Decentralised power and heating supply using combined heat and power plant

Feasibility Study

July 2022

Author

Nils Heine, inwl gGmbH, Rostock

Content

The study is co-financed by the European Regional Development Fund under the INTERREG South Baltic Program 2014-2020, under the project "Liquefied (bio-)gas as a driving force for the development and use of green energy technology.

1. Environmental protection with (Bio-)LNG

Turbulent times are currently (January 2022) prevailing on the raw materials market, with high prices for oil and natural gas. Political tensions are jeopardizing the supply situation and further heating up commodity prices. Today prices react very volatile to any world political news. Due to the uncertainty of supply on the natural gas market, the discussion about energy generation by coal and nuclear power plants has flared up again in Germany. According to experts, however, the continued operation of nuclear power plants beyond the foreseen shutdown date is unrealistic. The measures to shut down the nuclear power plants are already advanced and a prolonged operation of these would cause significant safety risks. Nuclear, LNG and coal-fired power plants are to be used as a transitional technology until renewables are widely expanded. This is also supported by the EU's classification of nuclear and gas-fired power plants as climate-friendly. According to the EU taxonomy, nuclear power plants are considered climate-friendly until 2045 and gas-fired power plants until 2030. However, newly built gas-fired power plants must be able to switch to hydrogen as an energy carrier from 2035. Therefore, hydrogen may be an important source of energy supply in the future. This is also supported by the new cooperation between the German government and Qatar in the production and research of hydrogen. In addition, Germany and Norway are currently examining the construction of a hydrogen pipeline between the two countries. In order to reduce dependence on Russian natural gas, greater reliance will be placed on imports of LNG in the future. Germany does not yet have the infrastructure to import LNG directly. Therefore, the construction of an LNG terminal in Brunsbüttel was decided, which is partly financed by the German government (KfW). The German government has made a change of agenda in energy policy. Previously, it refrained from importing LNG in large quantities because pipeline gas was cheaper. Due to the political situation, this view has now changed, and the missed expansion of LNG infrastructure must be pushed forward quickly. Germany is looking for LNG suppliers who can meet the demand that was previously covered by pipeline gas. Therefore, an energy partnership with Qatar has already been agreed. As a long-term solution, energy supply by LNG, renewable energies and hydrogen is intended. Energy prices are a burden for industry and private consumers. The average price of natural gas in January was about 4 times higher than a year ago. The oil price also doubled year-on-year. In Germany, 31% of natural gas is used in industrial production, so prices for many goods will continue to rise. Energy prices are also a major burden on the transportation sector. Especially in logistics, where profit margins are small, any cost increase is painful. For large trucks, the only environmentally friendly alternative to diesel that is already widely available is LNG. Despite the increased prices, LNG powered trucks are cheaper than diesel trucks. They also benefit from a toll exemption until 2023.

Comparison LNG-and Dieseltrucks in Germany		
	Scania R 410 LNG	Scania R 410 Diesel
Average consumption	24,59 kg/100 km	29,47 l/100 km
Prices petrol station	1,969€	2.169€
Average CO2 emissions	65,90 kg/100 km	74,85 kg/100 km
Fuel costs per 100km	48,42€	63,92€
Road charge 100km	0,00€	18,80€
Ad Blue costs 100km	0,00€	1,22€
Total cost per 100km	48,42€	83,94

***Ad Blue 0,50€ per liter**
*** Road charges in Germany 0,188 € per km**

*** Pollution class Euro 6, vehicle with more than four axles over 18 tons GG**

Source: http://media1.netzwerk-a.de/sixcms/media.php/5939/Test_LNG_Diesel

It is not clear which type of drive will prevail for heavy trucks. LNG, electric or hydrogen-powered vehicles are possible. Electric trucks are often only available as short-haul vehicles because the batteries with a longer range are too heavy. The heavy trucks with electric drive sometimes cost up to 200.000€ more than the diesel vehicles, for comparison LNG trucks cost about 40.000€ more. The necessary infrastructure is lacking for hydrogen as a propulsion system, since it would first have to be produced entirely by electricity from renewable sources. The development of this infrastructure is a long-term process. The use of biogas speaks in favor of the environmental balance of LNG trucks. The National Platform for the Future of Mobility (NPM) estimates that about 180.000 trucks in Germany can be powered by biogas by 2030. The production of biogas also increases independence from price fluctuations on the energy market. The expansion of the LNG infrastructure is continuing and with it the availability. Demand for LNG-fueled trucks and ships remains high and is a positive sign for future development. However, predictions are currently extremely difficult and only time will tell which type of engine will prevail.

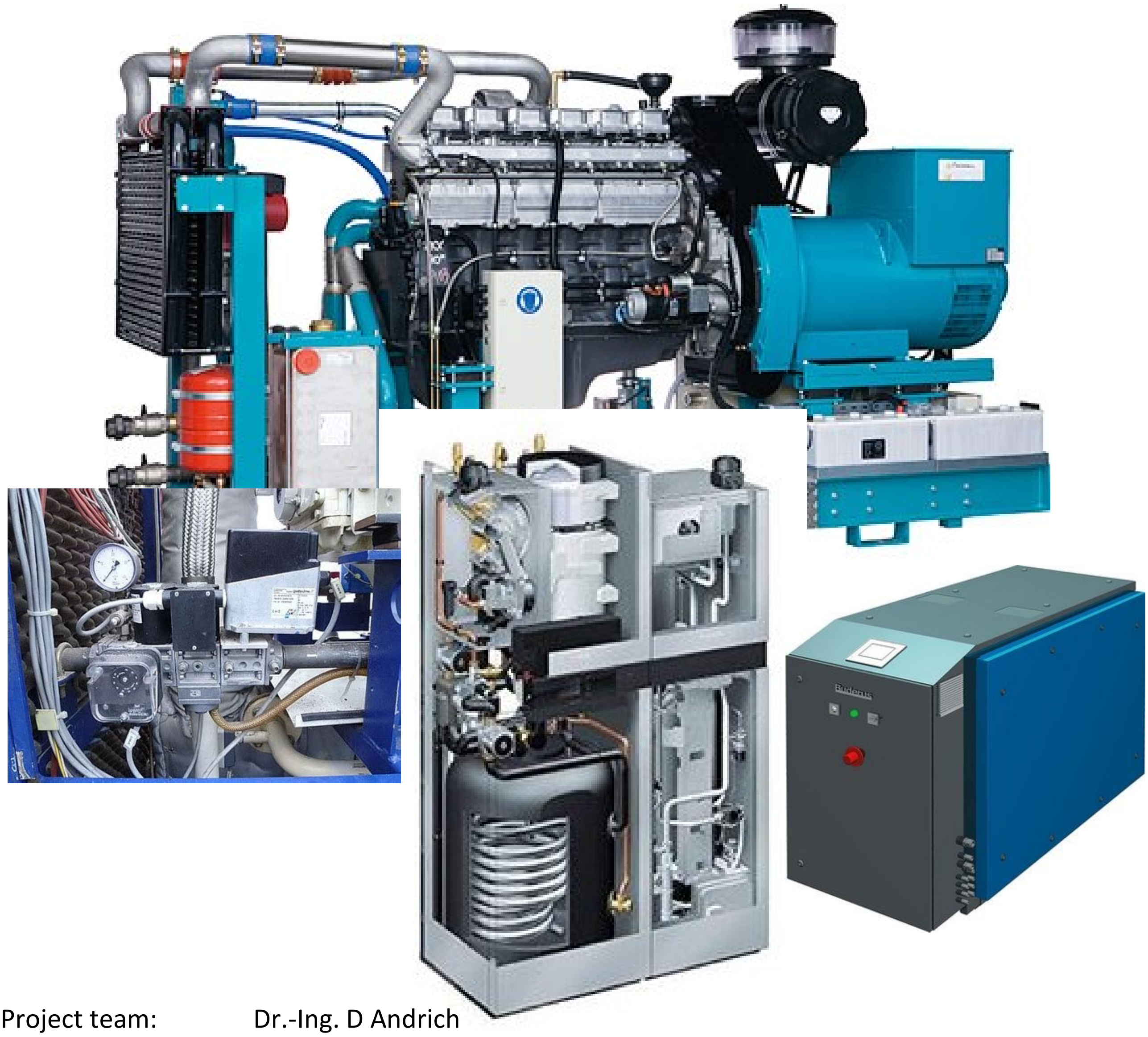
2. Analysis and design CHP in comparision to duel cell

External Study performed by Baltic Engineering Flare

September 30, 2021

Analysis and design CHP/fuel cell according to Liquid-Energy (availability, cost calculation)

Liquid Energy Conception for an office and production building



Project team: Dr.-Ing. D Andrich

Client: inwl institute for sustainable economics and logistics

Georg-Büchner-Str. 17

18055 Rostock, Germany

Date: Short report written September 30, 2021

Table of contents

Liquid Energy Conception for an office and production building

Determination of design specification

Determination of the primary energy consumption situation for heating with a building use of:

250 m^2 office space	specific consumption per m^2 per day	0.7 kWh/m^2
180 m^2 entrance, atrium		0.5 kWh/m^2
230 m^2 workshop area		0.4 kWh/m^2
460 m^2 storage area		0.3 kWh/m^2
60 m^2 conservatory area		0.6 kWh/m^2

Approach for the initial design according to the building specifications 55% heating, 45% hot water (125 L at 45°C per day)

Approach primary energy 500l LNG container (prototype) 110000 MJ/l <=> 3050 kWh

Determination of the primary energy consumption situation for the electrical supply when the building is used by:

320 m^2 building supply (lighting, communication, building technology)		5.0 kW
230 m^2 workshop area		5.0 kW
460 m^2 storage area		2.0 kW
30 office workplaces	specific consumption per workplace per day	0.3 kW
Tea kitchens	...stochastic	1.5 kW
Meeting areas	…stochastic	0.5 kW

Technical technological solution

Variant 1 CHP plant
3 x 500l BEER cryo containers
1 x CHP 50 kW with 3-5 m^3 buffer storage
Fluid-guided floor or panel heaters in the atrium, workshop and storage areas

Variant 2 fuel cell system (combination with other regenerative energy sources / converters)
3 x 500l BEER cryo containers as interchangeable containers
Methane reformer for fuel cells
1 x fuel cell 25 kW electrical output 30 kW heating output with 1-2 m^3 buffer storage (45% electrical energy, 35% heating, 20% hot water)
Fluid / electrically guided floor or panel heaters in the area of atrium, workshop and storage
Flow rate guided circulation pumps heating and hot water supply
customized electrical power supply system
Inverter cabinet for ENV feed

additional options

optionally up to 40 m^2 solar thermal 10-20 individual modules (up to 600 W/m^2 output)
optionally up to 80 m^2 photovoltaic 30-40 individual modules (up to 350 Wp monocrystalline)

Current legal status (EEG, VDE, TAR, ENV-VO)

- EEG expiry December 31, 2021 →no funding
- Change of current small / micro producers of thermal / electrical energy→ Status of an energy supplier →Standard feed-in into the ENV grid →Use of the company supply system (standard meter billing) for third parties (employees, etc.) possible (note: look for the direct source, so far only discussions)
- making the energy available to third parties
- Own use is still allowed, but not for refueling the vehicles

From February 1, 2021, the producer must opt for the KfW 433 program or the feed-in tariff for the electricity that is fed into the public grid. A combination is no longer possible. [13]

CHP systems are usually more expensive than fuel cell systems
CHP: Depending on the design and performance of the CHP, the acquisition costs including installation and accessories are around 25,000 to 35,000 euros for a micro CHP.[9]

Fuel cell: In terms of costs, you should budget at least 18,000 euros for a fuel cell heating system, including funding and installation.[9]

Fuel cell modulating/adjustable operation (performance adjustment) as CHP (only partial /full load) →Adjustment of the supply system.

CHP plant

Combined heat and power (CHP) units are currently one of the most economically efficient climate protection technologies. Depending on the output, the fields of application range from the energy supply of a family home using mini CHP units to the power and heat supply of entire districts or industrial areas using combined heat and power plants.

Regardless of whether internal combustion engines, Stirling engines, gas turbines or steam engines are used, all CHP systems work according to the principle of combined heat and power (CHP). The principle of combined heat and power generation consists in the decentralized use of the (simultaneously) provided electricity and heat. [1]

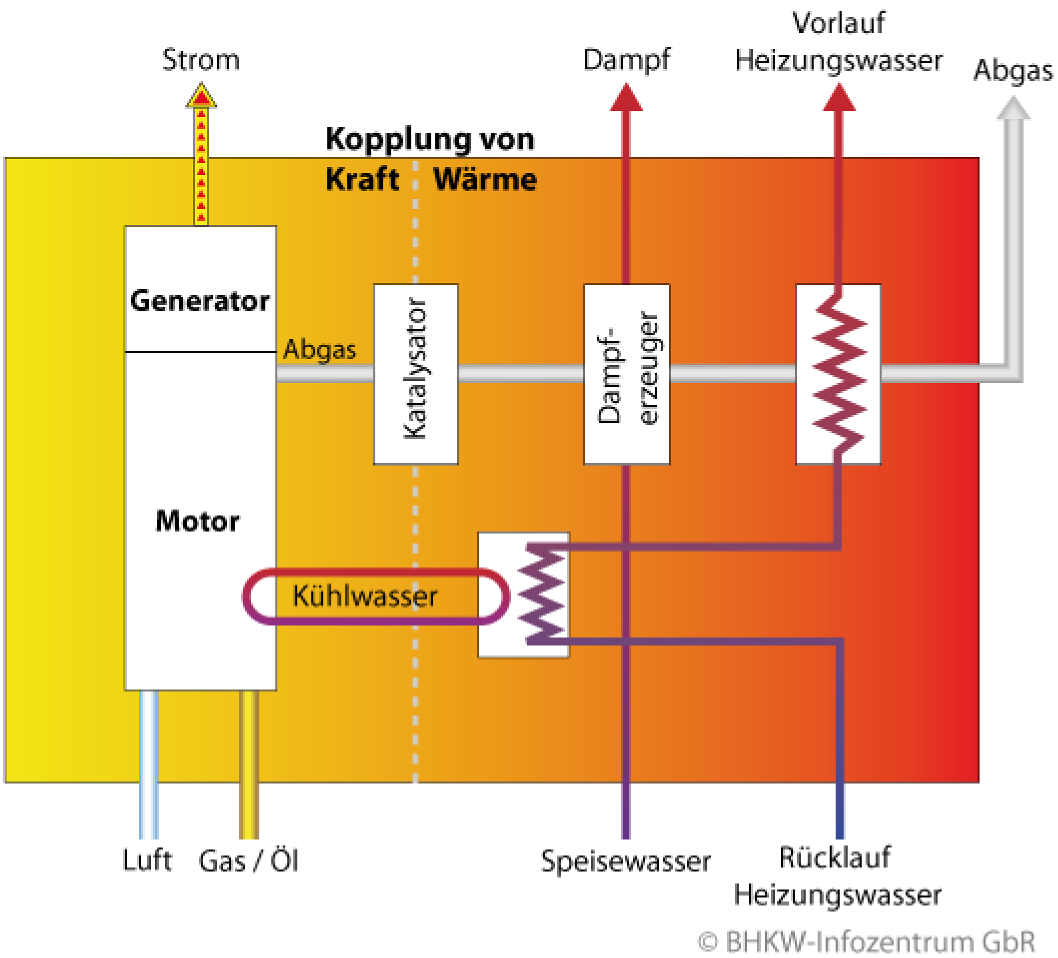


Figure 1: Main principle of combined heat and power generation

In the future, fuel cells could play an increased role within these high-efficiency technologies. Strictly speaking, in the case of fuel cells, combined heat and power (CHP) is transformed into direct power-heat coupling.

In the German-speaking area (Germany, Austria, Switzerland) there are more than 60 manufacturers. According to a recent survey by the BHKW information center, these BHKW manufacturers have more than 1,300 BHKW modules in the power range from less than 1 kW to 20 MW (20,000 kW) on offer.

Fossil energy sources such as natural gas, heating oil or liquid gas as well as renewable energies such as biogas, wood gas and vegetable oil are used as fuels for combined heat and power plants (CHP). However, biomethane and, in the future, possibly even more power- to - gas products such as " wind gas " are available for climate-neutral electricity and heat production.

Legal framework (KWK law, EEG)

The CHP Act (KWKG) is particularly relevant for fossil-fired combined heat and power plants. It regulates a contribution-financed subsidy for the joint and particularly efficient generation of electricity and heat. According to the KWKG, operators of subsidized CHP systems receive additional payments for a limited period of time .[2]

Usual price in the CHP Act: The average base load price (CHP index) achieved on the Leipzig electricity exchange EEX for the previous quarter is considered to be the "usual price". However, the remuneration is based on this electricity price only up to a certain electrical output. CHP system operators whose combined heat and power plants (CHP) with an electrical output of up to 100 kW are subsidized under the CHP Act 2017 (KWK-G 2017) can use the usual price as the assessment basis for the CHP electricity that is sold to the grid operator .
The legal provisions as well as the electricity price remuneration for a biogas or biomethane plant are determined by the Renewable Energy Sources Act (EEG). The EEG also determines the amount of the EEG levy to be paid for the CHP electricity generated in CHP plants.

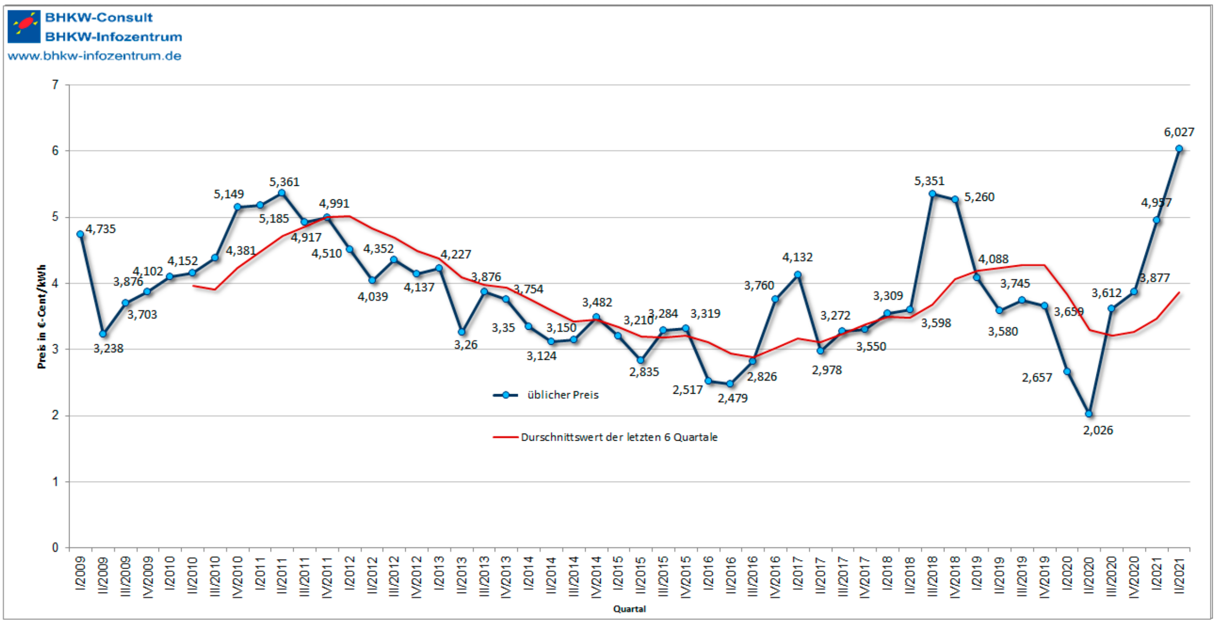


Figure 2: CHP index

The rule that operators of CHP systems with an electrical output of up to 50 kW are not subject to a reporting obligation, no restrictions on subsidies and no penalties with regard to negative hourly contracts has applied since the CHP Act 2020 came into force, regardless of the time of commissioning.[5]

The CHP surcharge is paid for every kilowatt hour of electricity generated by a CHP, regardless of the feed-in. In the case of self-consumption, the electricity tax will also be refunded.

Surcharge for CHP electricity from "new, modernized and retrofitted" CHP systems in accordance with Section 7 of the CHP Act in cents per kilowatt hour:

CHP - power share (kW)	**≤ 50**	**> 50 - 100**	**> 100 - 250**	**> 250 - 2000**	**> 2000**
Feeding into the general power grid	8th	6	5	4.4	3.1
CHP plants that do not feed in:					
CHP systems up to 100 kW	4	3	-	-	-
CHP contracting	4	3	2	1.5	1
CHP in electricity-intensive companies	5.41	4	4	2.4	1.8

Additional duration of the feed-in tariff for CHP

You will not receive unlimited additional payments. The funding period is given in hours of full use. The full utilization hours are not operating hours. The hours of full use result from the amount of electricity supplied divided by the electrical output of a system. According to Section 8 of the KWK - G , you receive a feed-in tariff for how many hours of full use you receive :

CHP type	**full usage hours**	**Conditions**
New	60,000	electrical power ≤ 50 kW
New	30,000	electrical power ≥ 50 kW
New	60,000	with electrical output < 2 kW - Optional according to § 9 KWK-G: Advance payment of the KWK surcharge of 4 cents per kilowatt hour for an assumed 60,000 full hours of use. However, this means that there is no longer any need for individual billing for the amount of electricity generated
Modernized	15,000	Modernization at the earliest five years after continuous operation or after continuous operation of an already modernized system
Modernized	30,000	Modernization costs amount to at least 50 percent of the costs of a new installation or modernization no earlier than 10 years after the first or repeated permanent operation
upgraded	10,000	Retrofitting costs are ≥ 10 and ≤ 25 percent of the costs of an equivalent new installation
upgraded	15,000	Retrofitting costs amount to ≥ 25 and ≤ 50 percent of the costs of an equivalent new installation
upgraded	30,000	Retrofitting costs amount to ≥ 50 percent of the costs of an equivalent new installation

The KWK-G defines the classes "modernized" and "retrofitted" in § 2 as follows:
"For the purposes of this law, "modernized CHP plants" means plants in which
a) essential parts of the system that determine efficiency have been renewed,
b) the modernization leads to an increase in efficiency and
c) the costs of the modernization amount to at least 25 percent of the costs that would have cost the construction of a new CHP plant with the same output according to the current state of the art,
"Retrofitted CHP systems" systems of uncoupled power or heat generation, in which

d) brand-new system parts have been retrofitted for power or heat extraction and
e) the costs of retrofitting amount to at least 10 percent of the costs that would have cost the construction of a new CHP system with the same output according to the current state of the art,"

The electricity from a CHP does not have to be distributed over long distances. The operator of the CHP is therefore entitled to remuneration for the non-use of various network levels in accordance with Section 18 of the Electricity Network Fees Ordinance (StromNEV) . Unfortunately, this is not uniformly defined. The VNNE usually ranges between 0.3 and 1.5 cents per kilowatt hour of electricity.
It looks different than described when the CHP is operated with renewable raw materials. In this case, the feed-in tariff is based on the EEG.

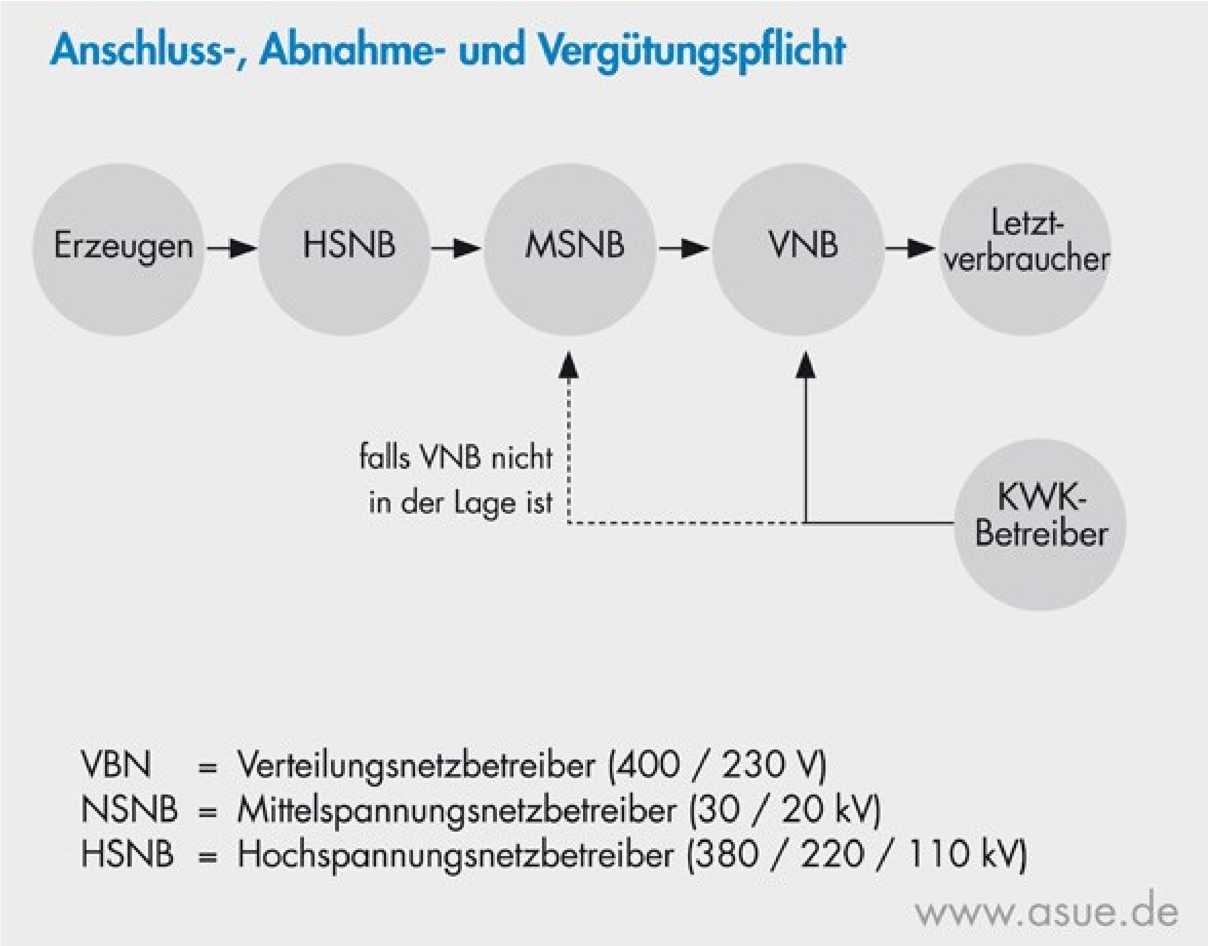


Figure 3: CHP feed-in

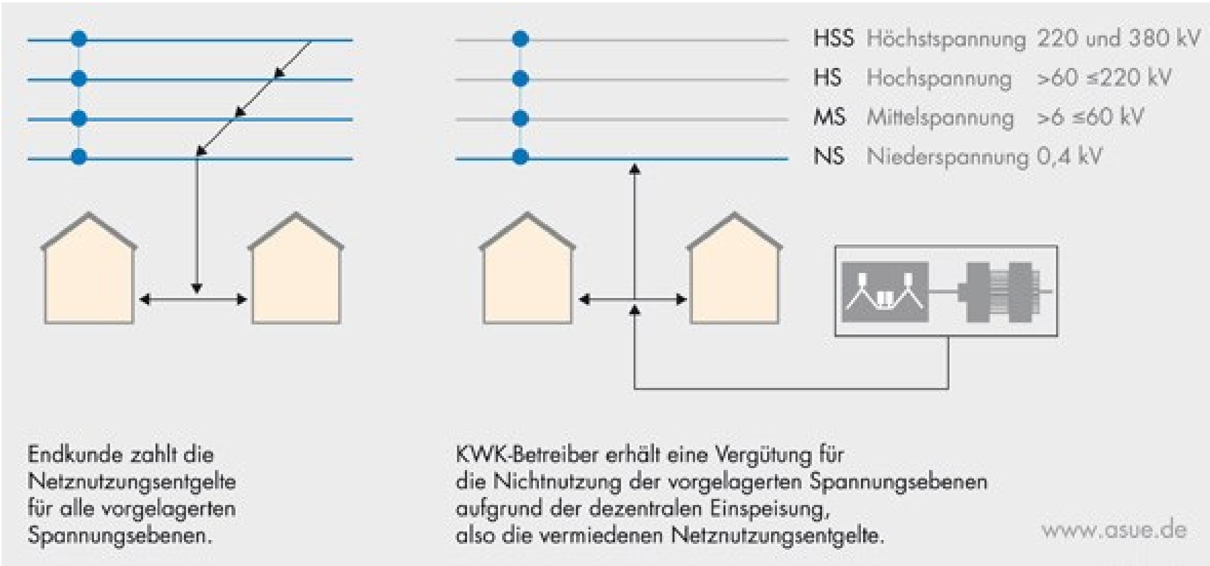


Figure 4: CHP grid usage avoided

Principle of combined heat, power and cooling (KWKK)

Many buildings such as hotels, office buildings or conference facilities not only need heat, but also the provision of cold.

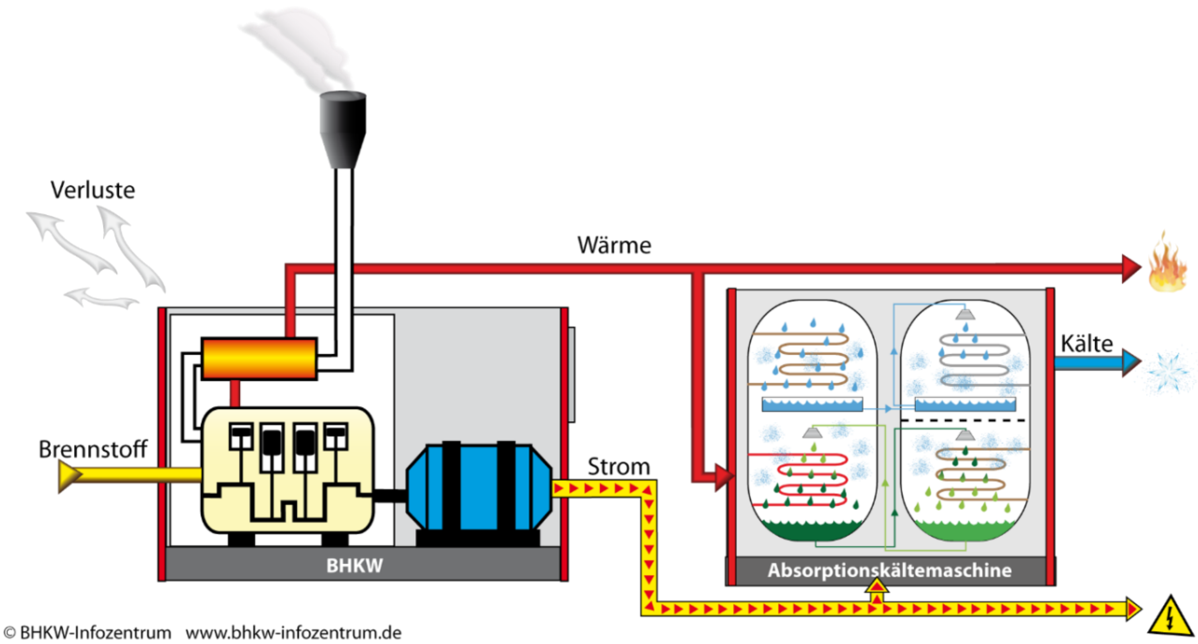


Figure 5: Combined heat, power and cooling

The actual cooling process in these systems occurs through the evaporation of water. In order for a continuous process to take place, the water vapor that occurs during evaporation must be "captured" again in a refrigeration machine. This is done by substances that absorb or adsorb the water. For an absorption process one uses z. B. lithium bromide. However, this salt becomes diluted through water absorption and thereby loses the ability to absorb more water
tie. In order to keep the process going, the water from the salt solution (lithium bromide) has to be boiled out again.

cogeneration technologies

A basic distinction is made between CHP technologies, in which the fuel is burned in a burner, and internal combustion engines. Combustion engines are used most frequently. Combustion engines and gas turbines belong to this category, whereby a distinction is made between spark igniters (petrol engines) and compression-ignition engines (diesel engines). The CHP technologies with burner technology include Stirling engines, steam engines, steam turbines, as well as ORC and Kalina cycle systems. Fuel cells also belong to the CHP technologies, even if they do not actually work according to the CHP principle. In fuel cells, electricity is generated electrochemically in a direct way. Strictly speaking, this is actually an electricity-heat coupling. [8th]

Advantages and disadvantages of the different engines:

CHP engine	functionality	fuel	Advantages	Disadvantages
Stirling engine	Converts external thermal energy (burner) into mechanical energy (circular or Stirling process)	Mostly gas, also runs on renewable energies	Lower emissions than petrol engines, low maintenance	Expensive to buy, lower efficiency than Otto engines
Otto engine	Classic 4-stroke combustion engine	natural gas or biogas	Proven principle, high efficiency, more economical than Stirling engine / pays for itself earlier	Expensive to buy, high maintenance, high wear and tear, high maintenance costs, more emissions than Stirling engines, noisy in operation
diesel engine	Internal combustion engine (compression ignition, 4-stroke, 2-stroke)	Heating oil, diesel, biodiesel	Economical, very high efficiency	Expensive to buy, high maintenance, high maintenance costs, formation of soot
steam engine	Converts external thermal energy (burners) into mechanical energy using steam	Gas, but other fuels are also possible	High efficiency, high thermal output, low emissions, low maintenance	Expensive to buy, low electricity production
fuel cell	Conversion of chemical energy into thermal and electrical energy	Hydrogen (usually obtained from natural gas in a so-called reformer) + air (oxygen)	Hardly any emissions, water as a waste material, very high electrical efficiency, hardly any wear parts, hardly any maintenance required,	Expensive to buy

Performance and efficiency range of CHP technologies

The table below shows the current technological data for CHP systems that are currently available. Only the module size up to a maximum of 20 MW electrical output was considered in order to be able to ensure a uniform picture of the electrical efficiencies.

KWK-Technologie	Aktuelles Leistungsspektrum	Realisierbare elektrische Wirkungsgrade[1]
Dampfturbine	ab 500 kW_{el}	10 - 20 %
Dampfmotor	150 - 1.500 kW_{el}	10 - 20 %
Gas-Ottomotor	1 - 9.700 kW_{el}	26 - 46 %
Heizölbetriebener Dieselmotor	2 - 17.100 kW_{el}	28 - 47 %
Zündstrahlmotor	30 - 18.300 kW_{el}	35 - 45 %
Gasturbine	ab 28 kW_{el}	20 - 40 %
Stirlingmotor	0,3 - 70 kW_{el}	10 - 30 %
Organic-Rankine Cycle (ORC)	100 - 500 kW_{el}	14 - 18 %
Brennstoffzelle	0,3 - 1.500 kW_{el}[2]	30 - 60 %

[1] Um ein einheitliches Bild gewährleisten zu können, werden in dieser Tabelle nur die Wirkungsgrade berücksichtigt, welche bei Aggregaten bis zu einer elektrischen Leistung von 20 MW_{el} erreicht werden.
[2] Bei Brennstoffzellen wurden die Leistungen der im Jahr 2016 in Deutschland realisierten Anlagen als Maßstab für das Leistungsspektrum zu Grunde gelegt. Aufgrund der modularen Bauweise sind auch Anlagen im zweistelligen Megawattbereich möglich und weltweit teilweise bereits realisiert.

BHKW-Consult
BHKW-Infozentrum
www.bhkw-infozentrum.de

Figure 6: Performance and efficiency spectrum of CHP technologies

The steam turbine and the steam engine are mostly used in the industrial sector. In combination with the gas turbine, gas and steam turbine combined heat and power plants (GuD) are used in industry and municipal district heating.
[1] (https://www.bhkw-infozentrum.de/)

Costs of a CHP plant

An important rule of thumb with regard to costs is: The more electricity a system can generate, the lower the investment costs per installed electrical output. This means: A large system is of course more expensive than a small system, but it is still more economical to operate. For the profitability calculation, it is also important that the electricity generated is used as much as possible and not fed into the grid.
Not only the prices of the combined heat and power plants have to be considered, but the complete costs for the installed and operational CHP system have to be included in the profitability calculation. [4] [6]

The investment costs for a combined heat and power plant essentially include the costs for the purchase of the combined heat and power plant, the costs for accessories such as e.g. B. buffer storage, additional heat exchangers or an additional control and regulation, the costs for the structural integration such as gas, water and electricity connections as well as planning costs and costs for the unforeseen.

Table: price overview spec. Costs, CHP module costs and additional costs
(Source: "BHKW calculator" Energy Agency NRW, 2017)

Electrical power	specific costs	module cost	extra cost	
			Transport to acceptance	integration
5kW	€4,000/ kWh el	€20,000	€2,000	€8,200
10kW	€2,750/ kWh el	€27,000	€2,700	€11,100
20kW	€1,900/ kWh el	€38,000	€2,300	€14,800
30kW	€1,650/ kWh el	€49,500	€3,000	€19,300
50kW	€1,400/ kWh el	€70,000	€4,200	€27,300
100kW	€1,080/ kWh el	€108,000	€6,500	€42,100
200kW	€760/ kWh el	€152,000	€9,100	€68,400
500kW	€550/ kWh el	€275,000	€16,500	€148,500
1,000kW	430 €/ kWh el	€430,000	€30,100	€288,100
2,000kW	€411/ kWh el	€822,000	€14,800	€485,000

The operating costs of a combined heat and power plant relate primarily to the use of fuel to operate the combined heat and power plant. The other operating costs of a combined heat and power plant therefore include costs for maintenance and repairs, for additional personnel costs for operation and

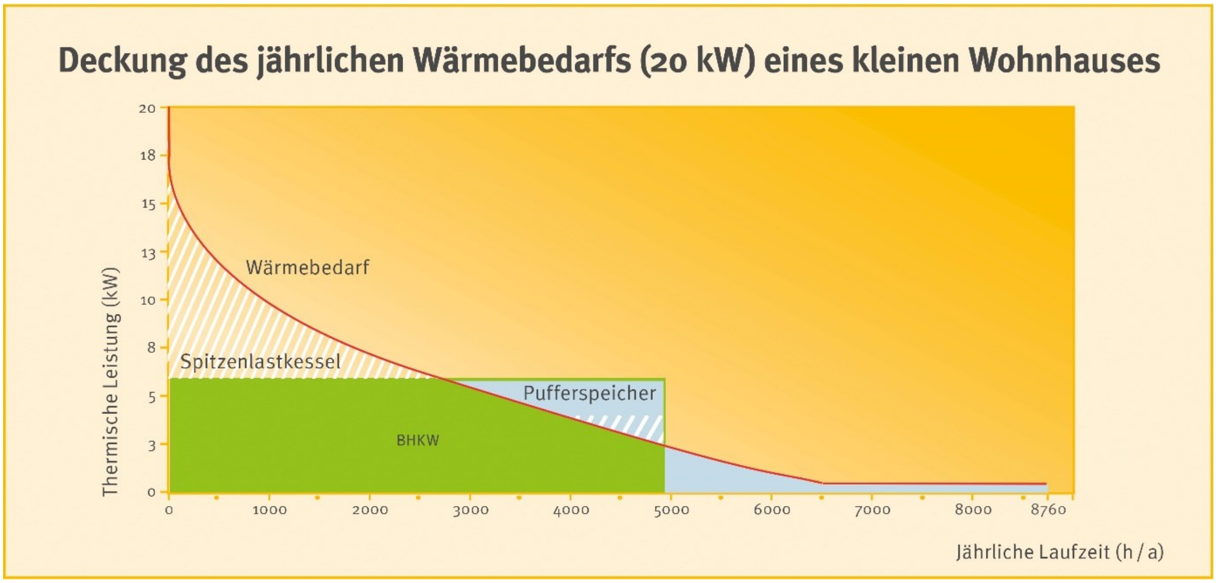
Supervision of the combined heat and power plant as well as for the administration and other expenses associated with the operation of the combined heat and power plant.

Manufacturers offer full maintenance contracts for servicing and maintenance, which include all the necessary life-time-dependent services from oil changes to general engine overhauls. For small combined heat and power plants with an electrical output of up to 20 kW, around 3 cents per kWh produced can be calculated for this. For larger combined heat and power plants with an electrical output of 200 kW, around 1 cent per kWh should be applied. Percentage flat rates depending on the investment costs without planning costs can be used as a basis for personnel expenses as well as for administration and other things in accordance with the VDI guideline 2067. For this reason, 3% for personnel expenses and 1.5% for administration and other items are assumed to be realistic benchmarks.

In most cases, combined heat and power plants only cover part of the electricity requirements of the CHP operator, so that he still has to buy additional electricity. However, since the total electricity requirement has been reduced by the operation of the combined heat and power plant, the electricity tariff of the CHP operator may also become more expensive due to lower purchase quantities. In addition, additional costs for the provision of reserve power by the electricity supplier may be due, which must be used in the event of a failure of the combined heat and power plant.

How big should the output of the CHP be?

As a rule of thumb, the thermal output of the CHP should be 10 to 30 percent of the required peak thermal output. In addition, a central hot water supply in the building is an important prerequisite for being able to use the CHP heat. In winter, when there is a high demand for heat, the peak load boiler is switched on.



Picture 7: Example of the CHP heat requirement [10]

The graphic shows the connection between the output and the running time of the CHP. In this example, the CHP with a thermal output of 12 kW takes over 30 percent of the maximum heating load of the building and thus covers around 75 percent of the annual energy requirement for heating and hot water. Designed in this way, the CHP achieves 5,000 operating hours a year, which is a good value in terms of cost-effectiveness. The peak load boiler takes care of the remaining output required (see top left area of the heat demand curve). [15]

Approval, registration and operation

CHPs must be registered with the network operator. If a cogeneration unit feeds electricity into the public grid, this electricity is subsidized under the Combined Heat and Power Act (KWK-Gesetz) with a surcharge that the grid operator pays out. Self-used CHP electricity is also rewarded with this subsidy. In order to receive the statutory surcharge, the system must be approved by the Federal Office of Economics and Export Control (BAFA).

There are 2 different procedures to obtain the approval. We will tell you how this works and what additional requirements you have to comply with:

1. Electronic Notification Procedure

BAFA has set up a simplified approval procedure for new CHP systems with an electrical output of up to and including 50 kWel (el = electrical). Electronic notification to the Federal Office of Economics and Export Control is sufficient. It is free of charge and can be used under the following conditions:

- The CHP system, i.e. the CHP, is listed in the BAFA type list.
- The CHP plant is brand new.
- There is no local or district heating network at the location of the CHP plant (ban on district heating displacement).
- The CHP plant is only operated at the specified location.
- No other CHP system has been put into continuous operation at the site in the last 12 months.
- Continuous operation started in the year of the electronic display or in the previous calendar year.
- Only one investment subsidy according to the mini-CHP directive was claimed, no other.

If one of the above conditions is not met, you cannot use the electronic notification procedure. You can then apply for the approval with the fee-based "Application for approval of a new system up to 50 kWel ".

In addition, you can only carry out the electronic display in the year in which continuous operation of the CHP system began or in the following calendar year. The approval granted is valid from the point at which the system begins continuous operation. Outside of this period, the CHP system can only be approved using the paper application process, which is subject to a fee.

2. Paper Application Process

If a requirement of the electronic notification procedure is not met (e.g. because the subsidy program is not on the BAFA cumulation list for investment grants or it is a used or modernized system), you must submit the "Application for approval of a new system by 50 kWe " use.

The completed application form must be submitted to BAFA by December 31 of the calendar year following the commencement of continuous operation of the CHP plant, together with the required documents. The evidence to be submitted is indicated on the respective application form

refer to. If the application is submitted later, the approval will be granted retroactively to January 1 of the calendar year in which the application was received by BAFA.

for processing a paper application for systems up to 50 kWel .

a) Approval of CHP plants that are not listed (once)

For CHPs that are not included in the BAFA list or that are not brand new, for example, you must submit an application for approval in paper form together with the manufacturer's data sheet and the record of commissioning.

b) Approval of modernized CHPs
CHP units in which components that are crucial for efficiency are renewed can also be approved by BAFA – but only if the costs for the renewal account for at least a quarter of the costs of a comparable new system. You will receive the relevant application form from BAFA.

Registration of the CHP for connection to the local power grid (once)

You must register the CHP with the local network operator. You must also enter into a contract with the company for both the grid connection and the use of the connection. The installer usually does this for you.

The network operator requires a copy of the BAFA approval for the system for the payment of the subsidies under the CHP Act. In addition, you must agree with the local grid operator how the electricity meter is to be read and how you will report your net electricity production, full utilization hours and the amounts of electricity fed into the grid in the future.

Annual reports to BAFA (annually)

In the meantime, the BAFA has waived all annual reports for CHPs with an electrical output of up to 50 kW. However, for systems with an electrical output of more than 50 kW, you still have to inform BAFA annually about the amount of CHP electricity fed into the public grid.

c) Application to the main customs office for a refund of energy tax (annually)
The fuels for the CHP are taxed at a reduced tax rate. You can apply for a full energy tax refund. The prerequisite according to the Energy Tax Act (EnStG) is that the CHP converts at least 70 percent of the energy used into electricity and heat. According to the currently valid law, the following amounts are reimbursed:

fuel	refund
fuel oil	6.135 cents per liter
Natural gas / gaseous hydrocarbons	0.55 cents per kWh*

*kWh: kilowatt hour, as of 2020

The tax refund or reimbursement is granted by the responsible main customs office. Applications for a calendar year must be submitted no later than March 31 of the following year.

Advantages & disadvantages of CHP plants

Advantages	Disadvantages
Very high efficiency (therefore environmentally friendly)	High acquisition costs
Eligible for funding according to BEG WG* (renovation + new construction) if the fuel for operation comes from 100% renewable energies (biomass)	High maintenance costs
Feed-in tariff for unused electricity	Usually not suitable for operation in single-family houses as it is uneconomical

Low running costs (applies to high heat + electricity requirements of the property; MFH with trade / industry + trade, does not apply to single-family homes)	High noise during operation (Otto / Diesel engine)

[8th]

CHP for industry and trade

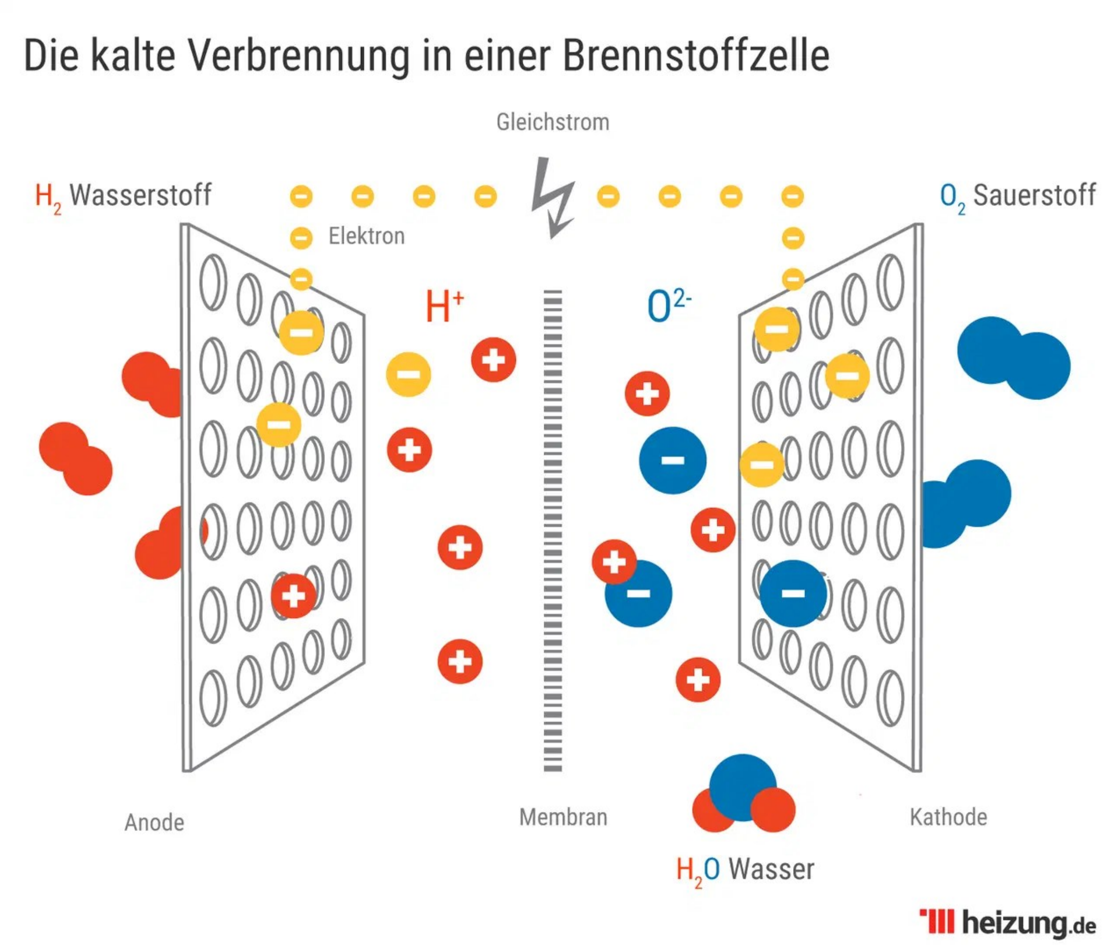
In a commercial or industrial company, it is easy to calculate with a sharp pencil how much can be saved with a CHP, because there is a high energy requirement and there is often even shift work around the clock. However, such an investment should always be compared with alternatives such as a large photovoltaic system in order to decide on the cheapest solution overall

The BUDERUS company is one of the current market leaders for CHP systems with an electrical output of up to 50 kW: [3]

fuel cell technology

Fuel cells are particularly efficient energy generators that achieve an efficiency of around 90 percent through the combined production of electricity and heat. For comparison: A conventional power plant usually does not achieve more than 40 percent. This means that around 60 percent of the energy used is released into the environment in the form of unused heat. [17]

The fuel cell is a galvanic cell: the fuel, e.g. B. hydrogen, reacts with an oxidizing agent such as oxygen. The resulting reaction energy is converted into electrical energy. In addition to electricity, heat is released in this reaction. The fuel cell is therefore a converter and not an energy store.
Fuel cells convert natural gas into hydrogen and use it to generate thermal and electrical energy at the same time. Natural gas is a hydrogen-rich compound. The hydrogen contained is obtained by a reformer and reacts with the oxygen supplied from the air in reverse electrolysis to form water. An electrochemical reaction occurs, producing heat and electricity. This process is also known as "cold combustion" because there is no classic combustion by engines or turbines. [12])



Picture 8: Representation of the cold combustion [10]

A fuel cell consists of two electrodes that are separated from each other by a membrane that is partially permeable. If hydrogen now reaches the negatively charged anode, electrons and protons are divided by a catalyst. If the free electrons migrate via the electrical conductor to the positively charged cathode, current flows. At the same time, the protons slip through the separating layer, which is only permeable to them, and combine with electrons and oxygen from the air on the other side to form water. [17]

The resulting direct current is converted into alternating current in an inverter or inverter and thus made usable for the consumer. The heat is transferred to a buffer tank via a heat exchanger and used to heat the drinking water or the heating circuit.

Different types

Fuel cell heaters come in a variety of designs. A basic distinction is made between low-temperature and high-temperature fuel cells.

PEMFC (Proton Exchange Membrane Fuel Cell): The PEM is a low-temperature fuel cell with a polymer membrane. It uses a reformer to obtain particularly pure hydrogen from natural gas. Working Temperature: 70-90℃

SOFC (Solid Oxide Fuel Cell): In SOFC, on the other hand, zirconium dioxide is used to separate ions and electrons. It can use natural gas directly, but as a high-temperature fuel cell, it requires significantly higher operating temperatures of up to 1,000 °C to produce the hydrogen.

Assumptions regarding the fuel cell cost structure

Since the fuel cell generates both forms of energy - i.e. electricity and heat - in a similar ratio, it generates more electricity than, for example, a CHP. They only work economically if they generate a lot of electricity, which, in the best case, is also consumed themselves. However, this can only be produced if there is also a heat requirement for heating or hot water in the house.
As with all heating devices, the costs of a fuel cell heating system are made up of various components:

- the cost of developing the fuel
- for purchasing the technology
- as well as the consumption costs of the fuel cell

Gas connection costs

Since the hydrogen for operating the fuel cell heating system is obtained from the methane stored in the natural gas, a gas connection is a prerequisite for a fuel cell. This consists of two parts: The first (between the street and the building) is called the house connection line and must be created by the utility. The costs for this are around 1,500 to 3,000 euros. They can be higher if the distance to the public gas line is long.
If there is no gas connection, the fuel cell can also be operated with liquid gas. To store this in your own home, you need a tank system. This is usually set up in the garden and costs around 1,500 to 3,000 euros. It should be mentioned at this point that most models available on the market are designed for classic natural gas. [12]

acquisition of technology

A fuel cell heating system can cost between 20,000 and 25,000 euros. However, the prices for a fuel cell heating system vary greatly depending on the region, manufacturer and service provider. In addition, the installation of the system usually costs around 2,000 to 2,500 euros. [11]

Promotion of fuel cell heating

The KfW (Reconstruction Loan Corporation) supports the innovative technology with large grants. In addition to a basic amount of 6,800 euros, there is another 550 euros per 100 watts of electrical output via program 433 "Energy-efficient construction and renovation - fuel cell subsidy". Overall, however, funding is limited to a maximum of 40 percent of the total costs (up to EUR 34,300). As well as the power classes from 0.25 to 5.0 kW electrical power. In addition, systems that are or have been operated in fewer than four units (prototypes) are excluded from funding. [10]

Operating costs of a fuel cell heating system

The costs that arise in the operation of a fuel cell are made up of fuel costs, remuneration and savings. Plant owners achieve the greatest savings when they use as much of the generated electricity as possible themselves. Because then no energy has to be drawn from the public grid. In comparison to the feed-in tariff of the CHP Act, which is currently around ten to twelve cents per kilowatt hour (composed of CHP surcharge, electricity price on the exchange and remuneration for the avoided use of the grid), the value of the self-used electricity is lower

today at around 28 cents - the price of electricity. However, how high the operating costs are depends on various factors.

Advantages of a fuel cell

It is considered the energy system of the future. A fuel cell heating system is the right choice for people who want to supply themselves with energy in an innovative and environmentally friendly way.

- Cold combustion is particularly efficient and ensures high efficiency.
- The energy is generated with particularly low emissions.
- High state subsidies
- Many manufacturers offer this innovative technology.
- The devices are particularly low-wear and low-maintenance, since there are hardly any moving parts.
- Installation, operation and maintenance are no more complicated than with a gas condensing boiler
  Fuel cells are lighter than accumulators, more reliable and quieter than generators and work more efficiently than internal combustion engines.

Disadvantages of a fuel cell

- depending on the gas & its price development
- Comparatively high acquisition costs
- Little data for long-term operation
- Simultaneous power and heat generation

Viessmann is the current market leader up to 50 kW: [16]

Summary Differences between fuel cell heating and CHP

There are clear differences between combined heat and power plant and fuel cell heating, which are compared in summary. [13]

	CHP	fuel cell heating
type of energy production	In a combustion chamber, mostly fossil fuels are burned. This generates mechanical energy that drives a turbine. This combination of combined heat and power generates electricity and waste heat that can be used to heat real estate.	For the fuel cell, hydrogen is obtained from natural gas. Chemical energy is then converted into electrical and thermal energy in the fuel cell.
power generator	Internal combustion engine, Sterling engine	fuel cell
emissions	CO2 is released when fossil fuels are burned and extracted.	The fuel cell works almost emission-free. Pollutants only occur to a small extent.
electrical efficiency	about 25 to 38 percent	about 60 to 70 percent
fitness	CHP units are more efficient the larger they are and are less suitable for single-family homes.	The modular structure of fuel cells also enables small devices for single-family homes.
maintenance	Combustion engines require regular maintenance.	Maintenance for fuel cell is hardly necessary.
Performance	The engine always delivers the same power.	Fuel cells can be expanded and upgraded per stack to achieve more power.
wear and tear	The rotating parts of the engine are subject to comparatively high wear, since the CHP usually runs in continuous operation.	The fuel cell heating works without rotating parts. The cells have to be replaced about every 25 years.
Cost (30 kWel)	~€95,000 (without funding)	~€80,000 (without funding)

Conclusion

A combined heat and power plant is only worthwhile for large residential units that have a high heating requirement and, for example, also need large amounts of hot water every day. This ensures that the BHWK works economically and generates electricity as well as heat.

Fuel cell heating, on the other hand, is also worthwhile for commercial buildings . The most important requirement is a gas connection or a gas tank for natural / biogas. Due to the compact size, the high performance and the low maintenance requirements, the fuel cell is also advantageous for the electrical energy supply and for heating.

The current development of funding programs clearly favors the installation of fuel cell technologies. As a technology with significantly lower overall efficiency, CHP combined heat and power will be disadvantaged in future funding guidelines. [14]

bibliography

[1] CHP information center. (September 21, 2021). *BHKW information center GbR* . https://www.bhkw-infozentrum.de/

[2] BMWI. (September 24, 2021). *Federal Ministry for Economic Affairs and Energy* . https://www.bmwi.de/Redaktion/DE/Article/Energy/moderne-kraftwerkstechnologie.html

[3] Bosch Thermotechnik GmbH. (September 30, 2021). *Buderus* . https://www.buderus.de/en/products/catalogue/buderus-products-fur-your-house/electricity-generation/block-heating-power-plant/

[4] Energy Experts . (June 12, 2021). *Greenhouse Media GmbH* . https://www.energie-experten.org/heizung/blockheizkraftwerk-bhkw/blockheizkraftwerk-kosten

[5] Frahm, T. (April 22, 2021). *heater finder* . https://www.heizungsfinder.de/bhkw/wirtschaftlichkeit/einspeiseverguetung

[6] Heimann, S. (September 22, 2021). *co2 online* . https://www.co2online.de/modernisiert-und-bauen/blockheizkraftwerk-kraft-waerme-kupplung/blockheizkraftwerk-kosten/

[7] Kabus, M. (2017). *Notes on the profitability analysis of combined heat and power plants.* Wuppertal: EnergyAgency.NRW.

[8] Kloth, P. (September 18, 2021). *energy hero* . https://www.energieheld.de/heizung/bhkw

[9] Kloth, P. (September 23, 2021). *energy hero* . ttps://www.energieheld.de/heizung/brennstoffzelle

[10] Credit Institute for Reconstruction. (September 24, 2021). *KfW* . https://www.kfw.de/inlandsfoerderung/UNTERNEHMEN/Energie-Umwelt/F%C3%B6rderprodukte/EE-Bauen-und-Sanieren-Zuschuss-Brennstoffzelle-(433)/

[11] Kunde, J. (July 1, 2021). *heating.de* . https://heizung.de/fuel-cell-heating/knowledge/vor-und-nachteile-der-brennstoffzelle/

[12] Rosencrantz, A. (September 20, 2021). *heating.de* . https://heizung.de/fuel-cell-heating/

[13] Sebastian. (18 Aug 2021). *Thermondo* . https://www.thermondo.de/performing/heating-system/fuel-cell-heating/costs/

[14] Sebastian. (September 27, 2021). *Thermondo* . https://www.thermondo.de/info/rat/erneuerbare-energie/brennstoffzellenheizung-vs-blockheizkraftwerk/

[15] Consumer Advice Center NRW eV; Consumer centers in Rhineland-Palatinate. (May 20, 2021). *consumer center* . https://www. Verbraucherzentrale.de/wissen/energie/heizungen-und-warmwasser/kleine-blockheizkraftwerke-die-heizung-die-auch-strom-liefert-6007

[16] Viessmann Climate Solutions SE. (September 30, 2021). *Viessman* . https://www.viessmann.de/de/wohngebaeude/kraft-waerme-kupplung/mikro-kwk-brennstoffzelle/vitovalor-pt2.html

[17] Future Gas GmbH. (September 24, 2021). *natural gas* . https://www.erdgas.info/neue-heizung/heizungstechnik/brennstoffzelle/funktionsprinzip-brennstoffzelle

3. Conclusions

The decision to opt for a used Combined Heat and Power (CHP) plant over Fuel Cell technology is grounded in several factors, intricately aligned with the specific requisites and circumstances of the project.

1. **Economic Considerations:** The acquisition costs associated with Fuel Cell technology can often surpass those of a CHP plant. Utilizing used CHP units can provide a cost-effective avenue to achieve the necessary energy generation capacity without exerting undue strain on the budget.
2. **Availability and Reliability:** CHP plants are well-established and proven technologies. Spare parts and expertise are readily available, streamlining maintenance and repair efforts. In contrast, Fuel Cell technology may still be less entrenched in certain regions, potentially leading to elevated maintenance and operational risks.
3. **Prompt Implementation:** Used CHP units can be swiftly installed and operational, which can be of paramount importance if the project demands a rapid realization.
4. **Proven Efficiency:** CHP plants have demonstrated themselves as remarkably efficient technologies, concurrently generating heat and electricity. They can achieve high levels of efficiency, contributing to energy conservation.
5. **Combined Heat and Power Generation:** CHP plants can concurrently generate heat and electricity, a characteristic particularly advantageous in applications spanning buildings, industrial facilities, and greenhouses. This aids in utilizing the generated energy in an efficient and sustainable manner.
6. **Operating Costs:** CHP plants often utilize conventional fuels like natural gas, which are typically readily available in many regions. This can lead to stable and predictable operating costs.

It's essential to underscore that the choice between a CHP plant and Fuel Cell technology hinges on various factors, encompassing the specific project needs, financial resources, technological maturity, and existing infrastructure.

The integration of decentralized power and heating systems, including combined heat and power (CHP) plants, solar energy, and smart control systems, is a key solution for achieving energy efficiency, sustainability, and resilience.

In summary, the integration of decentralized power and heating systems offers a pathway to achieve energy efficiency, cost savings, environmental sustainability, and resilience. By considering the principles and challenges we decide to deploy and integrate a combined heat and power plant in combination with a solar energy system and a smart control system to meet the energy goals in the project and contribute to a sustainable future.