BEcoop

UNLOCKING THE COMMUNITY BIOENERGY POTENTIAL

Technical catalogue on biomass co-generation for small scale applications

JANUARY, 2022

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 952930.

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About

Over the last years, the EU has witnessed some remarkable steps in Renewable Energy (RE) deployment. However, at the same time, we see an increasingly uneven penetration of RE across the different energy sectors, with the heating and cooling sector lagging behind. Community bioenergy schemes can play a catalytic role in the market uptake of bioenergy heating technologies and can strongly support the increase of renewables penetration in the heating and cooling sector, contributing to the EU target for increasing renewable heat within this next decade. However, compared to other RES, bioenergy has a remarkably slower development pace in the decentralised energy production which is a model that is set to play a crucial role in the future of the energy transition in the EU.

The ambition of the EU-funded BECoop project is **to provide the necessary conditions and technical as well as business support tools for unlocking the underlying market potential of community bioenergy.** The project's goal is to make community bioenergy projects more appealing to potential interested actors and to foster new links and partnerships among the international bioenergy community.

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1. Introduction

Combined heat and power (CHP) generation, or cogeneration, is one of the essential pillars in a modern, sustainable, and environmentally friendly energy generation era. This is due to the fact that cogeneration systems are energetically efficient and produce energy where it is needed. The major advantages include an increased fuel efficiency, reduced CO_2 emissions, reduced need for transmission and distribution networks, reduced energy costs and a beneficial use of local energy resources. Traditionally, CHP systems are often based on fossil fuels, e.g. natural gas, but the transition to efficient energy systems using renewable energy sources, such as biomass, is needed in order to achieve sustainability targets. CHP are mainly realized in medium and large-scale sector. However, small-scale cogeneration systems have attracted increased attention as they intend to replace or complement traditional heating equipment in small-scale applications such as in the residential sector.

The current technical catalogue provides an overview of the global importance of small scale biomass cogeneration units and the established technological approaches in cogeneration on the basis of solid, liquid, or gaseous biofuels. The current catalogue focuses on biomass CHP technology, mainly targeting micro (<50 kW_{el}) and small scale (< 1 MW_{el}) applications.

The current catalogue starts with an introduction to cogeneration concept where basic information on the concept and the CHP market are presented. Continuously, a section with technical information over CHP technologies is presented. The first subsection starts with a brief presentation of the biomass conversion technologies that can be implemented in biomass CHPs. Continuously, the power generation technologies that can be used in CHP units are also described. Furthermore, subsection 3.2 focuses on the power/ capacity of CHP units and the importance of assessing the capacity of the installation. In subsection 3.3, a list of indicative operational and maintenance costs is presented based on the technology that is implemented in a CHP unit. In addition, in subsection 3.4, policies and regulations on environmental aspects regarding the operation of CHP units are presented. Moreover, section 4 gives an overview of the investment costs of CHP units, based on their capacity and technology. This section further elaborates on the environmental impact of CHP technology compared to conventional energy generation methods. Additionally, section 5 provides basic guidelines on the actions and points that someone has to take in consideration before investing on a biomass CHP unit. Lastly, section 6 presents several success cases of small scale applications of biomass CHP units.

Important: This technical catalogue is based on general recommendations to be taking into account and facilitate the conversation at the time of establishing the first contact with the energy services /engineering companies that will carry out the project, being them finally, the ones that will decide how the installation should be distributed and the type of equipment and technologies they will count on.

2. Cogeneration concept

2.1 What is Cogeneration?

Combined heat and power (CHP), also known as a co-generation, is the simultaneous production of electricity and heat from one source of energy. CHP is a mature technology. The basic idea is based on the fact that electricity production releases a large amount of heat, which is usually wasted in the environment. Through cogeneration, the residual and available thermal energy is recovered and exploited. The electrical energy from cogeneration is either self-consumed or reinjected into the public electricity network and the produced heat or steam is used in industry or for space and water heating in buildings, directly or through a district heating network.

In brief, Figure 1 depicts a simplified biomass CHP system. Biomass fuel is firstly delivered from the storage area to the boiler (or gasifier), where it is converted accordingly to steam in the case of combustion boilers, or to syngas in the case of gasification. In the case of Organic Rankine Cycle systems, heat from the biomass boiler is passed via steam, thermal oil or high temperature hot water through a heat exchanger to another working fluid for use in an Organic Rankine Cycle unit to generate heat and power. In the case of steam turbines and steam expanders, steam can be used directly. For gasification systems, the resulting gas is firstly treated and cleaned before it is sent to a gas engine for power and heat generation [1].

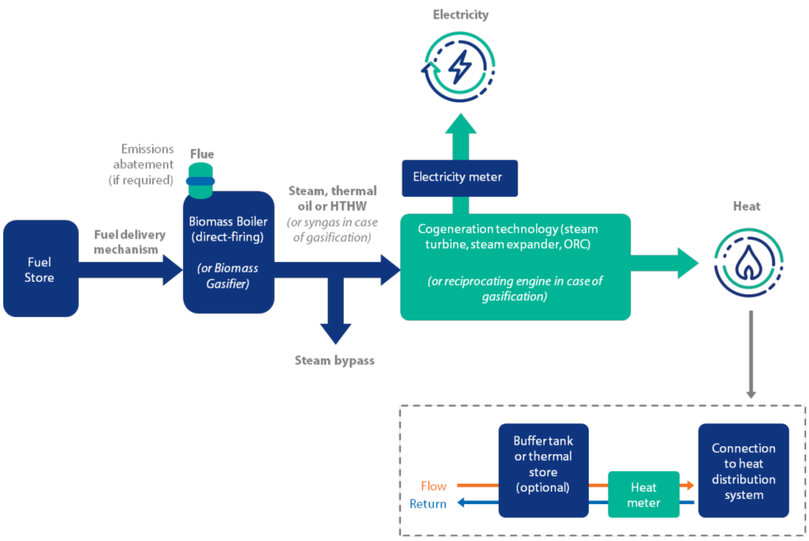

Figure 1: Typical biomass CHP components [1]

Generally, CHP systems can achieve higher overall efficiencies than the separate production of electricity and heat. CHP generates electricity while also capturing usable heat that is produced in this process. On the other hand, in coal and gas fired power stations where electricity is produced, up to two thirds of the overall energy consumed is lost due to the great amounts of heat that are wasted. Compared to power plants using solid fuels with efficiencies of 20-45 %, the overall process efficiency of CHP is significantly higher at 80-90 %, as the rejected heat is also exploited (Figure 2).

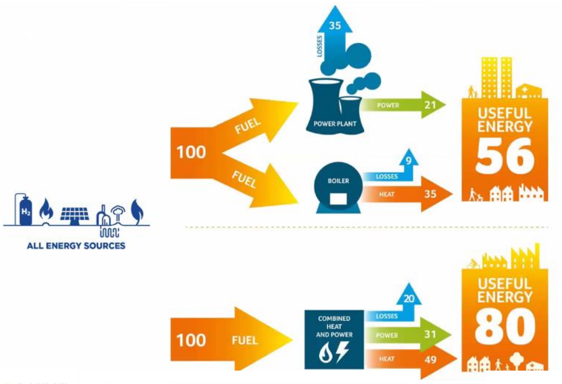

Figure 2: CHP benefits: efficiency [2]

2.2 Market overview of Cogeneration units and their fuel mix

The share of total electricity generation by CHP in EU-27 level has been around 11.7 % in 2019 [3], by fluctuating from 11.1 % (year 2014) to 12.4 % (year 2012) during the last decade. In the same period, the overall CHP electrical capacity has increased by approximately 30%. The total electrical capacity of CHP in EU-27 was at 133.3 MW_{el} in 2019 [4], from 94.9 MW_{el} in 2009 [5].

In general, CHP units can operate with a variety of fuels, such as solid fuels and peat, oil and oil products, natural gas, renewable sources and other fuels (including industrial wastes and coal gases). CHP fuel mix is influenced by the fuel prices, support/ funding schemes and availability of renewable fuels at local level. As it can be seen from Figure 3, natural gas is the main fuel used in CHP units. From 2009 to 2019, there is a slight decrease in the usage of natural gas (from 48.3% in 2009 to 45.5% in 2019). In the same way, there is a significant decrease in the use of solid fossil fuels and peat (from 22.4% in 2009 to 19.0% in 2019), as well as in the use of oil and oil products (from 6.5% to 4.1%). In the meantime, there is an increase of renewables, reaching around 25% in 2019 from 13% in 2009. Most of CHP with RES is biomass based. Regarding biomass CHP units, there were more than 1,000 biomass-fired and around 17,000 biogas CHP facilities that were operational in EU28 in 2016 [6]. Most commonly, biomass CHP units are based on either biomass combustion or anaerobic digestion. Biogas facilities typically have capacities below 1 MWel and biomass combustion CHPs are typically in the range of 1 - 50 MW_{el}, although there are several facilities in the EU from 50 MW_{el} up to 300 MW_{el} [7].

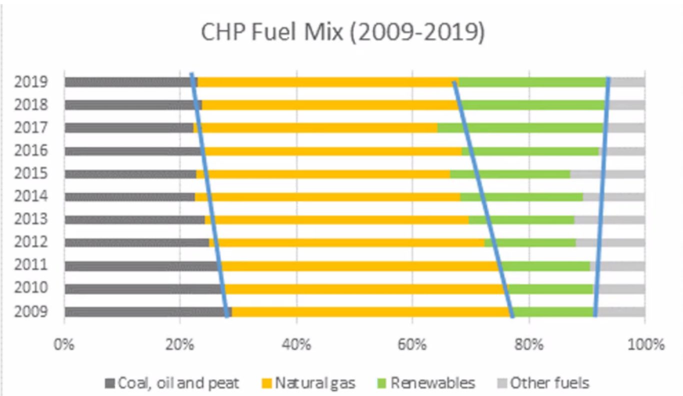

Figure 3: CHP Fuel mix in EU-27 [2]. Data based on Eurostat (2021)

Most CHP units were used in large scale applications. However, the recent development of efficient thermal prime movers for distributed generation is changing the focus of the production of electricity from large centralized power plants to local generation units. For instance, the size of the European Union (EU) market of domestic micro-CHP (1–10 kW) exceeded the 90 millions of units in 2020, deploying about 6.2 millions of new installations per year, showing a quick evolution of micro-CHP solutions to a higher efficiency comparable to condensing boilers [8]. In this regard, focus of the current catalogue has been directed to small scale application CHPs.

2.3 Biomass Cogeneration feedstocks and capacities

Biomass CHP units may operate with various types of biomass as feedstock in solid, gaseous or liquid forms or even residues. Figure 4 presents an overview of several routes that can be implemented in a biomass CHP unit, based on the feedstock type and the technology used. Most of solid fuels can be directly used in a combustion unit, where heat will be produced in a first step that will power a thermodynamic cycle such as an externally heated engine or ORC turbine cycle. Furthermore, advanced combustion technologies fulfil the relevant environmental requirements concerning harmful emissions. Another thermochemical path can be the gasification of the solid feedstock and the use of the produced gas (syngas) as a gaseous fuel. Gasification is possible via thermal processes, leading to product gases (syngas) with a certain heating. For the case of wet feedstocks, anaerobic fermentation is mostly an option that leads to biogas, with methane as the main energy source. Gaseous fuels from either thermochemical or biological process can be used, after cleaning, directly in internal combustion engines at efficiencies higher than steam and ORC turbines at smaller capacity. Moreover, liquid biofuels that are produced via chemical conversion such as biodiesel or ethanol, are normally not used in stationary applications e.g. CHP units, due to their high value as a fuel for mobile applications.

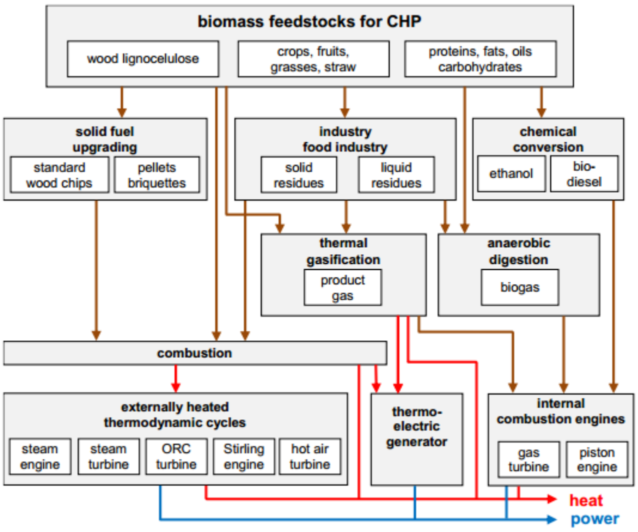

Figure 4: Most relevant paths of biomass feedstocks for CHP [9]

Biomass CHPs vary in terms of capacity. Their capacity depends on their potential applications, such as in domestic appliances, appliances in industry, district heating network or decentralized appliances for the residential sector etc. Thermal energy is mainly used either for space heating and for the production of domestic hot water or for industrial processes. Depending on the application, different technologies and capacities are used. Typical electrical capacities for various applications are listed in Table I together with the preferred technologies. The very small capacities that are applicable for domestic use are called “micro scale CHPs” (< 50 kW_{el}). Furthermore, “Small scale CHPs” are for larger buildings and local heating grids with capacities that range from 50 to 1,000 kW_{el}, whereas “medium and large scale CHPs” are used for industrial applications or district heating grids. In general, CHPs where only biomass is used can range up to 30 MW_{el}. However, biomass, can also contribute in larger CHPs where it is co-fired with fossil fuels (e.g. coal) to a scale up to 300 MW_{el} [10].

Table I: Biomass CHP application capacities and preferred technologies [10]

terminology	power range	typical application	preferred technology
micro scale CHP	0.01 - 0.5 kW_{el}	domestic appliances special appliances	thermoelectric generators
	0.5 - 50 kW_{el}	single family houses semidetached houses small and medium enterprises farms	micro steam engines micro ORC applications Stirling engines
small scale CHP	50 kW_{el} - 1 MW_{el}	multiple dwelling hotels local heating grids	steam engines ORC applications thermal gasification or anaerobic fermentation with gas piston engines
medium and large scale CHP	1 - 10 MW_{el}	hospitals commercial enterprises regional heating grids	ORC plants (< 6 MW_{el}) steam engines steam turbines
	10 - 30 MW_{el}	city heating grids industrial site	steam turbines gas turbines
	30 - 300 MW_{el}	district heating grids	steam turbines, co-firing with fossil fuels

3. Technical considerations

3.1 Main elements of a biomass co-generation installation

3.1.1 Biomass pre-treatment

Due to the inhomogeneity of biomass feedstocks (e.g. form, moisture etc.), a biomass pre-treatment step can be used when applicable, mainly in larger biomass plants. For micro-scale applications, it is more common that homogeneous biomass of high fuel quality (e.g. certified pellets) is used. However, at larger scale (e.g. 1 MW), the biomass feedstock that is sourced locally could be heterogeneous and of lower quality. A range of pre-treatment and upgrading technologies is available in order to improve biomass characteristics and make handling, transport, and conversion processes more efficient and cost-effective:

- Drying of biomass to reduce the moisture content and transport costs of biomass feedstock and improve combustion efficiency.
- Size-reduction step through milling, shredding or chipping where the feedstock material has its size reduced in order to be handled more efficiently and without causing any feeding issues.
- Pelletisation and briquetting where bulky biomass, such as sawdust or agricultural residues, are mechanically compacted.
- Torrefaction in which (woody) biomass is heated in the absence of oxygen to between 200-300°C and turned into char, with a process that is similar to traditional charcoal production. After torrefaction, woody biomass is usually pelletized, reaching an energy density that is 25%-30% higher than conventional pellets and have properties similar to coal.
- Pyrolysis is a further thermo-chemical pretreatment process during which biomass is heated to temperatures of 400-600°C in the absence of oxygen to produce pyrolysis oil, along with solid charcoal and a by-product gas. Oil from pyrolysis has twice the energy density of wood pellets. This makes it suitable for long-distance transportation [11].

3.1.2 Biomass conversion technologies

The following sections includes biomass conversion technologies that can be implemented in biomass CHP systems. More specifically, biomass conversion refers to the process of converting biomass into energy that will continuously be used to generate electricity and/or heat.

3.1.2.1 Combustion/ Direct- fired systems

The most common conversion technology for solid biomass fuel is that of direct combustion. A direct combustion system burns the biomass to generate hot flue gas, which is either used directly to provide heat or fed into a boiler to generate steam. In a boiler system, the steam can be used to provide heat for industrial processes or space heating, or a steam turbine can be used to generate electricity. The two most commonly used types of boilers are fixed bed boilers and fluidized bed boilers [12].

3.1.2.1.1 Fixed bed boilers

For small and medium-sized biomass combustion systems, fixed-bed combustion is one of the most used technologies as it can fire a wide range of fuels and requires less fuel preparation and handling. Primary air passes through a fixed bed, in which drying, gasification and charcoal combustion take place. The combustion gases produced are burned after secondary air addition has taken place, usually in a combustion zone separated from the fuel bed. There are various fixed-bed furnace technologies available: fixed grates, moving grates, travelling grates, rotating grates, vibrating grates and underfed stokers. All of these technologies have specific advantages and disadvantages, depending on fuel properties, so careful selection is necessary during the project planning phase. A well-designed and well-controlled grate guarantees a homogeneous distribution of the fuel and the bed of embers over the whole grate surface. Primary air should be divided into sections in order to be able to adjust the specific air amounts to the requirements of the different zones, allowing the furnace to operate at partial loads and control the primary air ratio needed to secure a reducing atmosphere above the grate (necessary for low NO_x operation). Gases released by biomass conversion in the grate continue to burn over the bed and secondary air plays an important role in mixing, burnout and emissions. An advanced secondary air supply system is one of the most important elements in the optimization of the gas phase combustion. The combustion chamber can either be water cooled or have refractory lining (with or without outside water or air cooling) [12].

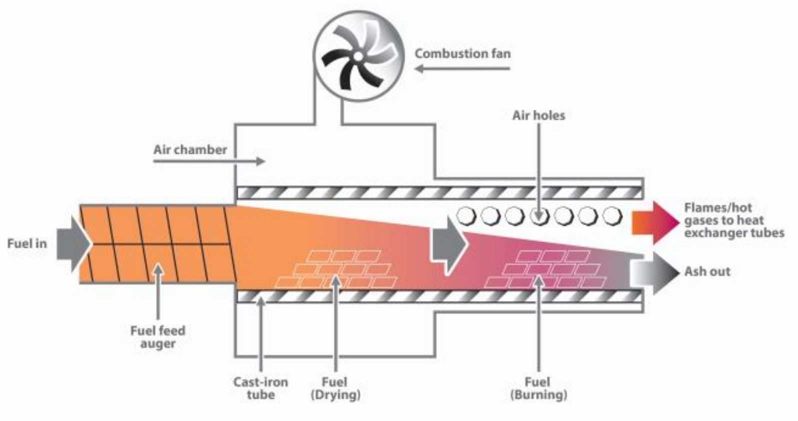

Figure 5: Fixed grate boiler [13]

3.1.2.1.2 Fluidized bed boilers

A fluidized-bed system feeds the biomass into a hot bed of suspended, incombustible particles (such as sand), where the biomass combusts to release the hot flue gas. Fuel is burned in a bed of hot inert, or incombustible, particles suspended by an upward flow of combustion air that is injected from the bottom of the combustor to keep the bed in a floating or “fluidized” state. The scrubbing action of the bed material on the fuel enhances the combustion process by stripping away the CO_2 and solids residue (char) that normally forms around the fuel particles. This process allows oxygen to reach the combustible material more readily and increases the rate and efficiency of the combustion process. This technology performs more complete combustion of the feedstock, resulting in reduced SO_2 and NO_x emissions and improved system efficiency. Fluidized-bed boilers also can utilize a wider range of feedstocks than fixed bed boilers. Given proper emissions-control technology, both systems can meet stringent emissions limits.

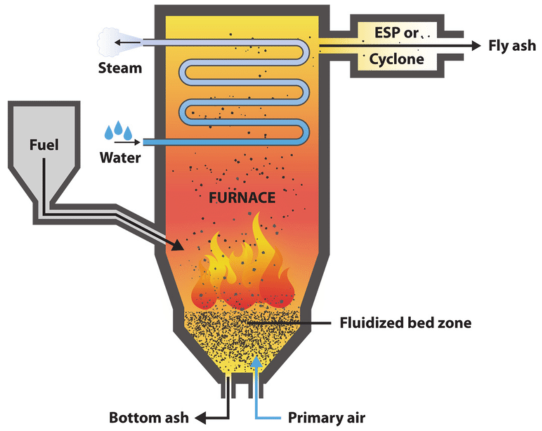

Figure 6: Fluidized bed boiler [14]

The primary difference in efficiency between a fixed-bed boiler and a fluidized bed boiler is the amount of fuel that remains unburned. The efficiency of fluidized bed boilers is better due to lower combustion losses. Fixed-bed boilers can have 30 to 40 % carbon in the ash and additional volatiles and CO in the flue gases, while fluidized bed boiler systems typically achieve nearly 100 % fuel combustion. The turbulence in the combustor combined with the thermal inertia of the bed material provide complete and controlled, combustion. These factors are key to maximizing the thermal efficiency, minimizing char, and controlling emissions [15].

3.1.2.2 Gasification

A revolutionary example of state of the art combustion systems with high fuel flexibility are biomass gasification boilers that include an updraft gasifier, a gas burner and a hot water boiler. Gasification systems convert biomass into a combustible gas/syngas (mixture of mainly H_2, CO, CH_4, CO_2, and N_2). In a close-coupled gasification system, the combustible gas is burned directly for space heat or drying, or burned in a boiler to produce steam. Alternatively, in a two-stage gasification system, tars and particulate matter are removed from the combustible gas, resulting in a cleaner gas suitable for use in a genset (generator set), gas turbine, or other application requiring a high-quality gas [16].

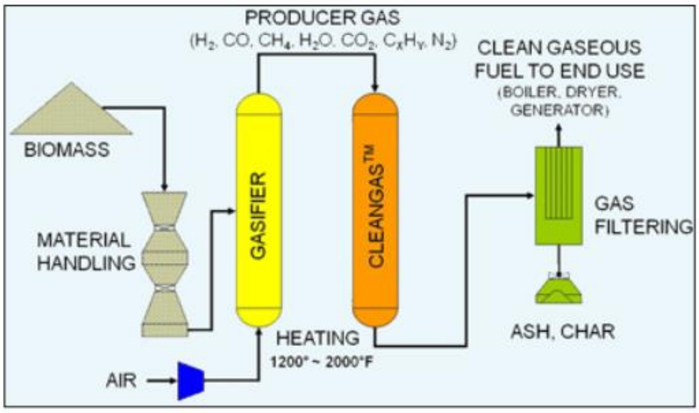

Figure 7: Example of two-stage gasification [16]

Fixed bed and fluidized bed are the main categories of gasification conversion technologies, both using similar types of equipment as that used in direct combustion systems. Such systems can achieve almost zero CO and OGC emissions, significantly reduced NO_x emissions (in comparison to conventional fixed-bed combustion technologies) and very low particulate matter emissions [12].

3.1.2.2.1 Fixed bed gasifiers

In fixed bed gasifiers, biomass is piled on top of a grate inside the gasification chamber. Such systems are a simple, inexpensive, proven technology, but typically they produce a gas with lower heat content. Fixed bed gasifiers typically have a fixed grate inside a refractory-lined shaft. The biomass fuel is typically placed on top of the pile of fuel, char, and ash inside the gasifier. A further distinction is based on the direction of air (or oxygen) flow: i) downdraft where air flows down through the bed and leaves as syngas under the grate; ii) updraft where air flows up through the grate and syngas is collected above the bed; and iii) crossflow where air flows across the bed, exiting as syngas. The fixed bed gasifier types are shown in Figure 8. Fixed bed gasifiers are usually limited in capacity, typically used for generation systems that are able to produce less than 5 MW. There has been identified a good match between fixed bed gasifiers and small-scale distributed power generation equipment. However, the variable economics of biomass collection and feeding, coupled with the gasifier's low efficiency, make the economic viability of the technology site-specific [15].

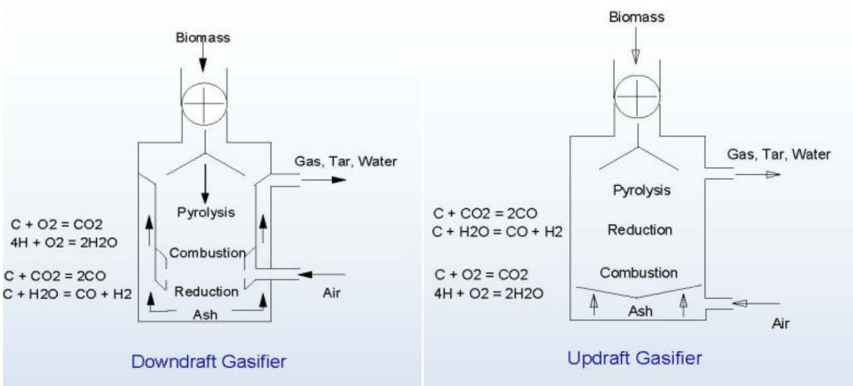

Figure 8: Fixed-bed gasification systems [17]

3.1.2.2.2 Fluidized bed gasifiers

Fluidized-bed gasification systems, in which the syngas is generated by feeding the biomass into a hot bed of suspended, inert material, generally offer improved performance, but with greater complexity and cost. Similar to fluidized bed boilers, the primary gasification process takes place in a bed of hot inert materials suspended by an upward motion of oxygen deprived gas. As the amount of gas is augmented to achieve greater throughput, the bed will begin to levitate and become "fluidized." Sand or alumina is often used to further improve the heat transfer. The fluidized bed design produces a gas with low tar content but a greater level of particulates as compared to fixed-bed systems. Compared to fixed bed gasifiers, fluidized-bed gasification systems have improved overall conversion efficiency and the ability to handle a wider range of biomass feedstocks [15].

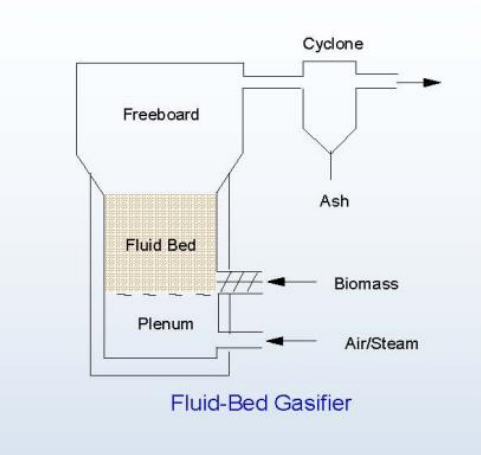

Figure 9: Fluidized-bed gasification systems [17]

3.1.2.2.3 Syngas cleaning

The produced gas from the outlet of a gasifier can contain several undesirable components, including particulate matter, tars and moisture. The relative proportion of these components is dependent on the gasifier type and its scale due to the nature of the gasification process. For example, syngas from updraft gasifiers contain significant amounts of tar and is unsuitable for power generation applications, whereas downdraft gasifiers have an order of magnitude less tar and are a suitable option [18]. Tar, along with particulate matter, must be removed from the syngas depending on end-use e.g. if they are used in IC engines, turbines or fuel cells [19]. For piston internal combustion and diesel engines, commonly cited levels required for syngas gas quality are < 100 mg/m^3 for tar and < 50 mg/m^3 for particulate matter [20–22]. The use of feedstocks other than clean biomass will generate undesirable contaminants in syngas other than tar and particulate matter, such as metal oxides and halogenated compounds. The primary approach to tar reduction in gasification systems should be through optimized operation of the gasifier. However, despite achieving optimal operation, more clean-up methods are often required. In fact, more than one unit operating of gas cleaning is typically required to achieve acceptable gas quality. The order of clean-up technologies is important, as temperature drop will occur throughout the process and the performance of previous steps can influence the effectiveness of the next process steps. Figure 10 presents a summary of some potential gas cleaning solutions (e.g. cyclone, bag filter, wet scrubbing, ESP filter etc.), along with their efficiency and applicable relative temperature range. Lastly, engine emissions may also require clean-up prior to release into the atmosphere [23].

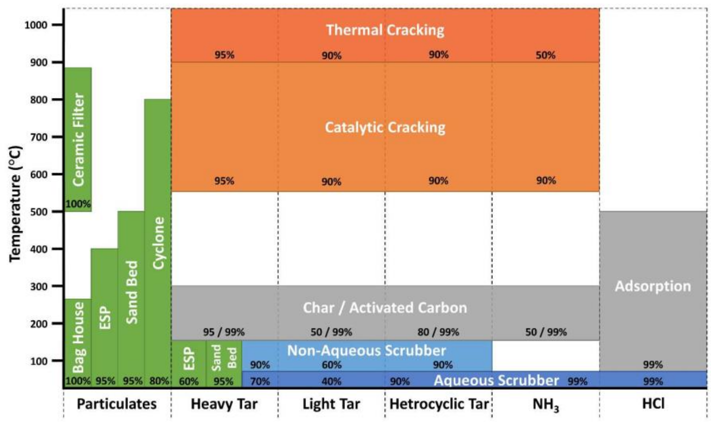

Figure 10: Syngas cleaning technologies including their applicable temperature range and efficiencies [23]

3.1.2.3 ORC applications

Although most direct combustion/ gasification systems generate power utilizing a steam-driven turbine, a few companies are developing direct combustion technologies that use hot, pressurized air or another medium to drive the turbine. The organic Rankine cycle is a process which can be compared with the operation principle of the steam power cycle. But instead of water, an organic medium is used as working fluid such as Isopentane, Iso-octane, toluene or silicone oil. These fluids are characterized by better vaporization conditions at lower temperatures and pressures compared to water which enables the utilization of low temperature heat sources like solar or biomass applications to produce electricity. To enable the usage of a boiler (heat source) which operates under atmospheric pressure, thermal oil is used for the heat transfer from the boiler to the evaporator [24].

Figure 11 shows the ORC process scheme. The heat is produced in the boiler where biomass fuel is fed. The produced energy gets transferred via the heat transfer circuit (e.g. thermal oil) to the evaporator. There the organic working medium in the ORC circuit gets vaporized and subsequently expanded in the circuit integrated turbine, which drives a generator. The remaining energy in the organic working fluid gets recuperated in a regenerator for increasing the electric efficiency. Afterwards the heat gets recovered in a condenser for the usage for district or process heat. Additional the flue gas heat from the boiler also gets a further usage after the heat exchange through an economizer [25].

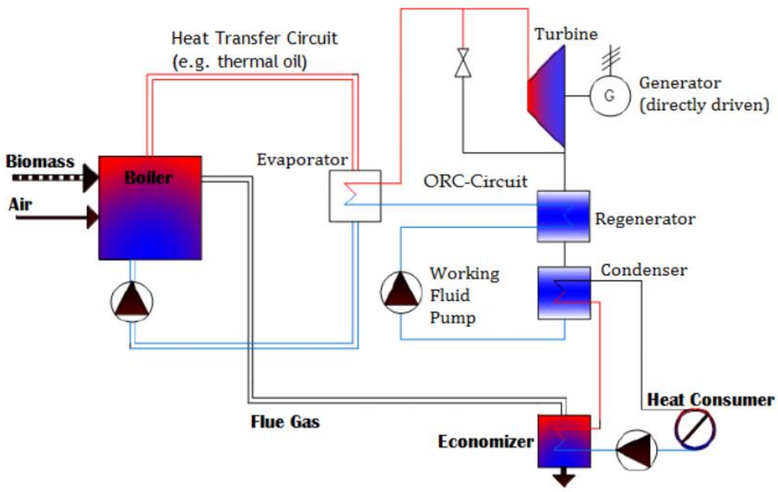

Figure 11: ORC process scheme [26]

3.1.3 Power generation technologies

Various technologies have been developed for energy conversion in biomass-fuelled CHP systems. Basically, these include a primary conversion technology that converts biomass into hot water, steam, gaseous or liquid products and a secondary conversion technology that transforms these products to heat and power. The primary conversion technologies have been mentioned in the previous section. Whereas, the secondary technologies or power generation technologies include steam turbines, gas turbines, internal combustion engines, micro turbines, fuel cells and Stirling engines are described in brief in the following sections.

3.1.3.1 Steam turbine

A steam turbine is a thermodynamic device that converts the energy in high-pressure, high-temperature steam into shaft power that can be used to turn a generator and produce electric power. Unlike gas turbine and reciprocating engine CHP systems where heat is a byproduct of power generation, steam turbine CHP systems normally generate electricity as a byproduct of heat (steam) generation. A steam turbine requires a separate heat source and does not directly convert fuel to electric energy. The energy is transferred from the boiler to the turbine through high-pressure steam, which in turn powers the turbine and generator. This separation of functions enables steam turbines to operate with an enormous variety of fuels. In CHP applications, steam at lower pressure is extracted from the steam turbine and used directly or is converted to other forms of thermal energy. In the thermodynamic cycle, called the Rankine cycle, liquid water is converted to high-pressure steam in the boiler and fed into the steam turbine. The steam causes the turbine blades to rotate, creating power that is turned into electricity with a generator. A condenser and pump are used to collect the steam exiting the turbine, feeding it into the boiler and completing the cycle [15].

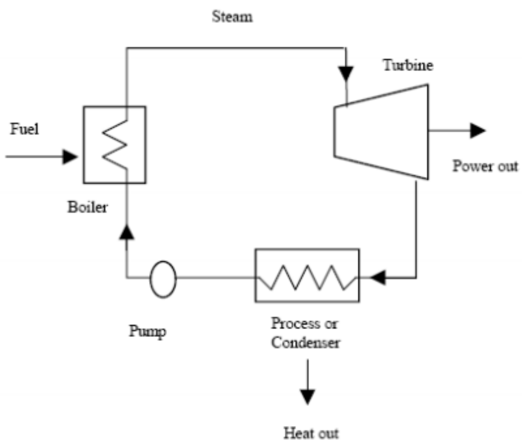

Figure 12: Steam turbine CHP system [27]

3.1.3.2 Gas turbine

Combustion turbines, or gas turbines, have been used for power generation for decades and are often the technology of choice for new electric generation due to their low capital cost, low maintenance, and low emissions. The gas turbine is an internal combustion engine that operates with rotational rather than reciprocating motion. An illustration of the configuration of a gas turbine is shown in Figure 13. As illustrated in the figure, gas turbine power generation systems use the Brayton cycle and consist of a compressor to compress the air to high pressure, a combustor chamber operating at high pressure, the gas turbine itself, and the generator. The turbine section comprises one or more sets of turbine blades that extract mechanical energy from the hot combustion products. Some of that energy is used to power the compressor stage, whereas the remaining energy is available to drive an electric generator or other mechanical load [15].

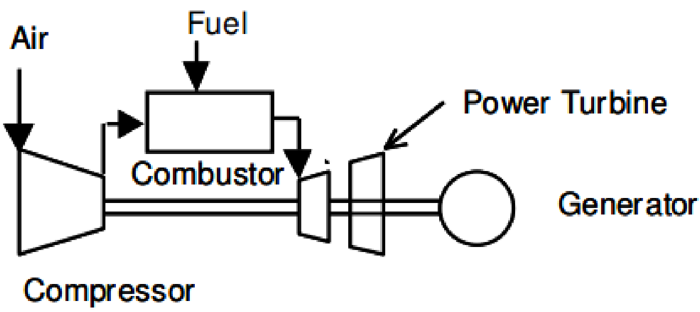

Figure 13: Components of simple-cycle gas turbine [28]

A biomass gas turbine system requires anaerobic digester gas, or a biomass gasifier to produce the biogas for the turbine. This biogas must be carefully filtered of PM to avoid damaging the blades of the gas turbine. Additionally, because a typical biomass gasifier produces a low-calorific biogas, the fuel compressor must be sized to handle about 10 times the gas flow compared to natural gas in order to provide the same amount of heat to the combustor, thereby reducing the turbine's efficiency [15].

3.1.3.3 Microturbine systems

Microturbines are small gas turbines that burn clean gaseous and liquid fuels to produce mechanical energy that turns an electrical generator or other load. Small high-speed gas turbines are referred to as micro gas turbines. The difference between micro gas turbines and conventional gas turbines lies in the power range and the rotation speed.

The combustion air is drawn in through a centrifugal compressor and heated up with the waste heat from the generator, while the generator is cooled at the same time with the cool combustion air. The air heated up this way flows into the combustion chamber, where it is combusted together with the fuel gas. The hot and compressed flue gas expands within the turbine driving the compressor and the generator. The resulting mechanical energy is converted by the generator into electrical energy. In the recuperator, the hot exhaust gases pass on part of their heat to the cooled down combustion air and are discharged from the turbine at a temperature of around 300°C, which can then be used in a downstream heat exchanger to provide process heat [29].

In recent years, natural gas powered micro gas turbines have reached the demonstration and market introduction phase and are available in the electrical capacity range of 30–200 kW with efficiency rates of 25–30%. The specific costs for micro gas turbines are between 1,000 and 2,000 € per installed electrical capacity in kW. The maintenance requirements for micro gas turbines are lower than those for piston engines since there are mostly rotating components in the system. Up to now, most manufacturers have approved the use of landfill gas, sewage gas, and biogas at calorific values between 3.6 and 11.7 kWh/mN^3 [29].

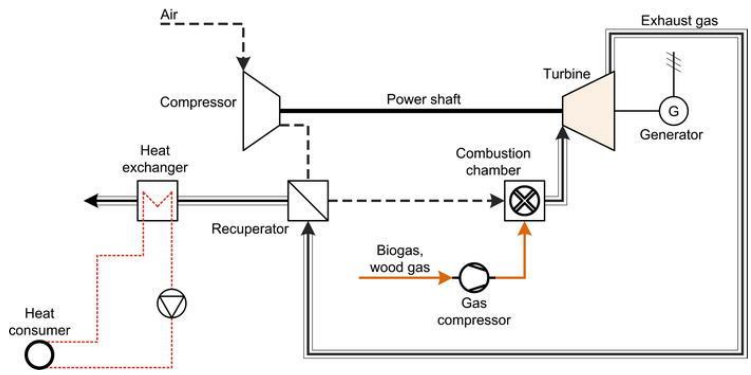

Figure 14: Microturbine-Based CHP System [30]

3.1.3.4 Reciprocating internal combustion (IC) engines

Reciprocating internal combustion engines are a widespread and mature technology. A variety of stationary engine products are available for a range of power generation market applications such as in CHP. Reciprocating IC engines are available for power generation applications in sizes ranging from a few kilowatts to more than 5 MW. The levels of electrical efficiency thereby range from 25% to 40%.

A biogas-fired reciprocating engine system will encounter many of the same operating issues as a biogas-fired gas turbine: i) an anaerobic digester, or a biomass gasifier is needed to produce the biogas fuel for the engine; ii) the biogas must be carefully filtered of PM to avoid damaging the engine; and iii) the engine must be derated for burning low-energy content biogas rather than natural gas.

The engines will require modification to accommodate higher flow rates and impurities. However, required modifications to reciprocating engines are achieved more easily, typically adding about 5 percent to the cost of a natural gas engine. Total non-fuel O&M costs for a biogas engine are approximately 60 to 70 % higher than for a natural gas engine [31]. The major advantages of internal combustion engines are the long history, large production and service infrastructure, and the generally lower power generation costs [29].

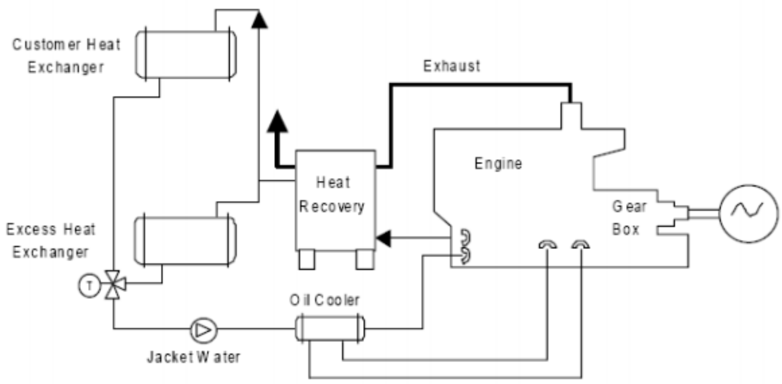

Figure 15: Closed-Loop Heat Recovery System for a Reciprocating IC Engine [27]

3.1.3.5 Fuel cells

Fuel cells are an emerging small-scale power generation technology with high electrical efficiency and very low emissions. In fuel cells, the fuel is chemically combined with oxygen to create electricity, with useful heat as a byproduct. Fuel cells can achieve electric efficiencies up to two times greater than internal combustion engines. Fuel cells can be sized for a wide variety of applications from laptops (50 to 100 W) to vehicles (50 to 85 kW) or event to central power generation (0.2 to 2 MW).

Cost and durability are the major challenges to fuel cell commercialization. Fuel cells are currently more expensive than internal combustion engines and have difficulty maintenance. The size, weight, thermal management, and water management of fuel cells are also barriers.

A fuel cell consists of an electrolyte and two catalyst-coated electrodes (a porous anode and cathode). Several different types of fuel cells are currently under development, each classified primarily by the kind of electrolyte it uses. The electrolyte determines the kind of chemical reactions that take place in the cell, the temperature range in which the cell operates, and other factors that affect the applications for which the fuel cell is most suitable, as well as its advantages and limitations. Fuel cells require hydrogen for operation. However, it is generally impractical to use hydrogen directly as a fuel source. Instead it is extracted from hydrocarbon fuels or biogas feed using a reformer. The reformers produce and/or increase the concentration of hydrogen and decrease the concentration of gas species toxic to the fuel cell.

While most operating experience with fuel cells has been with natural gas, there are a handful of fuel cell installations operating with biogas, digester gas or landfill gases. These systems require a different fuel reformer with larger fuel injectors and additional piping. Gasifiers typically produce contaminants, which need to be removed before the hydrogen enters the fuel cell anode. The contaminant levels are dependent upon both the fuel composition and the gasifier employed. To meet the fuel standards, the gas product from the gasifier must be processed, which might involve gas cleanup, reforming, and purification. Units operating on biogas would likely cost slightly more than natural gas units. Maintenance would also likely be higher as biogas with more impurities might require increased cleaning and maintenance of the fuel gas reformer. It is likely that both equipment and maintenance costs of a biogas-fueled fuel cell would be at least 10 percent higher than a comparable natural gas-fueled system [15].

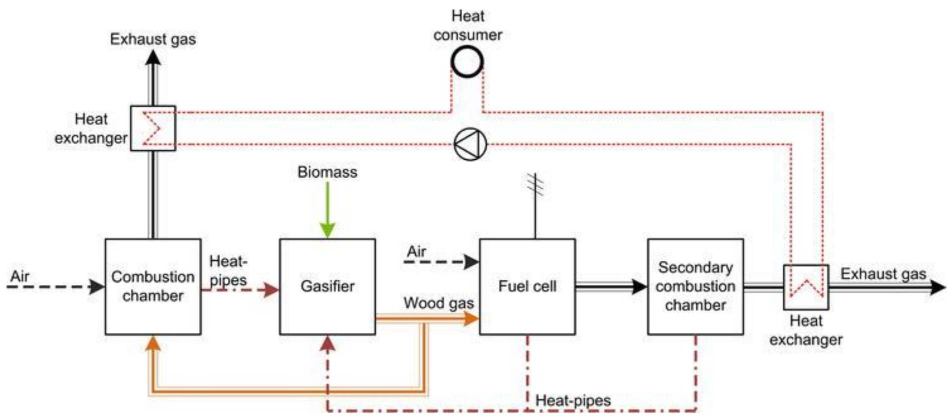

Figure 16: System diagram for a biomass CHP unit with fuel cell [29]

3.1.3.6 Stirling engines

Like internal combustion engines, the Stirling engine is a reciprocating engine, where the piston connected to the generator is not driven directly by the expansion of combustion gases. The power piston and working gas form a closed system whereby the expansion of the working gas is caused through the supply of energy from an external heat source. In this way, stirling engines can generally be used and optimized independent of the type of heat generation process. Because the Stirling engine heat is supplied externally, a wide variety of heat sources can be used (such as fossil fuels, solar, nuclear, and waste heat), but the Stirling engine is particularly well-suited to biomass fuels.

Stirling engines are available in a variety of designs, which essentially only differ in the arrangement of the expansion and compression cylinders. Characteristic for all designs is the use of a constant amount of working gas (air, helium, hydrogen, nitrogen) in a closed cycle. Every stirling engine has a high-temperature section and a low-temperature section (in Figure 17 referred as heater and cooler) between which the working gas is cyclically moved back and forth between the expansion and the compression cylinders. Depending on the design, the pistons will move at an angle of between 60° and 90° to one another in alternating phases. In single-cylinder systems, by contrast, both pistons are housed in one chamber. The conceptualized process consists of the compression and the expansion phase. During the expansion phase, the working gas expands under the external supply of heat leading to an expansion of the gas. The hot working gas flows through the regenerator toward the compression cylinder and release its thermal energy to the heat sink. In the compression phase, the working gas is once more compressed through the power piston and pushed back through the regenerator into the high-temperature section [29].

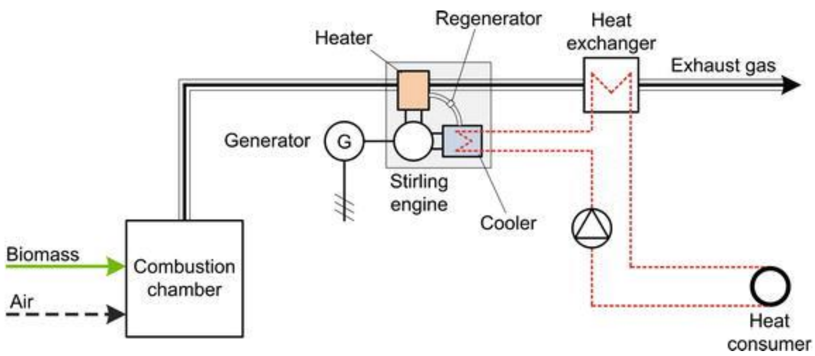

Figure 17: System diagram for a biomass CHP unit with a stirling engine [32]

The advantage of the stirling engine lies in the use of an external source of heat. Thus, the external combustion can be optimized without considering the operational status of the stirling engine. Due to its closed cycle design, the average useful lifespan of a stirling engine will generally also be higher than that of a comparable power generation system. On the other hand, due to the use of helium as working gas, regular checking and also refilling of the working gas may be necessary. For some models, this leads to a significant increase in operating costs. Additional problems might cause deposits at the heat exchanger. In the case of long servicing intervals, the use of high-quality wood pellets is required for optimized combustion with low particle content within the hot flue gas [29].

3.1.4 Wrap-up on biomass Cogeneration technologies and latest developments

From all the technologies mentioned above, combustion and steam turbine technologies is the most widely used combination, especially for large-scale and medium-scale biomass-fueled CHP systems. Moreover, the combination of combustion and Organic Rankine Cycle (ORC) technologies is receiving more and more attention in the development of small-scale biomass CHP systems. The cost of an ORC system is far less than that of a Stirling engine, with less than 60% of that of a Stirling engine, and is similar to that of gasification technology and steam turbine/engine [33]. ORC is appropriate for small-scale and micro-scale biomass CHP systems. For traditional steam engine or steam turbine systems, the typical electrical efficiencies are around 6–8% for small-scale CHP systems with a size of less than 30 kWe [34], that results in the steam-based CHP systems no longer attractive at such a small-scale. In contrast, ORC-based systems are able to produce about 15% of electricity and 60–70% of heat [35]. To increase the economic feasibility of the small-scale and micro-scale CHP plant units, more electricity should be produced from the process per produced heat unit. In addition to the higher electricity production, the increased power-to-heat ratio could also reduce the fuel consumption and the CO_2 production per produced energy unit. The factors that are limiting the power-to-heat ratios in the small-scale and micro-scale CHP plants are mostly material properties and economic issues. As a result, the trade-off between costs, the complexity of the process, and the increased power production is an important factor when defining the most profitable process for a small-/micro-scale biomass-fired CHP system investment and should be considered thoroughly [36]. In addition, as most small-scale and micro-scale CHP systems are operated according to the heat demand, the electricity production can be considered as the by-product of the heat production. However, it should also be noted that the operation mode of a small-scale or micro-scale CHP system based on the heat demand may not be the best choice in terms of CO_2 reductions and cost savings [37,38].

Apart from the direct biomass combustion technology, other potential technologies for micro-CHP include biomass gasification and micro-turbine. A gasification CHP system can potentially have higher electricity efficiency than a direct combustion-based CHP system. The gas obtained by gasification can be combusted in a diesel, gas engine, or in a gas turbine. Many efforts have been made to commercialize biomass gasification-based CHP system CHP system at micro scale. E.g., Community Power Corporation (CPC). CPC has developed modular micro-scale biomass gasification-based CHP systems with size ranging from 5 to 50 kWe [39]. CPC has reported that the systems have the advantages of fully automatic operation and control and with no harmful emissions and liquid effluents. CPC also developed a Biopower Battery Charger which is a unique product that uses the CPC biomass gasification technology to operate a free-piston Stirling engine generator. Despite all the efforts made over the past decade a large market share of small-scale biomass gasification systems for electricity production has yet to be achieved. This is due to the large variation in the key parameters determining the quality of biomass gasification product gases that can cause extreme engine wear due to tar contamination and unstable operation. On the other hand, the automatic measurement and control measures are rarely used in order to keep the system cost down and this often results in variable system performances [35]. Therefore, further research is certainly needed to improve and optimize the micro biomass gasification CHP systems.

Moreover, micro-turbine technology can also be combined with direct biomass combustion technology for applications in small- and microscale biomass CHP systems. Talbott's Heating Ltd. has developed and reported a biomass combustion-turbine system (100 kWe) with the electrical efficiency of 17% and the overall efficiency of 80–85% [34]. Furthermore, Compower reported the development of an externally fired micro-CHP systems in the range of 1–15 kW electricity that can operate on biogas and biomass [40]. Compower's first micro-CHP system was based on the reuse and reconfiguration of commercially off the shelf components 7 kW electricity and 17 kW heat. The main modules include a burner, a turbogenerator and a set of heat exchangers. Despite all the efforts on the development of micro-turbine technology, gas turbine technology is only widely used in CHP systems larger than 100 kWe with the electrical efficiency generally higher than 25% [38].

3.2 Power of the Cogeneration unit

When investing in a CHP unit, the first thing is to define the energy demands that the operator wants to cover, and thus define the capacity of the unit. In this sense, based on the technology that will be implemented, the efficiencies can vary.

Electrical efficiencies of small and micro-scale plants are between 13 % and 25 % and total efficiencies between 60 % and 74 %. At micro-scale, 25 – 30 % is the current technological limit of biomass conversion to electricity efficiency [10]. Figure 18 shows the electrical efficiencies of biomass conversion technologies which have been reached in different power ranges for small scale applications.

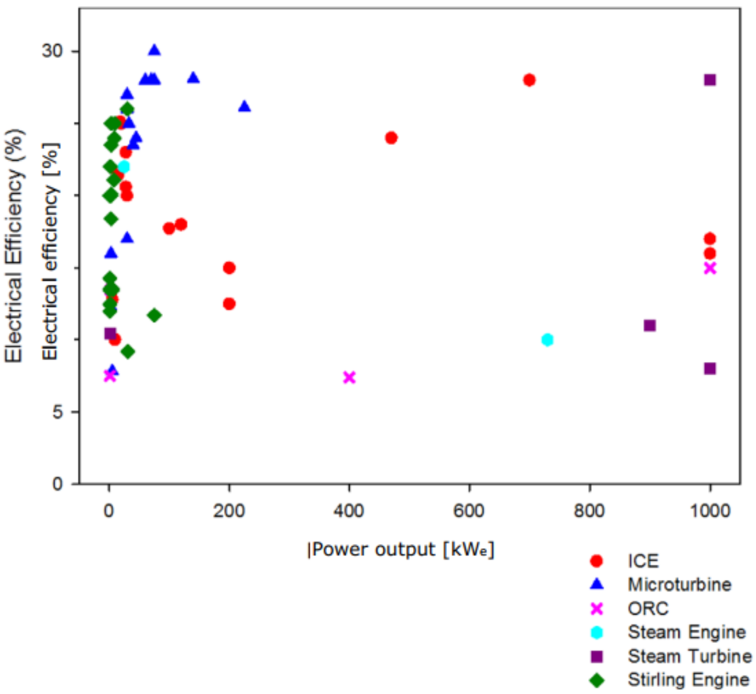

Figure 18: Electrical efficiencies of biomass conversion technologies based on power output [15]

In order for the investor of a small-scale CHP unit to decide on its power, the investor should first estimate the heating demands (and electrical) that will be covered. Information about how to estimate the energy demands can be found in the BECoop Catalogue "Direct Heating" and "District Heating".

The investor can also address an ESCO or an engineering company in order to assess the power of the CHP unit.

For example, an average household in central Europe (e.g. Germany) has annual heating demands of 13,000 kWh and electricity demands of 3,200 kWh_{el}. In order for the household to cover its heating demands, a biomass CHP is considered. If we take in consideration the efficiencies of the abovementioned efficiencies of micro-scale CHP, we can assume an average electrical efficiency and heating efficiency. Thus, with rough estimations, by considering an electrical efficiency of 19% and a heating efficiency of 48%, the amount of biomass that would be needed to cover the heat demands are around 5.4 tons of EnPlus A1 wood pellets[1]. This amount of biomass will be enough to cover the heating demands of the house (13,000 kWh) and also produce around 5,000 kWh_{el} that after covering self-consumptions and electricity demands of the house, the excess electricity can be sold to the grid. Furthermore, for this example, by considering a 700 kg/m^3, bulk density for the EnPlus A1 pellets, a storage area of 8 m^3 would be needed to store the biomass fuel. Based on the available micro CHP units that are commercialized in the market and are applied for domestic use, e.g. ÖkoFEN Pellematic Smart_e [41], the area needed for the installation of such CHP unit is around 1.5 m^2 as a rough estimation of the space needed to implement such CHP unit.

3.3 Operational and maintenance costs of cogeneration unit

In general, a biomass CHP system is more complex than a fossil fuel-based CHP system. In a fossil fuelled CHP system, the natural gas can be used directly in a reciprocating engine or a gas turbine without a need for a boiler or gasifier. Furthermore, in a gasification biomass CHP system, the syngas needs to be treated before it is combusted in an engine (syngas cleaning). Moreover, biomass CHP systems require a large physical space for the fuel delivery and storage of biomass, the boiler or gasifier and the buffer tank (if applicable). Biomass systems also have greater maintenance requirements and they need an ash disposal system. In comparison to traditional fossil-fuel-based boilers (e.g. gas, oil or coal), a biomass boiler system needs to be designed differently. The design has to take into account the particular characteristics of the boiler itself, including a slower response time than oil or gas boilers and a smaller turndown ratio [1].

Based on each technology implemented in the CHP unit and its power, the investment and maintenance costs vary. Table I presents an overview of the size of CHP unit, the fuels that can be used, the electrical efficiencies that can be achieved, operating issues, commercialization status, installed costs and maintenance costs of the CHP units based on the technology implemented.

[1] Considered 18 MJ/kg, as received Lower Heating Value for the EnPlus A1 wood pellets

Table II: Comparison of prime mover technologies applicable to biomass CHP [15]

Characteristic	CHP technology					
	Steam Turbine	Gas/ Combustion Turbine	Micro turbine	Reciprocating IC Engine	Fuel Cell	Stirling Engine
Size	50 kW- 250 MW	500 kW- 40 MW	30 kW-250 kW	<5 MW	< 1 MW	<200 kW
Fuels	Biomass/ Biogas fueled boiler for steam	Biogas	Biogas	Biogas	Biogas	Biomass or Biogas
Fuel preparation	None	PM filter needed	PM filter needed	PM filter needed	Sulfur, CO, methane can be issues	None
Sensitivity to fuel moisture	N/A	Yes	Yes	Yes	Yes	No
Electric efficiency (HHV)	5-30%	22-36%	22-30%	22-45%	30-63%	5-45%
Operating issues	High reliability, slow start-up, long life, maintenance infrastructure readily available,	High reliability, high-grade heat available, no cooling required, requires gas compressor, maintenance infrastructure readily available	Fast start up, requires fuel gas compressor	Fast start-up, good load following, must be cooled when CHP heat is not used, maintenance infrastructure readily available, noisy	Low durability, low noise	Low noise
Commercialization status	Numerous models available	Numerous models available	Limited models available	Numerous models available	Commercial introduction and demonstration	Commercial introduction and demonstration

Characteristic	CHP technology					
	Steam Turbine	Gas/ Combustion Turbine	Micro turbine	Reciprocating IC Engine	Fuel Cell	Stirling Engine
Installed cost (as CHP system)	€310 to €670/kW (without boiler)	~ €620 to €1,800/kW	€970 to €1,800/kW	€710 to €1,400/kW	€2,700 to €4,500 /kW	€900 to €9,000 /kW
Operational and maintenance (O&M) costs	<0.4 c/kWh	0.5-1 c/kWh	0.7-1.8 c/kWh	0.7-2.2 c/kWh	0.9-3.5 c/kWh	Around 1 c/kWh

3.4 Environmental policy aspects and regulations for cogeneration units

In the last years, several policies on EU and national level have been introduced to support CHP technology. In 2004, the CHP Directive 2004/8/EC[2] was published, focusing on supporting the use of CHP. The main scope of this Directive was to promote high-efficiency cogeneration of heat and power based on useful heat demand and primary energy savings. In 2012, the Energy Efficiency Directive 2012/27/EC[3] (EED) was published in order to replace the CHP Directive of 2004 and introduced more specific measures, related to CHP development in the EU countries. The EED forms today the basis for the CHP development on EU level. The EED aims to promote CHP, by activating the EU countries to make an assessment of their potential CHP periodically (every 5 years).

In addition to the above Directives, other Directives came into force in order to encourage the promotion of the CHP market, i.e. the Renewable Energy Directive (RED 2018/2001[4]), the Energy Performance of Buildings Directive (EPBD 2010/31/EU[5]) and the Ecodesign Directive (also referred as Energy related products/ ErP 2009/125/EC[6]).

The Ecodesign Directive 2009/125/EC forms a framework that sets minimum performance requirements for specific product groups. It provides consistent EU-wide rules for improving the environmental performance of products, such as household appliances, information and communication technologies or engineering. The directive sets out minimum mandatory requirements for the energy efficiency of these products. This helps prevent creation of barriers to trade, improve product quality and environmental protection. Regarding cogeneration aspects, e.g. regulation 2015/1189 applies to solid fuel systems with a nominal heat output of 500 kW_{th} or less as well as to solid fuel cogeneration boilers with an electrical capacity of less than 50 kW_{el}. The regulation sets

[2] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32004L0008
[3] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=celex:32012L0027
[4] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32018L2001
[5] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02010L0031-20210101
[6] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02009L0125-20121204

Minimum Energy Performance Standards (MEPS) and emission limit values for particulate matter, organic gaseous compounds, CO and nitrogen oxides. Manufacturers have to meet these requirements (from January 2020) in order to have their products in EU market. The minimum requirements of the Ecodesign Directive go together with the Energy Labelling Directive 2010/30/EU that provides depicted information to consumers on the efficiency of energy-related products that are sold in the EU market. Due to the increased demand for energy-efficient technologies, manufacturers are incentivized to develop more innovative products. In this light, the European Commission determined that energy classes A++ and A+ rated heating appliances, which indicate the most energy-efficient technologies in this product group, are reserved for cogeneration as well as renewable energy sources. Thus, the Commission directed investment decisions of consumers and investors towards low-carbon cogeneration technologies [42].

The RED and EPBD directives build a general policy framework. These framework Directives do not affect CHP directly but have strong influence in fostering the market. Thus, the RED has a role in influencing cogeneration applications with its specific role for biomass, such as its sustainability criteria and emission reductions targets. The directive also establishes objectives to expand the share of renewable energy in the energy mix of the Member States. Though RED does not include a specific target on the expansion of cogeneration, Member States can meet the EU renewable energy objectives also by biomass cogeneration.

Regarding the EPBD, the directive promotes the transition of buildings on becoming more energy-efficient. Existing buildings are supposed to meet energetic standards and new buildings should aim to be Nearly Zero Energy buildings. Moreover, for new buildings the Directive suggests that the technical, environmental and economic feasibility of high- efficiency alternative systems, such as cogeneration and district heating that rely on renewable resources, should be taken into account. In this light, the EPBD suggests that Member States focus on CHP and district heating for providing energy to buildings. However, based on the EPBD, it is expected that heat requirements of buildings will decrease as consequence of improved insulation and energy performance of buildings, thus causing a shift from single dwelling heating systems towards joint CHP system supplying several dwellings [42].

Further to these directives, the Medium Combustion Plant Directive (MCPD 2015/2193[7]) regulates emissions from combustion plants with a thermal input between 1 and 50 MW_{th}. This Directive fills the regulatory gap at EU level between large combustion plants (> 50 MW_{th}), covered by the Industrial Emissions Directive and smaller appliances (heaters and boilers <1 MW_{th}) covered by the Ecodesign Directive. The MCPD regulates emissions of SO_2, NO_X and dust to air. It aims to reduce those emissions and the resultant risks to human health and the environment. It also requires monitoring of carbon monoxide (CO) emissions. The emission limit values set in the MCPD apply from 20 December 2018 for new plants and 2025 or 2030 for existing plants.

Overall, the existing EU policies related to cogeneration, has a strong influence on the market of small scale biomass CHP units targeting efficient decentralized power and heat generation. The policies support the achieving of 2030 and 2050 climate and energy targets of EU and the transition to a decarbonized energy system. An overview of the abovementioned policies and how they affiliate with the power capacity of CHP units is presented in Figure 19.

[7] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32015L2193

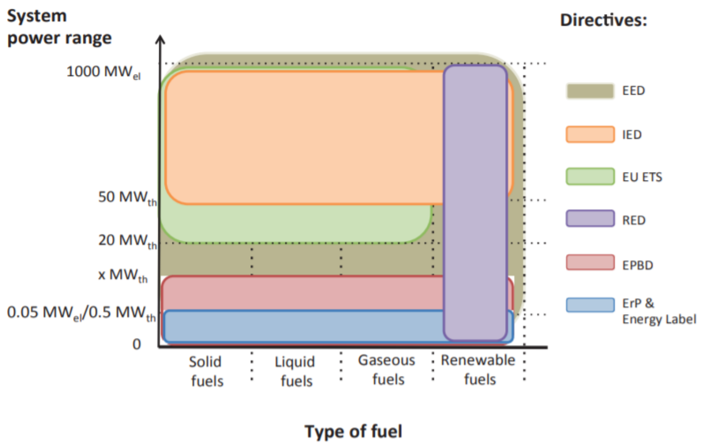

Figure 19: EU policies relevant for CHP based on fuel type and nominal power range [42]

4. Profitability of a cogeneration unit

Based on the recent energy crisis, it is clear that the price of fossil fuels is unsecured and severely fluctuating. On the other hand, local biomass fuels, can offer a price stability and independence on external events/ politics. In this sense, biomass CHP units can offer a profitable and secure solution while participating in the local energy market. Prior to investing, the user should first calculate the investment and operational costs that would be needed (Table II) for the CHP unit based on its power and technology. Afterwards, the investor should estimate the savings from using the biomass-fuelled CHP to cover the energy demands and/or estimate the revenues from selling electricity and/or heat if that is applicable. Attention should be put in case there are funding opportunities to support the investment on biomass CHP units. The stakeholder should also consider any investment subsidies, feed-in-tariff and feed-in premium, green certificate schemes, tax subsidies if applicable that would increase the profitability of the CHP unit. After such considerations, the investor should perform a feasibility study and estimate a payback period for his investment and decide whether his/ her investment on a biomass-fuelled CHP is feasible or not (how to calculate the payback can be found in BECoop Catalogue of District Heating). Based on the success cases that are also described in Section 6, in most cases of small scale applications of biomass CHPs, the payback time is in the range of 3-10 years, depending of course on the capacity of the CHP unit, its application and the specific circumstances for each case.

Further to the economic profitability, is CHP technology environmental friendly? The environmental impact of CHP units offers an additional reason for using such technology. CHP technology by its own offers environmental benefits compared to stand-alone, conventional energy production technologies. For instance, the standalone and conventional production of 35,000 MWh electricity and 52,498 MWh heat produced from a fossil fuel-fired power plant and a natural gas-fired boiler, produces 45 kt of CO_2 annually. Whereas for the same amount of energy, a 5 MW natural gas CHP with combustion-turbine produces 23 kt of CO_2 per year, that is almost 50% in CO_2 reduction [43]. In the occasion of biomass CHPs, the environmental savings are even better. Biomass combustion based CHP technologies have great potential to reduce CO_2 emissions because they use renewable energy sources, such as wood fuels, sawdust etc.

Results regarding the CO_2 reduction for using biomass CHP units, are not only dependent on the scale but also on the efficiency of a plant. This suggests that the relationship between airborne emissions and scale is rather complex and context specific. Overall, the bigger plants provide greater carbon emissions savings. However, when carbon emissions are expressed in per MWh produced, the picture becomes less clear, with size and type of feedstock co-determining environmental performance.

For large-scale applications of biomass CHP, based on the Renewable Energy Directive- RED II [44], installations producing electricity, heating and cooling or fuels with a total rated thermal input equal to or exceeding 20 MW in the case of solid biomass fuels, and with a total rated thermal input equal to or exceeding 2 MW in the case of gaseous biomass fuels should fulfil the sustainability and greenhouse gas emissions saving criteria. More specifically, the greenhouse gas emission savings from the use of biofuels, bioliquids and biomass fuels should be at least 70 % for electricity, heating and cooling production from biomass fuels used in such installations starting operation from 1 January 2021 until 31 December 2025, and 80 % for installations starting operation from 1 January 2026. However, small installations below 20 MW for solid biomass fuels and 2 MW for gaseous biomass fuels of thermal capacity are exempted.

Regarding small scale and micro CHP units, the environmental benefits should be estimated in a case-by-case basis. Carbon savings from micro-CHP depends on the carbon content of the fuel it uses to generate heat and power, and the carbon content of the grid supplied electricity that micro-CHP displaces. The carbon content of grid supplied electricity depends on the power generation mix and the fuels used to produce electricity. Compared with a conventional gas boiler and grid that supplied electricity, micro-CHP can significantly reduce carbon dioxide emissions from homes. For instance, based on [45], the implementation of micro CHP technology at the residential sector can achieve a 34% CO_2 reduction compared to the conventional way of covering the family's home demands with a gas boiler and electricity from the grid.

Finally, is scale relevant to the social acceptance of a biomass CHP plant? It can be assumed that the larger the scale of the plant, the more resistance should be expected from local people. Information days for the general public and communications to the media should be performed in case of implementing a large scale biomass CHP, in order to educate local people on the benefits of the technology and bioenergy. It has been shown that public engagement can contribute to the local acceptance of a project [46]. Nonetheless, in small and micro scale CHP applications, there should not be resistance to be expected by local people. Local people should be informed that by implementing small or even large scale CHP units, apart from the positive environmental impact, there would also be local economic impact for exploiting local biomass sources and mobilizing local stakeholders in such systems.

5. Steps to be followed, prior to investing on a cogeneration unit

There are many factors that can affect the success of a biomass CHP investment and to which the interested stakeholders should pay increased attention prior to advancing to such investment. For instance, biomass availability is a key aspect for bioenergy production. Biomass-based CHP are widely used in regions that have adequate woody resources such as forestry, agricultural residues or other biomass resources. A business plan, including costs of the biomass resource collection and logistics, is needed to ensure that CHP from solid biomass is economically viable. For larger scale biomass CHP units, a location close to large resource sites, large harbours, train stations or main highway routes is essential to facilitate biomass supply and delivery. Moreover, biomass use for CHP may be in competition with other, non-energy uses of agricultural and forestry residues or woody industrial waste (i.e., pulp and paper). In this light, increasing competition between different uses may increase the price of biomass that could potentially threaten the viability of the biomass CHP. In other words, biomass market stability is a critical issue. Furthermore, sustainability, environmental and social aspects (i.e. GHG reductions, food security, biodiversity, impact on soil, resistance from local people due to smoke, smell) could present significant barriers to biomass use if not properly addressed. Lastly, governments may improve the sustainability of bioenergy by establishing the appropriate criteria, indicators, certifications, support schemes and technical guidance to assess and monitor its impact.

In general, the one who is interested to invest on a CHP unit should have in mind the following [1]:

- Identify the energy demands (electricity and heat) that need to be covered. A key step in developing a CHP system is to define and quantify the heat and power demand profiles based on records.
- Identify the potential of biomass locally and define the amount that would be needed yearly. Contact local biomass provider to make sure that the supply of the biomass is available and secured. Selecting the most suitable biomass fuel, including its source, type, quality and quantity is also crucial.
- Contact engineering company and biomass boiler manufacturers to ensure a high-efficient biomass conversion technology, based on the selected biomass for the CHP unit.
- Contact an ESCO company that would help in the operation of the CHP unit.
- Estimate the CAPEX and OPEX of the CHP unit and don't underestimate the maintenance of the CHP unit and the corresponding costs. ESCO companies and engineering companies can provide such information and support the assessment of the power capacity of the CHP based on the needs.
- Consider the annual savings for using the CHP system or the revenues from selling the excess of electricity or heat. Identify and secure potential end-users if applicable
- Consider and comply with the local/national and European emission limits when applicable.
- Consider any investment subsidies, support funding, feed-in-tariff and feed-in premium, green certificate schemes, tax subsidies if applicable, that would boost the economic viability of the CHP investment.
- Perform a feasibility study. The main purpose of a feasibility study is to identify if the project is suitable for development. It is significant to establish the technical and financial viability as

earliest as possible. A feasibility study can be undertaken by qualified engineering consultants or technology suppliers.

Furthermore, it should be also highlighted that a key aspect in the biomass CHP investment is the sizing of the system. The approach to a biomass CHP system sizing and design is different from that of a gas-fired CHP system. As part of the feasibility of a biomass CHP system and its scheduling, the following aspects should be considered carefully, based on the needs:

- Availability of space for fuel delivery, handling and feeding. Biomass systems require more space than traditional fossil-fuel-fired CHP systems. Access for fuel deliveries and space for fuel storage should also be investigated.
- The type of biomass conversion system (boiler or gasifier) and the technology of power production.
- Cleaning of ash bins and additional maintenance requirements.
- The need for buffers/thermal stores.
- Integration with existing heating and electrical distribution systems and connection to the electricity distribution network. Determining where/how the CHP system will be installed and connected to fuel, heat and power systems.

6. Success cases

The following section includes success cases of small scale biomass CHP systems.

6.1 Volter Oy gasification CHP, Finland (40 kWel)

A CHP unit (Volter 40 CHP) by the Finnish company Volter Oy (https://volter.fi/) uses gasification to cogenerate heat (100 kW_{th}) and power (40 kW_{el}) from wood chips. The actual CHP device fits into a container for use outdoors or the same product comes as a model for indoors use (Volter 40 Indoor).

Volter 40 Indoor has Length 4820mm, Width 1270mm, Height 2500mm and needs a minimum free space for maintenance of 1200mm on both sides, 1000mm in control panel end and 1000mm in ash conveyor end. Its feeding unit has dimensions of Length 500mm, width 600mm, height 1800mm. It can operate for max 7,800 hours and it has an automatic ash removal system. The CHP operates with wood chips that have to be with less than 18% moisture (optimum <15%) and has a fuel consumption of approximately 4.5 m^3 per day or 38 kg/h at full power [47]. The unit cost (plus fuel conveyor) is approximately at 200,000 € [48].

Emåmejeriet (Emå Dairy) is a local producer of milk and dairy products in Hultsfred, Småland, Sweden. They decided to install a gasification plant (Volter 40 Indoor) where woodchips are converted into heat and electricity. The fact that Emå Dairy has replaced its oil-based heating system is partly due to reduced tax relief for the manufacturing industry, partly to the ambition to meet consumers' increased environmental awareness, but also to the fact that the existing heating system was in great need of redevelopment.

The wood chips (roughly fractioned woodchips) are fed to the top of the reactor and then move gradually downwards where they are consumed. Due to a lack of oxygen, a partial / incomplete combustion of the fuel takes place and gas is formed. The hot gas that is formed is energy-rich and combustible and can thus be used both to extract heat and to drive an ordinary internal combustion engine. The gas is led to an internal combustion engine which is connected to an electric generator. It transforms the mechanical work into electric energy that can either be used within the company or sold to the electricity grid. The residual product biochar can be used to bind nutrients and provide more efficient agriculture that does then not need additional fertilizer. A gasification process gives a high electricity yield, between 20 and 30%. At the plant in Hultsfred, the electricity yield is 23%. The CHP unit operates for maximum 6,000 hours per year, generating 240 MWh/year and 500 liters of ash per week. The repayment period was calculated in approximately 10 years (approximate total investment cost at 350,000 € [49]).

One of the lessons learned from the gasifier at Emå Dairy is that that a dry and homogeneous fuel is needed for the gasifier to function optimally. Moreover, the excess energy created inside the gasifier chassis is sufficient to dry incoming fuel to the gasifier down to the desired moisture content, which is below 15%. The results also show that a gasifier works best with an even heat production and an installation is therefore best suited for an operator with an even surface at a relatively low temperature, for heating buildings. At Emå Dairy, the heating system was supplemented with an accumulator tank to even out the heat demand, which can also be done in other places with fluctuating heat demand. Another important lesson was that the daily maintenance of the is important. The maintenance mainly consists of ash emptying, changing the oil in the engine and one general check of the system. Finally, it was concluded that if the right conditions are given to a gasifier, a gasifier will have a payback period of around 10 years. With higher electricity price, the repayment period can be shortened significantly [49].

In general, it is mentioned that based on the review of some of the 100+ examples of Volter projects that have been operating successfully, it can be seen that the biomass CHP solution achieves cost savings of >90%, a reduction in carbon footprint of 89% and a very healthy return on investment of 3 years [50].

Figure 20: The CHP unit by Volter Oy fits, Volter 40 CHP Indoor [47]

6.2CHP plant in Obertrum am See, Austria (132 kWel)

The end user is an energy contracting company operating several biomass plants in Austria. The HP142-132kW Heliex Genset was installed in May 2016 in Obertrum am See. The CHP (nominal power of 132 kW_{el}) was combined with a biomass district heating 6 MW_{th}. In 2014, Heliex's steam expander technology was presented to the end-user. They were interested in technologies that would generate electricity alongside the heat from their biomass system as part of an upgrade to their 6 MW biomass district heating plant in town. The Heliex GenSet offers a very simple, robust and cost effective power generation from systems that are built and designed to generate heat with steam as the heat transfer media. Investment costs per kW of the screw expander generator set (Heliex GenSet) are between 800 and 1,800 € per kW, depending on the size of the Heliex GenSet.

A Heliex GenSet was chosen by the end-user because it's an ideal solution for a district heating scheme due to its flexibility in operation, particularly at partial load conditions. It delivers a consistent power output, whatever are the demands of the network. The GenSet has a power output of 132 kWel. The availability of the installation was high with only very short outages for maintenance, where 8.600 operational hours were reached. Low maintenance costs and a low fuel price of around 30 € per MWh allowed a relatively low-cost production of electricity and guaranteed highly economical operation. Payback under the given conditions is expected under 3 years, even without subsidies [15].

Figure 21: Heliex GenSet installation in Obertrum am See (A) [15]

6.3ÖkoFEN Pellematic Smart_e, Austria (0.6 kWel)

ÖkoFEN is an Austrian company that specializes in pellet boilers and one of the leading suppliers of different solutions for various application areas based on renewable energy sources. From economical and convenient pellet heating systems to space-saving pellet tanks that can be applied to family homes, municipalities or industries.

ÖkoFEN also commercializes CHP solutions for small-scale applications. Such as their product ÖkoFEN Pellematic Smart_e (Figure 22) that is a combined heat and power pellet-fired boiler system that can be used in detached houses. The boiler produces up to 9kW of thermal energy and produces up to 0.6kW of electrical energy from the heat of the flue gases. The Austrian-designed boiler system uses an American-made Microgen Stirling engine-based generator to produce electricity which is available for the use in the house or for feeding into the public power grid. The whole unit needs only 1.5 m² of space and consists of a pellet boiler, a buffer storage tank with 600 l of hot water, the devices for both heating of spaces and domestic hot water, a stirling engine for electricity generation and an automatic pellet feeder. In addition, the system needs a storage for pellets [41]. An indicative cost for such system is at 24,000 € (incl. VAT).

Figure 22: ÖkoFEN Pellematic Smart_e CHP unit [41]

7. Conclusions

Combined Heat and Power Generation (CHP), or cogeneration, has been considered worldwide as the major alternative to traditional systems in terms of significant energy saving and environmental conservation. CHP is an important technology that through increased efficiency, it can produce both heat and electricity. Biomass CHP systems have received a great deal of attention over the past decade. Biomass CHP units, based on the state-of-the art technologies can be applied to a great range of capacity applications, from domestic appliances (less than 5 kW_{el}) to industrial or district heating appliances (up to 300 MW_{el}). Large and medium-scale CHP plant technologies based on biomass combustion have now reached a high level of maturity.

The most promising target in the application of CHP lies in energy production for buildings, where small scale and micro-scale CHP are usually installed. "Small-scale CHP" means CHP systems with electrical power less than 1,000 kW_{el} and 'Micro-scale CHP' is also often used to denote CHP systems with an electric capacity smaller than 50 kW_{el}. Small-Scale and micro-scale CHP systems are particularly suitable for applications in commercial buildings, such as hospitals, schools, industrial premises, office building blocks, and domestic buildings of single or multifamily dwelling houses. Small-scale and micro-scale CHP systems can help to meet a number of energy and social policy aims, including the reduction in greenhouse gas emissions, improved energy security and the potentially reduced energy cost to consumers. A micro-/small-scale CHP system is also able to provide a higher degree of reliability since the system can be operated decentralized and independently of the grid. Currently, micro-scale and small-scale CHP systems are undergoing rapid development, and are emerging on the market with promising prospects for the near future.

The current catalogue presents an overview of CHP technology and focuses mainly on small scale applications, based on biomass. Aim of the catalogue is to provide general knowledge and basic information on biomass CHP units. The current catalogue can be also used as general guidelines/ handbook for a stakeholder who wishes to invest on a biomass CHP unit, by pointing out some initial information on several aspects of CHP technology and by highlighting some basic points/ concerns that should be taken into consideration prior to investing.

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