COMBINING H-CHP WITH OTHER HOUSEHOLD SYSTEMS

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Abstract

The main purpose of this document is to list the various possible CHP (Combined Heat and Power) configurations that can be installed along other REG (Renewable Energy Generation) for a small community in the Western Isles (Outer Hebrides), in Scotland. Naturally, in the future, the same research could be extended to every other country in the NPA (Northern Periphery and Artic programme) area.

This fast examination has been focused on two CHP fuel classes: Biomass (i.e. scrap lumber, forest debris, wood pellets, etc.) and Biogas (type of biofuel that is naturally produced from the decomposition of organic waste) before deciding that, for the current location, Biomass in form of wood-related fuel for possible micro-CHP installations would have been the best choice.

However, this document will list descriptions, working parameters and details of both technologies, to give the reader the whole panorama, before analysing how can CHP be used with other electricity generation/heating systems.

In conclusion, a condensed list of the examination results will be provided, explaining every point with a brief description along with a paragraph containing the history of the development of this technology.

Introduction

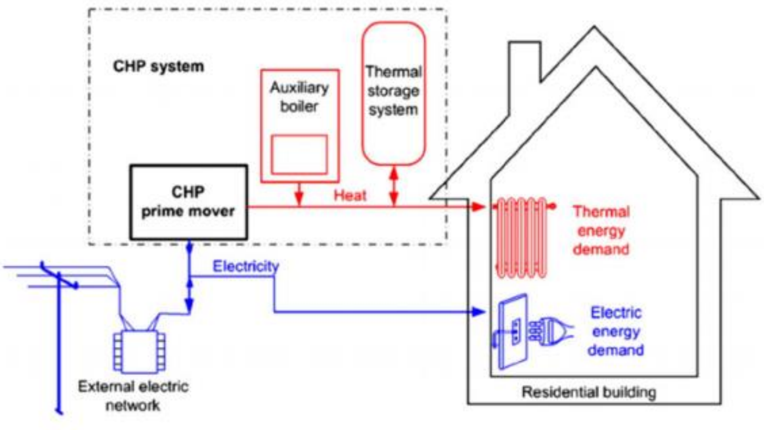
The H-CHP project aims to potentially increase energy efficiency and accelerate the adoption of renewable and sustainable energy solutions in any region. There is a specific focus on individual rural households with low population density and low accessibility to affordable energy. Domestic dwelling in sparsely populated areas is subject to unpredictable power interruptions. The proposed solution will:

- guarantee electricity during peak heat demand periods;
- place less strain on grids;
- reduce demand spikes;
- smooth the generation profile from power stations.

The purpose of the H-CHP project is to promote the uptake of Combined Heating and Power systems (CHP) in various areas, using solid renewable biomass and gasification methods that will be appropriate for remote households.

The Northern Periphery Area has abundant natural fuel resources but is subject to a harsher climate than the rest of Europe and this results in the need for increased domestic energy. Attempts to exploit natural energy resources for households have been mixed, and as a result, there is significant fuel poverty in the region. A key component is the high cost of electricity.

Background



CHP (Combined Heat and Power) are systems that produce electrical and thermal loads at the same time. Until recently the production of electricity was made in power plants where huge amounts of heat energy were lost in the environment. The principal idea of CHP is to take advantage of the thermal energy from the production of electricity. Thus, CHP are high efficiency systems.

As micro CHP the EU (2004/8/EC) has defined small scale systems (less than 50 kW). These usually are applied for space and water heating to individual dwellings and small commercial buildings replacing the conventional boilers.

CHP provides furthermore fuel savings, reducing as a result emitted gas and the operational cost. The systems can function in parallel to the grid exporting energy or backing it up in case of a break down.

Micro CHP seems like a promising new solution with substantial growth and prospects being appreciated worldwide. Governments consider these systems as reliable solutions. Industry is developing new technologies, introducing alternative fuels and making the systems simpler and more accessible to all.

The most commercial systems are the ICE (internal combustion engines) while the external combustion engines such as Stirling engines, micro gas turbines and ORC (Organic Rankine cycle) systems are aiming for the biggest market share. Fuel cells are still not commercially available.

Micro CHP are usually gas or petroleum fuelled. However, alternatives like biomass have become available maintaining high efficiencies and reducing carbon emissions to minimum levels.

Micro CHP systems are easily installed more or less as conventional boilers. They have similar volume and having to follow the same noise regulations, they are well sound insulated.

- *External combustion engines:*

  Most of the micro CHP systems are external combustion engines such as Stirling and Rankine cycle engines. These systems are providing higher efficiency, can work with various types of fuel, have low gas emissions, low levels of noise and vibration. External combustion engines are using a part of fuel gas to drive the engine and produce electricity. The fuel (helium, hydrogen, etc) has been preheated in a heater alternator. Due to the external combustion, damages to the engine are limited, but require good isolation to avoid leakage. Main disadvantage is the reliable life span;

- *Internal combustion engines:*

  These are more popular in bigger scale systems. Currently industry is constructing high efficiency engines also in small scale systems. These engines are applicable to a wide range of usage and their operation can work also with liquid and gas fuels. Their operation is similar to car engines. Their main disadvantage is high maintenance cost and higher level of noise and gas emissions;

- *Fuel cells:*

  Fuel cells are electrochemical engines that convert the chemical energy of fuel to electricity without combustion. The principal operation is that hydrogen and oxygen reacting with an electrolyte produce water electricity and heat.

  Main advantages of fuel cells are high electricity efficiency, easy in usage, low level of noise and emissions. Due to the high efficiency and the type of fuel used, the emissions are 10 to 100 times lower than other system. The disadvantages that are limiting their popularity are high cost and low lifetime. Two most common types of fuel cell systems are the PEM (Proton Exchange Membrane) and SOFC (Solid Oxide Fuel Cells).

External combustion engines are more popular in Europe, while in America internal combustion engines prevail. The Japanese market is focused mostly on fuel cells.

Generally, fuel cells seem to be a more promising technology due to the advantages over internal and external combustion engines such as the high efficiency in electricity production, low gas emissions, independent of high heat demand and more suitable for future buildings. However, the cost is very high and their lifetime very short.

The tables below are showing the efficiencies for different micro CHP systems and their prices.

External combustion	Electrical (kWe)	Thermal (kWt)	Cost (£)
WhisperGen	1	8	6 - 8000
Microgen	1	3 - 24	6 - 8000
Genlec	1	10	-
OTAG	0.2 - 3	2 - 16	-

ICE	Electrical (kWe)	Thermal (kWt)	Cost (£)
Ecowill	1	3	5600
Baxi Dachs	5.3	10.4	13000
Ecopower	4.5	12	-
EC Power	4-13	17-29	23000

Fuel Cells	Electrical (kWe)	Thermal (kWt)	Cost (£)
Hexis	1	2.5	-
Ceramic	1	0.3	-
Vaillant	1-4.6	25-50	-
Baxi Innotech	1	2-40	-

Micro CHP systems can convert more than 80% of the fuel energy to electricity and heat.

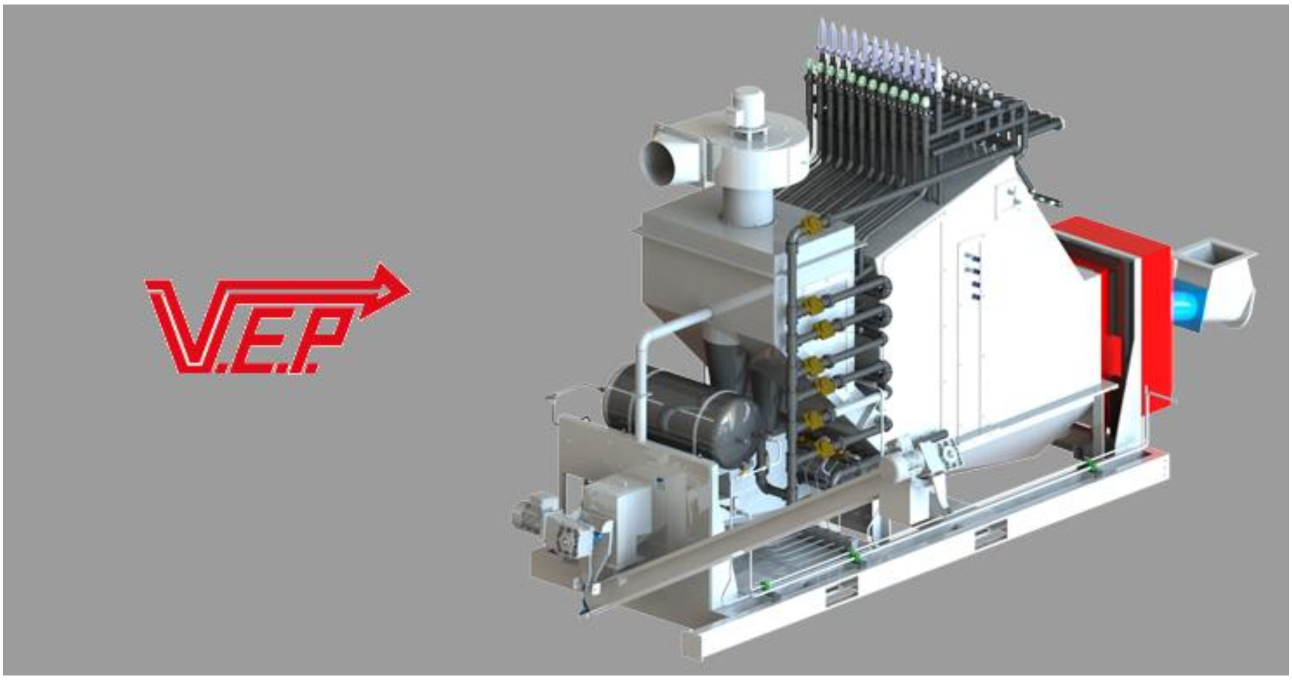
UK government support micro CHP installation recognizing the contribution of these systems concerning CO2 emissions. That is why from 1st April of 2010 no permission for installation of micro CHP systems is required.

The table below represents the economic benefits of a micro CHP.

Annual heating demand	18000	kWh
Running Hours	3000	hours
Electricity Generated	2400	kWh
Unit cost avoid import	6.5	p/kWh
Value avoiding import	133	£
Export value	2.5	p/kWh
Own use of Generation	85	%
Value of export	9	£
Marginal cost of unit	500	£

Simple payback	3-4	Years

Biomass H-CHP Systems



Combined Heat and Power (CHP) is a process that provides both heat and power on site in one single, highly efficient process.

CHP generates electricity and as a by-product of the generation process, heat is produced. This heat can be used on site while using the power generated. In contrast, our traditional coal and gas power stations can lose up to two thirds of the heat produced. By generating the heat and power on site, CHP systems can achieve in excess of 80% efficiency.

Wood Biomass is fed into the system similar to a normal biomass boiler. Instead of feeding it Oxygen to burn the fuel, it is heated in an environment that has no oxygen present. At around 700 degrees Celsius, all the gases from the wood are extracted and instead of being burnt, run through cooling coils and filters that produce a synthesis gas or Syngas. The gas is then fed to an engine that runs on the gas. Connected to the engine is a generator to provide electricity and the heat produced by the engine, instead of going to a radiator, can be fed into a heating system.

By using biomass, a carbon neutral fuel to power the CHP systems, substantial reductions in CO_2 emissions can be achieved.

With the government's commitment to reducing carbon emissions, several schemes have been initiated to help bring renewable technology to the market. Most renewable technologies take advantage of one or two of the tariffs to help pay back the cost on the system. Biomass CHP can take advantage of all the schemes due to generating both renewable heat and power.

The schemes are as follows:

- *The Renewable Heat Incentive:*

  This rewards people for generating heat from a renewable heat source such as biomass. A heat meter is placed on the system that records generation and the government's scheme pays the owner of the equipment a certain tariff depending on the technology and size. Biomass boiler installations over the last 5 years have boomed with the introduction of this tariff;

- *Renewable Obligation Scheme:*

  The RO scheme was initially implemented for large power generators using alternative fuel sources. For every 1000kW of energy generated, the scheme issues certificates. These certificates are bought by the energy supply companies, so they meet the government criteria on having some of their energy generated from renewables. Biomass CHP systems, including the system supplied by TW Power, are classed as advanced combustion technologies and gain the highest certificate value for the energy generated.

The use of biomass is classed as being 'Carbon Neutral' and therefore does not contribute to Global Warming. As trees grow, they absorb carbon dioxide from the atmosphere during photosynthesis. When the wood is subsequently burnt, that same amount of Carbon is released back into the atmosphere and thus there is no net increase in Carbon and no impact on the environment. Compare this with the burning of fossil fuels such as oil and gas where the Carbon has been locked away for millions of years – until it is burnt and released.

Biomass Renewable is also a renewable energy. Trees are specifically grown to produce biomass fuel in sustainable forests that are constantly replanted as trees are felled. The fuel can be grown in many parts of the world and thus we are not dependant on the traditional fossil fuel sources. Waste wood from sawmills and manufacturers which may otherwise end up as landfill can also be used for the production of wood pellets.

Even the ash makes a great fertilizer for the garden. Installing a Biomass CHP system will dramatically improve the Environmental impact of premises, reducing the use of fossil fuels and reducing the carbon footprint. This is a very valuable public relations story for the customers who are increasingly aware of global warming and the need to work with companies with impressive Green credentials.

Biogas H-CHP Systems

Biogas is formed by the anaerobic decomposition of putrescible organic material, a gas that is formed by anaerobic microorganisms. These microbes feed off carbohydrates and fats, producing methane and carbon dioxides as metabolic waste products. This gas can be harnessed by man as a source of sustainable energy.

Biogas CHP (combined heat and power or cogeneration) is the utilisation of biogas, typically in a biogas engine, for the production of electricity and useful heat, at high efficiency.

Biogas consists primarily of methane (the source of energy within the fuel) and carbon dioxide. It may also contain small amounts of nitrogen or hydrogen. Contaminants in the biogas can include sulphur or siloxanes, but this will depend upon the digester feedstock.

The relative percentages of methane and carbon dioxide in the biogas are influenced by a number of factors including:

- The ratio of carbohydrates, proteins and fats in the feedstock;
- The dilution factor in the digester (carbon dioxide can be absorbed by water).

Anaerobic digestion is the man-made process of harnessing the anaerobic fermentation of wastes and other biodegradable materials. Anaerobic microbes can be harnessed to treat problematic wastes, produce a fertiliser that can be used to replace high carbon emission chemical fertilisers. It also is the process that results in the production of biogas, which can be used to provide renewable power using biogas cogeneration systems.

Anaerobic digestion can occur at mesophilic (35-45˚C) or thermophilic temperatures (50-60˚C). Both types of digestion typically require supplementary sources of heat to reach their optimal temperature. This heat is most commonly provided by a biogas CHP unit, operating on biogas and producing both electricity and heat for the process.

Often, biogas plants that treat wastes originating from animal material, will also require the material to be treated at high temperature to eliminate any disease-causing bacteria in the slurry. These systems pasteurise the slurry, typically at 90C for one hour, to destroy pathogens, and result in the provision of clean, high quality fertiliser.

Biologically-derived gases can be utilised in biogas engines to generate renewable power via cogeneration in the form of electricity and heat. The electricity can be used to power the surrounding equipment or exported to the national grid.

Low-grade heat comes from the cooling circuits of the gas engine, typically available as hot water on a 70/90°C flow/return basis. For anaerobic digestion plants that are using a CHP engine, there are two key types of heat: high-grade heat as engine exhaust gas (typically ~450°C) and low-grade heat. The second one is typically used to heat the digester tanks to the optimum temperature for the biological system. Mesophilic anaerobic digesters typically operate at 35-40°C. Thermophilic anaerobic digesters typically operate at a higher temperature between 49-60°C and hence have a higher heating requirement.

High temperature exhaust gas heat can either be used directly into a drier, waste heat boiler or organic Rankine cycle unit. Alternatively, it can be converted into hot water using a shell and tube exhaust gas heat exchanger to supplement the heat from the engine cooling systems.

Waste heat boilers produce steam typically at 8-15bar. Driers may be useful to reduce the moisture content of the digestate to assist in reducing transportation costs. Organic Rankine cycle turbines are able to convert surplus waste heat into additional electrical output.

Compact (small) biogas CHP units – 100kW rating – (Sokraterm)

The compact CHP units of the 100-kW class belong to the most frequently sold cogeneration units. In this class Sokraterm regularly scores one of the top positions in the yearly ranking of the 'Energie & Management' newspaper. Especially the compact CHP unit GG 140 has been installed in a number of larger hotels, industrial sites, district heating centres and schools.

A smaller 50-kW unit is available from the same company, along 200, 400 and 500kW ones.

All these represent the below 1 MW capacities available from Sokraterm.

The CHP units of the 100-kW class have all core characteristics of the company cogeneration units:

- very compact design for cost-efficient installation also in narrow rooms;
- minimal installation cost by ready-to-connect tech with integrated switchgear cabinet;
- excellent efficiency by making best use of energy contained in the fuel gas;
- protection of the environment by operating the gas engine in range with lowest emissions;

- lowest sound emissions by excellent sound isolation and vibration decoupling;
- best connectivity by fully automating the internet-based remote monitoring and control;
- highest reliability and therefore low operation and maintenance cost.

As a pioneer of cogeneration, the aim of the company is to combine proven technology with new approaches leading to the creation of innovative, reliable products.

A list of its main innovations in the field can be found below:

- the CHP unit with fully integrated switchgear cabinet so the CHP units need less space and can start operation quicker;
- the mobile CHP unit for the operation at two sites (e.g. outdoor swimming pool and school) so it can be brought to where its heat and power are needed seasonally;
- the >Hot Cooler< configuration of CHP units to operate at a higher temperature level (95/80°C instead of the 90/70°C standard) which e.g. allows for the optimal operation of absorption chillers;
- the modem based remote monitoring "TeleManager" of the CHP controls and
- its web-based successor RemoteManager introduced in 2011, which – besides sophisticated remote monitoring – also combines the data of CHP controls via DSL or UMTS and makes the creation of virtual power plants possible;
- the online servicing fully implemented in 2014 in which customer service reports are entered online during the works, checked for plausibility and evaluated.

The company builds two different types of fuelled CHP unit, via *natural gas* or via *biogas*. The technical specifications of each one is in the tables below.

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Delivery Chart 2019

SOKRATHERM® Cogeneration

Compact CHP units driven by natural gas

Specification		Power data			Efficiency rates				Servicing		Dimensions				
CHP unit type	engine producer MAN, engine type	**electrical [kW]** [1]	**thermal [kW]**	**gas input [kW H_i]**	electrical [%]	thermal [%]	total [%]	power to heat ratio [2]	servicing interval [hours of operation]	general overhaul after ca. [h]	length [mm] (base pan)	width [mm]	height [mm]	operating weight [kg]	noise level [dB(A) in 1m]
		**50 kW class**													
GG 50 [3]	E 0834 E 302	**50**	**92**	**146**	34,2	63,0	97,2	0,53	1.500	60.000	2.200	900	1.830	1.950	62
GG 70	E 0836 E 302	**71**	**114**	**204**	34,8	55,9	90,7	0,61	1.500	60.000	2.400	900	1.800	2.070	63
		**100 kW class**													
GG 100	E 2676 E 302	**100**	**164**	**284**	35,2	57,7	92,9	0,59	1.500	50.000	2.900	900 [6]	2.000	3.220	71
GG 132	E 2676 E 302	**133**	**196**	**356**	37,4	55,1	92,5	0,66	1.500	50.000	2.900	900 [6]	2.000	3.220	71
GG 140	E 2876 E 312	**142**	**216**	**392**	36,2	55,1	91,3	0,64	1.500	50.000	2.900	900	2.000	3.280	69

Li_FG_19_1_JVO.xlsx

Delivery Chart 2019

SOKRATHERM® Cogeneration

Compact CHP units driven by sewage gas / biogas

Specification		Power data			Efficiency rates				Servicing		Dimensions				
CHP unit type	engine producer MAN, engine type	**electrical [kW]** [1]	**thermal [kW]**	**gas input [kW H_i]**	electrical [%]	thermal [%]	total [%]	power to heat ratio [2]	servicing interval [3] [hours of operation]	general overhaul after ca. [h]	length [mm] (base pan)	width [mm]	height [mm]	operating weight [kg]	noise level [dB(A) in 1m]
		**50 kW class**													
FG 34	E 0834 E 312	**35**	**65**	**112**	31,3	58,0	89,3	0,51	1.000	60.000	2.200	900	1.830	1.870	62
FG 50	E 0836 E 312	**51**	**91**	**159**	32,1	57,2	89,3	0,54	1.000	60.000	2.400	900	1.800	1.970	63
		**100 kW class**													
FG 73 [4]	E 0836 LE 302	**75**	**117**	**212**	35,4	55,2	90,6	0,61	1.000	50.000	2.900	900	2.000	3.080	69
FG 95 [4]	E 0836 LE 302	**95**	**138**	**258**	36,8	53,5	90,3	0,65	1.000	50.000	2.900	900	2.000	3.080	69
FG 123	E 2876 TE 302	**123**	**180**	**341**	36,1	52,8	88,9	0,67	1.000	50.000	2.900	900	2.000	3.330	67

Compact (small) biomass CHP units – 100kW nominal rating – (Qalovis)

The Qalovis Q PowerGen system is a Stirling engine-based biomass gasification CHP for parallel generation of heat and electricity.

It produces in steady state operation 36 kW electrical and 120 kW thermal power (kWel and kWth).

Q PowerGen system consisting essentially of gasifier VHG 30, air supply, recuperator, exhaust heat exchanger, burner and combustion chamber, Hot gas duct, Stirling generator unit FleXgen G38 and control via PLC.

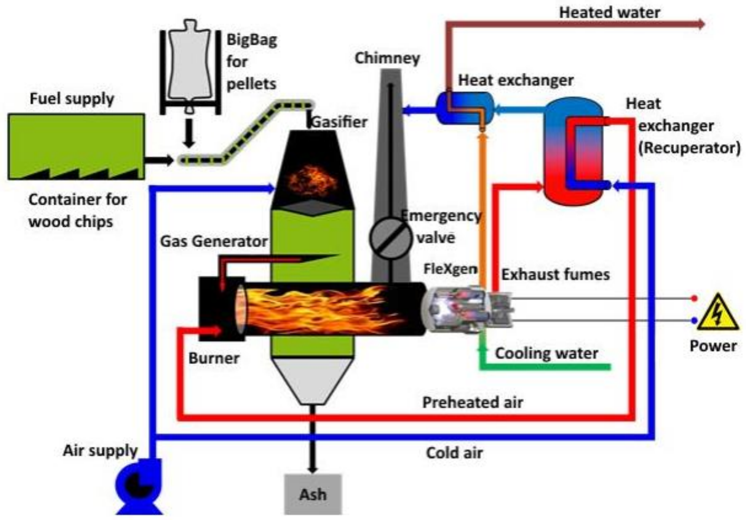
Technical Specification:

Power:	36 kW electric up to 120 kW thermal
Biomass consumption:	depending on product quality > 52 kg / hr (36 kW el)
Product:	Natural wood as <chips, wood pellets, Biomass Pellets with N <1 wt -%, CI uS <0.01 wt -%; general: water content <20 wt -%; Pellet diameter and length at least 6 mm
Exhaust Gas Flow:	1500 m^3 / h at 120 Grd C
Space:	at least 5 m + 1,5 m freedom
Additional necessary installations:	Fuel supply (continuous, automatic), Ash container and respective conveyors, Power supply, heat transfer (for example, Buffer tank), the hydrogen gas supply Stirling engine (from commercial gas cylinders), Chimney

Part-load capacity given by Stirling engine (lower limit at about 20 kW electrical and 75 kW thermal).

The biomass solids CHP can use biomass in form of wood chips and pellets. The chips can be supplied over a sliding floor container and pellets via a mounted station.

With a tubular chain conveyor, the product reaches the upper end of the reactor/gasifier, where the fuel will be dropped from the tube chain conveyor, falling over a feed chute into the gasification fixed bed reactor.



The chute is superimposed of the Barrier gas air principle. Also, a slider, which is opened only for the charging process, prevents in a standard case the exit of producer gas upwards into the chute. With a level sensor inside the fixed bed reactor the loading operation will be initialized and terminated.

At different heights the air will be supplied to the fixed-bed reactor. After one single electric ignition of the gasification process the Gasification process runs autothermally. Ash and generator gas will be distributed to the lower part of the reactor, there the ash will be separated and discharged from the reactor by screw conveyors (level sensor controlled). The gas is removed from the reactor via the so-called gas guide tube and supplied to the burner.

This burner is mounted in front of the combustion chamber, which crosses the lower part of the reactor. In the burner uncooled generator gas will be mixed and burned to about 400 °C Temperature level by means of preheated air. At the back end of the combustor 1000 °C can be achieved. This hot gas stream then impinges on the heat exchanger head of the Stirling engine, which extracts the heat from hot gases and convers them first into mechanical work A generator is ultimately seated on the drive shaft, it converts the mechanical energy into electrical energy.

The exhaust gases of combustion are cooled in the Stirling up to app. 600 °C and then enter the recuperator in which it is further cooled. While the burner supply of Combustion is supplied to the exhaust gases pass again an air-water Heat exchanger and exit via the exhaust fan the plant towards the chimney.

A supply air fan with an "air tree" said air distributor ensures on the entrance side for the supply of the gasification and the combustion air but ensures on the other hand the required air flows for cooling and the capacity of air needed as safety air.

The heat extraction from the system is carried out through the cooling water of the Stirling and secondly through the already mentioned air-water heat exchanger in the exhaust stream behind the recuperator.

A special feature of the system is the so-called "emergency chimney": in the case of abnormal operating condition, such as a power failure, a hard wired safety chain and / or spring-loaded actuators ensure that the air supply is cut off from the gasification reactor, the combustion process run out safely and over the emergency chimney the exhaust gas passes the Stirling-Motor.

How can CHP be used with other electricity generation/heating systems?

Most heating systems can be used in-conjunction with others. CHP units work particularly well with biomass boilers, photovoltaics and ground source heat pumps, but there are other possibilities for this system.

- **Steam**

  Steam can only be raised from a high-grade heat source, and for spark ignition systems it is therefore only the exhaust heat that can be used for this purpose. The low-grade heat from the engine cooling water system must be used elsewhere, for example to preheat cold boiler feedwater.

  To produce steam, the exhaust gases must be passed through steam raising equipment. In small scale systems, this would normally be by a steam generator. In medium to large scale sizes, the gases would be passed through a waste heat boiler or a heat recovery steam generator (HRSG). Such systems have to be carefully designed to ensure that the steam is raised safely and the steam conditions (temperature, pressure, dryness fraction) meet the requirements of the existing system;

- **Tri-generation**

  By integrating an absorption chiller, chilled water can be generated in addition to heat and power. Absorption chillers can utilise both steam and LPHW – the higher the input temperature, the greater the Coefficient of Performance of the chillers. Where a spark ignition engine is used, the LPHW from the engine cooling circuit can be used to operate the chiller, leaving the high-grade heat of the exhaust to be used elsewhere.

  Absorption chillers are a good application where there is a cooling demand at times when not all of the heat from the CHP can be utilised. Where systems have a COP < 1, then it is economically better to utilise heat from the CHP directly, rather than convert this into cooling. Absorption chillers are generally more expensive than their equivalent vapour compression system, however the cost of maintenance is lower;

- **Organic Rankine Cycle - ORC**

  The operation of ORC is similar to that of the Rankine cycle in a steam turbine. In an ORC, instead of the mass flow of the steam turning the turbine, waste heat evaporates an organic refrigerant, the expansion of which drives a turbine. The operation of the turbine generates electrical power through an alternator coupled to the turbine drive shaft.

  In an ORC application, high grade waste heat can be used to heat the organic medium which is the input media to an ORC turbine. The exhaust gases from a CHP system (Reciprocating or Gas Turbine) can also be used as the thermal input to an ORC. Here, the heat is converted into power, which may be more economically beneficial to a site than the heat from the CHP;

- **Quad-generation**

  This is an extension of the application of Tri-generation to generate a fourth utility – food grade carbon-dioxide. In this application, some or all of the exhaust gases from a CHP system are passed through a system which selectively extracts the carbon-dioxide from the gas stream.

  An amine-based chemical is employed which has a strong affinity for CO_2, that captures the gas, which is then purified, and the amine regenerated. As bulk gases are becoming increasingly expensive, it can be an attractive consideration for manufacturers of products containing CO2 e.g. fizzy soft drinks, beer etc;

- **Absorption Chilling**

  There are many different types of absorption chillers, but they all work on a similar principle. In a low-pressure system, an absorption fluid is evaporated, removing heat from the chilled water. A heat source such as steam, exhaust gas or hot water is used to regenerate the absorption solution.

  Essentially, it is a refrigerator that uses a heat source (e.g., solar energy, a fossil-fuelled flame, waste heat from factories, or district heating systems) to provide the energy needed to drive the cooling process.

  The principle can also be used to air-condition buildings using the waste heat from a gas turbine or water heater. Using waste heat from a gas turbine makes the turbine very efficient because it first produces electricity, then hot water, and finally, air-conditioning (called cogeneration/trigeneration);

- **Ground Source Heat Pumps**

  A Ground Source Heat Pump transfers heat from the ground into buildings. Radiation from the sun heats the earth. The earth then stores the heat and maintains, just two metres or so down, a temperature of around 10°C even throughout the winter.

  A ground source heat pump uses a ground heat exchange loop to tap into it constantly replenished heat store to heat buildings and provide hot water. The technology used is the same as that used in refrigerators. Just as a fridge extracts heat from the food and transfers it into the kitchen, so a ground source heat pump extracts heat from the earth and transfers it into a building;

- **Air Source Heat Pumps**

  Different from a ground source heat pump, an air source heat pump extracts heat from the outside air in the same way that a fridge extracts heat from its inside.

It can get heat from the air even when the temperature is as low as -15° C. Heat pumps have some impact on the environment as they need electricity to run, but the heat they extract from the ground, air, or water is constantly being renewed naturally;

Development of the technology

In 2008, IEA sums up several country policies in order to promote CHP. Feedback from several test countries pointed out that incentive policies can have important effects on the development of CHP. Countries first set targets and created dedicated government departments in charge of identifying CHP potentials. These departments, then promote policy tools and solutions to develop CHP.

The main conclusions are that CHP contributes to around 10% of the electricity production in the world, and that only four countries (Denmark, Finland, Russia and Latvia) have successfully implemented CHP in their electricity production (more than 30%). These countries have obtained successful CHP markets due to favourable government policies.

In Europe, CHP development incitation has been done with success in Denmark with the "integrated approach to heat and electricity planning", which has immediately decreased its energy consumption and achieved energy self-sufficiency. Denmark also became the first European user of CHP and a world CHP leader. Common measures mainly deal with economic, regulatory and social issues. Modest and targeted policies seem efficient to improve the realization of the CHP potential.

If Denmark and other north European countries clearly appear as leaders in this domain usually, CHP remains marginal in the other national power productions. The previous study and figures tend to show that incentive policies are vital for the development of CHP technology and can be extended for the development of micro-CHP. It clearly appears that non-renewable energy sources are mainly used for CHP. In 2013, natural gas represented 45% of the CHP fuel mix. This can be explained by the maturity of the technologies using this energy source. Renewable sources accounted for 18% of this fuel mix. However, this value has continuously increased from 9% in 2005.

In 2013, Germany, Italy, and the Netherlands were quantitatively the three major users of CHP. Category "Other fuels" includes industrial wastes and coal gases. Among the main European CHP users, Finland and Sweden appear as the major users of renewable sources, while the biggest European producer (Germany) mainly uses natural gas.

CHP tech can be divided in, as also stated previously, Internal Combustion Engine (ICE), Organic Rankine Cycle (ORC), Stirling Engine (SE), Proton Exchange Membrane (PEM), and Solid Oxide Fuel Cells (SOFC). European sales increased from 2008 to 2012, to a maximum of 7000 sales, and then decreased to 5000 sales in 2014. The expected sales increase after 2015 is mainly based on the development of fuel cells.

If the micro-CHP wide spread can vary over time, mini-cogeneration market can vary between countries. Mini-CHP increases in the majority of European countries, while micro-CHP market increases in some of them. The development of this latest technology is deeply linked to the government support and people's awareness. In 2015, the UK, Germany, Belgium, Czech Republic, Slovenia and Turkey were the main favourable countries for micro-CHP development.

Conclusions

In conclusion, it is possible to compile the following lists, regarding the possible integrations of CHP systems with other renewable technologies:

- **Renewable Electricity Generation**

  1. *Wind power (small scale wind energy):*
     Wind turbines are used to produce electricity. They are attached to outside of buildings - require a structural survey and planning permission;
  2. *Solar electricity (photovoltaics):*
     Solar photo voltaic (solar PV) panels or cells convert sunlight into electricity. They are attached to outside of buildings - require a structural survey and may require planning permission;
  3. *Small-scale hydro-electric power:*
     An immersed turbine uses flowing water to produce electricity. This technology is highly site-specific. It requires a near body of water that is flowing and has a drop-in level that can be exploited;

- **Renewable Heat Generation**

  1. *Solar water heating (solar thermal):*
     Uses energy from the sun to heats water up to 55-65°C. Systems should be roof-mounted and ideally integrated into your current immersion-heated, hot-water system;
  2. *Biomass:*
     Generating power by burning organic material, such as wood, straw, dedicated energy crops, sewage sludge and animal litter. Lots of space is required for the boiler and storage of fuel. Site access is also important for deliveries of fuel;
  3. *Anaerobic Digestion:*
     Bacteria break down organic material in the absence of oxygen, producing a combustible methane-rich biogas. Requires access to large amounts of high-strength liquid organic wastes. Planning permissions will be required;
  4. *Ground Source Heat Pumps*
     Using naturally-occurring underground low-level heat. Most suitable for 'new builds' with appropriate geological features;
  5. *Air Source Heat Pumps:*
     Converting low-level heat, occurring naturally in the air, into high-grade heat. System must be attached to outside of buildings - planning permission may be required.