this technology is to use renewable power for these processes in order to produce renewable (CO_2-free) gas. For example, the power used can be generated by wind turbines or photovoltaic cells.

With Power-to-Gas produced hydrogen and methane could therefore replace the use of natural gas in all previous applications in order to decarbonise them. For instance, methane can be stored and transported with the already existing gas network and is therefore a bit easier to handle than hydrogen. The produced methane can be used for generating electricity and heat within a CHP unit. Therefore, the storage of electricity as gas can be an economically attractive option for a secure, flexible and climate-friendly energy supply, especially for CHP units and reduce their dependency on fossil fuels. Moreover, CHP-applications become a key technology of sector coupling and as an important interface between the power and heating sector as the following figure shows:

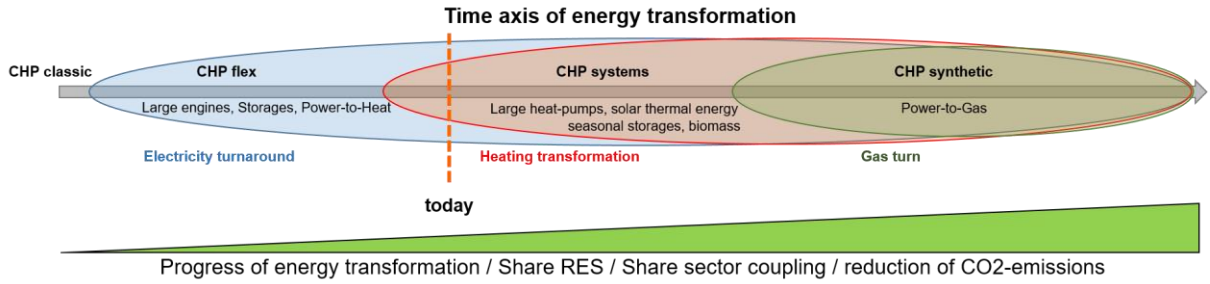

Figure 53: Time axis of energy transformation and the role of CHP (Source: AGFW 2019)

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