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BECoop
UNLOCKING THE COMMUNITY BIOENERGY POTENTIAL

D2.8 BECoop catalogue for the provision of technical support services – Final

APRIL, 2023

www.becoop-project.eu

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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.

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952930.

Project partners

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Abbreviations

CAPEX	Capital expenditures
CHP	Combined Heat and Power
CPC	Community Power Corporation
DH	District Heating
EED	Energy Efficiency Directive
EPBD	Energy Performance of Building Directive
ESCO	Energy service company
EU	European Union
GHG	Greenhouse gas emissions
MCPD	Medium Combustion Plant Directive
OPEX	Operating expenses
ORC	Organic Rankine Cycle
RED	Renewable Energy Directive
SPBT	Simple payback period

Executive summary

The present document constitutes the updated catalogue for the provision of technical support services of the BECoop project, funded by the European Union's Horizon 2020 Research and Innovation programme.

In particular, this updated version of the BECoop technical catalogue, in comparison to the initial one, includes the following enhancements:

1. **Minor revision to chapters 1, 2, 3, 4 and 5**.

2. Addition of a **new chapter (6)** based on the biogas plant catalogue, which follows the same structure as the previous catalogues. A **new Annex (IV)** has also been included to provide **more detailed information**.

3. **In chapter 7, a new section (7.4 - factsheet of biomass feedstock evaluation)** has been incorporated, which follows the same structure as the previous section.

4. **Abbreviations, References, Tables, and Figures have been updated** considering the new information included in the document.

BECoop project aims to unlock the bioenergy community potential. In order to achieve this goal, different actions are being developed along the project, such as workshops (about bioenergy, community, engagement of stakeholders, etc.), support of specific initiatives, identification of needs and challenges, and development of tools and services for the uptake of community bioenergy. BECoop wants to generate technical and business support to unexperienced stakeholders trough different documentation in order to avoid the barrier related to the lack of the information associated with the uptake of community energy/REScoop and the bioenergy initiatives. This documentation was reported in two deliverables, one associated with the technical support services (Deliverable 2.7 and 2.8) and the other associated with business and financial support services (Deliverable 2.9 and 2.10). Both have a first version published in January 2022 and a final version in April 2023.

Deliverable 2.8, which is associated with technical support services, comprises two types of inputs. The first is a technical catalogue format that describes different heating technologies by providing an overview of the technical considerations, information required for a preliminary profitability assessment, steps to be taken before deciding on investment, and stakeholders who can help obtain this information. The second input is based on factsheets that consist of several visual pages containing recommendations for specific topics related to biomass use that are important to keep in mind, even if they are not strictly related to the employed technology.

As a result, this report includes technical catalogues for: (i) biomass direct heating, (ii) biomass district heating, (iii) biomass co-generation for small-scale applications and (iv) biogas plants. At the same time, four factsheets are presented for: (i) solid biomass for small-scale applications, (ii) biomass logistic supply chain, (iii) solid biofuels production and (iv) biomass feedstock evaluation.

The reasons to select these technical services are explained in chapter 2, a deep overview of the information that can be found in each technical catalogue is reported in chapter 3 (direct heating), 4 (district heating), 5 (small-cogeneration) and 6 (biogas plants), the content of the factsheets together with some screenshots is detailed in chapter 7 and finally some conclusions in chapter 8.

In the Annexes, all the technical information is reported in case the promoter is interested in a specific technical catalogue and/or factsheet, and therefore it is highly recommended to also take a look at these sections' relevant information.

1. Introduction

This deliverable summarizes the main information carried out in the Task 2.4 of BECoop project, based on the provision of technical support services for unexperienced users that are interested in launching bioenergy communities.

According with this goal, the deliverable has been organized as follows:

- Initially, the methodology followed for the provision of technical support services, based on two different structures is described: technical catalogues and factsheets. The selection rationale of the technical solutions described are also indicated in this chapter, together with the structure that follow each technical catalogue and factsheet and therefore the information that can be found by the reader in these documents.
- Secondly, chapters 3, 4, 5 and 6 provide a deep overview of the main information of the four technical catalogues developed: (i) direct heating, (ii) district heating, (iii) small-cogeneration and (iv) biogas plants. The structure followed is the same in all chapters. It starts with the definition of the concept, the main technical considerations that should be considered, some aspects about how to assess the profitability, the stakeholders that can provide support, and the general steps to be followed to start with this initiative. Also, some real success cases are briefly presented.
- Thirdly, chapter 7, summarizes the information that can be found in the factsheets carried out based on: (i) solid biomass for small-scale heating applications, (ii) logistic supply chain, (iii) solid biofuels production and (iv) biomass feedstock evaluation.
- The last chapter includes the conclusions extracted from the current catalogues/ factsheets.
- Finally, since the chapter 3, 4, 5, 6 and 7 have been summarised with the goal to increase readability of this deliverable, an Annex section has been incorporated with the aim that the reader who is interested in a specific technical catalogue/factsheet can increase their knowledge about this topic with the information included in the Annex.

2. Methodology

2.1 What are the technical catalogues and factsheets?

The technical catalogues and factsheets were developed for the provision of technical support to community bioenergy projects. The aim is to offer potential communities access to easily understandable information that could help them to understand basic knowledge about the technical solutions in order to identify which one could fit better according to their needs and some recommendations to uptake a specific project based on bioenergy communities.

In order to carry out this technical support services, two different documents were proposed, one named "technical catalogue" and the other "factsheet".

The technical catalogue is based on a report, which main goal is to present, to the target audience and in an easy-to-understand manner, the bioenergy heating solutions selected by BECoop (see section 2.2), seeking to provide an overview of the technology process but also the steps that should be followed for its implementation. Additionally, the type of stakeholders (not to be confused with a list of stakeholders), that can help in order to achieve this aim, is provided. If the user wants to identify specific stakeholders, the e-market platform (BECoop T2.3 - https://www.becoop-project.eu/tools/e-market-environment/) should be used.

The factsheets focus on key technical services that can complement the technical solutions compiled in the catalogue for the uptake of community bioenergy heating. Each factsheet has a two pages length and is presented in a visual way in order to provide some general information and recommendations about different technical services that the stakeholders could be interested in promoting.

2.2 Technical catalogues and factsheets rational

Once the basic configuration of the technical support services was proposed, the effort was allocated to define the technical catalogues and factsheet to develop. For this aim, the previous work carried out under the BECoop project was considered. D 2.2 [1] concluded that the most relevant technologies for the goal pursued by BECoop (residential sector ad small-heating applications) were based on (i) direct heating, (ii) district heating, (iii) small-cogeneration and (iv) biogas. Each of these technologies have been described in an independent technical catalogue, Table 1.

Additionally, other activities were also identified due to their relevance: biomass logistic supply chain and solid biofuels production, or general necessities about gaining knowledge based on solid biomass for small-scale heating applications and biomass resource assessment. These four key technical services were agreed by the consortium and as result it was decided to develop a factsheet for each one of them.

The technical catalogues and factsheets selected were discussed and ranked by all consortium partners with the aim to ensure and confirm that all the technical necessities indicated in [1] were the most interesting to develop in order to unlock the potential of bioenergy communities. As a result, the most voted were district heating technical catalogue and biomass logistic supply factsheet, even though all the technical catalogues and factsheet were considered important by the consortium partners.

Table 1 summarizes the technical catalogue and the factsheets which are part of the BECoop technical support services.

Table 1. Technical catalogues and factsheet that

Technical catalogue	Factsheet
Direct heating with biomass	Solid biomass for small-scale heating applications
Biomass district Heating	Biomass logistic supply chain
Biomass co-generation for small scale applications	Solid biofuels production
Biogas plant with biomass for small scale applications	Biomass feedstock evaluation

2.3 Technical catalogues and factsheets rational structure

In order to define the structure of the technical catalogues and the factsheet, various meetings were carried out between the technical partners of the consortium (CIRCE, CERTH and WUELS) to agree about the structure and the information that each technical support services should include.

2.3.1 Technical catalogues

The main goal of these technical catalogues is to have a reference document that will let the promoter/s of an idea to better identify and address the dialogue with the proper group of stakeholders in order to optimise the time and the decision making (according to the technology selected).

All the technical catalogues maintain the same core structure. Firstly, the technology concept is defined, seeking to avoid misunderstandings. Then, the following chapter provides an overview of technical considerations that the stakeholder should take into account in order to have a better idea of the bioenergy heating solution. The structure of this chapter can slightly change according to the technical catalogue considered, even though the main elements of the technical solution considered can be found in all of them. Furthermore, recommendations about how to determine the power required by the new installation and some operational and maintenance information related to the use of biomass for the technology selected, are provided.

Once the concept and the technology are understood by the promoter, the following step address the importance to provide some guidelines about how to assess the profitability of the new activity. It is important to point out that the profitability should be assessed for each specific case, while in this chapter only general considerations are given that might be applicable for some case but not for others. For this reason, the last chapters focus on the stakeholders that can support the promoter to uptake the new project in each of the steps needed in the process prior to investing in the new initiative.

2.3.2 Factsheets

The factsheet goal is to display in a visual and direct way the main considerations that needs to be considered by the promoter.

All the factsheets follow the same basic structure. Firstly, a summary of the information together with some key words are included aiming to provide an overview of the information that can be found. Then, a general description of the steps to be considered, followed by the main technical section, which differs according to the topic of the factsheet. Finally, some recommendations about the relationships with other stakeholders or the market conditions can be found.

Each individual catalogue and factsheet can be found on the BECoop website, via the following link: https://www.becoop-project.eu/resources/technical-support/

3. Direct heating technical catalogue

This chapter summarizes the technical catalogue about direct heating with biomass with the aim of providing a deep overview of this technical technology and the steps to be followed in order to be implemented, even though if the reader wants to develop a direct heating it is highly recommended to read the Annex 1, in which more information it is provided, mainly about the technical considerations to be taken into account.

Important: This technical catalogue provides general recommendations that should be considered to facilitate initial communication with energy services/engineering companies for a project. However, the final decisions on the installation and the types of equipment and technologies to be used will be made by these companies.

3.1 Direct heating concept

Biomass direct heating/cooling refers to the systems in which the conversion of energy into heat takes place in the independent boiler at the site to be heated. In other words, in the direct heating systems the heat generation and consumption is realized in the same object. Therefore, the direct heating system may take place not only in the strictly single households, but also in smaller family buildings, institutional buildings or offices, where the heating unit is located within or by the building. Whereas, district heating/cooling systems distribute thermal energy from a centralized source to many residential and commercial buildings through a network of pipes to provide space heating/cooling and/or hot water [2]. Examples of direct heating systems are shown in Figure 1.

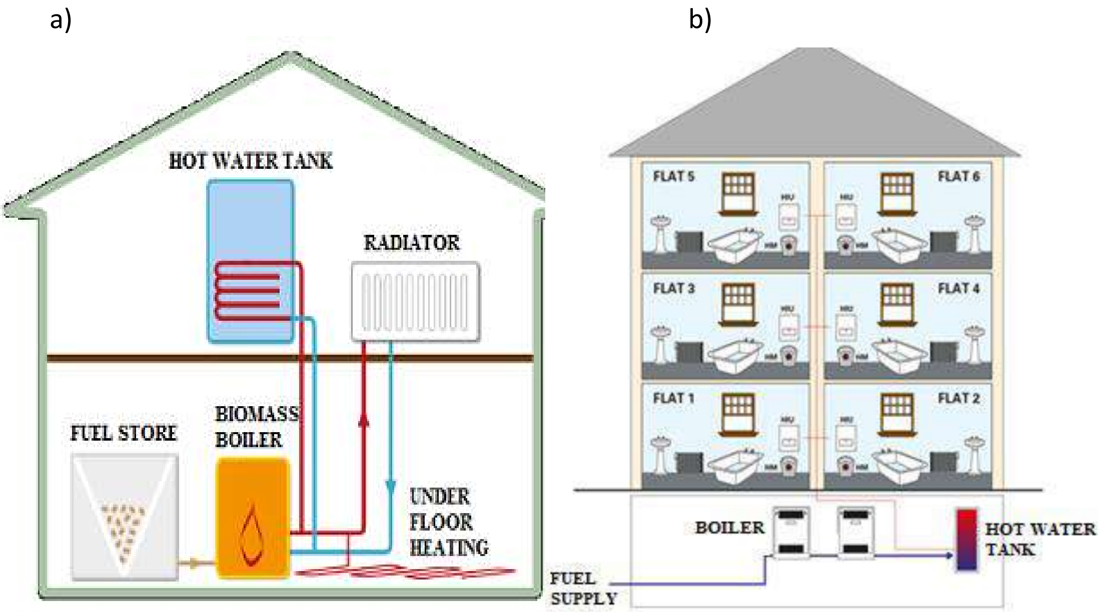

Figure 1. Scheme of direct heating system: a) single-family house [3], b) residential block [4].

3.2 Technical considerations

3.2.1 Main elements of a direct heating installation

In general, direct biomass heating installation consists of (Figure 2): (i) fuel storage/feeding system, (ii) the device for solid biofuel combustion, and (iii) heat distribution system in the object.

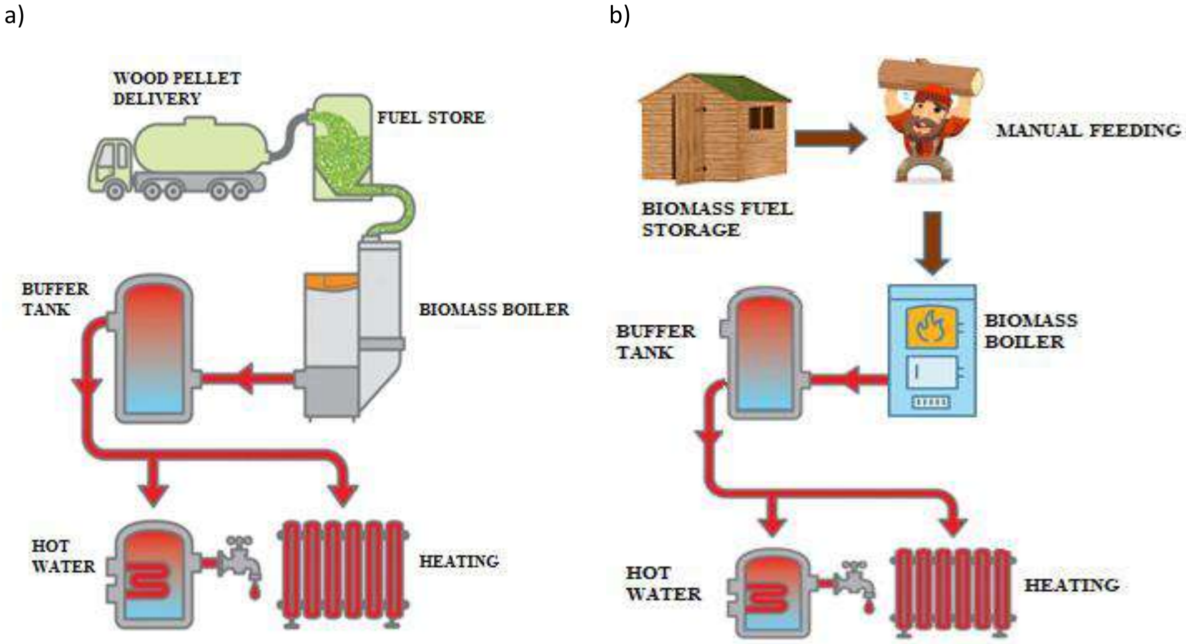

Figure 2. Main components of typical biomass direct heating installations [5]:

a) automatic system of direct heating; b) manual system of direct heating.

Depending on the form of biomass, thermal heat conversion technologies and final heat source carrier, the following devices for biomass combustion can be defined:

a) biomass boilers with water heating system (water is a heat carrier),
b) biomass ovens/stoves with air heating system (air is a heat carrier),
c) biomass gasifiers with water heating system (water is a heat carrier),
d) biomass gasifiers with air heating system (air is a heat carrier),
e) hybrid systems.

In practise, most of the solutions where biomass is used for direct heating purposes are characterized by its combustion in the boiler to heat the water. In these systems the buffer tanks (heat tanks, heat accumulators, thermal stores) are built-in to insure stable and effective operation of the heating system (the role of the biomass boiler is to boost temperatures in the tank rather than starting from cold each time heat is required [5]). Hot water (heat) accumulated in the tank is distributed to various types of the radiators located in the rooms (heat exchangers) or directly to the collection points for sanitary purposes.

In case of biomass boilers, the storage and/or feeding systems have to be foreseen that will insure the access to the biomass for a defined period of time (from few days to whole heating season). Depending on the form of the fuel (pellets, briquettes, logs, chips, bales, cubes) there are different solutions and possibilities related to the biomass storage and feeding systems.

The generated heat in the boiler from biomass combustion is distributed to the heated rooms/object. Different heat exchangers in the room are in use. It depends on many factors, such as temperature of the heating medium and technical solution of the system (floor heating, wall heating, roof heating, radiators under the windows, hot air heating). It is important that every kind of biomass boiler can be adapted to the existing/planned heating solution in the building.

3.2.1.1 Biomass boiler technologies

According to the form of biomass, different biomass boilers/technologies are developed. The biomass boiler can be powered by the following forms of solid biofuel:

a) pellets,
b) briquettes,
c) chips,
d) logs,
e) bales/cubes.

a) b) c)

d) e)

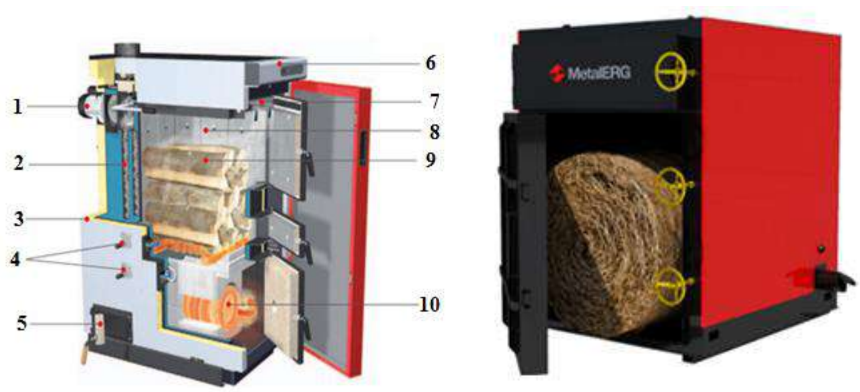

Figure 3. Different technology of biomass boiler according the form of the biomass resource to be fed. a) pellet boiler [6], b) briquette boiler [7], c) Wood Chip Boiler [8], d) wood logs fired boiler [9], e) straw bales fired boiler [10].

Additionally, the heat generation during thermal biomass utilization can be realized by its combustion process or gasification process. According to the EU Directive, all new boilers (lower than 500 kW for heating water or lower than 50 kW for heating air) must comply with the requirements of ECODesign [11].

Further information about the biomass boilers fired by each form of solid biofuel can be found in Annex I.

3.2.1.2 Storages and feeding systems

There are many solutions for the storage of solid biofuel, depending on the size, construction and form of biomass. The storage area should be large enough to be filled max. 3-4 times per year and also, and also to maintain the good quality of fuel, the storage method should prevent ingress of moisture and be free from any contaminants (stones, animal carcasses, metals, coatings or preservatives) [5]. The storage room requires proper ventilation to avoid rooting, decomposition and insure air access for maintenance of the proper hygienic/climatic conditions. It is recommended to clean a storage room once a year (after the heating season) [12].

Further information about storage and feeding systems by each form of solid biofuel can be found in Annex I.

a) b) c)

d) e)

Figure 4. Examples of fuel storage according to its size distribution. a) pellet storage in silo [13], b) briquettes storage in foiled pallets inside the room [14], c) woodchips storage [14], d) wood logs [16], e) bales storing outside logs [17].

3.2.2 Power of the direct heating

In general, the thermal power of the boiler is determined from the balance of thermal needs of the facilities supplied from the boiler room. It depends on many factors, such as: the type of the object, operation time (seasonal or full year), heat losses (house insulation), parameters of the heating medium, heating circuits, daily heat distribution (constant or variable power), ventilation system, technology and preparation of central hot water, the size of the heat buffer, or the proportion of individual components of the demand. As a result, the accurate estimation of the power and capacity of the biomass boiler is complex. However, there are some methods and indexes that enable the calculation of the thermal power of the boiler, for example:

a) European standards (EN 15316-3:2017),
b) approximate power of the boiler regarding the heat losses of the object,

c) cumulated boiler power determination regarding the biomass potential (i.e. in the region).

The power of the heating installation (boiler) and the amount of required biomass using European regulations and standards EN 15316-3:2017 [18] are determined based on the calculation of heat demand, efficiency of heat acquisition, storage, transfer, and total efficiency of the heating system. Its power is obtained by analysing the needs for specific purposes for a specific time (e.g. winter, summer, transition periods, etc.) according to the general formula:

$$Q_B = Q_{CH} + Q_{Vent} + Q_{Tech} + Q_{HW},$$

where:
Q_B – boiler room power, kW
Q_{CH} – heating power demand, kW
Q_{Vent} – demand for thermal power for ventilation or air conditioning, kW
Q_{Tech} – demand for thermal power for technological purposes, kW
Q_{HW} – heating power demand for domestic hot water preparation, kW.

The heat power demand for heating Q_{CH} is calculated according to the current standards or according to cubature indices. The demand for ventilation Q_{Vent} is determined according to air exchange ratio in the building (with possible reduction of ventilation intensity at low outside temperatures). Heat demand for domestic hot water preparation Q_{HW} is determined according to the consumption of hot water (e.g. for individual hygiene activities or according to the average indicators of daily consumption per inhabitant or user of a public facility). The components Q_{CH} and Q_{Vent} are a function of the outside temperature, while QTech and QHW usually do not depend on the outside temperature. This procedure requires some professional knowledge and should be performed by expertise person.

Less accurate, but much simpler method of thermal power of the biomass boiler estimation refers to the required unit power of the heating source necessary to cover heat losses per 1 m^2 of the surface (or per 1 m^3 of cubature) in the considered object. The formula is, as follow:

$$Q_B = UPD_{SA} \cdot SA$$

alternatively:

$$Q_B = UPD_{BC} \cdot BC$$

where:
Q_B – thermal power of the boiler, W,
UPD_{SA} – unit thermal power demand to heat the object's surface (Table 2), W/m^2,
UPD_{BC} – unit thermal power demand to heat the object's cubature (Table 2), W/m^3,
SA – surface area of the heated object, m^2,
BC – cubature of the heated object, m^3.

Table 2. The unit power and energy demand for heating the buildings [19] [20] [21].

Energy class	**Energy rating**	**Unit thermal power demand UPD**		**Final energy consumption FE, kWh/(m²·year)**	**Year of construction**
		W/m²	W/m³		
A+	Passive	<25	<10	<20	today
A	Low energy	40	15	20-45	2019-today
B	Energy saving	50	18	45-80	2010-2018

Energy class	Energy rating	Unit thermal power demand UPD		Final energy consumption FE, kWh/(m²·year)	Year of construction
		W/m²	W/m³		
C	Medium energy efficient	60	22	80-100	2000-2010
D	Moderately energy-intensive	70	25	100-150	Up to 1999
E	Energy-consuming	100	37	150-250	Up to 1998
F	Highly energy-consuming	120	48	over 250	Up to 1982

Additionally, based on the yearly heat demand by the object it is possible to determine the amount of biomass fuel required for heating purposes:

$$M_B = \frac{\mathrm{FE} \cdot \mathrm{HS}}{LHV \cdot \eta_b \cdot} \cdot 3.6$$

where:
M_B – the required amount of biomass to cover the annual heat demand by the object, kg/year,
FE – final energy consumption by the object, kWh/(m^2·year),
HS - heated surface of the object, m^2,
η_b – thermal efficiency of the boiler (η_b=0.85-0.92),
LHV – lower heating value of the biomass fuel, MJ/kg.

In case of lack of knowledge/data about the annual heat demand by the object, the approximate estimation of the thermal power of the biomass boiler can be estimated based only on the value of the heated surface area of the object/building/household. The example of such relationship for temperate climate is shown in Figure 5. It should be noted that under certain circumstances/conditions this value may differ significantly from the actual demand, and should be consulted with a specialist.

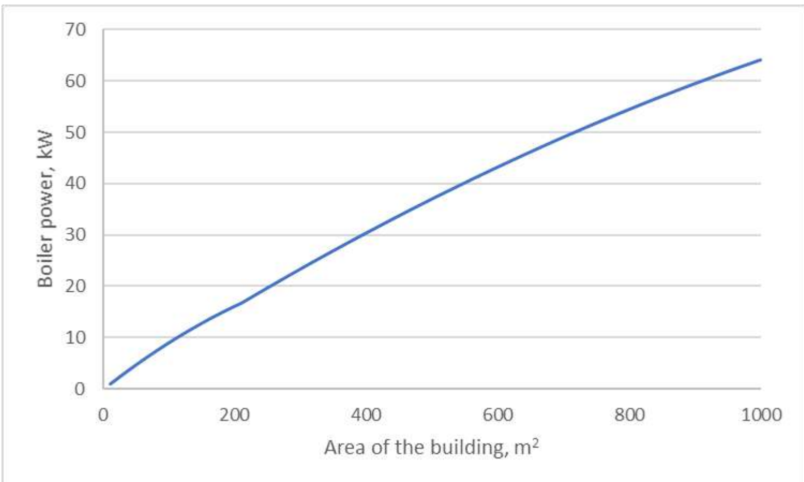

Figure 5. Thermal power of the boiler vs. Heated surface area of the building (in a temperate climate) [22].

3.2.3 Operational and maintenance of a biomass boiler

Operation and maintenance of a biomass boiler is highly sensitive to the quality of the biomass. The appropriate quality of biomass ensures safe and trouble-free operation of the boiler while maintaining high emission standards and a minimum involvement of use in the household heating process. In turn, it should be underlined, that the use of sub-standard fuel or municipal waste for heating can cause a range of issues/problems like:

- burning instability,
- increased pollutant emission,
- low combustion efficiency and increased fuel consumption,
- joking of conveyors,
- corrosion,
- slagging.

To avoid exploitation problems, biomass boilers should be selected according to the biomass fuels that will be consumed. Additionally, these biomasses should be sourced from sustainable suppliers. Some of the parameters of the biomass fuels that should always be considered are the following:

- moisture content – boilers are optimized for fuels with a moisture content within a specific range. Improper moisture can cause inefficient combustion, and excessive smoke and tar, as well lead to increased emissions.
- particle size – boilers are designed for specific particle dimensions. Using a fuel with another dimension than the one for which the boiler has been designed, can cause problems in the feeding or storage system.
- chemical composition of the biomass - for some fuels it may be also important to check for sulphur and chlorine content (to estimate corrosion hazard) and the amount of potassium and sodium (those alkali metals cause slagging and fouling).

A properly planned maintenance of a biomass boiler should ensure:

- the safe operation of the system.
- minimized breakdowns (failures).
- maximization of the operation lifetime of the boiler.

To plan the exploitation properly:

- the boiler's overhauls should be made minimum once a year,
- only high-quality biomass should be used,

- the biomass moisture, size and chemical composition should comply with the technical requirements of the boiler.

The main exploitation recommendation still remains to read the service or maintenance documentation of the boiler, although the biomass quality and chemical composition should be controlled as well.

3.3 Profitability of a direct heating

The profitability of the heating system basing on biomass utilisation depends on many factors, such as: range of the modernization work, the size of the system, how often it is used, a chosen fuel type or the reference fuel and heating system (to be compared with: oil, gas, coal, electricity etc.). Actually, each case requires to be assessed as an individual case study. However, taking into consideration some assumptions, the simple payback time period (SPBT) can be calculated from following formula:

$$SPBT = \frac{I_o}{AC_a}$$

where:
I_0–the value of the investment outlays, €,
AC_a – annual avoided costs, €.

The formula of annual avoided costs is as follows:

$$AC_a = (HP_2 - HP_1) \cdot EC_a$$

where:
HP_2 – unit heat price from conventional energy source, €/GJ,
HP_1 – unit heat price from biomass fuel, €/GJ,
EC_a – annual energy consumption, GJ.

Table 3. Estimated unit heat prices depending on the type of the fuel (Poland) [23].

Fuel	Unit heat price,	
	€/GJ	€/kWh$_t$
Eco-pea coal	9.56	0.03
Culm coal	6.19	0.02
Hard coal	8.26	0.03
Pellet class A1	11.05	0.04
Pellet class A2	10	0.04
Pellet class B	10	0.04
Briquette	7.65	0.03
Wood	5.71	0.02
Gas (methane)	8.82	0.03
LPG	21.6	0.08
Oil	15.79	0.06
Electricity	36.1	0.13

Therefore, it is difficult to give the annual running costs of a biomass boiler without knowing the specifics of the project, the local fuel prices and servicing options.

In case of the investment outlays in heating unit, the cost of the biomass boiler (ca. 20-25 kW) for a single household is in the range of 1,300-4,500 €, which is very similar to coal, gas or oil boilers (in case of simple solutions), or likely higher (in case of more sophisticated and fully automatic solutions).

The small capacity boilers (up to 100 kW) used for space heating may require only one single service per year. In case of larger boilers with more extensive utilization for process heating, more frequent maintenance is required/recommended (2-3 times per year).

It terms of biomass fuels, wood chips are cheaper than wood pellets, so this will influence the running costs. If owners have their own fuel supply (own forest/woodland, straw from field, pruning from orchards), then wood logs/straw bales/pruning (if they contain low moisture content) can be directly used for energy purposes which leads to significant reduction (30-50%) [24] [25] of heating costs.

Besides the economic aspects, there are many other benefits relating to the use of biomass for energy purposes, especially over fossil fuels:

- combustion of biomass residues reduces the disposal and removal costs,
- biomass from local resources is cheaper, and the fuel price is more stable,
- the process is carbon neutral (the amount of CO_2 released during its combustion is the same as the amount of the CO_2 absorbed during the plant growing),
- it is a sustainable and renewable fuel that can reduce the pollutants emission by up to 96% [24] [26] [27],
- supports local development (job creation, taxes) of the whole biomass chain market,
- much lower ash generation than coal (reduction of the problem of furnace waste management),
- biomass ash can be used as fertilizer avoiding disposal costs,
- biomass contains much less ash reducing the frequency of emptying the ash bin in the boiler,
- no or much lower sulphur oxides emission during combustion (in comparison to coal or heavy oil).

The approximate environmental savings/differences for most common fuels used for heating are shown in Table 4 and Table 5.

Table 4. Characteristics of commonly used solid fuels and electricity [28] [29].

Fuel	Density, kg/m^3	Unit CO_2 emission, g CO_2/kWh	Unit calorific value, kWh/kg
Wood chips	250	7	3.5
Wood pellets	650	15	4.8
Wood logs	350	7	4.1
Miscanthus (chopped, 25% MC)	140-180	8.3	3.6

Fuel	Density, kg/m^3	Unit CO_2 emission, g CO_2/kWh	Unit calorific value, kWh/kg
Wheat grain (15% MC)	760-780	86	3.9
Hard coal	800-1,000	354	7.5-8.6
Peat	400	382	3.8
Coke	450-650	461	8.0
Electricity	n/a	530	n/a

Table 5. Characteristics of commonly used liquid and gaseous fuels [28] [29].

Fuel	Litres	Unit CO_2 emission, g CO_2/kWh	Unit calorific value, kWh/l
LPG	1	323	6.6
Heating oil	1	350	10
Natural gas (methane)	1	330	11.4

3.4 Stakeholders needed

In case of direct heating of households using biomass boilers the need of engagement of different stakeholders might be required, in example:

a) Biomass producer/provider,
b) Biomass boiler producer/seller,
c) Biomass boiler and heating system installer,
d) Adviser specialized in founding acquisition.

Biomass producer/provider.

In terms of the development of local cooperatives or energy communities, heating households and other buildings with biomass depends on its availability in the region and the final form/shape that is required by the boiler. Therefore, the identification of the local biomass potential (amount and type of biomass available), suppliers (farmers, forest owners, national forest authorities, wood processing companies) and producers (companies processing biomass into pellets, briquettes or wood chips) is of key importance from the point of view of planning the heating system/installation. In some cases, biomass (straw bales, logs and even wood chips) can be sourced directly from the biomass producers, which reduces fuel costs and, therefore, it could improve the project profitability since intermediate steps with other stakeholders are avoided. These data are needed for the selection of the boiler structure, storage system and investment scheme. Moreover, in the case of demand for larger quantities of biomass, long-term contracts for its supply may be required (ensuring continuity of supplies, determining fuel costs, agreeing on the requirements as to its type, form and quality). In case you need to contact local biomass producers/suppliers, it is recommended to visit the e-market platform (https://www.becoop-project.eu/tools/e-market-environment/) where you can find local biomass suppliers.

Biomass boiler producer/seller.

In case of decision making on the type of biomass used for heating purposes, it is necessary to purchase an appropriate heating unit that will be able to provide the required thermal power and meet the current standards requirements in the context of emission of pollutants into the atmosphere or the achieved combustion efficiency. There are many solutions for biomass boilers available on the market, which differ in appearance, design, fuel supply, ignition system, flue gas cleaning, and ash removal from the furnace. The mentioned aspects have an impact not only on the usability of the boiler, but also on the final price. It should be noted that direct contact with the boiler manufacturer is recommended only in the case of installations for larger objects or a larger group of users (power above 100 kW), where heat will be produced in one heating unit of greater power. This is due to the fact that it may be necessary to individually adjust the boiler to the existing or planned boiler room or the required heat flux with specific physical parameters. It is also possible to change the design in order to adapt the boiler to the combustion of a specific biomass fuel available on the local market or adopted in a given project. In higher power boilers, their manufacturers often allow some design modifications. In the case of lower-capacity boilers, typical for households, a direct contact with the boiler manufacturer is rather unnecessary. Producers usually have their distributors and sales representatives in given regions, who are responsible for the site visit and advice on the selection of the heating unit. In this case, it is recommended to contact a sales representative and an installation and service company (ESCO) that operates in the local market. Before the final selection of the heating boiler, however, it is recommended to review (webpage visit) the existing solutions in order to gain knowledge of not only technical but also visual possibilities. The list of potential producers or suppliers of biomass boilers can be found on the e-market platform (https://www.becoop-project.eu/tools/e-market-environment/).

Biomass boiler and heating system installer.

In order to replace the existing heating system, boiler or install a new heating system, you may need to contact the installation and service company, which has the appropriate qualifications and will professionally carry out the necessary installation works. These types of companies also provide appropriate technical advice in the selection of thermal power, the necessary additional equipment and the scope of installation works (sometimes the modification of flue gas outlet system or chimney is required). It is recommended that the entire investment process from the technical side (boiler delivery, materials and installation works) to be performed by one contractor. This will allow you to avoid possible problems related to the liability and warranty for the service provided by the installation and service company. It is also advisable that the contractor is an authorized installation company of the boiler manufacturer, which additionally guarantees the quality of service and the confirms contractor's experience. Carrying out maintenance services and having a company headquarters in a given region is an additional advantage, as it shortens the time of potential response to service requests and arrival at the customer. The e-market platform (https://www.becoop-project.eu/tools/e-market-environment/) can help in looking for local installation and service companies.

Adviser specialized in funds acquisition.

At the investment stage, it may be necessary to obtain additional funds necessary for the implementation of the project. A financial advisor has the appropriate knowledge where to look for financial support, the current national or local support programs, can propose the best financing model or banks offering convenient loans and repayment schemes. The right advisor can help you develop an appropriate business plan and project implementation strategy. It should be noted that in the area of activities related to environmental protection in the region, appropriate advisors also work at the local commune office. It is worth remembering that among consulting companies you can find institutions that help in writing applications and projects enabling the acquisition of funds from EU programs. The support can be found also in organizations such as research centres, energy cooperatives, energy clusters, etc. which can advise on the procedures and steps of the investment process. Consulting companies operating in this area can be found on the e-market platform (https://www.becoop-project.eu/tools/e-market-environment/).

3.5 Steps to be followed

This chapter intends to summarize and chronologically order the general steps to be done by the promoter of the idea of a biomass direct heating starting from the beginning.

Check if there is a heating network nearby that distributes the heat generated in the biomass combustion process

The direct contact with local heat distributing/operating company (if there is in the region) is recommended to validate the possibility and conditions of connection to the central heating network. The final user can contact also a local municipal office about the potential options/plans and regulations related to the heat supply of your building.

Check if there is an interest and the possibility of creating an energy cooperative in the immediate vicinity

The contact with the local municipal office about the existence or potential plans related to energy community creation is recommended. Furthermore, you can ask your neighbours if they are interested to create an energy community. You can also look for a local energy cluster for help or potential engagement in this field.

Select/choose the type and form of biomass to be used for heating your household

It is recommended to visit the website www.becoop.eu, where are the adequate helping/supporting materials such as: fact sheets about biomass, its form and properties. You should read section 3.1.1 including the description of biomass boiler technologies to be more familiar with the practical aspects of biomass utilization for energy purposes. It should help you make a decision.

Determine the power of the heating boiler

It is recommended to read section 3.2. It will help you estimate the boiler power based on your heating demands. You can also visit the e-market platform (https://www.becoop-project.eu/tools/e-market-environment/) to find the contact data of professional companies or energy advisors in your region, that will help you in this issue.

Contact the company providing services in the field of heating installations for consultation and determination of the scope of installation works

It is strongly recommended to visit the e-market platform (https://www.becoop-project.eu/tools/e-market-environment/). It will help you find the professional company dealing with biomass boiler installation.

Look for a local biomass supplier for your boiler

You should visit the e-market platform (https://www.becoop-project.eu/tools/e-market-environment/) to find a local biomass fuel supplier. It is important to secure the fuel of your boiler beforehand.

Check the space for your boiler in the technical room

You should familiarize yourself with the guidelines contained in the boiler's technical and operational documentation. You can also use the e-market platform (https://www.becoop-project.eu/tools/e-market-environment/) to find an installation company or a boiler supply company that will advise you on this issue. Optionally, you can contact the boiler manufacturer for the necessary information.

Prepare a place for biomass storage during the heating season

It is recommended to read section 3.1.2, where you can find basic information related to storage conditions of a given form of biomass.

3.6 Success cases

In this section some initiatives already implemented will be described seeking to raise awareness regarding the possibility to successfully develop a biomass direct heating and get a better idea of the average cost.

3.6.1 Gospodarstwo Sadownicze, Poland (600 kWth)

Gospodarstwo Sadownicze (Komorów, Poland) is the local pioneer that in 2013 started a commercial use of pruning biomass from apple orchards for energy purposes. In Mazovia Province there are more than 103,000 ha of orchards available, and more than 77,000 ha are apple orchards. The owner, thanks to his engagement and determination, created a whole logistics value chain of biomass utilization (Figure 6). The harvested biomass from his orchard (ca. 130 t/year) is delivered, in the form of large bales (90x120 cm), to the final users he has found during the market research.

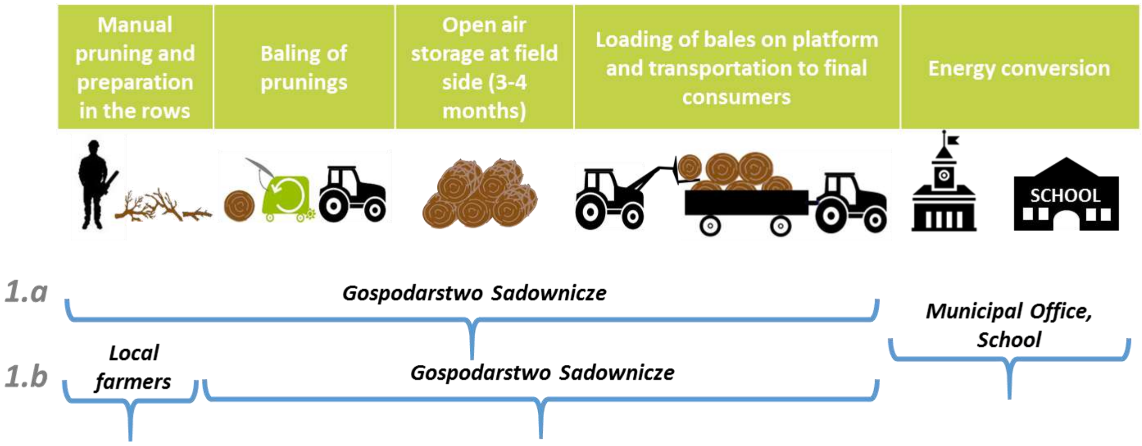

Figure 6.The logistics value chain of biomass utilization for energy purposes in rural area [30].

The bales of prunings are used for heating the municipal buildings in the village of Wieniawa (the Municipal office, the Secondary School Complex and the Healthy Centre) which are at a distance of up to 15 km from the orchards. The biomass is burnt in the medium-sized boilers (thermal capacity 250-600 kW) to heat the object and produce hot water (Figure 7).

a) bales from biomass

b) heat plant

c) biomass boiler

Figure 7.Use of local biomass for direct heating [30].

3.7 Summary

This report allows to acquire the basic information on direct heating of households, small public buildings, workshops and private plants using solid biomass fuel. The most important solutions of direct heating, heating units as well as methods and guidelines for storing biomass fuels of various forms were discussed. The attention was paid to the operational and environmental aspects of using biomass for heating purposes. The guidelines for the potential end-user and the issues requiring answers that are necessary when using / changing a biomass-based heating system are presented. Simple equations have been proposed that allow to estimate the required boiler power, the amount of biomass covering the annual heat demand, and to calculate the savings resulting from the use of biomass and a simple payback period. The final part contains examples of existing solutions for heating systems based on solid biomass.

4. District heating technical catalogue

This chapter summarizes the technical catalogue about biomass district heating with the aim of providing a deep overview of this technical technology and the steps to be followed in order to be implemented, even though if the reader wants to develop a district heating it is highly recommended to read the Annex II, in which more information it is provided, mainly about the technical considerations to be taken into account and the information that can be provided by each type of stakeholders.

Important: This technical catalogue provides general recommendations that should be considered to facilitate initial communication with energy services/engineering companies for a project. However, the final decisions on the installation and the types of equipment and technologies to be used will be made by these companies.

4.1 District Heating concept

A "district heating" or centralized systems for heat production based on district networks, is understood as a centralized system of production and distribution of thermal energy (heat) to an entire neighbourhood, district or municipality, which allows connecting multiple energy sources to multiple points of energy consumption and distributing it to the buildings through a piping system that transports a thermal fluid (hot water, cold water, thermal oil...) to the exchange points in the buildings [31].

Figure 8. Scheme of a District Heating [32].

In particular, district networks allow the efficient use of heat generated by waste heat from industrial processes, natural geothermal sources, energy recovery from solid urban waste and the use of renewable sources that are easier to integrate into centralized systems, such as biomass or solar energy. In particular, this specific catalogue will be focused on biomass district heating networks.

The use of biomass enables the use of autochthonous and renewable energy resources while contributing to create local employment in the municipalities where the valorisation initiative is implemented. From the economic perspective, biomass usually has a lower price than conventional fuels and, additionally, environmental benefit derive in terms of forest cleaning, which contributes to reduce forest fire risk, prevention of open-fires (as for instance of agricultural pruning) and the reduction of CO_2 emissions due to the substitution of conventional fuels by biomass.

From the point of view of the users, modern district networks could offer economic and technical benefits. It could contribute to reduce operation and maintenance costs related to the boilers placed in each building, and the district network producer can offer more efficient energy services to the consumer.

District networks also facilitate competition between different heat sources and fuels. For this reason, it can become an important element in a liberalized energy market.

There are other factors to consider, for instance, district networks facilitate the provision of a range of efficient energy services throughout the community. They provide fuel flexibility for the future, boosting the use of new renewable sources, and due to the low CO_2 emissions achieved they can be integrated more easily than individual installations, whether they are detached houses or buildings, where the grid quickly provides an easy route for supply to a large number of consumers.

Finally, it should be remarked that there is another catalogue addressing direct heating (chapter 3 and Annex I) that should not be confused with district heating. The district heating catalogue, as previously mentioned, focus on a central installation covering the energy demands of different buildings (physically separated) while in the direct heating the central installation covers the energy of a single building.

4.2 Technical considerations

4.2.1 Main elements of a District heating installation

The main goal of this chapter is to provide a general overview of the main technical elements of a district heating in order to facilitate the conversation and the agreements with the energy service/engineering company in charge of the design and development of the district heating installation. The main elements to consider are:

- Generation plant: heat production in these systems is carried out centrally to meet the demand of the several consumers. This way, individual equipment that should be placed otherwise at the points of consumption (houses or buildings) can be avoided, while it is possible to have more energy-efficient technologies installed at the generating plant (more efficient equipment and operation & maintenance are carried out by professional staff in order to avoid operational problems).
- Distribution piping network: the piping network allows the distribution of fluids (normally water) through insulated pipes to minimize thermal losses. By means of a thermal fluid, the energy is transported to the users, where the heat is transferred to the consumption points by cooling the fluid. The network also has a return circuit to the plant. The pipes are usually distributed in subway trenches that follow the layout of streets in urban areas.
- Substations: the heat transfer between the distribution network and the consumers (buildings or houses) is carried out through a substation consisting of a heat exchanger and the elements that regulate, measure and control the correct operation of the installation.
- Control and management of district heating networks

4.2.1.1 Generation plant

When establishing the technical requirements to be met by the installation to be able to use biomass, it is important to focus not only on the boiler, but also on the entire feeding and storage system, since many times it is where the greatest source of clogging occur.

Storage area

Next to the generation plant, it is essential to have enough space to store at least the amount of material necessary to supply the boiler for a minimum period of time (a minimum period of at least 2 weeks is recommended). This storage must be located adjacent to the room where the boiler is located but cannot be located together according to the regulations.

The volume of the storage area will be defined considering the following aspects:

- Amount of biomass to be stored, where the self-sufficient target of the plant for a certain period of time has to be considered.
- Bulk density of the biomass to be stored, it will depend on the biomass selected and the size distribution of this biomass. In order to have an estimative value of the bulk density of different biomass, the BECoop Factsheet "Solid Biomass for Small-Scale Heating Applications" (Annex IV) can be consulted.
- Average consumption of biomass per day.

Taking into account the previous considerations, the approximate storage area can be calculated by means of the following formula:

$$\text{Usable volume needed} = \frac{\text{consumption of biomass per day}\left(\frac{\text{kg}}{\text{day}}\right) \times \text{ number of days to be self} - \text{sufficient (days)}}{\text{bulk density of the biomass }(\frac{\text{kg}}{m^3})}$$

Even though, the final surface needed will depend upon the equipment selected for biomass storage. It is possible to choose between a vertical silo, a feeding chamber or pit, a top loader or even a mobile floor. This final decision must be made by the energy services company that carries out the installation, taking into account the final location of the generation plant, the biomass selected and the available space. More information about storage systems, according to the size distribution of the biomass selected, can be found in the section 3.1.2 of the BECoop technical catalogue "Direct Heating" (Annex I).

Feeding systems

The feeding system is also usually a critical point for three reasons:

- Biomass is sometimes heterogeneous (which makes its flow very difficult in certain systems) and can cause clogging, therefore it is necessary to ensure a homogeneous particle size.
- Possibility that the shredded material contains exogenous materials of non-negligible size (stones, wires, ...), it is not very common in the case of forestry woody biomasses, although in the case of agricultural resources it can occur.
- High inorganic content in the fines (soil, sand, dust) that can affect the accelerated wear of the feeding systems, this will be influenced by the collection system used on the field and the pre-treatments carried out to obtain the final biomass product.

Generally, the most common feeding system (in small installations) used is by means of screws conveyors (in this sense, it should be noted that normally the lower the angle of inclination, the lower the probability of clogging).

Thermal power plant

The generation plant is the core element of a district heating network and where the heat is generated and distributed to the buildings through the distribution network.

The generation plant is located inside a building built for this purpose, exclusively for the production and pumping of hot and cold water. The power generating elements (boiler room), as well as the main pumping units, which drive the heat transfer fluid to the different consumption points, are located inside this building.

The thermal power plant operates automatically, depending on demand, regulating its operation with a control system that takes data from the consumption points and from the plant itself. The operating time of the generation equipment depends on the installed power compared to the thermal demand and the capacity of the existing accumulation systems (water accumulators, buffer tanks, etc.).

The connection of the water supply network supplied to the boiler room will consist of valves, pipes and manholes that allow the cutting or isolation of sections in case of failure of any of them.

As previously mentioned, more information can be found in the original file of the technical catalogue in Annex II.

4.2.1.2 Distribution piping network

The distribution network is a network of insulated pipes that distributes the thermal energy (thermal fluid) from the generation plant to the different buildings.

The heat transport line consists of two pipelines (with their corresponding collectors), one for the supply and one for the return. In the case of centralized heating and cooling networks, it might be necessary to insure four pipes.

There are three main factors to be considered to design the distribution piping network:

- Where the pipes should be located? The current trend is to install underground installations for visual and safety reasons, even though the investment cost is lower in surface installations.
- Type of material to be used. Larger pipes are usually made of carbon steel and for smaller diameter pipes plastic materials are being used, such as cross-linked polyethylene.
- The selection of the type of insulation is quite relevant since it has an influence on the overall efficiency of the system. It should be taken into account that in the distribution networks is where the greatest performance losses occur in this type of installations, which can range between 5 and 10 % (taking the latter as a very conservative value).

In addition to the pipes, the distribution network incorporates other elements necessary for its proper and optimum operation: fixed points for expansion control, pre-insulated sectioning valves, air trap located at high points, discharge or emptying points (valves) located at low points, expansion elements, branches for service connections, manholes, junctions with existing services, filters, pressure and temperature gauges, etc.

4.2.1.3 Substations

The heat produced in the generation plant is transported through the distribution network and finally reaches the consumer through substations located near the consumption points. At the substations, the pressure and temperature of the network are adapted to the conditions of consumption.

In each building there is a heat transfer substation, consisting of a heat exchange system, without fluid or pressure exchange, through which heat is transferred to the terminal elements for heating, cooling and domestic hot water service.

In the substations, in addition to the heat exchanger, there are regulation and control elements and metering equipment for billing the thermal energy supplied from the network to each end user.

4.2.1.4 Control and management of district heating networks

The main aim of the control of the district heating networks entails the regulation between the generation of energy and the real demand in the network in each moment. Another important variable to regulate is the control of the supply and return operating temperatures, which is usually based on the outside temperature.

In order to adjust the supply of the thermal energy, the most common solution is to regulate the supply temperature and the flow of the thermal fluid.

This control is usually managed through a “supervisory control and data acquisition” (SCADA), this supervision will allow the optimization of the operation of the network and will increase the safety of its operation. The control and monitoring of the installations include the elements of the power plant and, in some cases, the regulation and measurement substations of the consumption points.

4.2.2 Power of the District Heating

The real power of the installation should be calculated by an expert company in this field, as for instance an energy service company with expertise in biomass district heating, even though in order to assess this profitability the user should provide some input information.

4.2.2.1 Buildings

It is necessary to identify the buildings to be covered by the district heating network, here two stages can be differentiated:

- 1st stage: This step refers to the buildings, which the current energy demands should be covered at the moment of the implementation of the district heating.
- 2nd stage: Additionally, it is often the case, where there is a possibility that other buildings will join in the future. If possible, an estimation of these building should be also done at the initial stage, since this could be also considered at the moment of the design of the district heating, but without making the mistake of greatly oversizing or downsizing the installation from the beginning.

The location of the buildings should be indicated along with their distance to the plant. If possible, a map considering the roads, buildings, and so forth will facilitate this information and the future steps regarding the design of the piping network.

4.2.2.2 Energy demand

From the buildings previously identified, the energy demand of each of them should be known in order to determine the power of the installation. To obtain this data, the invoices can be checked and reported. It is recommended to provide the data from, at least the last three years, in order to have a representative energy demand of each building.

Additionally, if possible, the power of each individual installation should be provided along with a consumption curve of each building. This will allow to know when the power consumption is carried out in each building throughout the day.

Sometimes, the previous data cannot be obtained. In that case, it could be useful to provide information about the building to be heated, as for instance:

- What type of building is it? Residential? Office? Sports centre? Swimming pool?
- Year of construction of this building? What type of insulation?
- Useful surface to be heated in each building?
- Are people living/working all the time?
- Number of hours that it is heated along the day.

The same information should be provided about the domestic hot water (DOC) and cooling (if cooling wants to be covered in the DH), if possible.

4.2.2.3 Power of the installation

Taking into account the buildings to be covered, where they are located, and the energy consumption of each building, a first estimation about the power needed of the installation can be done. In order to do so, these main considerations should be taken into account:

- Final energy consumption: it means the sum of all the useful energy of each building, this will imply the average thermal demand to be consumed and therefore the minimum amount to be generated each year.
- Maximum power to be supplied: since there are moments where the heating demand will be higher than the average, this should be assessed to calculate the power of the installation, normally through the consumption curve. In this sense, the accumulation systems can mitigate these punctual moments, and therefore an appropriate design of the volume of this equipment and the power of the installation should be properly established.
- Heating losses in the network: as mentioned, there will be energy losses in the distribution of the thermal fluid to the different substations. These energy losses will depend on the parameters indicated in the section 3.1.2 of the Annex II. As starting point, 5 and 10% [26] of energy losses

could be considered (taking the latter as a very conservative value). This mean, that 5-10 % more of energy should be generated in the output of the biomass boiler.

- Yield of the biomass boiler: biomass boiler doesn´t have a yield of 100 % (although in the case of condensation biomass boiler this can happen), normally the yield ranges between 85-93 %. This fact should be considered in order to assess the real power of the installation.
- Additionally, more specific aspects should be considered as for instance the climate conditions of the area where the district heating is going to be located.

Figure 9 provides a basic estimation of the energy that should be provided in the different elements of the district heating network, even though this calculation is more complex and, therefore, should be carried by an expert in this field.

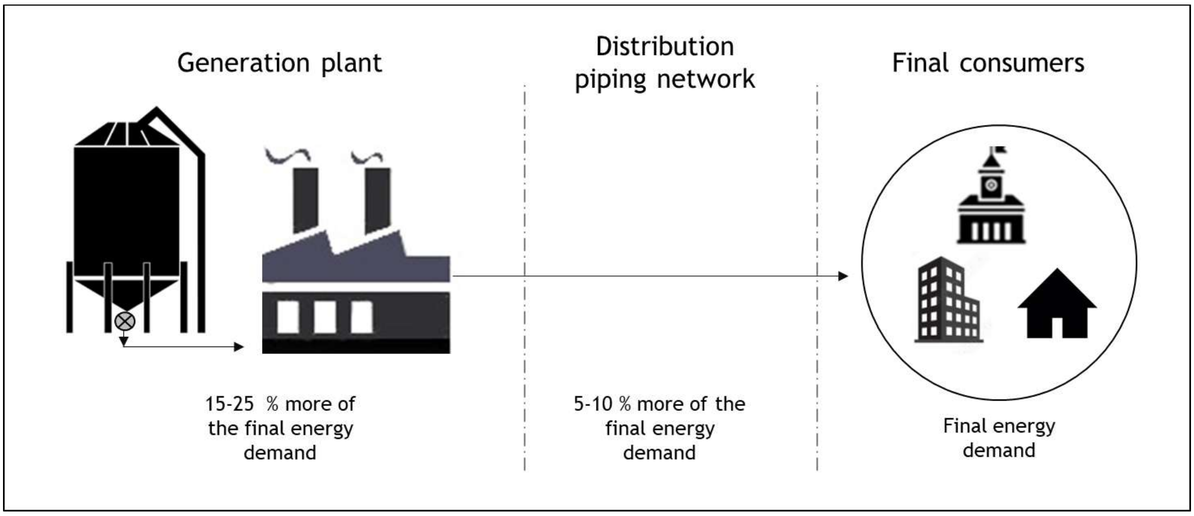

Figure 9. Basic scheme of the energy to be supplied in each part of the district heating system.

4.2.2.4 Amount of biomass needed

At the same time, once the amount of energy to be produced in the generation plant is obtained, an estimated number of the amount of biomass required can be assessed. In order to do so, the low calorific value and the moisture content of the biomass selected should be obtained. If these parameters are unknown the BECoop factsheet "Solid biomass for small-scale heating applications" can be consulted where average values are provided.

$$Energy\ to\ be\ produced\ in\ the\ generation\ plant\left(\frac{MWh}{year}\right) = \frac{Final\ energy\ demand\ of\ the\ consumers\ (\frac{MWh}{year})}{Efficiency\ of\ the\ piping\ network\ (\%)}$$

$$Energy\ to\ be\ covered\ by\ biomass\ (\frac{MWh}{year}) = \frac{Energy\ to\ be\ produced\ in\ the\ generation\ plant(\frac{MWh}{year})}{Efficiency\ of\ the\ generation\ plant\ (\%)}$$

$$Amount\ of\ biomass\ needed\ (\frac{t}{year}) = \frac{Energy\ to\ be\ coverd\ by\ biomass\ (\frac{MWh}{year})}{Low\ heating\ value\ of\ the\ biomass\ (\frac{MWh}{t})}$$

4.2.3 Operational and maintenance of the installation

Although biomass is a cheaper fuel than fossil fuels (natural gas, heating oil, propane, etc.), its operation and maintenance cost are slightly higher, considering that more frequent maintenance operations should be carried out due to the significant amount of ash generated during the combustion of the biomass in order to guarantee the correct operation (and therefore do not decrease the yield of the installation) and to guarantee the service life of the installation:

- The frequency of the bottom ash accumulated removal will depend upon the installation characteristics and the biomass to be consumed, but it is recommended to perform it at least once each two weeks.
- Removing the fly ash, that can be located in the heat exchangers tubes and other auxiliary/cleaning emissions systems, can be done automatically by means of a pneumatic system (or other technologies). It is also recommended to be performed at least once per year, (normally after the winter season) and invest additional time to deeply clean all the installation.

Normally these operations are carried out by the company in charge of the operation of the installation.

If these maintenance operations are being done and the design of the installations is based on the energy to cover and the biomass resource to be fed, no malfunctions should arise.

4.3 Profitability of a District Heating

Profitability should be measured in economic, social, and environmental terms, since all of them are important, even though, it is well known that economical aspects are one of the main considerations in order to carry out the final decision. So let’s focus on how to assess the economical profitability of a biomass district heating.

The first aspect that should be addressed is related to the information previously mentioned in section 4.2, regarding the energy demand to be covered annually. Additionally, information should be retrieved regarding the current fuel used in these installations/buildings and the annual price that is paid. With this input data, the annual cost to cover the heating demands for all the buildings will be calculated, without taking into account the amortization of the installations, since it is understood that the installations are currently amortized.

At this point, it could be considered not just the current annual price, but also the tendency in the future years, since the stability of the prices will not be the same for all the fuels. Also, if the current fuels used are fossil fuels, it should be considered that in the coming years fossil fuels are expected to have an extra tax according to the specific emission factor of the fuels used. The same is currently happening in the industry sector (Figure 10), which can lead to a significant increase of the final price of the fossil fuels used.

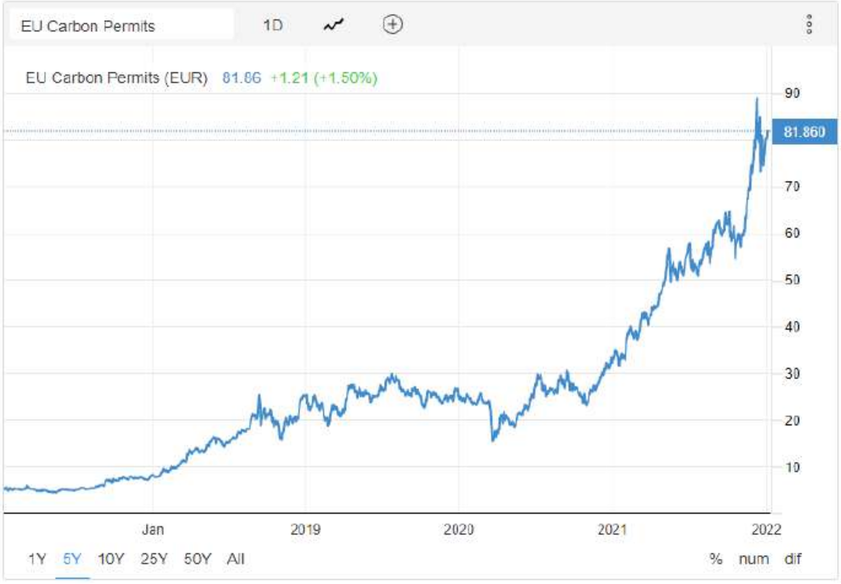

Figure 10. Evolution of the price of CO_2 emission in the last 5 years [33].

Complementarily, in order to have a good overview of the current and future scenarios with the current fuels, a sensitive analysis (final price and emission prices of the current fuel) can be done in order to have more information to take the final decision.

Once the current situation is well analysed, it should be compared with the future installation, and thus, two main aspect should be considered:

- Investment (CAPEX) of the new biomass district heating installation: it includes the investment cost, the assembly and the transportation of all of the equipment required, together with the civil engineering costs (installations necessary for the operation of the DH, as for instance the building of the generation plant, and the civil engineering of the piping network). This number is very sensitive to the specificities of each case (location where the initiative will be implemented, expertise of the company in charge of the operations, the equipment selected, the biomass fed, the linear meters of the piping network, etc.). An initial estimation with uncertainty ranges for heat biomass plants based on DH is provided by the Danish Energy Agency [34] for a power of 6 MW fed with different biomasses, Table 6.

Table 6. Investment costs according to the Danish Energy Agency for a DH of 6 MW fed with different biomasses [34].

CAPEX (€/kWth – heat output)	Woodchips	Pellets	Straw
Equipment	410 (350-470)	440 (380-510)	460 (370-550)
Installation	300 (250-340)	290 (240-330)	460 (390-530)
Nominal investment	710 (600-810)	730 (620-840)	920 (760-1,080)

- Operational and maintenance cost (OPEX): considers the actions mentioned in the section 4.2.3, and it can be divided in two groups: fixed cost (biomass cost, periodic maintenance, etc) and variable cost (electricity, etc.). According to the Danish Energy Agency Table 7 depicts some reference figures.

Table 7. Operational and maintenance cost according to the Danish Energy Agency for a DH of 6 MW fed with different biomasses [34].

OPEX (referred to heat output)	Woodchips	Pellets	Straw
Fixed O&M (€/MW_{th}/year)	27,800-37,700	28,000-37,900	43,900-59,600
Variable O&M (€/MWh)	2,34-3,71	1,81-2,30	1.92-2.59
- of which is electricity costs (€/MWh-heat)	1,51-1,99	1,40-1,61	1.43-1.71
- of which is other O&M costs (€/MWh-heat)	0,83-1,72	0,41-0,69	0.49-0.88

Once, the CAPEX and OPEX of the new installation are estimated, in order to assess the economic profitability, the annual savings regarding the OPEX of the new installation should be calculated. After having estimated all the investment and operating costs along with the potential savings/ revenues, a simple way to calculate the payback period (this parameter indicates the necessary years to obtain the return of the investment carried out), is obtained through the division of the CAPEX and the annual savings associated with the new installation. The lower the payback, the lower the risk associated with the new installation. It should always be lower than the service life of the new DH installation (an average service life is between 20-30 years) for being economically profitable.

$$Payback = \frac{CAPEX\ (€)}{Annual\ savings\ (\frac{€}{year})}$$

As mentioned, this is a simple way of doing a first estimation, but to be more accurate other parameters should be considered as the inflation or the tax rate. If the CAPEX is covered by own or external resources, loans, etc., in order to obtain more information about business and financial considerations, the BECoop Catalogue for the provision of business and financial support services can be consulted.

Nowadays, due to the high percentage of the fossil fuels used to cover the energy demands of the residential sector (Figure 11), supporting financial mechanisms are available to accelerate and mitigate the risk of new investments in renewable energies, as in this particular case of biomass district heating. If this happens, the payback period will be lower than the one initially calculated (without financial support), since the CAPEX will be lower.

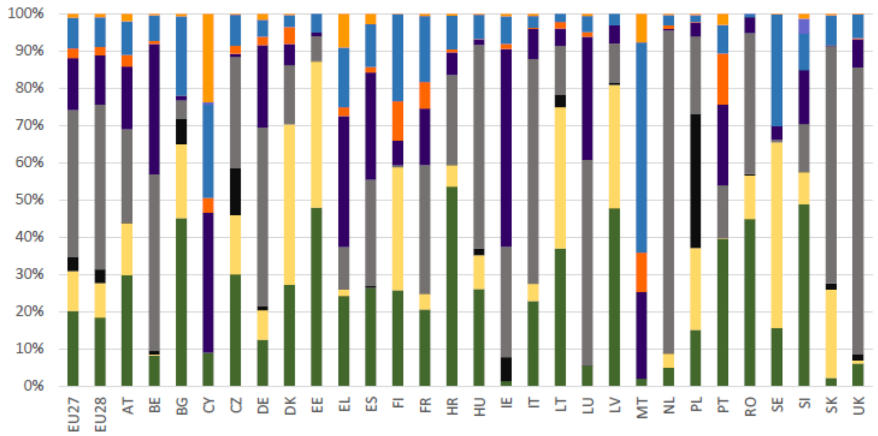

Figure 11. Shares of energy used for heating and cooling in the residential sector by Member States in 2018 (%) [35].

Table 8 summarises the information mentioned in this section, through an example of investing on a new biomass DH and replacing the current consumption of a total of 250,000 litters of heating oil in all the buildings. In this example an inflation rate of 2 % has been considered for the case of heating oil and 1 % for the case of the biomass (since the price it is more stable, as previously mentioned), as a result a 10 year payback period is obtained.

Table 8. An example of a breakdown of savings, expenses and investment obtained for a DH.

Items	Unit	Data year 1
Savings (current situation)		
Consumption of heating oil	Litter/year	250,000
Price considered of heating oil	€/l	0.8
Annual heating cost	€/year	200,000
LHV heating oil	kWh/l	9.98
Yield of the oil boiler	%	85
Useful heating consumption	MWh/year	2,120
Expenses (future situation)		
LHV woodchips (at 30-35 moisture content)	kWh/kg	3.1
Yield of the district heating	%	75
Amount of the biomass needed	t/year	911

Items	Unit	Data year 1
Nº of hour of operation	h/years	1,400
Power of the installation	MW	2
CAPEX cost (taking into account the average value of the Table 6)	€	1,443,887
OPEX cost (taking into account the average value of the Table 7)	€/year	70,488
Financial considerations		
Inflation of heating oil	% of inflation per year	2
Inflation of biomass	% of inflation per year	1
Grant	%	0
Loans	%	0
Payback		
Payback	Years	10

Environmental and social aspects, that sometimes are forgotten, should be also considered. In the case of biomass, these aspects are very relevant, since in order to develop new initiatives, these resources should be collected and consumed in the nearby areas in order to be economically profitable. This implies that employment is generated locally and normally in rural areas since it is where the biomass is located. Also, the use of biomass, can contribute to a good forest management that can prevent forest fires, avoid uncontrolled pruning burning on the fields, contribute to pest control, etc. And, of course, the mitigation of the dependence of fossil fuels, keeping in mind that the EU has a clear commitment to achieve carbon neutrality in 2050, and to contribute to the development of rural areas. Both goals are properly addressed with the promotion of district heating based on local biomass resources.

4.4 Stakeholders needed

In order to develop a district heating unit, the users, in the majority of the cases, would most likely need the support from other stakeholders, that sometimes can be integrated inside the community/RESCoop or in other cases they will provide external support by subcontracting. Some of the stakeholders that could be necessary are listed below (in Annex II you can find the main contribution that these stakeholders can provide):

- Biomass producers/suppliers
- Energy Services/Engineering Company (ESCO)

- Equipment manufacturers
- Public/Local institutions
- RESCoops
- Consumers
- Transversal stakeholders (as research centre, biomass associations, investors)

  a) Research centres.

  b) Biomass association/local action groups.

  c) Investors.

In case the promotor of the idea needs to contact or find out a specific stakeholder, it is advisable to visit BECoop e-market platform (https://www.becoop-project.eu/tools/e-market-environment/) where you can find useful information in this regard.

4.5 Steps to be followed

This section aims to summarize and establish a chronology order of general steps to be performed by the promoter of the idea of a biomass district heating unit starting from the beginning.

Table 9. General steps to be followed to develop a biomass DH from the beginning.

Order	Action	Description	Stakeholders that can help
1	To define the buildings to be covered by the district heating and the energy demand to be covered	Should be considered to understand the capacity of the district heating to be developed. See section 3.2.1.	All the final consumers of the DH, as individual homes, commercial buildings, public institutions, RESCoops, etc.
2	Current energy demand of these building	It is needed to assess the current situation and to compare with the future DH. See section 3.2.2 about the information required	All the final consumers of the DH should provide this information. If support is needed, they can contact Research centres or ESCOs to carry out an energy audit or doing some estimations.
3	To do a pre-feasibility assessment about the implementation of a DH unit	Based on the information described in chapters 3 and 4. It is needed in order to decide whether to go further with this idea or not.	It should be done by an expert in this field, it could be a Research centre or even the ESCO that if feasible will be in charge of the design and implementation.

Order	Action	Description	Stakeholders that can help
4	To identify and contact different ESCOs and communicate the initiative	Preliminary contact with ESCOs should be done with the goal of communicating the project and investigate if they are interested to collaborate	It can be done by the promoter of the idea with the support of the company that carried out the pre-feasibility assessment (if previously wasn't done by an ESCO)
5	To start with the definition of the business model and to identify the members of the community	Who will design and implement the DH? Who is in going to be in charge of the operation of the DH? Which is the business model selected? In the case of public institutions these are the more frequent models: - Concession model (by public tender) by the city council for the operation and maintenance of the facility ceded to a private company. - Public company operating model, with the council's own resources (subcontractors). - Operating model with a company or investee company. - Mixed public-private operation model. Who will be in charge of the investment? What stakeholders are interested in being part of the energy community? Etc. See chapter 5 about stakeholders than can be needed and the main role that of each of them can provide, and the BECoop "Business and Financial Catalogue"	The previous conversation with the ESCOs can help, but also RESCoops can provide support about community business models.
6	To select the business model and the company in charge of the design and the implementation	According to the information previously indicated, the final decision about the stakeholders selected and role of each of them should be defined. In the case of public institutions, public tenders are needed.	It should be done by the promoter and/or stakeholders currently involved in the community. Also, if needed, the company in charge of the pre-feasibility assessment can provide support about technical support to

Order	Action	Description	Stakeholders that can help
			facilitate the decision-making to the promoter.
7	To carry out the design and the implementation of the DH	To develop the project of the biomass DH and the implementation, selecting the biomass to be fed, the equipment needed, to obtain the administrative licenses, etc.	By the ESCO selected.
8	To guarantee the supply of the biomass	Biomass should be guaranteed with the proper quality for the design of the installation carried out.	It depends on the business model selected, and the role of each stakeholder of the community. Normally, the agreement with the biomass supply it is carried out by the same stakeholder that is in charge of the operation and maintenance of the DH.
9	To start with the operation of the DH and distribution of the energy to the final consumers	To guarantee the correct operation of the installation, securing the energy supply to the final consumers and the correct maintenance of the installation to ensure its useful life.	ESCO or the stakeholders selected to be in charge of the operation and distribution of the energy.

4.6 Success cases

In this section some initiatives already implemented will be described seeking to raise awareness regarding the possibility to successfully develop a biomass district heating and get a better idea of the average cost.

4.6.1 Vilafranca del Penedés, Spain (500 kWth)

Vilafranca del Penedés is a town located in Catalonia (Spain), in which the project VinyesXCalor (http://vineyards4heat.eu/es/) was developed. The initiative was promoted by the municipality of Vilafranca del Penedés as a political commitment to set an efficient low carbon economy through the use of an abundant source of biomass in the area (vineyard prunings), currently underused with the goal of covering the energy demands (heating and hot water) of four buildings (one more is expected to be connected to the network in the near future). For this purpose, multiple local public and private actors have been involved to create a new and sustainable value chain guaranteeing the profitability of the energy production from vineyard prunings: farmers, a harvesting service company, an energy service company, several consumers and the municipality. This value chain starts from the collection phase of the resource until the generation and distribution of the energy.

Part of the motivation came from the subscription of the Municipality to the Covenant of Mayors for Climate & Energy (EC initiative) in which several Sustainable Energy Action Plans were promoted. The rest of the motivation was triggered: (1) by the reality of the pruning residues management, which needed to be improved; (2) by the willingness to increase the competitiveness of the county economy;

and (3) following the wine tourism local initiatives in the area, promoting sustainability and a zero km economy as a flag.

The selection of the equipment was performed according to the biomass to be consumed, average moisture content of 20 % on wet basis, an ash content of 6 % on dry basis, a low heating value of 14.8 MJ/kg and a particle size distribution classified as G50. The low density and irregular shape make the hog fuel required an adaptation of the boilers feeding system: the silo was designed to avoid bridges and the feeding screw is prepared for particles with longer size. Regarding the combustion system, the higher ash content and lower density compared to regular forest wood fuels, was taken into account in the selection of the system and in the operational parameters. As a result, a Heizomat RHK-AK-500 boiler of 500 kWth was installed. It fully runs on vineyards pruning wood hog fuel. The saving in natural gas and electricity are up to 153 and 13 MWh, respectively, thanks to the use of biomass.

The total investment of the installation was 600.000 €, the consumption of biomass from vineyard pruning it is of 225 t/y (on average during the project although the potential can be up to 30,000 t/y in the area) that comes from 375 ha in a radius lower than 15 km. The emissions avoided are 125 t CO_2/y, and 4 permanent jobs were created in the entire value chain.

This information was obtained from uP_running project [36].

4.6.2 Sabando, Spain (400 kWth)

Sabando it is a small village of 40 houses that belong to the town of Arraia-Maeztu located in Euskadi (Spain). The village of Sabando, with 89 inhabitants, is situated in a hidden valley, surrounded by mountains, beech and oak forests.

One of the residents of the villages, had the idea of taking advantage of the existing resources seeking to (i) use the local biomass, (ii) reactivation of the rural environment, (iii) generation of local employment, (iv) reduction of carbon dioxide emissions. In order to achieve these goals, the decision focused on the creation of a small district heating to supply sanitary hot water and heating through micro heating networks in the municipality (all the houses), optimising the performance of these common systems with respect to the individual ones, generating local work and contributing to cleaning the forest, with all that this implies in terms of fire prevention.

In 2013, the installation and undergrounding of networks was undertaken and the appropriate tests were carried out prior to paving. Two biomass boilers of 200 kWth each, were installed with an accumulation vessel of 5.000 liters. For this installation, 300 t/y of local forestry biomass was consumed (with an average of 35-45 % of moisture) and stored in the village.

Regarding the economic data, the investment reached 582.128 €, with 80 % funded by the Basque Government and 20 % by the Sabando Administrative Board. Furthermore, the inhabitants had to pay 1,000 € for connecting to the district network and 300 € for maintenance. As a result, the final price of kWh_{th} was at 0.025 €/ kWh_{th}. Taking into account these data, the annual savings obtained were around 40 %. Per habitant, the average heating cost was of around 2,500 €/year (using heating oil) and now is around 1,500 €/year (with the DH, and taking into account the heating but also the hot water).

This information was obtained from Promobiomasse Interreg project [37] and REHAU [38].

4.7 Summary

This catalogue intends to provide the user with a better idea of what a district heating is, the information that should be retrieved in order to carry out an economic assessment such as the energy demands of the building to be covered by the DH, how to assess the power of the installation, the amount of biomass needed, and how to calculate the economic profitability based on simple equations. Additionally, it provides a guideline of the common steps to be followed and the group of stakeholders than can provide support if necessary.

Taking into account all this information, this report can serve as general guidelines/ handbook for a stakeholder willing to promote a district heating unit, but who lacks technical knowledge or a general overview of the steps that need to be followed prior to investing.

5. Small co-generation technical catalogue

This chapter summarizes the technical catalogue about biomass co-generation for small scale applications with the aim of providing a deep overview of this technical technology and the steps to be followed in order to be implemented, even though if the reader wants to develop a small co-generation it is highly recommended to read the Annex III, in which more information it is provided, mainly about the technical considerations to be taken into account.

Important: This technical catalogue provides general recommendations that should be considered to facilitate initial communication with energy services/engineering companies for a project. However, the final decisions on the installation and the types of equipment and technologies to be used will be made by these companies.

5.1 Small co-generation concept

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 12 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 [39].

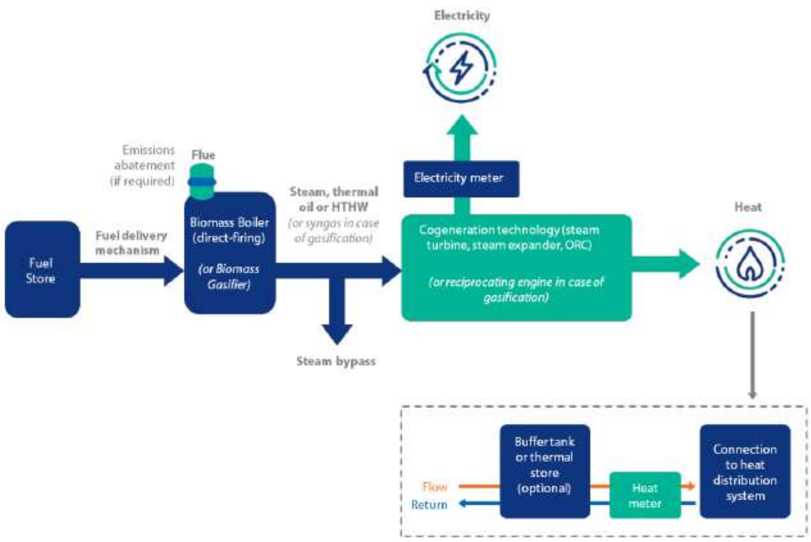

Figure 12: Typical biomass CHP components [39].

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 13).

Figure 13: CHP benefits: efficiency [40].

5.2 Technical considerations

5.2.1 Main elements of a small co-generation installation

5.2.1.1 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 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 in 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 [41].

5.2.1.2 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.

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 [42]. In Annex III these types of boilers are analysed.

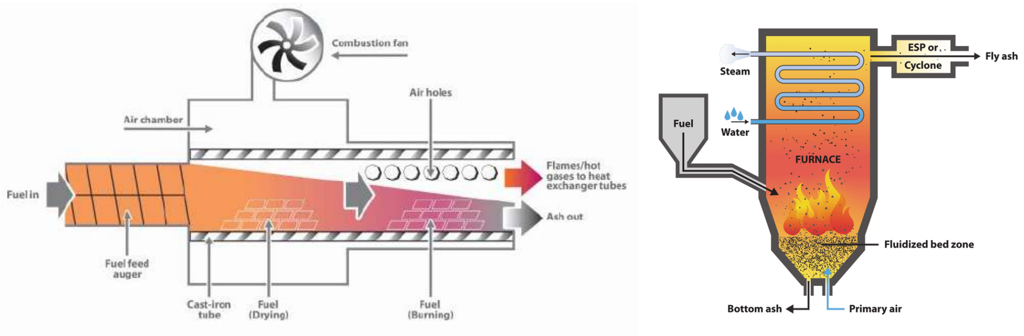

Figure 14. Fixed grate boiler (left) [43] and fluidized bed boiler (right) [44].

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 [45].

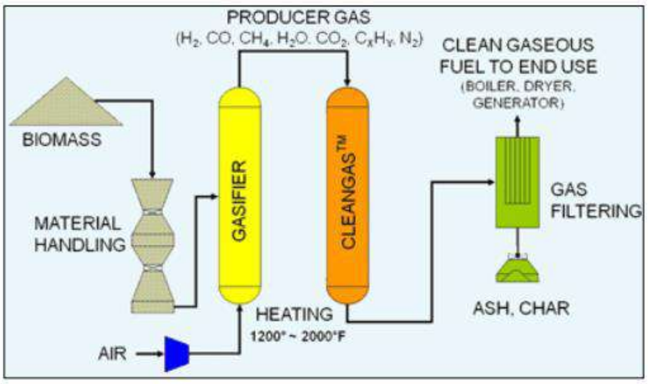

Figure 15: Example of two-stage gasification [45].

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 [42].

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. 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 [46].

More information about these technologies can be found in Annex III.

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 [47].

Figure 16 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 [48].

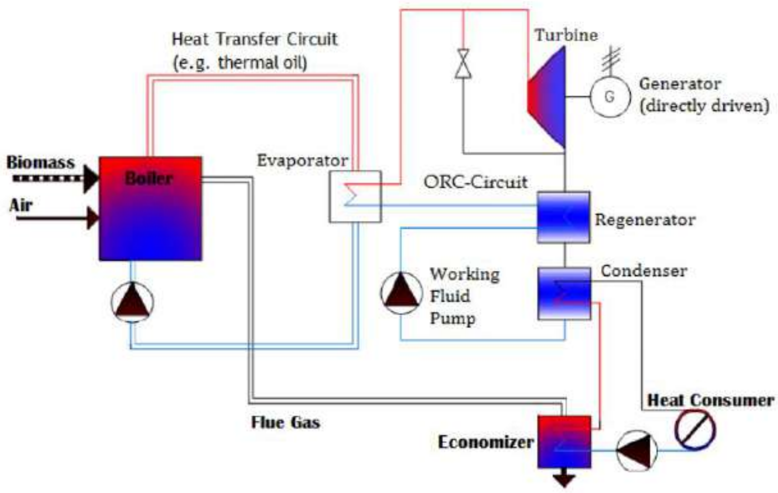

Figure 16. ORC process scheme [49].

5.2.1.3 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 and fuel cells and are described in brief in the Annex III.

5.2.1.4 Wrap-up on biomass Cogeneration technologies and latest developments

From all the technologies mentioned above and deeply explained in Annex III, combustion and steam turbine technologies is the most widely used combination, especially for large-scale and medium-scale biomass-fuelled 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 [50]. 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 [51], 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 [52]. 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. Further 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 [53]. 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 [54] [55].

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 at micro scale. E.g., Community Power Corporation (CPC) has developed modular micro-scale biomass gasification CHP systems with size ranging from 5 to 50 kWe [56]. 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 [52]. 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% [51]. 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 [57]. 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% [55].

5.2.2 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 [58]. Figure 17 shows the electrical efficiencies of biomass conversion technologies which have been reached in different power ranges for small scale applications.

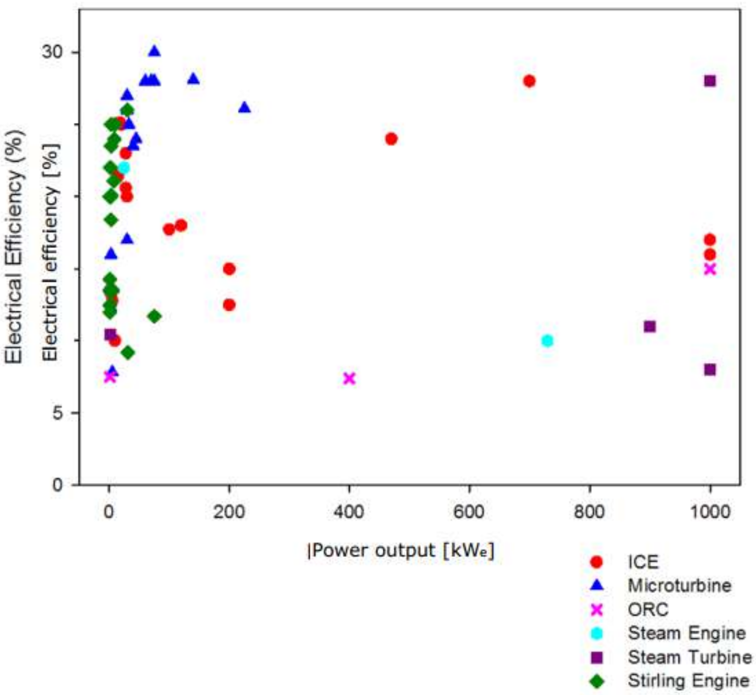

Figure 17. Electrical efficiencies of biomass conversion technologies based on power output [59].

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" (Annex I) and "District Heating" (Annex II). 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 [60], 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.

5.2.3 Operational and maintenance of the installation

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 (syngas cleaning) before it is combusted in an engine. 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 [39].

Based on each technology implemented in the CHP unit and its power, the investment and maintenance costs vary. Table 10 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 10. Comparison of prime mover technologies applicable to biomass CHP [59].

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
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

5.2.4 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 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 reduction 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 sources, 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 [61].

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.

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

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 18.

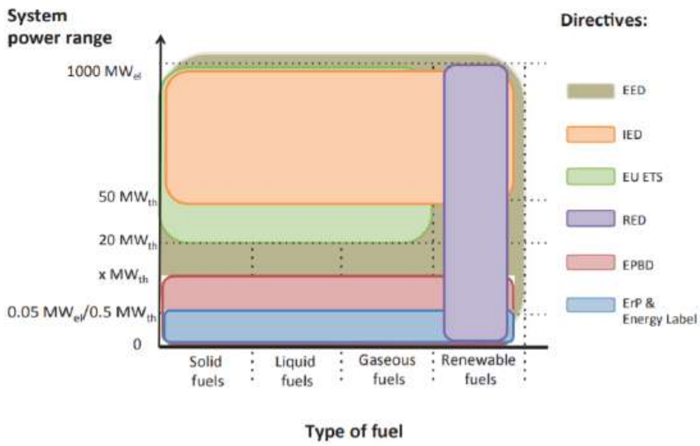

Figure 18. EU policies relevant for CHP based on fuel type and nominal power range [61].

5.3 Profitability of a small co-generation installation

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 10) 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 the excess 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, Annex II). Based on the success cases that are also described in Section 5.5, 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 environmentally 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 [62]. 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 [63], 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 [64], 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 [65]. 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.

5.4 Stakeholders needed

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.

Some of the stakeholders that could be necessary are listed below:

- Biomass producers/suppliers
- Energy Services/Engineering Company (ESCO)
- Equipment manufacturers
- Public/Local institutions/Governments
- RESCoops
- Consumers
- Transversal stakeholders (as research centre, biomass associations, investors)
    a) Research centres.
    b) Biomass association/local action groups.
    c) Investors.

In case the promotor of the idea needs to contact or find out a specific stakeholder, it is advisable to visit BECoop e-market platform (https://www.becoop-project.eu/tools/e-market-environment/) where you can find useful information in this regard.

5.5 Steps to be followed

In general, the one who is interested to invest on a CHP unit should have in mind the following [39]:

- 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.

5.6 Success cases

In this section some initiatives already implemented will be indicated with the goal to make visible that it is possible to develop a biomass CHP plant and have a better idea of the typical cost.

5.6.1 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 4,820 mm, Width 1270mm, Height 2,500 mm and needs a minimum free space for maintenance of 1,200 mm on both sides, 1,000 mm in control panel end and 1,000 mm in ash conveyor end. Its feeding unit has dimensions of Length 500 mm, width 600 mm, height 1,800 mm. 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 [66]. The unit cost (plus fuel conveyor) is approximately at 200,000 € [67].

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 € [68]).

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 [68].

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 [69].

Figure 19. The CHP unit by Volter Oy fits, Volter 40 CHP Indoor [66].

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

Figure 20. Heliex GenSet installation in Obertrum am See (A) [59].

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 kWel) was combined with a biomass district heating 6 MWth. 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 [59].

5.6.3 ÖkoFEN Pellematic Smart_e, Austria (0.6 kWel)

Figure 21. ÖkoFEN Pellematic Smart_e CHP unit [60].

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 (**Error! Reference source not found.**) 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 0.6 kW 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 [59]. An indicative cost for such system is at 24,000 € (incl. VAT).

5.7 Summary

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.

6. Biogas technical catalogue

This chapter provides the technical catalogue about biogas plants, including the technical considerations and necessary steps for successful implementation. However, for those interested in developing biogas plants, it is highly recommended to also refer to Annex IV for additional information on technical considerations and stakeholder contributions.

Important: This technical catalogue provides general recommendations that should be considered to facilitate initial communication with energy services/engineering companies for a project. However, the final decisions on the installation and the types of equipment and technologies to be used will be made by these companies.

6.1 Anaerobic digestion concept

The concept of "anaerobic digestion" is related to the compilation of biochemical reaction (methane fermentation) that bacteria and several microorganisms carry out to degrade organic matter into simpler compounds and by-products for its metabolism [70].

Organic matter is decomposed into two different main fractions: a gaseous phase named **biogas** and a solid phase named **digestate**. Both fractions have been reported to offer various applications and both material and energetical valorisation as shown in Figure 22.

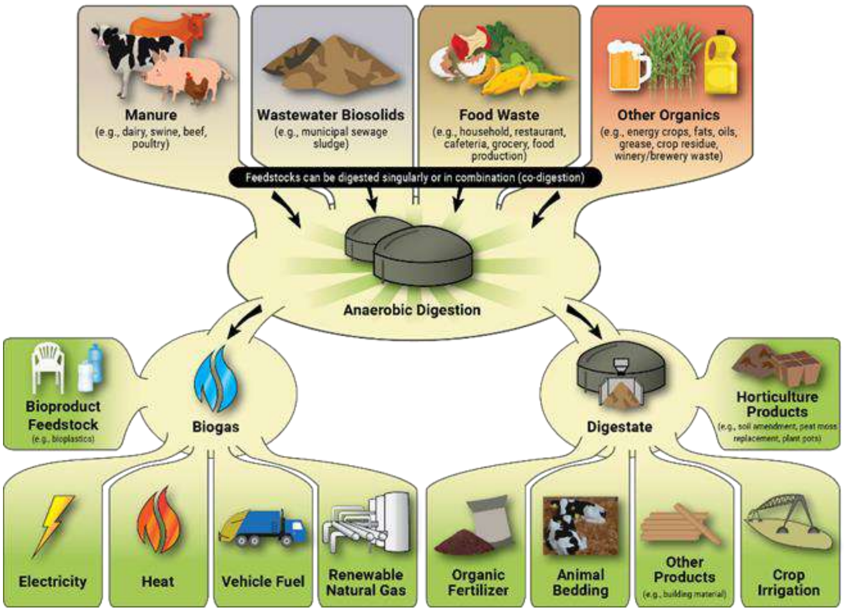

Figure 22. Anaerobic Digestion for waste valorisation. Source: EPA, [71]

Biogas is a mixture of gases like natural gas which exhibits high heating values ranging 16-28 MJ/m^3. Methane (CH_4) is the main compound with near 45-75% share of overall biogas content, whilst carbon dioxide is the second main product holding a 20-30% share. Carbon monoxide, hydrogen sulfide and other trace compounds/elements are also found in biogas.

Because of its similarities with natural gas, biogas thus shows great potential to directly substitute natural gas as an environmental-friendly fuel solution for heating and co-generation applications. On the other hand, biogas production also offers a promising opportunity for waste valorisation, landfill management and processes decarbonization. Table 11 shows main similarities between biogas and natural gas properties.

Table 11. Biogas and natural gas properties comparison [70,72-74].

Components	Units	Natural gas	Standard Biogas
CH_4	% vol.	70-90	45-75
CO_2	% vol.	0-8	47-25
N_2	% vol.	4-0	3-0
O_2	% vol.	0	< 0.5
H_2S	mg/m^3	2-20	3,000-10,000
NH_3	mg/m^3	-	50-100
HHV	kWh/m^3	11.3	6.6-7.5
Density	kg/m3	0.85-0.93	1.15-1.25

Biogas production enables efficient energy recovery from organic waste streams generated by domestic and/or industrial processes, producing carbon-neutral fuels that can be used to generate heat and/or electricity in facilities. Biogas is particularly promising as an energy solution for communities, as it allows for direct valorisation of community biomass waste streams.

Biogas production facilities may not be economically feasible unless they undergo a thorough assessment. The processes that involve biological reactions and microorganism, are susceptible to suffer from various difficulties, such as unaffordable capital expenditures and technical barriers that may hinder the techno-economic viability. Furthermore, while anaerobic digestion parameters can be optimized to maximize biogas potential within feedstocks, the supply of biomass may be subject to intermittent availability throughout the year or changes in chemical composition over time. In consequence, biogas production performances are usually very sensitive to feedstock (batch) changes, hindering its viability. As result, it is important to assess the supply chain, as well as the biomass providers and storage units, when proposing a project.

The use of biomass, waste streams and biogas facilities installation enable the use of autochthonous and renewable energy resources while contributing to create local employment in the municipalities where the valorisation initiative is implemented. From an economic perspective, organic waste streams usually have a lower price than conventional fuels and, additionally, environmental benefit derived in terms of forest cleaning, contributing to reduce forest fire risk, prevention of open-fires (as for instance of agricultural pruning) and the reduction of CO_2 emissions, due to the substitution of conventional fuels by biomass.

From the users' point of view, biogas production facilities could offer economic and technical benefits. It could contribute to reducing fossil fuel dependence, local energy safety, raising energy savings as well as solving domestic and industrial waste management issues.

6.2 Technical considerations

6.2.1 Main elements of a biogas production facility

The main goal of this chapter is to provide a general overview of the main technical elements of a biogas production plant in order to facilitate the conversation and the agreements with the energy service/engineering company in charge of the design and development of the installation. The main elements to consider are:

- Feedstock: The feedstock is the organic material that is fed into the biogas plant. It can be a variety of organic materials, such as agricultural waste, food waste, and animal manure.
- Anaerobic digester: The anaerobic digester is the main vessel where the anaerobic digestion process takes place under controlled conditions. It is a sealed tank that is designed to create an environment where microorganisms can break down the organic matter and produce biogas.
- Storage or Gas holder unit: The gas holder is a tank that stores the biogas produced by the anaerobic digester. It is designed to hold the gas at a constant pressure so that it can be used as a fuel whenever there is a high energy demand.
- Sludge treatment: The sludge treatment system is used to process the sludge that is produced as a by product of the anaerobic digestion process. The sludge is treated and stabilized, and then it can be used as an organic fertilizer or a soil conditioner.
- Upgrading unit: Such as gas scrubber units, devices that removes impurities from the biogas, such as hydrogen sulphide and moisture.
- CHP unit: The gas engine is a device that converts the biogas into electricity and heat. It is typically fuelled by natural gas or propane, but it can also be fuelled by biogas.
- Control and management of biogas plant.

6.2.1.1 Biomass storage

The properties, nature, and mass flow of the feedstock are key parameters for the proper operation of biogas plants. For this reason, it is essential to ensure a continuous, safe, and homogenous supply. One way to address this issue is through biomass storage, which can provide a direct solution. More information about feedstock's importance can be found in Annex IV.

In conclusion, the volume of the storage area will be defined considering the following aspects:

- Amount of biomass to be stored, where it has to be considered the self-sufficient target of the plant for a certain period of time.
- Bulk density of the biomass to be stored, which depends on the biomass selected and the size distribution of this biomass.
- Average consumption of biomass per day. For this, digester retention times must be assessed.

Taking into account the previous considerations, the approximate storage area can be calculated by the following formula:

$$\text{Usable volume needed} = \frac{\text{consumption of biomass per day}\left(\frac{\text{kg}}{\text{day}}\right) \times \text{ number of days to be self} - \text{sufficient (days)}}{\text{bulk density of the biomass }(\frac{\text{kg}}{m^3})}$$

Even though, the final surface needed will depend upon the equipment selected for biomass storage. This final decision must be made by the energy services company that carries out the installation, considering the final location of the generation plant, the biomass selected and the available space.

6.2.1.2 Digester

The digester represents the core of the biogas production plant. It is the main unit where biochemical anaerobic digestion processes take place, which involves the action of different microorganisms that decompose and break down the organic matter (in an oxygen-free atmosphere) to produce methane (CH_4) and carbon dioxide (CO_2) as primary products and main components in biogas. Furthermore, solid residue is also obtained - commonly named digestate - which can offer several further applications. The configuration of a digester, which is essentially a chemical reactor, depends on the feedstock and operation conditions, and can impact the particular purposes for which the produced biogas is used [75].

There are different technologies (described in Annex IV: Technical catalogue on biogas plants). Table 12 summarizes the main features of most common digesters.

Table 12. Main digester operational features and characteristics [75]

Factors	Fixed dome	Floating drum	Tubular design	Plastic containers
Gas storage	Internal Gas storage up to 20 m³ (large)	Internal Gas storage drum size (small)	Internal eventually external plastic bags	Internal Gas storage drum sizes (small)
Gas pressure	Between 60 and 120 mbar	Up to 20 mbar	Low, around 2 mbar	Low around 2mbar
Skills of contractor	High	High	Medium	Low
Availability of Material	yes	yes	yes	yes
Durability	Very high >20 years	High; drum is weakness	Medium; Depending on chosen liner	Medium
Agitation	Self-agitated by Biogas pressure	Manual steering	Not possible; plug flow type	Evtl Manual steering
Sizing	6 to 124 m³ digester vol	Up to 20 m³	Combination possible	Up to 6 m³ digester vol
Methane emission	High	Medium	Low	Medium

It is important to carefully consider the main purpose of biogas application, as well as the daily amount of biomass entering the process and the acceptable range of biogas yield. These factors are key to estimating the sizes of other units, such as biogas storage and use facilities, and should be taken into account by both the constructor and the designer.

6.2.1.3 Biogas storage units

After anaerobic digestion, the produced biogas will likely be stored in the short or medium term for further application. This may include direct use for on-site cogeneration or transport to an off-site application or distribution point.

The storage tank for biogas can either be located inside the digester or downstream as an independent unit. Additionally, it is important to consider the pressure ranges for the storage system, which will depend on the expected production outcome and storage needs [76].

6.2.1.4 Sludge treatment

Sludge treatment refers to the processes that involve the treatment of solid by-products of anaerobic digestion. With these, different purposes might be considered, as simply as its volume reduction, weight, or toxicity. As expected, the treatment will be different depending on the characteristics of the sludge, the desired end-product and the available possibilities. Summing-up, the purposes for sludge (or digestate) semi solid by-product are:

- Volume reduction: easing transport, handling or storing.
- Pathogen reduction: the disposal of anaerobic digestion sludge increases risks for health due to elevated potentials of pathogens, thus its treatment is mandatory to reduce those risk when disposed or handled.
- Nutrient recovery: sludge or “digestate” is a promising strategy for recovering phosphorus and nitrogen inorganic compounds, which can be potentially used as fertilizers. In fact, currently most potential application of digestate pathway is its processing as fertilizer or soil amendment.
- Energy recovery: as any other end-waste, sludge and digestate can be energetically valorised by incineration to produce heat and electricity when coupled to a combined cycle plant.

Figure 23 shows various strategies and treatment methods that can be taken into account for the sludge treatment. While composting is currently the preferred method for converting digestates into a soil amendment product that benefits soil structure, other less effective methods focus on decreasing the amount of digestate generated rather than producing valuable by products. Drying and thickening digestate streams are simpler and more cost-effective ways to reduce the volume of solid or liquid digestate after anaerobic digestion, making it easier to dispose of. Lastly, the least efficient and ecological route followed by biogas producers is incineration of residual digestate streams. However, it is still the most common pathway after biogas production when no market or further application is assessed.

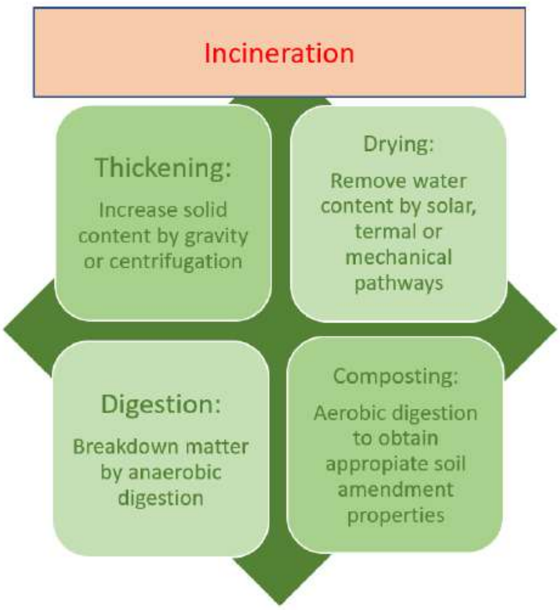

Figure 23. Anaerobic digestion sludge by-product treatment strategies

6.2.1.5 Biogas use: boiler, CHP or upgrading unit

After production, biogas may be converted into other useful forms of energy as heat, electricity or upgraded into biomethane to applicate as natural gas substituent. The design of a biogas production plant should take into consideration the intended application of the produced biogas prior to construction, in order to ensure that all necessary units are incorporated into the design. For this, different units and strategies for valorisation are considered:

- **Combustion engine**: Most direct biogas application is as fuel for combustion engines or boilers with the goal of producing heat, mechanical power for any vehicle or equipment, or electricity when integrated into CHP unit (for more information about CH units, you can consult the BECoop technical catalogue “co-generation”).
- **Upgrading units:** Some upgrading units can convert biogas into biomethane by removing impurities as sulphur compounds and CO_2 and adding hydrogen. This biomethane can be injected into natural gas grid and sold as renewable fuel.
- **Fuel cell:** Biogas can be used as a fuel source for fuel cells, which convert the chemical energy of the gas into electricity through an electrochemical process. This application is rarer than the previous ones explained, as its economic feasibility remains much lower.

6.2.1.6 Control and management of biogas plants

The main objective of controlling a biogas plant is to regulate the generation of biogas, the feedstock stream fed into the digester, and the distribution, application, or storage of the produced biogas. Another important variable to regulate is the control operating temperatures, digestion retention times and/or pressures, which is usually based on the technical specifications of the different units.

Temperature is a defining parameter for the biogas plant and production. A biogas plant can operate at a range of temperatures, depending on the specific microorganisms used in the digestion process. These microorganisms and commonly classified as thermophilic (relatively high temperatures) and mesophilic (mild temperatures).

Mesophilic systems, which use microorganisms that thrive at moderate temperatures, can operate between 25-35°C. The optimal temperature range for most types of anaerobic digestion is between 35-40°C. However, some thermophilic systems, which use microorganisms that thrive at higher temperatures, can operate at temperatures between 55-60°C.

The control of the different parameters as digester temperature, feeding rates, biogas pressures and feedstock retention times are usually managed through a “supervisory control and data acquisition” (SCADA), this supervision will allow the optimization of the operation and will increase the safety of its operation. The control and monitoring of the installations include the elements of the biogas generation and power plant.

6.2.2 Power of biogas plant

To assess the power of the installation, the user should provide some preliminary input data such as their energy requirements to be covered and the biomass to be used.

6.2.2.1 Feedstock´s biogas potential and performance efficiency

The maximum power output of a biogas plant can be estimated using several methods. One common method is to use the amount of feedstock that will be used by the plant as a starting point. By knowing the composition of the feedstock, you can estimate the potential amount of biogas that will be produced by the plant.

The biogas potential of feedstocks is an important factor when considering biogas production activity. A proper biogas production rate can be assessed through feedstock's biogas potential, which results will also impact on other considerations, such as economics, regulatory issues, feedstock availability on and off the facility, and end use of the biogas, that should also be evaluated. This data can be easily collected online, whereas expert companies are used to manage these technical concepts.

It is necessary to identify the biogas potential range that our chosen feedstocks can offer. For these:

- 1st stage: This step refers to the potential and availability of all suitable feedstock in the surrounding area that may be applied to biogas plant (e.g. manure, crop residues, organic waste etc.) and its biogas potential. Feedstocks from outside purchases or supplies may suffer from intermittences or supply issues. It should be ensured to have the most homogeneous feedstock supply to ensure anaerobic digestion stability.
- 2nd stage: Once the overall annual feedstock capacity is defined, it would be possible to estimate the overall maximum biogas potential for the available feedstock. For example, after considering a total available amount of 300 tons of pig manure per year, and considering pig manure BMP[8], a maximum annually biogas potential of 6,000 m^3 could be estimated.

Another important factor that can be used to estimate the maximum power output of a biogas plant is the efficiency of the plant's anaerobic digestion process. The efficiency of the process can be affected by a number of factors, including the temperature, pH, and pressure of the digester, as well as the type of microorganisms that are used. If an efficient coefficient of 60% is considered for the previous examples, a total annual biogas potential of 3600 m^3 should be finally inferred.

Table 13. Various feedstock's biogas potential.

Feedstock Type	Biogas Potential (m^3/ton)
Industry waste	457
Wood residues	225
Food organic waste	281
Sugar beet	321
Wheat	202
Soybeans	229
Rice	229
Sugar cane	202
Pig slurry	20
Sewage Sludge	15

Once you have an estimation of the potential biogas production and the efficiency of the anaerobic digestion process, you can use that information to estimate the maximum power output of the plant.

[8] *BMP, Biomethane Potential test: The biomethane potential (BMP) test is a laboratory analysis used to determine the potential amount of methane that can be produced from a given organic substrate, such as agricultural waste, sewage sludge or manure.*

It's important to keep in mind that these are just estimates and that actual performance may differ. Many site-specific factors like feedstock quality, digester design, and process monitoring and control also have a large impact on the performance of the plant. It is always recommended to consult with experienced biogas plant designers or operator for accurate estimation and effective plant operation.

6.2.2.2 Biogas end-use application

During the conception phase of any biogas production facility, it should be addressed which would be the final application of the produced biogas based on the community's objectives.

Some of the most common applications for biogas production include:

1. Energy generation: Biogas can be used as a source of energy for heat and electricity production in power plants. It is often used to fuel internal combustion engines or gas turbines to generate electricity.
2. Off-grid or on-grid: Most biogas production facilities are aimed to satisfy off-grid energy requirements as for self-consumption heating and electricity production. However, bigger anaerobic digestion projects also aim the conversion of organic waste into electricity with selling purposes to the electrical grid system. Biogas production applications could also aim both in-site heating and to-grid electricity sells.
3. Biomethane upgrading: Biogas can be purified to remove carbon dioxide and other impurities to produce biomethane, which is almost pure methane, it can be used as fuel for natural gas vehicles (NGV) and for injection into the natural gas grid.

It is crucial to define the intended application of the produced biogas, as it will impact the design and estimation of output power and capital expenditures. For instance, if the final application is electricity generation, there may be a need to purchase biogas upgrading units or combined heat and power (CHP) units. Many small-scale biogas plant facilities are designed for off-grid applications to increase energy savings for heating or other uses.

6.2.2.3 power output estimation

There are several ways to estimate the maximum power output of a biogas plant, but the most common method is to use the lower heating value[9] (LHV) of the biogas and the maximum biogas production potential. This estimation allows to identify the highest theoretical power that the plant could produce taking into account that all the energy contained in feedstock is transformed into biogas. It needs to be highlighted then, that anaerobic digestion performance will define real conversion rates and biogas yields.

As LHV may vary from one biogas to another, due to possible differences on their composition and from different feedstocks, typical average values can be used for estimating the total primary energy of the biogas potential input. The following formula may help to estimate the primary maximum power output of the biogas plant depending on the amount of feedstock used:

$$Maximum\ Power\ Output\ (kW) = \frac{V_{biogas\ (m^3/year)} \times LHV_{(MWh/m^3)}}{h} \times C_i$$

[9] *The lower heating value (LHV) of biogas is the amount of energy released when the biogas is burned and is typically measured in units of energy per volume. LHV of biogas can vary depending on the composition of the biogas, but it is typically around 55 MJ/m³*

Whereas:

- V_{biogas} refers to estimated annual maximum biogas potential for the specific case
- LHV refers to chosen standard or specific biogas lower heating value
- *h* refers to the expected annual total running hours for the plant
- C_i refers to the different efficiency coefficients that must be applied for the boiler, co-generation or other biogas application unit.

**E.g. Biogas used for heat production by boiler unit shows typical efficiencies C_{boiler}=0.75 for most commercial equipments. Biogas used for electricity production by co-generation unit shows typical efficiencies C_{boiler}=0.45 for most commercial equipments*

It should be noted that this method is just a rough estimation and real power output performance will depend on many factors including the design and operation of the biogas plant.

Additionally, you may also refer to other inputs and outputs of the plant such as feedstock, digester volume, and type, mixing method, temperature control, pre-treatment, etc; to get a more accurate estimation.

6.2.3 Operational and maintenance of the installation

Even though biomass and waste feedstocks are more cost-effective than fossil fuels, the operation and maintenance costs of biomass valorisation technologies are slightly higher to ensure proper operation and service life of the installation. This is due to the significant amount of inorganics and impurities that remain after biomass digestion, necessitating more frequent maintenance operations:

- The frequency of sludge and digestate removal will depend upon the installation characteristics and the biomass to be consumed. Biogas plant constructors and operators are expected to have experience and a background in maintenance of digesters and other units, particularly with regard to the retention and digestion times specified in the technical specifications of the units.
- When considering boilers or CHP for biogas use, removing the contaminants that can be located in the heat exchangers tubes and other auxiliary/cleaning emissions systems, can be done automatically by means of a pneumatic system (or other technologies). It is noteworthy to remark that biogas may contain small quantities of sulphurous compounds and other contaminants that may produce corrosion of the units, thus it is also recommended maintenance to be performed at least once per year, (normally after the winter season) and invest additional time to deeply clean all the installation.

Normally these operations are carried out by the company in charge of the operation of the installation. If these maintenance operations are being done and the design of the installations is based on the biomass resource to be fed, no malfunctions should arise.

Sometimes the bad experiences associated to the use of biomass, are due to the following issues:

- The biogas plant has been oversized and therefore the installation usually operates at very low capacity.
- The installation may encounter issues when the biomass fed is significantly different from the design specifications, as for instance: (i) different moisture content, (ii) size distribution (this can cause problems in the feeding system), (iii) chemical composition (be careful with that since it cannot be visually identified, high alkali and chlorine content, if the digester it is not designed

properly, can considerably decrease the service life of the installation), (iv) low biomethane potential, (v) ash content, etc.

6.3 Profitability of a biogas plant

Biogas plant profitability is greater than just economic issues. In first term, environmental challenges are roughly tackled by anaerobic digestion. Methane is one of the most contaminant greenhouse gases, thus its profitability as an energy carrier is further than only economic, but climate change mitigation. Moreover, anaerobic digestion emerges as a great application for the improvement of waste management strategies, otherwise, most waste streams end up disposed in landfills and contribute to pathogenic threats and environmental disasters.

In social terms, biogas plants also profit from great benefits regarding the economy and activities in rural areas, which are indeed the ones that hold the biggest potential for biogas explorations. Biogas plants create jobs that satisfy their construction, operation, maintenance, and supply, in addition to promoting local development, agricultural waste, and food waste management, reducing farm industry odours and health risks. In fact, rural areas may offer suitable symbiosis with biogas plants providing valuable local feedstock in exchange for cheaper and greener energy and waste management. All these facts result in cost savings for both the biogas plant and the agroindustry involved.

The main aspect that should be considered are (more described in Annex IV):

- Investment (CAPEX) of the new biogas plant installation: it includes the investment cost, the assembly and the transportation of all of the equipment required, together with the civil engineering costs. This number is very sensitive to the specificities of each case (location where the initiative will be implemented, expertise of the company in charge of the operations, the equipment selected, the biomass fed, etc).
- Operational and maintenance cost of the installation (OPEX): it includes the raw materials cost, labour cost, maintenance cost, energy cost, etc.
- Once, the CAPEX and OPEX of the new installation are estimated, in order to assess the economic profitability, the annual savings and/or energy sales of the new installation should be calculated. A simple way to calculate the payback period (this parameter indicates the necessary years to obtain the return of the investment carried out), is obtained through the division of CAPEX and profit of the operation (the annual savings and/or revenues discounted with OPEX costs) associated with the new installation. The lower the payback, the lower the risk associated with the new installation. It should always be lower than the service life of the new biogas facility (an average service life is between 20-30 years) for being economically profitable.

$$Payback = \frac{CAPEX}{\left(Annual\ savings\ \left(\frac{€}{year}\right) + Energy\ Sales\ \left(\frac{€}{year}\right)\right) - OPEX}$$

  - Annual savings refers to the substitution of heat and or electricity consumptions by biogas valorisation.
  - Energy sales refers to the revenues obtained by biogas, biomethane, electricity, heat or by products sold to other consumers or injected to the grid.

As mentioned, this is a simple way of doing a first estimation, but to be more accurate other parameters should be considered as the inflation or the tax rate. Table 4summarises the information mentioned in this section, through an example of investing on a new small-scale biogas plant production replacing electricity household consumption[10] of an average 10,000 population community (16,000 MWh_e) producing 5,000 tons of urban organic waste[11] (biogas potential of 0.280 m^3/kg as shown in section 3.3.1). In this example an inflation rate of 2% has been considered for household electricity consumptions and 1% for OPEX increase annually, as a result a 10-year payback period is obtained.

Table 14. An example of a breakdown of savings, expenses and investment obtained for a biogas plant.

Items	Unit	Data year 1
Savings (Current situation)		
Consumption of electricity	MWh/year	16,000
Price of electricity considered	€/MWh	150
Annual electricity cost	€/year	2,400,000
Biogas production	MWh/year	5,800
Yield of electricity production	%	35
Useful electricity production	MWh/year	2,030
Total energy satisfied by biogas		13%
Annual electricity savings	**€/year**	**304,500 €**
Expenses (future situation)		
Power of the installation (see section 3.3.3) with 7920h of work per year	MW	0.30
CAPEX cost (taking into account investment trends in bibliography [13]	**€**	**1,845,900**
Annual total cost: amortisation of investment cost, electricity consumption of the plant, feedstock costs, transport of feedstocks, salaries and maintenance costs (see section 4.2)	€/year	121,800
Total earning (Savings – OPEX)	**€/year**	**182,700**

[10] Energy consumption per capita in the household's sector in the EU in 2020 was 1.6 MWh per capita

[11] When expressed in relation to population size, the EU generated, on average, 4 813 kg per capita of waste excluding major mineral waste in 2020, whereas household shares 9.15%. Thus, organic municipal waste is estimated on **500 kg per capita annually** [77]

Items	Unit	Data year 1
Financial considerations		
Inflation of electricity	% of inflation per year	2
Inflation of OPEX	% of inflation per year	1
Grant	%	0
Loans	%	0
Payback		
Payback	**Years**	**9,3**

6.4 Stakeholders needed

In order to develop a biogas installation, the users, in the majority of the cases, would most likely need the support from other stakeholders, that sometimes can be integrated inside the community/RESCoop or in other cases they will provide external support by subcontracting. Some of the stakeholders that could be necessary are listed below:

- Biomass producers/suppliers
- Energy Services/Engineering Company (ESCO)
- Equipment manufacturers
- Public/Local institutions
- Consumers
- Transversal stakeholders (as research centre, biomass associations, investors)

  a) Research centres.

  b) Biomass association/local action groups.

  c) Investors

In case the promotor of the idea needs to contact or find out a specific stakeholder, it is advisable to visit BECoop e-market platform where you can find useful information in this regard (https://www.becoop-project.eu/tools/e-market-environment/).

6.5 Steps to be followed

This section aims to summarize and establish a chronological order of general steps to be performed by the promoter of the idea of a biogas production plant unit starting from the beginning.

Table 15. General steps to be followed to develop a biogas facility from the beginning.

Order	Action	Description	Stakeholders that can help
1	To define the available amount of biomass for anaerobic digestion and the potential of biogas than can be produced with it.	The first step is to understand the dimensions of the biogas plant to be developed, which relies on the estimated production of biogas.	Biomass suppliers and producers are important stakeholders in determining the available amount of biomass. Additionally, other community members can also be involved in the process. In cases where support is needed, they can reach out to research centers or ESCOs to carry out estimations and provide guidance on the design and implementation of the biogas plant.
2	Biogas final use or application.	The way biogas is going to be valorised or used is very important to envision the type of technologies that will be implemented within the plant and its cost.	Final consumers should provide the type of energy to be covered with the biogas (thermal, electricity, both, etc). Research Centres and ESCO can provide support for the selection of the technology.
3	To do a pre-feasibility assessment about the implementation of a biogas plant.	Based on the information described in chapters 3 and 4, it is key to evaluate the economical KPIs in order to decide whether to go further with this project or not.	It is recommended that the design and implementation of a biogas plant be carried out by an expert in the field, such as a research center or an Energy Service Company (ESCO).
4	To identify and contact different ESCOs and communicate the initiative.	Preliminary contact with ESCOs should be done with the goal of communicating the project and investigate if they are interested to collaborate.	It can be done by the promoter of the idea with the support of the company that will carry out the pre-feasibility assessment (if it wasn't previously done).
5	To carry out the design and the implementation of the biogas plant.	To develop the project of the biomass anaerobic digestion for biogas production and its implementation, selecting the biomass to be fed, the equipment needed, to obtain the administrative licenses, etc.	Usually done by the ESCO selected and/or an engineering company.
6	To guarantee the supply of the biomass.	The proper quality of biomass is crucial for the successful design and operation of a biogas installation.	It depends on the business model selected, and the role of each stakeholder of the community. Normally, the agreement with the biomass supplier is carried out by the same stakeholder that is in charge of the operation and maintenance of the biogas facility.

Order	Action	Description	Stakeholders that can help
7	To start with the operation of the biogas plant	Guaranteeing the correct operation of the installation, securing the energy (biogas, biomethane, electricity or heat) supply to the final consumers and the correct maintenance of the installation to ensure its useful life.	ESCO, the community or other stakeholder selected to be in charge of the operation and distribution of the biogas application products should be responsible of this.

6.6 Success cases

This section describes an initiative that has already been implemented with the goal of raising awareness about the potential benefits of successfully developing a biogas plant, as well as gaining a better understanding of its average techno-economic performance.

6.6.1 Combination of anaerobic digestion with composting in Girona, Spain

Pla de l'Estany is a poblation of Girona province (Catalonia, Spain) designed as vulnerable zone according to Government. In order to improve land fertilization and minimize environmental pollution when applying manure, it is compulsory to farmers to establish Nutrient Managing Plans (NMP) which farmers had to design and validate according to the dosage of nutrients applicable to their crops. Enhancements in animal feeding, manure transportation and treatments may be also considered [78].

In this context, the dairy farm SAT Sant Mer, decided to build a biogas plant to process the manure produced together with other organic wastes.

The project of Apergas plant is the result of the synergy of three companies: SAT San Mer, EnErGi, and BIOVEC. The design of the plant was done in 2007, the construction during 2008 and the startup in 2009. It treated slurry from dairy farms of SAT San Mer altogether with organic wastes from other agribusiness facilities. A total of 18,771 m3 of cow slurry and 3,129 m3 of co-substrates were digested.

Figure 24. General view of Apergas biogas plant (left), anaerobic digesters (right).

Biogas at a flow rate of 322 ton per year was valorized in CHP unit of 500 kW with an electrical production of 4,000 MWh per year. A total of 1,100 tons CO_{2eq} per year savings were estimated for the operation of the plant during 2010 and 2011. Furthermore, CAPEX data were reported with a total of 1.4 M€, whereas main digesters and CHP units share a 50% of the investment. Also cost of operation (OPEX) were reported regarding electrical consumptions, salaries, maintenance, and other costs as a total of 200 k€ per year.

Table 16. CAPEX and OPEX of the project.

CAPEX	
Unit Description	Cost (€)
Equipment (stirrers, pumps, valves, CHP engine, etc.)	522,800 €
Concrete works (Anaerobic digesters, composting platforms and trenches, etc.).	292,000 €
Facilities (gas, water, electricity)	132,000 €
Grid connection	136,200 €
Mechanical separator	28,300 €
Hydrogen sulphite control	18,000 €
Soil movement, levelling, etc.	89,500 €
Other (roads, fees, contingency, etc.)	63,000 €
Toilets, landscaping, etc.	15,000 €
Project engineering	114,000 €
Total Investment	**1,410,800 €**
OPEX	
Concept	Cost (€)
Salaries	33,100 € / y
Operational control (sampling, analysis, etc.)	27,830€ / y
Maintenance	61,200 € / y
Electricity	12,976 € / y
Other	70,000 € / y
Total operational cost	**205,106 € / y**

6.7 Summary

This document establishes the main terms and elements that must be understood and considered when thinking on implementing a biogas production facility. For such assessment, it is clearly defined which are the key- parameters to develop for these kinds of projects: available biomass in the area, biogas capacity and potential, and a clean economic assessment to ensure the feasibility of the facility. Moreover, it also offers several examples of stakeholder's groups that may enable and offer synergies for the implementation of biogas production and valorisation projects. Some steps to follow are also given. Finally, this catalogue may serve as a guide for promoters to enable their actions with stakeholders, energy communities and biomass owners. However, bioenergy projects require some technical knowledge and experience, thus it is highly recommended to further consult experts and engineering companies to facilitate the decision-making process prior to investing.

7. Key technical factsheets

7.1 Factsheet of solid biomass for small-scale heating applications

This factsheet intends to help the stakeholders understand the main aspects that should be considered when solid biomass is purchased. This factsheet includes information about:

- The different types of biomasses according to their origin: agricultural, forestry, agro-industrial and from urban parks and gardens.
- The different tradeable form that biomass be offered in the market: bales, firewood, woodchips, hog fuel, granular material, briquettes and pellets.
- Some average physicochemical characteristics of each of these biomasses, in order for the stakeholder to have a first idea of their quality.
- Biomass fuel quality certification schemes and why they are needed. The quality of the biomass, even if it is from the same resource, it can change a lot depending on different factors (logistic operations, characteristic of the soil, etc.). Therefore, with the aim of guaranteeing the quality, there are different quality certification schemes in the market that are mentioned (EnPlus® and Biomasud®).
- Finally, the factsheet highlights the main parameters and aspects to be taken into account when solid biomass is used for small-scale heating applications.

Figure 25 shows a screenshot of the factsheet. The original file with all the information can be found in Annex IV.


BECoop UNLOCKING THE COMMUNITY BIOENERGY POTENTIAL

FACTSHEET OF SOLID BIOMASS FOR SMALL-SCALE HEATING APPLICATIONS

Summary of the factsheet

Bioenergy – energy produced from biomass – is the most widely used renewable energy source in Europe as well as the most versatile, being able to provide heat, electricity or fuels for transport. The current factsheet focuses on the use of biomass as a solid biomass fuel, especially targeting small-scale heating applications.

KEYWORDS:
Biomass
Types of Biomass
Biofuel Characteristics
Certification of biomass

Types of biomass: The following main types of biomass can be discerned depending on the activity which produces them.

- **Agricultural biomass:** usually, the term refers to crops residues that are generated after the harvesting of the main product (e.g. straw) or from regular prunings of permanent crops (e.g. olive trees, vineyards, orchards), etc. The term can also apply to dedicated, non-food plant species, such as miscanthus, willow, poplar, etc. that are cultivated with the intend of being used as feedstock for energy purposes.
- **Forestry biomass:** a wide range of materials that derive from the sustainable management activities of forests (firewood, forest residues, etc.) and from the forest wood processing sector (sawdust, wood shavings, etc.). Most of the bioenergy in Europe is coming from forest biomass, especially in heating applications.
- **Agro-industrial biomass:** residues that are generated after processing a main agricultural crop in an agro-industry. They include olive stones, exhausted olive cake, almond shells, sunflower husks and others. Since they are generated in a specific point, they do not require harvesting operations and are thus a very cost-competitive option for energy generation.
- **Biomass from urban parks and gardens:** often referred to as "green waste", it mostly consists of tree prunings and other cuttings that are generated in an urban setting. They are typically handled in the framework of municipal waste management schemes.

Tradeable Forms of Biomass:

Bales | *Firewood* | *Chips or hog fuel (mixed shavings)* | *Granular material* | *Pellets* | *Briquettes*

Indicative fuel properties of various solid biofuels

Property	Units	Wood Pellets A1	Vineyard pruning pellets	Sunflower husk pellets	Olive tree pruning (hog fuel)	Wheat Straw	Olive Stones	Almond shells	Miscanthus
Moisture content	w-%, a.r.	≤10	10	10	27	15	15	11	15
Ash content	w-%, d.b.	≤0.7	4.5	4.0	4.2	5.0	1.2	1.6	4.0
LHV	MJ/kg, a.r.	≥16.5	15.7	15.7	12.9	14.6	15.8	16.1	14.7
Bulk Density	kg/m³, a.r.	600≤BD ≤750	710	550	230	200 (bales)/ 85 (chopped)	730	410	130 (chopped)
Nitrogen, N	w-%, d.b.	≤0.3	0.81	0.8	0.93	0.5	0.3	0.4	0.7
Sulphur, S	w-%, d.b.	≤0.04	0.07	0.1	0.08	0.1	0.02	0.01	0.2
Chlorine, Cl	w-%, d.b.	≤0.02	0.02	0.06	0.04	0.4	0.1	0.02	0.2

a.r: as received; d.b: dry basis; LHV: Low Heating Value; More information on biomass properties on D3.2 of the Biomasud Plus project and Annex B, EN ISO 17225-1; Solid biofuel composition can vary significantly. The given values are only indicative of typical values.

Biomass Fuel Quality Certification Schemes:

A biomass fuel quality certification scheme is meant to provide assurances to small-scale, i.e. domestic, biomass end-users that the fuel they purchase does indeed comply with specific quality parameters. Such schemes require that biofuel producers adopt specific quality control measures, which is then certified through third-party audits. The most widespread quality certification scheme is **ENplus®** for wood pellets. Other schemes, such as **BIOmasud®** allow for certification for more assortments, such as olive stones and nut shells.

What makes a solid biofuel suitable for small-scale heating applications?

Generally, all types of biomass can be converted to energy with the use of appropriate technology. However, in small-scale heating applications there are several technical and other limitations that influence the choice of the appropriate fuel. Some of the most important ones are:

- **Low moisture content:** increases the energy received from the fuel and helps maintain a clean and efficient combustion.
- **Low ash content:** reduces emissions of dust, while also minimizing the cleaning intervals.
- **Homogeneous / consistent particle size:** helps to avoid issues in the fuel feeding system.
- **High energy density:** minimizes storage requirements and transportation costs.

Ultimately, a consumer should never forget that in order to be **effective** and **low-emissions**, bio-heat should be produced in **properly installed and well-maintained** appliances and using the **appropriate fuel assortments!**

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Figure 25. Screenshot of the Factsheet of solid biomass for small-scale heating applications

7.2 Factsheet of biomass logistic supply chain

This factsheet aims to provide some information about biomass logistic supply chains in order to facilitate the uptake of these initiatives. This factsheet includes:

- Initial consideration that should be taken into account before selecting and implementing the logistic operations as: CAPEX needed, amount of biomass to be mobilized, distribution of the resource and soil conditions, quality requirements of the client etc.
- According to the type of biomass (agricultural biomass, forestry biomass and biomass from urban parks and gardens), the machinery and the logistic strategy could be different, so specific recommendations are provided in this factsheet regarding the targeted resource by the user. In addition to these logistic considerations, a reference document with much more information is indicated to go deeper into it.
- Finally, and regardless of the biomass resource, some general recommendations are indicated for the logistic operators, not just focusing on their operations, but also focusing on the agreements and communications that they should perform with the owners and the clients of the biomass that they are going to collect.

Figure 26 shows a screenshot of the factsheet. The original file with all the information can be found in Annex V.

Figure 26. Screenshot of the Factsheet of biomass logistic supply chain

7.3 Factsheet of solid biofuels production

As mentioned in the factsheet of section 7.1, biomass can be found in the market with different size distribution, therefore this factsheet focuses on the considerations that should be taken into account if a stakeholder wants to produce solid biofuels focusing on the three more frequently tradeable forms: pellets, woodchips and briquettes.

- Although processing biomass implies higher cost, it also has the advantage of obtaining a more homogeneous fuel with stable quality. The first section of the factsheet points out some reference quality certification schemes that guarantee that the biofuel has the proper quality.
- The following section indicates the main equipment for the production of pellets, woodchips and briquettes and some ranges about the production costs. These ranges should be taken with caution as there is a big difference between different EU countries.
- Hereafter, the CAPEX of these installations based on the capacity are mentioned, but as same as the production cost, this investment can highly change among EU countries and depending on the technology and provider selected.
- Finally, the market audience of each of these tradeable forms and some ranges about their current market prices are indicated.

Figure 27 shows a screenshot of the factsheet. The original file with all the information can be found in Annex VI.


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FACTSHEET OF SOLID BIOFUELS PRODUCTION

Summary of the factsheet

Production of pellets/woodchips/briquettes are characterized by high homogeneity as well as stable physical and chemical properties. These solid biofuels production can take place with different technologies and in a wide range of installation capacity. Various options of production lines (automatic, half-automatic with manual operations, etc) create possibilities to adjust properly the installation to the fuel requirements, producer's expectations, investment needed and final price of the solid biofuel.

KEYWORDS: Installation capacity; Uniform shape; Stable quality; Investment cost

Why processing biomass?

- Production of good quality biomass fuel in the form of pellets, woodchips and briquettes is intended for achieving a homogenous biofuel with a stable quality. This fact will facilitate the following operations with high efficiency to produce heat in a controlled, maintenance-free, and environmentally friendly manner.
- Reference quality standards/certification:
  - Pellet: ENPLUS, DINPlus, ISO 17225-2/6
  - Woodchips: ISO 17225-4, Biomasud
  - Briquettes: ISO 17225-3/7

Parameter	Pellet	Woodchips	Briquettes
Moisture content, %, a.r.	8-12	15-35	10-20
Ash content, %, a.r.	<0.5	<3.0	<3.0
LHV, MJ/kg, a.r.	18-19	13-16	15-18
Bulk density, kg/m³, a.r.	600-750	150-350	350-550

a.r: as received; d.b: dry basis; LHV: Low Heating Value

Pellet production

- The pellets production technological line consists of the following units: (i) shredding/milling system, (ii) drying/mixing section, (iii) pelletizing (granulator) unit, (iv) pellet's cooling system, and (v) packing line.
- The expenditures related to the pelletizing line (without buildings and feedstock cost) depend on its capacity and automation rate. The approximate production cost of pellets is from 60-120 €/t (in dependance on the labor costs, electricity price etc.)

*Drying operations with herbaceous material is not always required

Woodchip production

- The essential parameters of woodchips are proper particle size and moisture content. The wood chips production line is very simple, and its costs depends on the capacity and automation rate.
- The approximate production cost of wood chips is from 20 to 50 €/t (without feedstock cost).

Briquettes production

- In the briquette production process, it is very important to select the appropriate mill for the processed type of biomass and its form (logs, branches, straw, boards, chips) and the briquetting device that will produce a product of a specific shape.
- The production costs are in the range 45-150 €/t (without feedstock cost).

Investment costs

- The investment can highly change between EU countries, and the technology selected, but some ranges are:

Installation capacity, kg/h	Pellets Investment costs, k€	Woodchips Investment costs, k€	Briquettes Investment costs, k€
200	10-60	2-4	10-50
700	55-110	5-12	40-80
1000	110-600	10-15	55-120
2500	250-1,000	25-60	80-250

Market audience of these solid biofuels

- Pellets are recommended for fully automatic domestic boiler with a small amount of storage spaces.
- Wood chips are rather suggested for medium-sized and industrial boilers (above 50 kW) due to the storage conditions and higher moisture content (the volume of wood chips store is 3-4 times larger than that of pellets).
- Briquettes can be utilised in boilers/fireplaces of all sizes, but their feeding to the combustion chamber in small heating units must be done manually.
- The market price of these solid biofuels for a final consumer depends on many factors (biomass type, fuel accessabillity, alternative fuel prices etc.), and are, as follow: pellets (170-350 €/t), briquettes (150-400 €/t), and wood chips (50-100 €/t).

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Figure 27. Screenshot of the factsheet of solid biofuels production

7.4 Factsheet of biomass feedstock evaluation

A biomass feedstock evaluation helps to assess the quantity of feedstock in a particular region and if it can be guaranteed in the future. This information is essential to assess the technical and economic viability of biomass-based projects. This factsheet includes:

- Information about how to assess the biomass feedstock potential from statistical yearbooks, from online tools (included in the Toolkit), and more advanced techniques.
- A table with some range of biomass productivity per ha that can be expected depending on the type of target biomass and the peculiarities of each one.
- How to make the transition from biomass potential to biomass availability due to technical, horticultural, logistical barriers or local peculiarities.
- Finally, since calculating the available biomass can be a complicated process, different types of stakeholders that can provide support are proposed.

Figure 28 shows a screenshot of the factsheet. The original file with all the information can be found in Annex VI.


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FACTSHEET OF BIOMASS FEEDSTOCK EVALUATION

Summary of the factsheet

The current factsheet tackles the topic of biomass feedstock evaluation: (i) why it should be considered, (ii) how to assess the biomass potential (iii) from biomass potential to biomass availability and (iv) stakeholders that can provide support.

KEYWORDS:

Biomass potential
Biomass availability
Feedstock evaluation
Stakeholders support

Why feedstock evaluation should be considered?

One of the most important aspects to be taken into account when considering any activity around local biomass is to know if there is biomass potential in a nearby area and if it can be guaranteed in the future.

In this sense, it is necessary to differentiate between the potential biomass that may exist and the biomass that will be available and accessible.

How to assess the biomass potential?

A methodology to assess the biomass potential to follow could be:

- To *define the sourcing radius (km)* for assessing the biomass potential (normally should be lower than 100 km). It should be taken into account that a large part of the cost associated with the supply of biomass is due to the transportation of biomass.
- To consult the *agricultural and forestry statistical yearbooks*, in order to assess the amount of ha of each crop at least from the last 3 years.
- To identify the most representative crop in your local area and its corresponding *biomass productivity* that you can obtain *per ha*. This will depend on the type of biomass and:
    - the type of crop species
    - whether the biomass comes from whole tree or only from tops and branches (always respecting the criteria set by RED II)
    - if the biomass comes from pruning, plantation removals, maintenance operations, forestry fires, etc.
    - Frequency of horticultural practices
- In the case of agroindustrial biomass, it will depend on the amount of crops collected and processed each year during the treating/ refining processes in the agroindustries.

Other option if you want to do a first assessment is to consult *some open-source tools* described in the BECoop toolkit that provides a first estimation of the biomass potential, as: *BIORAISE, S2BIOM*. These online tools are very general but can provide a preliminary idea of the biomass potential.

There are *more advanced techniques* such as to create your *own geographical information system, remote sensing technologies* (as for instance LIDAR), etc but this are more complicated for an unexperienced user.

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FACTSHEET OF BIOMASS FEEDSTOCK EVALUATION

Biomass Productivity Ratios

Resource	Productivity per ha (t/ha, d.b.)	Comments
Forestry biomass	20-100	When maintenance operations are needed.
Agricultural biomass from pruning operations	0.7-4.0 (rainfed land) 1.5-8 (irrigated land)	It depends on the crop and the type of land (rainfed or irrigated). Pruning operations are carried once per year or every two years (mainly with olive crops).
Agricultural biomass from plantation removals	1.7-40	It is becoming more and more common to renovate plantations, either by changing variety, crop or to make the plantation more productive. It depends on the crops but between 10-60 years the plantations are usually renovated.
Agroindustrial resources (olive pit, exhausted olive cake, almond shells, etc)	-	Highly depends on the quantity of harvested crop collected each year and the type of agro-industry. It is usually derived as a by-product of refining/treating a crop product.
Biomass from urban parks and garden	15-30	When maintenance operations are needed.

From biomass potential to biomass availability

Once you know the biomass potential, you should consider other aspects in order to assess the biomass availability, as for instance:

- *Technical considerations for the harvesting of biomass* (access to the fields, slopes, distances between plantations etc.)
- To *get in contact with some local owners of biomass* (farmers, cooperatives, public and private forest owners) in order to obtain *information about the standard practices* that the owners of this biomass are doing in the area of interest.
- *Biomass logistic operators are needed*, if they do not exist, it can be a barrier.
- *Current consumers of biomass*. Is there other biomass consumers? Are they expected in the future? Such consumers could threaten the secured supply of the biomass.
- *Other current or future use* of biomass as for instance organic matter.

Once you collect all this information you can have a better picture of the biomass availability in your local area.

Stakeholders that can provide support

To carry out a feedstock evaluation can be a complicated task, so the following stakeholders can provide support:

Research Centers Universities | *Public Institutions Biomass associations* | *Biomass owners/ agricultural/forest co-operatives* | *Biomass suppliers* | ***Look for them in the BECoop e-market***

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Figure 28. Screenshot of the factsheet of biomass feedstock evaluation.

8.Conclusions

BECoop, through this deliverable, is expected to deal with one of the main barriers that were identified in previous workshops carried out, related to the lack of technical requirements and the potential absence of identified and reported steps to be followed prior to investing on a bioenergy heating solution. On this basis, this deliverable offers access to easily understandable information that could help bioenergy community initiatives identify the feasibility of the biomass bioenergy solutions for what they want to achieve.

In particular, our work was focused on the most common bioenergy technologies that could be implemented in the residential sector through a community model. Such technologies were reported as technical catalogues, whereas transversal information with recommendations and advice about other activities associated with the use of biomass, were depicted in factsheets.

This documentation is also highly linked with the other tasks of WP2, for instance the rational is that, after using the self-assessment tool (T2.1), interested stakeholders will be able to consult this catalogue, since it will facilitate the identification of the technical needs and the group of stakeholders that can provide support (which can be search in the e-market platform, T2.3), thus facilitating the resources needed for the decision-making.

Additionally, this report has contributed to these tasks of BECoop:

- it complements the self-assessment tool carried out (https://www.becoop-project.eu/tools/assessment-tool/) in WP2, since these technical support services will be linked (when necessary) in the recommendations that this tool provide to the user.
- it contributes in the preparation for the training workshops and capacity building webinars in WP3.
- It facilitates technical support providing in WP4 for the uptake of the new bioenergy communities.
- Content presented herein is also linked or fused to the BECoop Knowledge Exchange Platform, the BECoop Replication Handbook and broadcasted through the follower cases' support activities within WP5.

9.References

[1] BECoop H2020 Project (952930) D2.2 Self-assessment tool for evaluating current regional status and future potential – Final 82021)

[2] https://www.sciencedirect.com/topics/engineering/district-heating-system. [Available online: 06 12 2021]

[3] http://www.wattenergysaver.co.uk/biomass.html. [Available online: 06 12 2021]

[4] http://business.insite-energy.co.uk/what-is-heat-network/. [Available online: 06 12 2021]

[5] https://www.treco.co.uk/news/article/what-is-biomass-heating. [Available online: 06 12 2021]

[6] https://kotly.com/pl/82-kociol-na-pellet-eg-pellet.html. [Available online: 06 12 2021]

[7] https://www.atmos.eu/poland/index.php?rw=1&page=kotle-007. [Available online: 06 12 2021]

[8] http://www.shs-renewables.ie/images/wood_chip_boiler_xsection.gif. [Available online: 06 12 2021]

[9]https://www.froeling.com/fileadmin/content/produkte/Prospekte_Flyer/EN/EN_Prospekt_S3_Turbo.pdf. [Available online: 06 12 2021]

[10] https://kotlynaslome.pl/en/biomass-boilers-ekopal-rm-series/parameters/. [Available online: 06 12 2021]

[11] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products.

[12] EPC Storage Guidelines. Recommendations on the design, installation and operation of fuel stores for heating appliances.

[13] https://www.abs-silos.de/en/wood-pellet-silos/general-information.html. [Available online: 06 12 2021]

[14] https://sc04.alicdn.com/kf/UTB8UH1kIarFXKJk43Ovq6ybnpXaz.jpg. [Available online: 06 12 2021]

[15]https://www.herz-energie.at/pl/produkt/systemy-magazynowania-i-technologie-transportu-paliwa/do-zrebek-i-peletu/. [Available online: 06 12 2021]

[16] https://www.trimetals.co.uk/2017/12/store-logs-outside/. [Available online: 06 12 2021].

[17] https://arbena.pl/wp-content/uploads/2020/05/Magazyn-na-baloty-w-malowniczym-otoczeniu-1.jpg. [Available online: 06 12 2021]

[18] Energy performance of buildings - Method for calculating the heat demand by installation and system efficiencies - Part 4-4: Heat sources, integrated cogeneration systems, Module M8-3-4, M8-8-4, M8-11-4

[19] https://www.as-gips.pl/jak-dobrac-moc-kotla/. [Available online: 06 12 2021].

[20] http://www.rynekinstalacyjny.pl/artykul/id4799,efekty-termomodernizacji-i-zastosowania-oze-w-budynku-jednorodzinnym. [Available online: 06 12 2021].

[21] http://www.drevohaus.pl/?drev=energooszczednosc. [Available online: 06 12 2021].

[22] Own evaluation basing on database of Ministry of Technologies and Development: https://rejestrcheb.mrit.gov.pl/

[23] https://kb.pl/. [Available online: 06 12 2021].

[24] Treco webpage (https://www.treco.co.uk/) [Available online: 06 12 2021].

[25]https://naturequebec.org/wp-content/uploads/2019/05/Depliant_biomasse_Chaudiere_WEB-1.pdf [Available online: 06 12 2021]

[26] http://www.globalbioenergy.org/uploads/media/0904_Environment_Agency_-_Minimising_greenhouse_gas_emissions_from_biomass_energy_generation.pdf [Available online: 06 12 2021]

[27] Lachman P (2013) Porównanie emisji zanieczyszczeń różnych technologii grzewczych wg raportu IPTS dla Komisji Europejskiej [Comparison of emissions of various heating technologies by IPTS report for the European Commission] InstalReporter 2013. No. 01. pp. 29–30 (on-line version, date of access 15.12.2021)

[28] https://www.volker-quaschning.de/datserv/CO2-spez/index_e.php. [Available online: 06 12 2021]

[29] Steen M. Greenhouse Gas Emissions from Fossil Fuel Fired Power Generation Systems.. EUR19754 EN. 2001. JRC21207

[30] uP_running (691748): Take-off for sustainable supply of woody biomass from agrarian pruningand plantation removal, D6.4: Flagship success cases update v2, Annex: The Gospodarstwo Sadownicze flagship case, 2018

[31] Climatización Urbana en las Ciudades Españolas. Red Española de Ciudades por el Clima.

[32] https://www.efidistrict.eu/en/new-district-heating-network/application-to-district-heating-systems/

[33] https://tradingeconomics.com/commodity/carbon

[34] Danish Energy Agency, "Technology Data for Energy Plants Updated chapters," Danish Energy Agency, 2016.

[35] Bioenergy Europe Statistical Report 2020

[36] uP_running (691748): Take-off for sustainable supply of woody biomass from agrarian pruning and plantation removal, D6.3: Flagship success cases update v1, Annex II: Vineyards4heat flagship report, 2017

[37] Promobiomasse Interreg project. https://promobiomasse.eu/tag/plan-de-gestion/

[38] REHAU. https://www.rehau.com/es-es/pueblo-de-bioenergia-en-sabando-alava

[39] Sustainable Energy Authority of Ireland, Biomass CHP: Implementation Guide, (2020). https://e-rational.net/applications/biomass-chp.html

[40] COGEN Europe, "Cogeneration in the Fit for 55 strategy" from webinar: Biomass CHP in the clean energy transition, organized by BIOCOGEN 2030, (2021)

[41] IEA-ETSAP and IRENA, Biomass for heat and power, (2015)

[42] AgroBioHeat H2020 project (818369), D4.2: Agrobiomass fuels and utilization systems, (2020)

[43] Sustainable Energy Authority of Ireland, Biomass Boilers - Technology Guide, (2019) 1–14. https://www.seai.ie/publications/Biomass-Boilers-Technology-Guide.pdf

[44] J. Yliniemi, Alkali activation-granulation of fluidized bed combustion fly ashes, 2017

[45] D. Peterson, S. Haase, Market Assessment of Biomass Gasification and Combustion Technology for Small- and Medium-Scale Applications Market Assessment of Biomass Gasification and Combustion Technology for Small- and Medium-Scale Applications, Contract. (2009)

[46] T.A. Milne, R.J. Evans, N. Abatzaglou, Biomass Gasifier "'Tars'": Their Nature, Formation, and Conversion, United States, 1998. https://doi.org/10.2172/3726

[47] Mühlstein Jan, Mühlstein Jan; Unternehmen – SteamCell geht Dampf aus; Energie & Management GmbH; 25.11.2005, (n.d.). https://www.energie-und-management.de/free-archive/feview3/10901

[48] Mühlstein Jan, Mühlstein Jan; Unternehmen – SteamCell geht Dampf aus; Energie & Management GmbH; 25.11.2005, (n.d.)

[49] G. Zweiler, R.; Doczekal, Ch.; Paar, K.; Peischl, Energetisch und wirtschaftlich optimierte Biomasse-Kraft-Wärmekopplungssysteme auf Basis derzeit verfügbarer Technologien – Endbericht; Projektnr. 812771; 2. Ausschreibung Energie der Zukunft; Bundesministerium für Verkehr, Innovation und Technologie (BMV, (n.d.)

[50] I.J. Fischer, Technologies for small scale biomass CHP – plants – an actual survey, 2003. http://www.risoe.dk/rispubl/presentations/%0Afischer.pdf

[51] D. Pritchard, Biomass Combustion Gas Turbine CHP, 2002. http://www.dti.gov.uk/files/file14922.pd

[52] H. Kopetz, Present Development in Small Scale Combined Heat and Power (CHP), n.d. http://www.svebio.se/attachments/33/293.pdf

[53] P.A. K. Sipila, E. Pursiheimo, S. Tuula, C.J. Fogelholm, I. Keppo, Small-Scale Biomass CHP Plant and District Heating, 2005

[54] A.D. Hawkes, M.A. Leach, Cost-effective operating strategy for residential micro-combined heat and power, Energy. 32 (2007) 711–723. https://doi.org/10.1016/j.energy.2006.06.001

[55] L. Dong, H. Liu, S. Riffat, Development of small-scale and micro-scale biomass-fuelled CHP systems - A literature review, Appl. Therm. Eng. 29 (2009) 2119–2126. https://doi.org/10.1016/j.applthermaleng.2008.12.004

[56] CPC, (n.d.). http://www.gocpc.com

[57] A. Malmquist, Swedish Micro-CHP Solution – Externally Fired Microturbine System, n.d. http://www.svebio.se/attachments/33/306.pdf

[58] R. Padinger, S. Aigenbauer, C. Schmidl, J.D. Bentzen, Best practise report on decentralized biomass fired CHP plants and status of biomass fired small-and micro scale CHP technologies, IEA Bioenergy. 32 (2019) 1–83

[59] U. S. Environmental Protection Agency, Biomass Combined Heat and Power Catalog of Technologies, Biomass. (2007) 122. http://www.epa.gov/chp/documents/biomass_chp_catalog_part1.pdf.

[60] ÖkoFEN, Pellematic Smart_e 0.6, Electricity and heat for single family homes, n.d. https://stroomop.eu/data/documents/okofenefolderen.pdf.

[61] W. Götz, Thomas ; Saurat, Mathieu ; Tholen, Lena ; Adisorn, Thomas ; Obernberger, Ingwald ; Brunner, Thomas ; Kerschbaum, Michael ; Purushothaman Vellayani, Aravind ; Makkus, Robert ; Megel, Stefan ; Hauth, Martin ; Zappa, Green on-site power generation : environmental considerations on small-scale biomass gasifier fuel-cell CHP systems for the residential sector, Proc. 9th Int. Conf. Energy Effic. Domest. Appliances Light. (EEDAL ’17). (2017) 909–921. https://doi.org/10.2760/113534.

[62] U.S.E.P.A. EPA, CHP Benefits, (n.d.). https://www.epa.gov/chp/chp-benefits.

[63] RED II (Renewable Energy Directive) 2018/2001/EU, (2018). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC.

[64] COGEN Europe, Delta Energy & Environment, The benefits of micro-CHP, (2016) 24.

[65] A. Proka, M. Hisschemöller, E. Papyrakis, The scale of transition: an integrated study of the performance of CHP biomass plants in the Netherlands, J. Integr. Environ. Sci. 11 (2014) 225–241. https://doi.org/10.1080/1943815X.2014.966113.

[66] Volter, Datasheet of Volter 40 Indoor, (n.d.). http://www.bkvab.se/downloads/Volter 40 Indoor_Datasheet.pdf.

[67] Anton Gissek, OPERATIONAL ENVIRONMENT FOR BIOMASS-BASED SMALL-SCALE CHP UNIT, Lappeenranta University of Technology, 2017.

[68] Small-scale CHP Life+ Project, Emå Dairy Lessons learned Factsheet, (n.d.).

[69] College on tap to receive gasifier, article on WhiteHorse Daily Star, Canada, (n.d.). https://www.whitehorsestar.com/News/college-on-tap-to-receive-gasifier.

[70] An introduction to biogas and biomethane – Outlook for biogas and biomethane: Prospects for organic growth – Analysis - IEA n.d. https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane (accessed February 2, 2023).

[71] How Does Anaerobic Digestion Work? | US EPA n.d. https://www.epa.gov/agstar/how-does-anaerobic-digestion-work (accessed January 9, 2023).

[72] Rasi S, Veijanen A, Rintala J. Trace compounds of biogas from different biogas production plants. Energy 2007;32:1375–80. https://doi.org/10.1016/J.ENERGY.2006.10.018.

[73] BASIC DATA ON BIOGAS 2012.

[74] Jacob Jørgensen P, for Day R. Biogas-green energy. Process. Design. energy suPPly. environment Biogas-green energy Process • Design • Energy supply • Environment n.d.

[75] Anaerobic System Design and Technology | US EPA n.d. https://www.epa.gov/agstar/anaerobic-system-design-and-technology (accessed January 20, 2023).

[76] Types of Biogas Storage Systems | BioEnergy Consult n.d. https://www.bioenergyconsult.com/biogas-storage/ (accessed January 19, 2023).

[77] Waste statistics - Statistics Explained n.d. https://ec.europa.eu/eurostat/statistics-explained/index.php?oldid=503519 (accessed January 31, 2023).

[78] Foged R, Lyngsø H, Flotats X, Bonmati Blasi A, Martin Schelde K, Palatsi J, et al. Assessment of economic feasibility and environmental performance of manure processing technologies 2012.

Annexes

Annex I: Technical catalogue on biomass direct heating

1. Introduction

This report focuses on presenting bioenergy heating solutions in the form of technical catalogue. It provides a comprehensive study of direct heating implementation in households. The work presented here is based on extensive review of the literature and existing solutions using biomass boilers for direct heating purposes.

In the first part, the report presents to the reader, in an easy-to-understand manner, the principle of operation of the direct heating system in a single-family house and a multi-family house. Furthermore, this work discusses the technical aspects of this type of installation, the basic elements of this system, and the thermal conversion methods of biofuels. Based on existing solutions, it shows the construction of boilers powered by the following forms of solid biofuels: pellets, briquettes, chips, logs, bales/cubes. The report presents the best solutions for biofuels storage, both outside and inside buildings, to maintain the good quality of the material. The report also provides guidelines for estimating the capacity and maintenance of direct heating installations that should be followed by a person interested in implementing this solution in his household. The methodology of the economic efficiency assessment of the installation and the factors that influence it is also discussed. The need for engagement of different stakeholders in the example of: biomass producer/provider, biomass boiler producer/seller, biomass boiler and heating system installer, and adviser specialized in founding acquisition are also determined.

Finally, some examples of direct heating systems in small and medium scale operating in pilot areas are presented to demonstrate the usefulness of a given heating solution.

The key findings of this work shed light on aspects that need to be further inspected (in dependence on the kind of stakeholder), different steps or activities should be taken concerning the promotion of direct heating installation. This is vital information upon which BECoop can better target and fine-tune the project's foreseen actions.

Summarising this report should help the reader to understand the concept of direct heating in the buildings. The task's specific goals include:

- overview of the process based on literature as well as technical tools to determine the best available technologies in biomass fuels storage and combustion;
- making a preliminary selection of a biomass boiler suitable for a given form of biomass to avoid potential system failures;
- enabling preliminary calculation of the boiler thermal power as well as the amount of the biofuel required to cover annual heat demand
- identification of crucial stakeholders for direct heating implementation and defining essential aspects/issues requiring deeper analysis to uptake this solution in other Project Pilot Areas;
- review of successful cases of direct heating implementation which enable the analysis of the strengths and weaknesses of a given project to avoid potential errors during the construction and operation of the bioenergy installation.

Important: This technical catalogue is based on general recommendations to be taken 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. Direct Heating concept

Biomass direct heating/cooling refers to the systems in which the conversion of energy into heat takes place in the independent boiler at the site to be heated. In other words, in the direct heating systems the heat generation and consumption is realized in the same object. Therefore, the direct heating system may take place not only in the strictly single households, but also in smaller family buildings, institutional buildings or offices, where the heating unit is located within or by the building. Whereas, district heating/cooling systems distribute thermal energy from a centralized source to many residential and commercial buildings through a network of pipes to provide space heating/cooling and/or hot water [1]. Examples of direct heating systems are shown in Figure 1.

a) b)

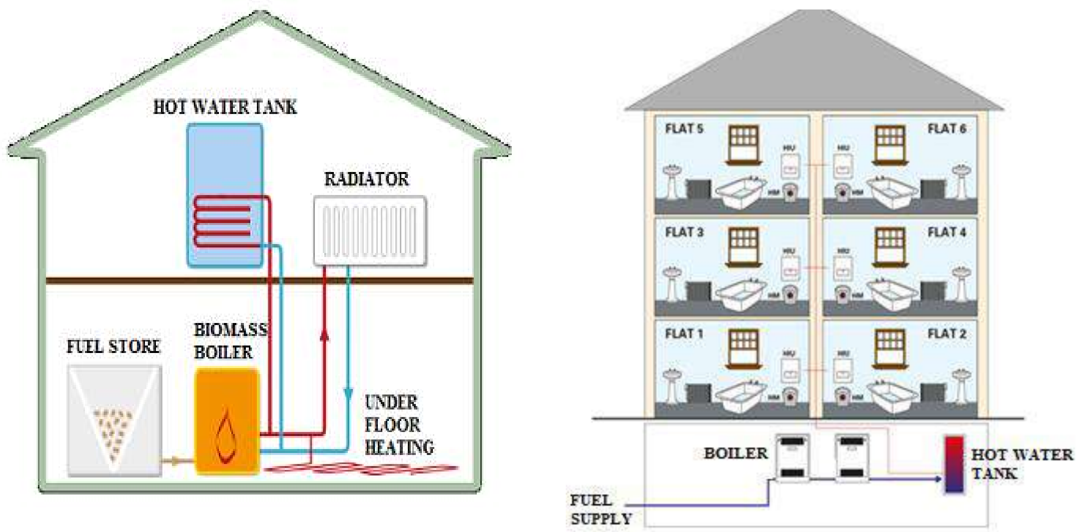


Figure 1. Scheme of direct heating system:

2. single-family house [2], b) residential block [3].

3. Technical considerations

3.1 Main elements of a direct heating installation

In general, direct biomass heating installation consists of (Figure 2): (i) fuel storage/feeding system, (ii) the device for solid biofuel combustion, and (iii) heat distribution system in the object.

a) b)

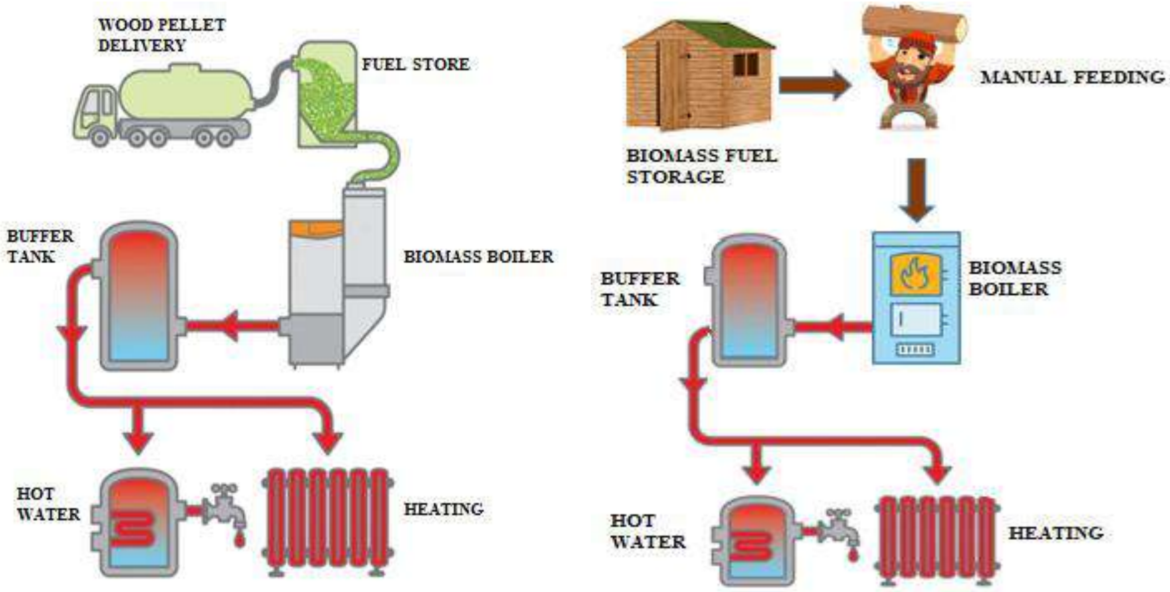


Figure 2. Main components of typical biomass direct heating installations [4]:

a) automatic system of direct heating; b) manual system of direct heating.

Depending on the form of biomass, thermal heat conversion technologies and final heat source carrier, the following devices for biomass combustion can be defined:

f) biomass boilers with water heating system (water is a heat carrier),
g) biomass ovens/stoves with air heating system (air is a heat carrier),
h) biomass gasifiers with water heating system (water is a heat carrier),
i) biomass gasifiers with air heating system (air is a heat carrier),
j) hybrid systems.

In practise, most of the solutions where biomass is used for direct heating purposes are characterized by its combustion in the boiler to heat the water. In these systems the buffer tanks (heat tanks, heat accumulators, thermal stores) are built-in to insure stable and effective operation of the heating system (the role of the biomass boiler is to boost temperatures in the tank rather than starting from cold each time heat is required). Hot water (heat) accumulated in the tank is distributed to various types of the radiators located in the rooms (heat exchangers) or directly to the collection points for sanitary purposes.

In case of biomass boilers the storage and/or feeding systems have to be foreseen that will insure the access to the biomass for a defined period of time (from few days to whole heating season). Depending on the form of the fuel (pellets, briquettes, logs, chips, bales, cubes) there are different solutions and possibilities related to the biomass storage and feeding systems.

The generated heat in the boiler from biomass combustion is distributed to the heated rooms/object. Different heat exchangers in the room are in use. It depends on many factors, such as temperature of the heating medium and technical solution of the system (floor heating, wall heating, roof heating, radiators under the windows, hot air heating). It is important that every kind of biomass boiler can be adapted to the existing/planned heating solution in the building.

3.1.1 Biomass boilers technologies

In dependence of the form of biomass, different biomass boilers/technologies are developed. The biomass boiler can be powered by the following forms of solid biofuel:

a) pellets,
b) briquettes,
c) chips,
d) logs,
e) bales/cubes.

Additionally, the heat generation during thermal biomass utilization can be realized by its combustion process or gasification process. According to the EU Directive, all new boilers (lower than 500 kW for heating water or lower than 50 kW for heating air) must comply with the requirements of ECODesign [5].

3.1.1.1 Biomass boilers fired by pellets

Pellets are a biomass fuel made from compressed sawdust, produced from various type of forestry and agricultural resources. Their shape is achieved by compression at the pellet processing plant and their shiny surface is from the natural glues found in the sawdust. In case of wood pellets, they should be accredited to the ENPlus A1 or A2 Standard, 5-30 mm in length, 5-6 mm in diameter, with a water content of 8-10% and ash content of 0.5%. This gives a bulk weight of 650 kg/m^3 and produces heat 4.9 kWh/kg. If produced pellets do not meet ENPlus A1 or A2 Standards, they can still be burnt in the boiler but it can require some more activity by the customer (i.e. more ash is generated, more frequent boiler cleaning is recommended).

The stabilized form and calorific value of pellets make such biomass fuel attractive for combustion in boilers. The specific and standardized form of fuel is very important from the point of view of its use for heat production, because it allows the use of the technology of full automation of the boiler with the ignition system and control of its operating parameters, without the need for periodic (daily) loading of the furnace or ash removal, which has so far been a significant disadvantage in relation to maintenance-free installations powered by gaseous or liquid fuel. The basic condition is that the size of the biomass does not exceed the permissible values for the fuel supply system from the place of storage (container) to the combustion chamber. An additional advantage of pellet-fired boilers is the possibility of building a thermal circuit in a closed (pressure) system as well as with the flue gas condensing system, as in the case of boilers powered by gas or liquid fuels. As a result, there is no need to install an overflow vessel and a separate open system. Furthermore, these boilers are characterized by higher efficiency.

The example of the pellet biomass boiler construction EG-PELLET is shown in Figure 3, and the main technical parameters are presented in Table 1.

a) b)

Figure 3. Pellet boiler EG PELLET with a power of 10-60 kW [6]:

1 – burner, 2 – combustion chamber, 3 – rotary sluice for pellet dosing, 4 – ignition device managed by a microprocessor, 5 – turbulators, 6 – exhaust outlet, 7 – burner feed screw, 8 – ash container, 9 - flue gas temperature sensor - controls the ignition and also manages the boiler power, 10 – lambda probe - optimizes combustion efficiency depending on the characteristics of the granulate, 11 – pellet tank.

Table 1. Technical parameters of EG PELLET boilers [6].

Model	EG-10	EG-10P	EG-15	EG-15P	EG-25	EG-25P	EG-40	EG-40P	EG-60	EG-60P
Power, kW	10	10	15	15	25	25	40	40	60	60
Mass, kg	320	340	320	340	320	340	375	395	420	440
Width, mm	1155	1460	1155	1460	1155	1460	1155	1460	1155	1460
Height, mm	1275	1360	1275	1360	1275	1360	1375	nd	nd	nd
Depth, mm	765									
Efficiency, %	91-95									

3.1.1.2 Biomass boilers fired by briquettes

Briquettes are produced in the process of pressure agglomeration and take a shape with specific geometrical dimensions. All types of waste biomass, lignocellulose materials, wood and straw, including energy crops, can be used for the production of briquettes. After appropriate preparation, initial grinding, drying and basic grinding, the material is compacted without adding a binder. The size of briquettes varies from 25 mm to over the dozen of cm. Mechanical or hydraulic presses are most often used for the production of briquettes. Depending on the design of the working elements, the briquettes can be produced in the following shapes: cylinder, cube or octagon (fireplace).

The use of briquettes has many advantages, such as: high bulk density, easy storage and transport, high calorific value, low pollutants emission to the atmosphere during the combustion. Briquettes are biomass with favourable utility values, it can be burnt in many furnaces, which previously used coal, coke or firewood. They are also often used for firing in central heating boilers in smaller boiler rooms, kitchen and tiled stoves, mainly due to the slow combustion process and increased energy density in relation to non-compacted biomass [7]. However, in the domestic boilers it requires a manual feeding of the boiler. Figure 4 shows an example of a briquette boiler and its basic parameters.

Figure 4. ATMOS DC 24 RS briquette boiler [8].

3.1.1.3 Biomass boilers fired by chips

Chips differ depending on the source of origin (forest, short rotation coppice) and the chipper used for their production. It is recommended that wood must be fully seasoned to a maximum moisture content of 30% prior to chipping. The chips are most often 20-50 mm long, but some particles can reach even 100 mm long. It is important that the chips do not exceed this length due to the potential for blockages and breakdowns in the chip supply system [9].

Chips boilers, due to the type of fuel feeding system, are often classified as multi-fuel, as they can also be fired with pellets, and in some cases also with energy plants. Wood chip boilers are therefore characterized by high flexibility and safety, because in the absence of one fuel supply, it is easy to switch to the other with similar quality. These boilers currently have an efficiency greater than 90%, which makes them highly efficient [10]. These boilers belongs to the group of fully automated ones.

An exemplary view of the wood chips boiler as well as its construction and technical parameters are presented in Table 2 and Figure 5.

a) b)

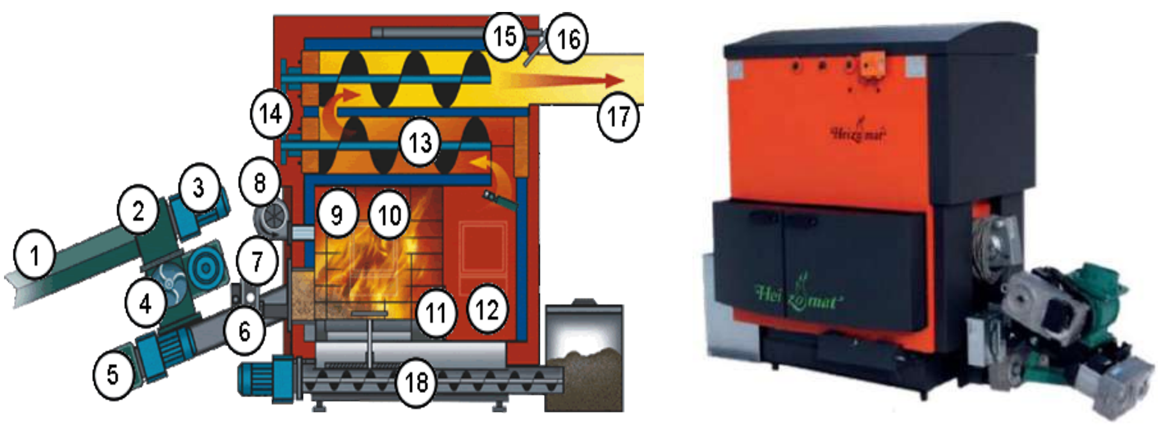


Figure 5. RH-AK 30-990 kW Wood Chip Boiler Cross Section [11]:

1 – discharge channel, 2 – maintenance flap, 3 – discharger system motor, 4 – rotary valve, 5 – feed auger motor, 6 – ignition, 7 – primary combustion blower, 8 – secondary combustion blower, 9 – combustion chamber, 10 – combustion chamber door, 11 – post combustion/drop out chamber, 12 post combustion chamber door, 13 – heat exchanger tuber with de-ashing, 14 – drive for de-ashing auger, 15 – flue gas temperature sensor, 16 – lambda sensor, 17 – flue gas blower/connection, 18 – ash cleaning system.

Table 2. Technical parameters of RH-AK Wood Chip boiler series [11].

Model	RH-AK 30	RH-AH 60	RH-AK 100	RH-AK 155	RH-AK 204	RH-AK 300	RH-AK 400
Heat capacity, kW	0-36	0-60	0-101	0-149	0-199	0-300	0-400
Weight, kg	900	1150	1500	2865	3108	5400	6200
Length, mm	1700	2100	2200	2865	3290	3490	3990
Width, mm	860	860	1085	1150	1565	1880	1880
Height, mm	1585	1585	1645	2065	1895	2035	2035

3.1.1.4 Biomass boilers fired by logs

Wood logs, as a biomass fuel, are typically 50 cm in size and 12-15 cm in thickness. They should be seasoned for minimum 1-2 years to ensure a moisture content below 20% (4 years storage is recommended). Unseasoned or wet logs burn inefficiently, reducing the heat produced, and lead to production of excessive soot and tar which can cause unexpected flue fires. Logs to be burned as biomass fuel should not contain any coatings and preservatives. Logs can be loaded directly into the log boiler without any other fuel handling process, like exists with wood pellets or wood chips. Logs must be manually loaded into the boiler, so day to day activity is required (even few times per day during the winter season). Most modern log boilers are characterized by 90% of efficiency.

Example of the wood logs fired boiler is presented in Figure 6.

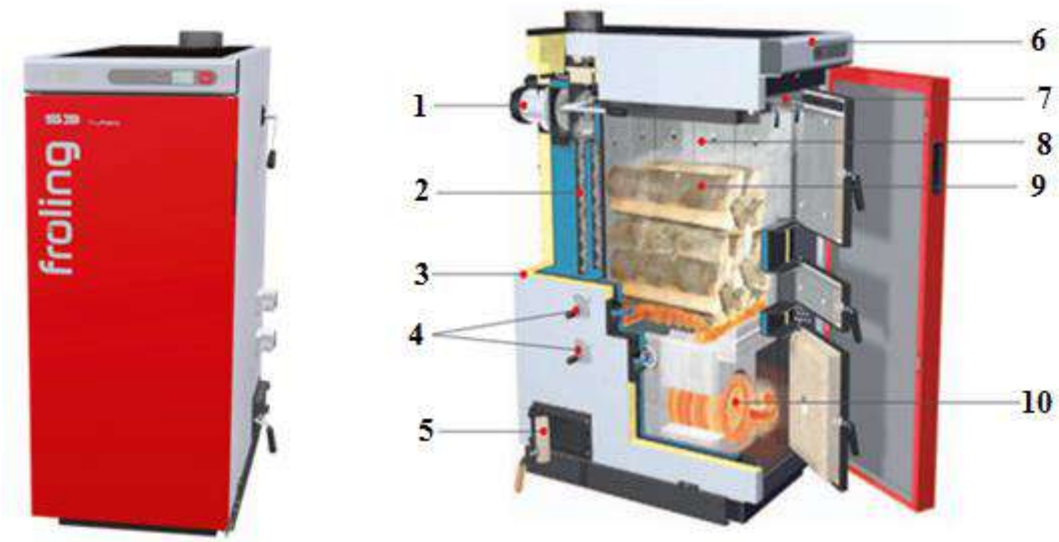


Figure 6. Construction of the wood logs fired boiler [12]:

1 – speed-regulated induced draught fan for maximum ease of use, 2 – EOS (efficiency optimisation system) for high efficiency and easy cleaning, 3 – top quality thermal insulation, 4 – manual adjusters (actuators with Lambdatronic) for primary and secondary air, 5 – large maintenance openings for easy cleaning, 6 – S-Tronic controller or Lambdatronic controller, 7 – carbonisation gas extraction system prevents flue gas from escaping during reloading, 8 – aprons (hot cladding) to protect the inner wall of the boiler for a longer service life, 9 – large fuel loading chamber for half-meter logs ensures long reloading intervals, 10 – separate pre-heating chamber door for easy pre-heating.

3.1.1.5 Biomass boilers fired by bales/cubes

In the form of bales or cubes, mainly straw and branches coming from trees/shrubs of permanent crops can be burned, the dimensions of which are usually: pressed rectangular cubes (80x40x40 cm, 180x70x120 cm or 250x120x80 cm), cylindrical bales (diameter: 30-120 cm and height 40-120 cm). It is recommended that the moisture of straw or branches intended for combustion in low and medium power boilers amounted to 13-17%.

Due to the usually limited space of the boiler room and the lack of space for building a line for continuous feeding of pressed straw to the combustion chamber, these are grateless batch boilers with bottom combustion, relatively simple in their construction and requiring periodic loading with fresh fuel. The combustion process is carried out until the fuel burns out completely. Using this type of boilers, the heating installation should be equipped with an appropriately sized heat tank in which heat is accumulated for heating purposes [13]. Example of the cubes/bales fired boiler is presented in Figure 7.

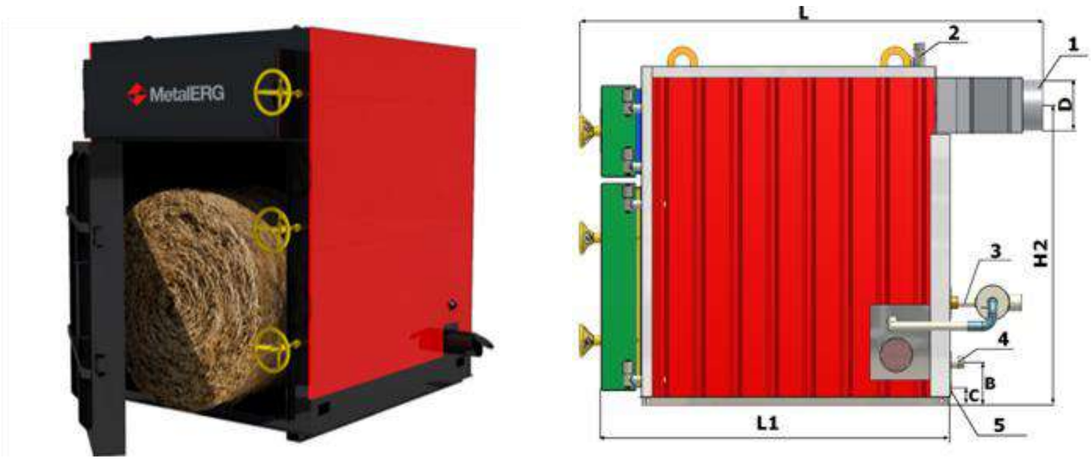


Figure 7. Construction of the straw bales fired boiler [13]:

1 – combustion flare, 2 – the outlet of water to the tank, 3 – air collector, 4 – the return pipe to the tank,

5 –drain plug, 6 –opening light.

3.1.2 Storages and feeding systems

There are many solutions for the storage of solid biofuels, depending on the size, construction and form of biomass. The storage area should be large enough to be filled max. 3-4 times per year. To maintain the good quality of fuel, the storage method should prevent ingress of moisture and be free from any contaminants (stones, animal carcasses, metals, coatings or preservatives). The storage room requires proper ventilation to avoid rooting, decomposition and insure air access for maintenance of the proper hygienic/climatic conditions. It is recommended to clean a storage room once a year (after the heating season).

3.1.2.1 Storage/Feeding systems for pellets

Pellets are free flowing and so the fuel stores are built at a slant and fed into the boiler. Pellets should be stored in purpose-built and enclosed stores with an access and inspection hatch. External filler tubes support the usually 'blown' delivery of pellets (delivered by tanker in a similar manner to oil) (Figure 8). These vehicles are equipped with compressed air supply devices so that pneumatic transport through the external filler pipe is possible.

Figure 8. Pellets delivery process with the use of a tanker [14]: 1 – tanker, 2 – delivery pipe, 3 – prefabricated silos.

Pellet supply systems for heating devices

a) stored in tanks integrated with the heating device (the capacity of the tank is usually enough for several hours of operation),
b) storage in tanks adjacent to the main component of the heating device (the capacity of the tank should ensure operation for up to several days),
c) storage in separate tanks (the capacity of the tank may be sufficient for monthly work in the winter),
d) storage in a specially designed room or external tank (capacity even for a whole year of operation).

Supplying the boiler with solid biomass throughout the heating period requires a sufficiently large utility room that will serve as a pellet storage or an external tank (above-ground or underground) for storing pellets or other forms of fragmented biomass.

The most frequently used storage systems are above-ground based systems. They are available in various shapes and sizes, so that the tank can be easily adapted to the existing room where the pellets are to be ultimately stored. The most common are square, rectangular and pyramidal tanks. The tanks can be made of various materials (polyester fabric, metals or plastics). The most commonly used silos are shown in Figure 9**Error! Reference source not found.**.

a) b) c)

Figure 9. Most commonly used pellet silos [15]: a) conical; b) flat bottom; c) trough.

Conical silo is similar in appearance to an inverted pyramid. Pellet extraction takes place at the lowest point. This tank is usually closed with a shutter placed between the silo and the pellet conveyor to the boiler. Flat bottom silo has no slope. Pellets are taken from above (by suction), or from below (by screw conveyor). Their disadvantage is that they cannot be completely emptied. Trough silos are volume-optimized conical silos that are used in narrow spaces where they provide high capacity. Pellets are extracted by a screw conveyor that transports them directly to the boiler or the blowing system.

Underground storage tanks (Figure 10) are not so popular as they must meet strict technical requirements (be watertight and protected against hanging on the groundwater). Pellet extraction is carried out solely by suction (from the top or the bottom).

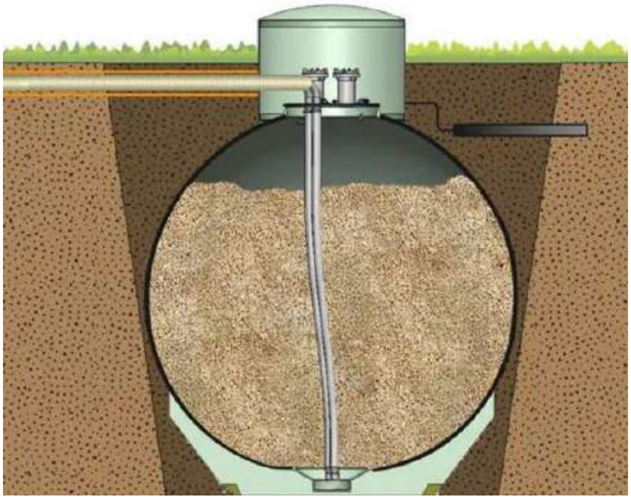


Figure 10. Underground pellet storage silo [16].

The pellets can also be stored directly in the storage room. It should be oblong or rectangular in shape. It is also important to ensure good access to the injection and suction connections. The storage room should not include electrical installations, air ducts and water installations. The walls of the storage room should be covered with an appropriate mat to protect them against the effects of pellets [17], [18].

Due to the fact that pellets are a material that easily absorbs moisture, special care should be taken that the storage room is dry all year round, and the air humidity should be around 80%. When there is a risk of damp walls, pellets should be stored in a prefabricated silo. However, when this risk does not exist, the pellets can be stored directly on a specially constructed sloping floor, which is designed to drive the pellets by gravity towards the auger/suction system, thus facilitating emptying the storage.

Sloping floor should have a slope of 40^0 - 50^0. A lower slope may prevent the fuel from sliding over the surface. A sloping floor should be made of appropriate materials, preferably wood with a smooth surface, 20-25 cm thick (Figure 11). A stable structure should be provided by supports that can support the weight of the pellets (the bulk density is within the range of 650-700 $kg{\cdot}m^{-3}$) [17] [18].

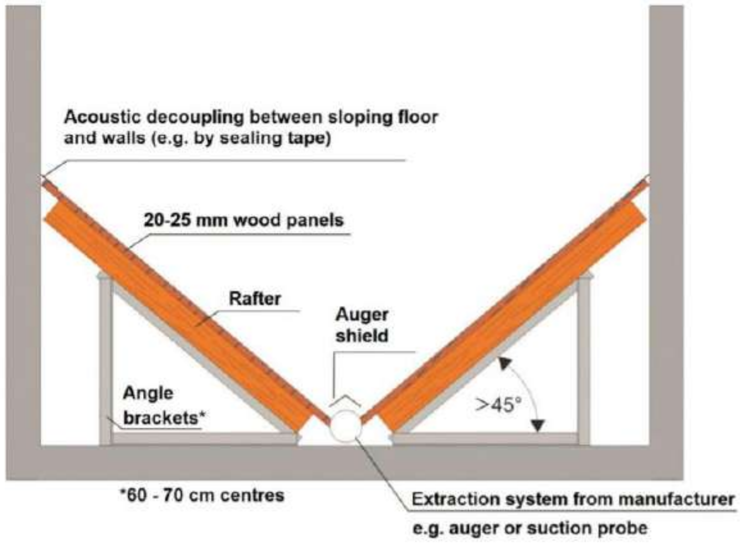


Figure 11. Sloping floor dedicated for pellets storage [18].

The combination of a storage system with a pellet boiler depends on the technical capabilities of the end user. The heating device and the storage system can be placed in the same or in separate room (Figure 12). However, the appropriate distribution of cables is required to not interfere with the functionality at home.

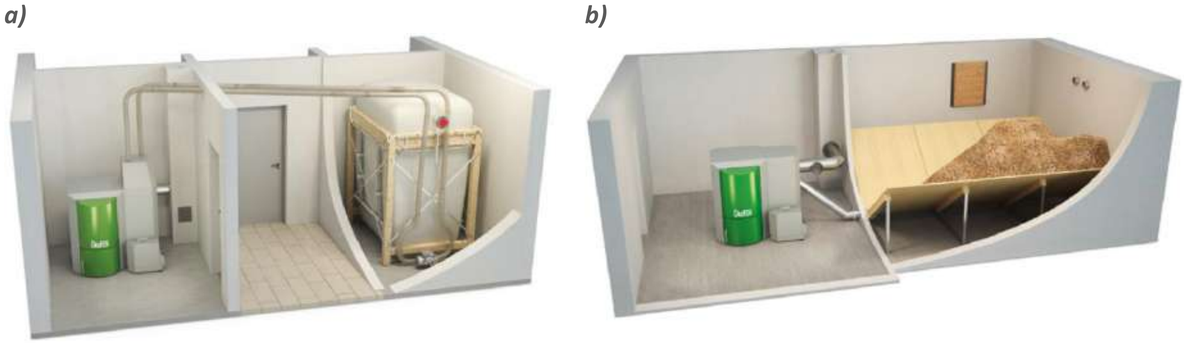


Figure 12. Examples of connecting a pellet boiler with a storage system [19].

3.1.2.2 Storage/Feeding systems for briquettes

The quality of the briquettes is badly damaged if they are exposed to the weather (sun, rain) without protection. Strong solar radiation or storage in warm places causes the briquettes to dry out, which loosens the packaging straps. The following instructions must be noted and implemented for fire prevention and the maintenance of optimum levels of briquette quality [20].

a) *the temperature of briquette packs must be checked during delivery. only cooled and dry goods may be stacked,*
b) *for reasons of stability, the pallets must be stacked in a group on a solid base. the result is a stepped and graduated stack,*
c) *in the interests of fire protection, stability, and quality, the height of the stack must be limited to a maximum of four pallets at the retailer,*
d) *the walkways must be suitable for pallet trucks,*
e) *a gap of approx. 20 cm must be left between each pallet row when putting goods into storage.*

f) a gap of 5 to 10 cm (hand width) must be kept between the pallets in one row,

g) a moist storage environment (air moisture > 60% if possible), must be provided (this is achieved by lightly spraying the ground), it is not acceptable to moisten the briquettes directly,

h) the storage stack must be accessible from all sides at all times (for fire extinguishing),

i) if horizontal liners are inserted to protect the goods, the material used must allow the air to circulate freely between the layers,

j) should moist, or heated pallets be detected during checks, these must be removed from the stack and stored separately. the sales partner must be contacted without delay,

k) should, however, the straps around the pallets become slack during correct storage, the vertical strap may be retightened by using a handheld tensioning device (electric or pneumatic). damaged packs must be replaced during remedial action.

Do store your briquettes in [21]: watertight shed, dry garage, porch or conservatory, inside house, dry outbuildings, some plastic garden stores, as long as they are watertight. Examples of storage options for briquettes are shown in Figure 13.

a)

b)

Figure 13. Examples of storage options for briquettes [22], [23]: a) foiled pallets inside the room; b) bags.

3.1.2.3 Storage/Feeding systems for chips

Fuel stores for chips should be covered and enclosed. It is recommended to build a large store in order to minimise the number of fills. The store should have an access and inspection hatch and the floor should be level with the agitator sweep arms. The stores should be cleaned out annually, during summer when the boiler may not need to be operational. It is also important to visually inspect any delivery of wood chips. As part of the delivery paperwork, the moisture content of each load should be stated on your receipt.

Depending on the technical capabilities of the end user, delivery can take place in various ways. One of the most common delivery options is tipped delivery into a bulk fuel store, where a moving floor truck delivers the wood chips to an intermediate storage area, which is most often covered with a shim. However, the customer must have a tele handler/loader to move the fuel to the final storage. Another method of delivery is also delivery including chip blowing, where a vacuum pipe driven by a hydraulic pump, included in the delivery vehicle, blows the chips into the storage through the access hatch. Customers can also use a mechanical auger and trough delivery. The purchased fuel is poured directly into the trough, and the screw conveyor transfers it to the fuel storage. However, it should be remembered that this option is dedicated to smaller installations, as unloading wood chips from a truck would take much longer than in the case of classic deliveries [24].

For installations with a capacity of 100 kW or more, it is also possible to deliver chips to an underground or above-ground storage facility via a ramp and to discharge the chips by a fuel delivery vehicle. However, it is required to build a larger ramp, which may be associated with greater financial outlays. However, the design should be consulted with a structural engineer to ensure proper construction. Fuel deliver options, depending on the storage scenarios, are shown in Figure 14.

a) b)

Figure 14. Chips deliver options, depending on storage scenarios [24]: a) tipped delivery into a bulk fuel store with tele handler chips moving; b) fast feed auger delivery; c) ramped delivery; d) blown delivery.

The wood chips should be stored under a roofed, dry place to reduce the risk of moisture absorption by the fuel. The storage location is properly ventilated and easily accessible. For this purpose, you can use the existing farm buildings (sheds, roofed drive-through silos, small household buildings, arched halls) or use one of the rooms located directly in the heated building.

The choice of the storage location and options should depend on the technical capabilities of the end user, the scale of the project and financial possibilities. Outdoor storage in underground and above-ground warehouses is dedicated to larger installations, while the use of small outbuildings and rooms in heated buildings as warehouses is [25] dedicated to smaller installations (Figure 15).

a) b)

Figure 15. Outdoor chips storages for larger installation [25] [26]: a) arched hall; b) shed.

Wood chips are stirred by an agitator, made up of a rotating disk with sprung arms. Then, fuel drops into an auger, and a corkscrew moves the fuel smoothly from the store to the boiler. Depending on whether the storage system is on the same level or the boiler (as well as the distance between the storage and the boiler), different feeder systems can be used to optimally match the loading of chips to the boiler. Examples of storage and loading solutions for wood chips are shown in Figure 16.

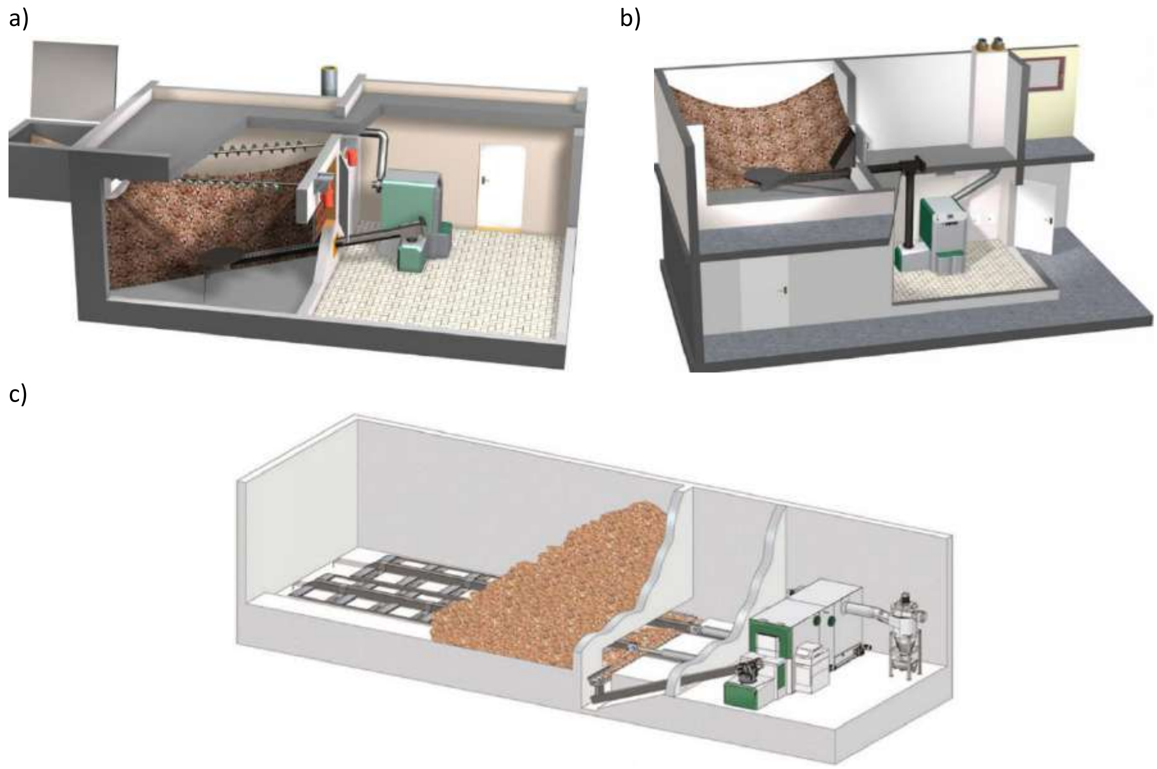


Figure 16. Examples of storage and loading solutions for chips [27]:

a) chips store and the boiler room are on the same level (leaf reel and 2 feeders); b) chips storage and boiler at different levels: horizontal leaf reel, feeder, slope system; c) hydraulic floor systems.

3.1.2.4 Storage/feeding systems for logs

When using logs, the fuel needs to be manually fed into the boiler. In the cold winter months, the fire or log burner will require a ready supply of quality, dry (seasoned) logs to work effectively. The following instructions for storing woof logs outside in a practical, convenient and safe way that will keep them dry all winter long.:

a) *stack logs neatly* - seasoned logs are traditionally stacked neatly, close to (not touching) a wall or fence, it is important to be quite precise as tight stacking will ensure that only the top layer will get damp if it rains,
b) *consider location carefully* -think about the location, if the prevailing winds usually blow rain in a certain direction then place the logs in an area that it as sheltered as possible; remember to always place them on a flat and stable surface,
c) *avoid tree cover* - don't place log stacks under trees as these will drip water down and also avoid low lying areas which can be prone to dew, mist or fog,

d) *don't leave logs in a heap* - never just dump the logs in a heap (especially on grass) as they will get wet and be useless; careful stacking will pay dividends in the long run.

e) *use pallets where possible* - preferably, logs should be placed on wooden pallets as these keep them off the ground and provide a free flow of air underneath; the ideal height of the wood stack (including the pallet) should be no more than 3ft (1m) as the logs can become unstable if piled too high,

f) *provide good circulation* - remember to leave a good amount of space between your logs and any wall, fence or shed to help with air circulation, a gap of about 4 Available online (10cm) all round is ideal, remember also that a log pile is a potential fire risk so consideration should be made to its placement.

Although logs can be left in the open space, they do benefit from the extra protection of a cover or dedicated storage area. However, never cover your logs completely with tarpaulin (this will create a seal to stop the air circulating round), ensure the sides stay uncovered for proper ventilation. An extra effective protection against moisture is to use the dedicated, made of various materials, log stores (Figure 17).

a) b) c)

Figure 17. Examples of storage solutions for logs [28] [29]: a) wooden log store; b) tarpaulin cover; c) metal log store.

3.1.2.5 Storage/Feeding systems for bales/cubes

For power generation purposes, the straw harvested from the field, in the form of bales (round or cuboid), should be stored under the roof to avoid wetting. The boilers can burn only dry straw with a maximum moisture content of up to 20%. In the front part of the boiler is a gate that permits bales of straw to be manually stoked easily into the combustion chamber [30].

A way to reduce the risk of a straw fire is to ensure that stored straw remains dry [31]:

a) when storing straw inside (Figure 18b), make sure the barn or storage area is weathertight and has proper drainage to prevent water from entering the barn,

b) when storing straw outside (Figure 18a), cover it with plastic or another type of waterproof material. If you cannot cover the bales, arrange the bales so that air can circulate between them to promote drying. Bales can be protected from ground moisture by storing them on a bed of gravel or lifting them off the ground on used tires, poles, or pallets,

a) b)

Figure 18. Examples of storage solutions for logs [32]: a) storing outside; b) storing inside.

Straw bales/cubes can be transported to the boiler in two options (Figure 19): manually using the strengh of human hands, or automatically using the conveyor or other machinery.

a) b)

Figure 19. Straw bales/cubes feeding systems [33] [34] : a) manual ; b) automatic.

3.2 Power of your installation

In general, the thermal power of the boiler is determined from the balance of thermal needs of the facilities supplied from the boiler room. It depends on many factors, such as: the type of the object, operation time (seasonal or full year), heat losses (house insulation), parameters of the heating medium, heating circuits, daily heat distribution (constant or variable power), ventilation system, technology and preparation of central hot water, the size of the heat buffer, or the proportion of individual components of the demand. As a result, the accurate estimation of the power and capacity of the biomass boiler is complex. However, there are some methods and indexes that enable the calculation of the thermal power of the boiler, for example:

d) European standards (EN 15316-3:2017),
e) approximate power of the boiler regarding the heat losses of the object,
f) cumulated boiler power determination regarding the biomass potential (i.e. in the region).

The power of the heating installation (boiler) and the amount of required biomass using European regulations and standards EN 15316-3:2017 [35] are determined based on the calculation of heat demand, efficiency of heat acquisition, storage, transfer, and total efficiency of the heating system. Its power is obtained by analysing the needs for specific purposes for a specific time (e.g. winter, summer, transition periods, etc.) according to the general formula:

$$Q_B = Q_{CH} + Q_{Vent} + Q_{Tech} + Q_{HW}, \quad (1)$$

where:
Q_B – boiler room power, kW
Q_{CH} – heating power demand, kW
Q_{Vent} – demand for thermal power for ventilation or air conditioning, kW
Q_{Tech} – demand for thermal power for technological purposes, kW
Q_{HW} – heating power demand for domestic hot water preparation, kW.

The heat power demand for heating Q_{CH} is calculated according to the current standards or according to cubature indices. The demand for ventilation Q_{Vent} is determined according to air exchange ratio in the building (with possible reduction of ventilation intensity at low outside temperatures). Heat demand for domestic hot water preparation Q_{HW} is determined according to the consumption of hot water (e.g. for individual hygiene activities or according to the average indicators of daily consumption per inhabitant or user of a public facility). The components Q_{CH} and Q_{Vent} are a function of the outside temperature, while Q_{Tech} and Q_{HW} usually do not depend on the outside temperature. This procedure requires some professional knowledge and should be performed by expertise person.

Less accurate, but much simpler method of thermal power of the biomass boiler estimation refers to the required unit power of the heating source necessary to cover heat losses per 1 m^2 of the surface (or per 1 m^3 of cubature) in the considered object. The formula is, as follow:

$$Q_B = UPD_{SA} \cdot SA \quad (2)$$

alternatively:

$$Q_B = UPD_{BC} \cdot BC \quad (3)$$

where:
Q_B – thermal power of the boiler, W,
UPD_{SA} – unit thermal power demand to heat the object's surface (Table 3), W/m^2,
UPD_{BC} – unit thermal power demand to heat the object's cubature (Table 3), W/m^3,
SA – surface area of the heated object, m^2,
BC – cubature of the heated object, m^3.

Table 3. The unit power and energy demand for heating the buildings [36] [37] [38].

Energy class	***Energy rating***	***Unit thermal power demand UPD***		***Final energy consumption FE, kWh/(m²·year)***	***Year of construction***
		W/m²	***W/m³***		
A+	Passive	<25	<10	<20	today
A	Low energy	40	15	20-45	2019-today
B	Energy saving	50	18	45-80	2010-2018
C	Medium energy efficient	60	22	80-100	2000-2010
D	Moderately energy-intensive	70	25	100-150	Up to 1999
E	Energy-consuming	100	37	150-250	Up to 1998
F	Highly energy-consuming	120	48	over 250	Up to 1982

Additionally, based on the yearly heat demand by the object it is possible to determine the amount of biomass fuel required for heating purposes:

$$M_B = \frac{\mathrm{FE{\cdot}HS}}{LHV{\cdot}\eta_b{\cdot}} \cdot 3.6 \quad (4)$$

where:
M_B – the required amount of biomass to cover the annual heat demand by the object, kg/year,
FE – final energy consumption by the object, kWh/(m^2·year),
HS - heated surface of the object, m^2,
η_b – thermal efficiency of the boiler (η_b=0.85-0.92), -,
LHV – lower heating value of the biomass fuel, MJ/kg.

In case of lack of knowledge/data about the annual heat demand by the object, the approximate estimation of the thermal power of the biomass boiler can be estimated based only on the value of the heated surface area of the object/building/household. The example of such relationship for temperate climate is shown in Figure 20. It should be noted that under certain circumstances/conditions this value may differ significantly from the actual demand, and should be consulted with a specialist.

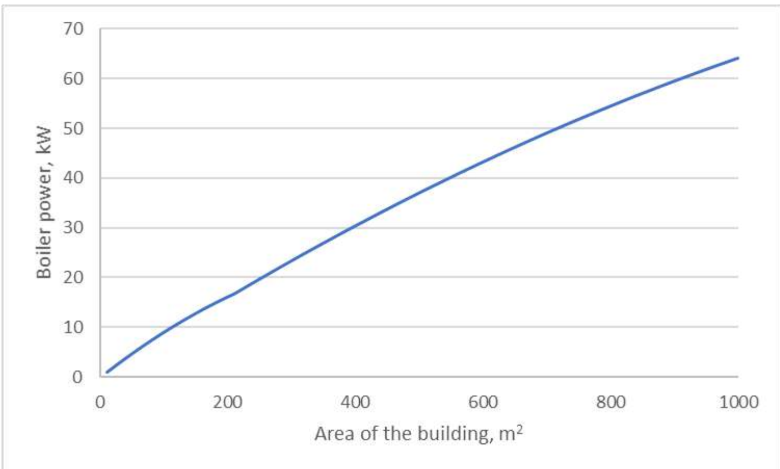


Figure 20. Thermal power of the boiler vs. Heated surface area of the building (in a temperate climate)[12].

3.3 Operational and maintenance of a biomass boiler

Operation and maintenance of a biomass boiler is highly sensitive to the quality of the biomass. The appropriate quality of biomass ensures safe and trouble-free operation of the boiler while maintaining high emission standards and a minimum involvement of use in the household heating process. In turn, It should be underlined, that the use of sub-standard fuel or municipal waste for heating can cause a range of issues/problems like:

- burning instability,
- increased pollutant emission,
- low combustion efficiency and increased fuel consumption,
- joking of conveyors,

[12] Own evaluation basing on database of Ministry of Technologies and Development: https://rejestrcheb.mrit.gov.pl/

- corrosion,
- slagging.

To avoid exploitation problems biomass boilers should be selected according the biomass fuels that will be consumed. Additionally, these biomasses should be sourced from sustainable suppliers. Some of the parameters of the biomass fuels that should always be considered are the following:

- moisture content – boilers are optimized for fuels with a moisture content within a specific range. Improper moisture can cause inefficient combustion, and excessive smoke and tar, as well as lead to increased emissions.
- particle size – boilers are designed for specific particle dimensions. Using a fuel with another dimensions than the one for which the boiler has been designed, can cause problems in the feeding or storage system.
- chemical composition of the biomass - for some fuels it may be also important to check for sulphur and chlorine content (to estimate corrosion hazard) and the amount of potassium and sodium (those alkali metals cause slagging and fouling).

A properly planned maintenance of a biomass boiler should ensure:

- the safe operation of the system.
- minimized breakdowns (failures).
- maximization of the operation lifetime of the boiler.

To plan the exploitation properly:

- the boiler's overhauls should be made minimum once a year,
- only high quality biomass should be used,
- the biomass moisture, size and chemical composition should comply with the technical requirements of the boiler.

The main exploitation recommendation still remains an advice to read the service or maintenance documentation of the boiler, although the biomass quality and chemical composition should be controlled as well.

4. Profitability of a direct heating

The profitability of the heating system basing on biomass utilisation depends on many factors, such as: range of the modernization work, the size of the system, how often it is used, a chosen fuel type or the reference fuel and heating system (to be compared with: oil, gas, coal, electricity etc.). Actually, each case requires to be assessed as an individual case study. However, taking into consideration some assumptions, the simple payback time period (SPBT) can be calculated from following formula:

$$SPBT = \frac{I_o}{AC_a} \qquad (5)$$

where:
I_0–the value of the investment outlays, €,
AC_a – annual avoided costs, €.

The formula of annual avoided costs is as follows:

$$AC_a = (HP_2 - HP_1) \cdot EC_a \quad (6)$$

where:
HP_2 – unit heat price from conventional energy source, €/GJ,
HP_1 – unit heat price from biomass fuel, €/GJ,
EC_a – annual energy consumption, GJ.

Table 4. Estimated unit heat prices depending on the type of the fuel (Poland) [39].

Fuel	Unit heat price,	
	€/GJ	€/kWh$_t$
Eco-pea coal	9.56	0.03
Culm coal	6.19	0.02
Hard coal	8.26	0.03
Pellet class A1	11.05	0.04
Pellet class A2	10	0.04
Pellet class B	10	0.04
Briquette	7.65	0.03
Wood	5.71	0.02
Gas (methane)	8.82	0.03
LPG	21.6	0.08
Oil	15.79	0.06
Electricity	36.1	0.13

Therefore, it is difficult to give the annual running costs of a biomass boiler without knowing the specifics of the project, the local fuel prices and servicing options.

In case of the investment outlays in heating unit, the cost of the biomass boiler (ca. 20-25 kW) for a single household is in the range of €1300-4500, which is very similar to coal, gas or oil boilers (in case of simple solutions), or likely higher (in case of more sophisticated and fully automatic solutions).

The small capacity boilers (up to 100 kW) used for space heating may require only one single service per year. In case of larger boilers with more extensive utilization for process heating, more frequent maintenance is required/recommended (2-3 times per year).

It terms of biomass fuels, wood chips are cheaper than wood pellets, so this will influence the running costs. If owners have their own fuel supply (own forest/woodland, straw from field, pruning from orchards) then wood logs/straw bales/pruning (if they contain low moisture content) can be directly used for energy purposes which leads to significant reduction (30-50%)[13][14] of heating costs.

Besides the economic aspects, there are many other benefits relating to the use of biomass for energy purposes, especially over fossil fuels:

a) combustion of biomass residues reduces the disposal and removal costs,
b) biomass from local resources is cheaper, and the fuel price is more stable,

[13] Biomass Boilers | Wood Pellet | Wood Chip | Log | Treco
[14] https://naturequebec.org/wp-content/uploads/2019/05/Depliant_biomasse_Chaudiere_WEB-1.pdf

c) the process is carbon neutral (the amount of CO_2 released during its combustion is the same as the amount of the CO_2 absorbed during the plant growing),
d) it is a sustainable and renewable fuel that can reduce the pollutants emission by up to 96%[15][16][17],
e) supports local development (job creation, taxes) of the whole biomass chain market,
f) much lower ash generation than coal (reduction of the problem of furnace waste management),
g) biomass ash can be used as fertilizer avoiding disposal costs,
h) biomass contains much less ash reducing the frequency of emptying the ash bin in the boiler,
i) no or much lower sulphur oxides emission during combustion (in comparison to coal or heavy oil).

The approximate environmental savings/differences for most common fuels used for heating are shown in Table 5 and Table 6.

Table 5. Characteristics of commonly used solid fuels and electricity [40] [41].

Fuel	Density, kg/m^3	Unit CO_2 emission, g CO_2/kWh	Unit calorific value, kWh/kg
Wood chips	250	7	3.5
Wood pellets	650	15	4.8
Wood logs	350	7	4.1
Miscanthus (chopped, 25% MC)	140-180	8.3	3.6
Wheat grain (15% MC)	760-780	86	3.9
Hard coal	800-1000	354	7.5-8.6
Peat	400	382	3.8
Coke	450-650	461	8.0
Electricity	n/a	530	n/a

Table 6. Characteristics of commonly used liquid and gaseous fuels [40] [41].

Fuel	Litres	Unit CO_2 emission, g CO_2/kWh	Unit calorific value, kWh/l
LPG	1	323	6.6
Heating oil	1	350	10
Natural gas (methane)	1	330	11.4

[15] http://www.globalbioenergy.org/uploads/media/0904_Environment_Agency_-_Minimising_greenhouse_gas_emissions_from_biomass_energy_generation.pdf
[16] Lachman P (2013) *Porównanie emisji zanieczyszczeń różnych technologii grzewczych wg raportu IPTS dla Komisji Europejskiej* [Comparison of emissions of various heating technologies by IPTS report for the European Commission] InstalReporter 2013. No. 01. pp. 29–30 (on-line version, date of access 15.12.2021)
[17] Biomass District Heating Advantages | Treco

5. Stakeholders needed

In case of direct heating of households using biomass boilers the need of engagement of different stakeholders might be required, in example:

a) Biomass producer/provider,
b) Biomass boiler producer/seller,
c) Biomass boiler and heating system installer,
d) Adviser specialized in founding acquisition.

Biomass producer/provider.

In terms of the development of local cooperatives or energy communities, heating households and other buildings with biomass depends on its availability in the region and the final form/shape that is required by the boiler. Therefore, the identification of the local biomass potential (amount and type of biomass available), suppliers (farmers, forest owners, national forest authorities, wood processing companies) and producers (companies processing biomass into pellets, briquettes or wood chips) is of key importance from the point of view of planning the heating system/installation. In some cases, biomass (straw bales, logs and even wood chips) can be sourced directly from the biomass producers, which reduces fuel costs and, therefore, it could improve the project profitability since intermediate steps with other stakeholders are avoided. These data are needed for the selection of the boiler structure, storage system and investment scheme. Moreover, in the case of demand for larger quantities of biomass, long-term contracts for its supply may be required (ensuring continuity of supplies, determining fuel costs, agreeing on the requirements as to its type, form and quality). In case you need to contact local biomass producers/suppliers, it is recommended to visit the e-market platform (https://www.becoop-project.eu/tools/e-market-environment/) where you can find local biomass suppliers.

Biomass boiler producer/seller.

In case of decision making on the type of biomass used for heating purposes, it is necessary to purchase an appropriate heating unit that will be able to provide the required thermal power and meet the current standards requirements in the context of emission of pollutants into the atmosphere or the achieved combustion efficiency. There are many solutions for biomass boilers available on the market, which differ in appearance, design, fuel supply, ignition system, flue gas cleaning, and ash removal from the furnace. The mentioned aspects have an impact not only on the usability of the boiler, but also on the final price. It should be noted that direct contact with the boiler manufacturer is recommended only in the case of installations for larger objects or a larger group of users (power above 100 kW), where heat will be produced in one heating unit of greater power. This is due to the fact that it may be necessary to individually adjust the boiler to the existing or planned boiler room or the required heat flux with specific physical parameters. It is also possible to change the design in order to adapt the boiler to the combustion of a specific biomass fuel available on the local market or adopted in a given project. In higher power boilers, their manufacturers often allow some design modifications. In the case of lower-capacity boilers, typical for households, a direct contact with the boiler manufacturer is rather unnecessary. Producers usually have their distributors and sales representatives in given regions, who are responsible for the site visit and advice on the selection of the heating unit. In this case, it is recommended to contact a sales representative and an installation and service company (ESCO) that operates in the local market. Before the final selection of the heating boiler, however, it is recommended to review (webpage visit) the existing solutions in order to gain knowledge of not only technical but also visual possibilities. The list of potential producers or suppliers of biomass boilers can be found on the e-market platform (https://www.becoop-project.eu/tools/e-market-environment/).

Biomass boiler and heating system installer.

In order to replace the existing heating system, boiler or install a new heating system, you may need to contact the installation and service company, which has the appropriate qualifications and will professionally carry out the necessary installation works. These types of companies also provide appropriate technical advice in the selection of thermal power, the necessary additional equipment and the scope of installation works (sometimes the modification of flue gas outlet system or chimney is required). It is recommended that the entire investment process from the technical side (boiler delivery, materials and installation works) to be performed by one contractor. This will allow you to avoid possible problems related to the liability and warranty for the service provided by the installation and service company. It is also advisable that the contractor is an authorized installation company of the boiler manufacturer, which additionally guarantees the quality of service and the confirms contractor's experience. Carrying out maintenance services and having a company headquarters in a given region is an additional advantage, as it shortens the time of potential response to service requests and arrival at the customer. The e-market platform (https://www.becoop-project.eu/tools/e-market-environment/) can help in looking for local installation and service companies.

Adviser specialized in funds acquisition.

At the investment stage, it may be necessary to obtain additional funds necessary for the implementation of the project. A financial advisor has the appropriate knowledge where to look for financial support, the current national or local support programs, can propose the best financing model or banks offering convenient loans and repayment schemes. The right advisor can help you develop an appropriate business plan and project implementation strategy. It should be noted that in the area of activities related to environmental protection in the region, appropriate advisors also work at the local commune office. It is worth remembering that among consulting companies you can find institutions that help in writing applications and projects enabling the acquisition of funds from EU programs. The support can be found also in organizations such as research centres, energy cooperatives, energy clusters, etc. which can advise on the procedures and steps of the investment process. Consulting companies operating in this area can be found on the e-market platform (https://www.becoop-project.eu/tools/e-market-environment/).

6. Steps to be followed

In dependence on the kind of stakeholder, different steps or activities can be taken in relation to the promotion of direct heating installation.

In case of biomass consumer/user:

- Check if there is a heating network nearby that distributes the heat generated in the biomass combustion process,

  The direct contact with local heat distributing/operating company (if there is in the region) is recommended to validate the possibility and conditions of connection to the central heating network. The final user can contact also a local municipal office about the potential options/plans and regulations related to the heat supply of your building.

- Check if there is an interest and the possibility of creating an energy cooperative in the immediate vicinity,

  The contact with the local municipal office about the existence or potential plans related to energy community creation is recommended. Furthermore, you can ask your neighbours if they are interested to create an energy community. You can also look for local energy cluster for a help or potential engagement in this field.

- Select/choose the type and form of biomass to be used for heating your household,

  It is recommended to visit the website www.becoop.eu, where are the adequate helping/supporting materials such as: fact sheets about biomass, its form and properties. You should read point 3.1.1 including the description of biomass boiler technologies to be more familiar with the practical aspects of biomass utilization for energy purposes. It should help you make a decision.

- Determine the power of the heating boiler,

  It is recommended to read point 3.2. It will help you estimate the boiler power based on your heating demands. You can also visit the e-market platform to find the contact data o professional companies or energy advisors in your region, that will help you in this issue.

- Contact the company providing services in the field of heating installations for consultation and determination of the scope of installation works,

  It is strongly recommended to visit the e-market platform. It will help you find the professional company dealing with biomass boiler installation.

- Look for a local biomass supplier for your boiler,

  You should visit the e-market platform to find a local biomass fuel supplier. It is important to secure the fuel of your boiler beforehand.

- Check the space for your boiler in the technical room,

  You should familiarize yourself with the guidelines contained in the boiler's technical and operational documentation. You can also use the e-market platforms to find an installation company or a boiler supply company that will advise you on this issue. Optionally, you can contact the boiler manufacturer for the necessary information.

- Prepare a place for biomass storage during the heating season,

  It is recommended to read point 3.1.2, where you can find basic information related to storage conditions of a given form of biomass.

7. Success cases

7.1. Gospodarstwo sadownicze, Poland (600 kW_{th})

Gospodarstwo Sadownicze (Komorów, Poland) is the local pioneer that in 2013 started a commercial use of pruning biomass from apple orchards for energy purposes. In Mazovia Province there are more than 103,000 ha of orchards available, and more than 77,000 ha are apple orchards. The owner, thanks to his engagement and determination, created a whole logistics value chain of biomass utilization (Figure 21). The harvested biomass from his orchard (ca. 130 t/year) is delivered, in the form of large bales (90x120 cm), to the final users he has found during the market research.

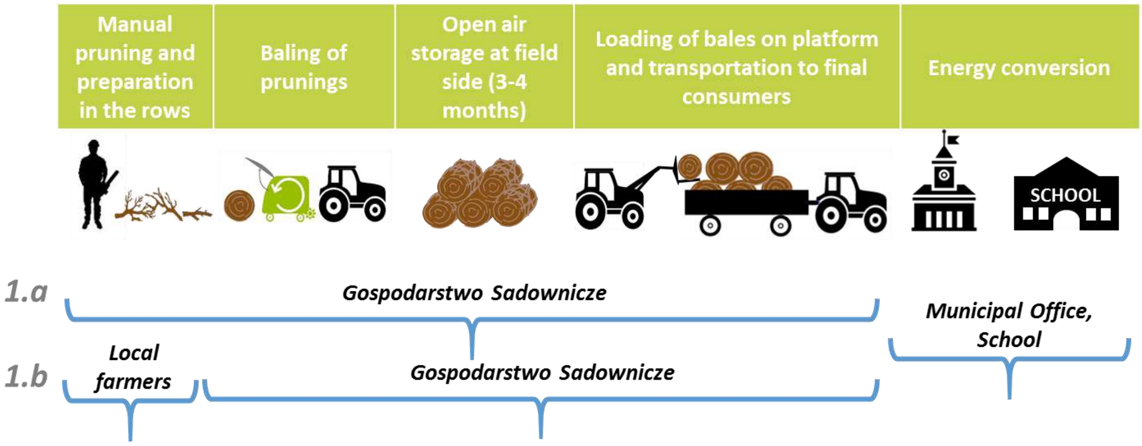


Figure 21. The logistics value chain of biomass utilization for energy purposes in rural area [42].

The bales of prunings are used for heating the municipal buildings in the village of Wieniawa (the Municipal office, the Secondary School Complex and the Healthy Centre) which are at a distance of up to 15 km from the orchards. The biomass is burnt in the medium-sized boilers (thermal capacity 250-600 kW) to heat the object and produce hot water (Figure 22).

a) bales from biomass b) heat plant c) biomass boiler

Figure 22. Use of local biomass for direct heating [42].

8. Conclusions

This report allows to acquire the basic information on direct heating of households, small public buildings, workshops and private plants using solid biomass fuel. The most important solutions of direct heating, heating units as well as methods and guidelines for storing biomass fuels of various forms were discussed. The attention was paid to the operational and environmental aspects of using biomass for heating purposes. The guidelines for the potential end-user and the issues requiring answers that are necessary when using / changing a biomass-based heating system are presented. Simple equations have been proposed that allow to estimate the required boiler power, the amount of biomass covering the annual heat demand, and to calculate the savings resulting from the use of biomass and a simple payback period. The final part contains examples of existing solutions for heating systems based on solid biomass.

9. References

[1] https://www.sciencedirect.com/topics/engineering/district-heating-system. [Available online: 06 12 2021].

[2] http://www.wattenergysaver.co.uk/biomass.html. [Available online: 06 12 2021].

[3] http://business.insite-energy.co.uk/what-is-heat-network/. [Available online: 06 12 2021].

[4] https://www.treco.co.uk/news/article/what-is-biomass-heating. [Available online: 06 12 2021].

[5] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products .

[6] https://kotly.com/pl/82-kociol-na-pellet-eg-pellet.html. [Available online: 06 12 2021].

[7] J. Szlachta, A. Dyjakon i A. Luberański, Energia z biomasy, Wrocław: Oficyna Wydawnicza Atut - Wrocławskie Wydawnictwo Oświatowe, 2013.

[8] https://www.atmos.eu/poland/index.php?rw=1&page=kotle-007. [Available online: 06 12 2021].

[9] https://www.forestresearch.gov.uk/tools-and-resources/fthr/biomass-energy-resources/fuel/types-of-woodfuel/wood-chips/.
[Available online: 06 12 2021].

[10] https://www.treco.co.uk/wood-chip-boilers. [Available online: 06 12 2021].

[11] http://www.shs-renewables.ie/images/wood_chip_boiler_xsection.gif. [Available online: 06 12 2021].

[12] https://www.froeling.com/fileadmin/content/produkte/Prospekte_Flyer/EN/EN_Prospekt_S3_Turbo.pdf. [Available online: 06 12 2021].

[13] https://kotlynaslome.pl/en/biomass-boilers-ekopal-rm-series/parameters/. [Available online: 06 12 2021].

[14] http://biomassmagazine.com/uploads/posts/magazine/2013/07/resize/Markets-BMM-. [Available online: 06 12 2021].

[15] https://www.abs-silos.de/en/wood-pellet-silos/general-information.html. [Available online: 06 12 2021].

[16] https://www.archiexpo.com/prod/hargassner/product-56204-. [Available online: 06 12 2021].

[17] Recommendations for storage of wood pellets. UK Pellet Council. Translated from Deutscher Energieholz- und Pellet-Verband e.V. (DEPV) (German Wood Fuel and Pellet Association). Deutscher Energieholz- und Pellet-Verband e.V. (DEPV): Berlin, Germany, 2012 .

[18] EPC Storage Guidelines. Recommendations on the design, installation and operation of fuel stores for heating appliances .

[19] https://www.organicenergy.co.uk/products/pellet-storage-systems. [Available online: 06 12 2021].

[20] http://www.freecompany.cz/en/storage-briquettes-by-wholesalers.html. [Available online: 06 12 2021].

[21] https://www.woodfuel.coop/top-tips/storing-your-briquettes/. [Available online: 06 12 2021].

[22] https://sc04.alicdn.com/kf/UTB8UH1kIarFXKJk43Ovq6ybnpXaz.jpg. [Available online: 06 12 2021].

[23] https://ireland.apollo.olxcdn.com/v1/files/huzlvqo72pg73-. [Available online: 06 12 2021].

[24] https://www.treco.co.uk/options-for-wood-chip-fuel-store-design. [Available online: 06 12 2021].

[25] https://www.canadianbiomassmagazine.ca/wp-content/uploads/2019/09/wood-chips-storage-630x344.png. [Available online: 06 12 2021].

[26] https://miraclespan.co.uk/wp-content/uploads/2014/01/MiracleLite-woodchip-storage-building-840x290.jpg. [Available online: 06 12 2021].

[27] https://www.herz-energie.at/pl/produkt/systemy-magazynowania-i-technologie-transportu-paliwa/do-zrebek-i-peletu/. [Available online: 06 12 2021].

[28] https://www.trimetals.co.uk/2017/12/store-logs-outside/. [Available online: 06 12 2021].

[29] https://img.joomcdn.net/4b0f54e91050fdc38e31ba7327032a109de5f59f_original.jpeg. [Available online: 06 12 2021].

[30] https://www.eco-energ.co.uk/wp-content/uploads/2014/06/metalerg_zmiany_eng2-web2.pdf. [Available online: 06 12 2021].

[31] https://ag-safety.extension.org/preventing-fires-in-baled-hay-and-straw/. [Available online: 06 12 2021].

[32] https://arbena.pl/wp-content/uploads/2020/05/Magazyn-na-baloty-w-malowniczym-otoczeniu-1.jpg. [Available online: 06 12 2021].

[33] https://ocdn.eu/pulscmstransforms/1/YJTk9kuTURBXy85ZjQyMmI1NS1jYWNmLTQxYWUtOGY3Mi01MDVmMDc4MzdiYWIuanBlZ5GVAs0CZwDDw4GhMAU. [Available online: 06 12 2021].

[34] https://www.greenhousecanada.com/images/stories/2009/October/2441-Vanco-conveyor.jpg. [Available online: 06 12 2021].

[35] Energy performance of buildings - Method for calculating the heat demand by installation and system efficiencies - Part 4-4: Heat sources, integrated cogeneration systems, Module M8-3-4, M8-8-4, M8-11-4 .

[36] https://www.as-gips.pl/jak-dobrac-moc-kotla/. [Available online: 06 12 2021].

[37] http://www.rynekinstalacyjny.pl/artykul/id4799,efekty-termomodernizacji-i-zastosowania-oze-w-budynku-jednorodzinnym.
[Available online: 06 12 2021].

[38] http://www.drevohaus.pl/?drev=energooszczednosc. [Available online: 06 12 2021].

[39] https://kb.pl/. [Available online: 06 12 2021].

[40] https://www.volker-quaschning.de/datserv/CO2-spez/index_e.php. [Available online: 06 12 2021].

[41] Steen M. Greenhouse Gas Emissions from Fossil Fuel Fired Power Generation Systems.. EUR19754 EN. 2001. JRC21207 .

[42] uP_running (691748): Take-off for sustainable supply of woody biomass from agrarian pruningand plantation removal, D6.4: Flagship success cases update v2, Annex: The Gospodarstwo Sadownicze flagship case, 2018 .

Annex II: Technical catalogue on biomass district heating

1. Introduction

A biomass district heating, basically it is a heating power plant that generates heat and through a piping network supply this thermal energy to different consumers that belongs to different buildings. Taking into account the BECoop audience (residential sector), these consumers could be municipalities, community of neighbours, individual houses, swimming pools, local business, nursing home, hospitals, etc.

This technical catalogue about biomass district heating has the aim of facilitating the steps that a stakeholder, that want to promote this technology, needs to do in order to analyse the feasibility of developing a DH. In order to assess this goal, the information that can be found in this report it is the following.

- A general overview of what a district heating is in order to guarantee that this is the project that you want to promote.
- Technical considerations that should be known before contacting with stakeholders that can help you to develop your initiative. It should be known the main elements of the district heating, the information necessary to assess the power of the DH, and the operational and maintenance requirements for this type of installations.
- Although, the best option (if you don´t have technical experience) it is than an expert carried out a feasibility study, the point 4 explains how to assess a first estimation of the economic profitability of a DH, but as indicated, this is just a starting point and then needs to be studied in more detail by an expert. Also, environmental and social benefits are mentioned in this point.
- The point 5 indicate the group of stakeholders that can help you in the development of your initiative, and what kind of activities can be expected for each group of stakeholders. Not all of the stakeholders should be involved to develop a biomass DH, it will depend of each particular case according to your necessities.
- The point 6 gives the general steps that should be carried out from the idea to the final implementations, with suggested stakeholders that can provide support if needed.
- Finally, some success cases are mentioned in order to provide some real examples of biomass district heating that are properly working.

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.District Heating concept

A "district heating" or centralized systems for heat production based on district networks, is understood as a centralized system of production and distribution of thermal energy to an entire neighbourhood, district or municipality, which allows connecting multiple energy sources to multiple points of energy consumption and distributing it to the buildings through a piping system that transports a thermal fluid (hot water, cold water, thermal oil...) to the exchange points in the buildings [1].

Figure 1. Scheme of a District Heating [2].

In particular, district networks allow the efficient use of thermal energy generated by waste heat from industrial processes, natural geothermal sources, energy recovery from solid urban waste and the use of renewable sources that are easier to integrate into centralized systems, such as biomass or solar energy. In particular, this specific catalogue will be focused on biomass district heating networks.

The use of biomass enables the use of autochthonous and renewable energy resources while contributing to create local employment in the municipalities where the valorisation initiative is implemented. From the economic perspective, biomass usually has a lower price than conventional fuels and, additionally, environmental benefit derive in terms of forest cleaning which contributes to reduce forest fire risk, prevention of open-fires (as for instance of agricultural pruning) and the reduction of CO_2 emissions due to the substitution of conventional fuels by biomass.

From the point of view of the users, modern district networks could offer economic and technical benefits. It could contribute to reduce operation and maintenance costs related to the boilers placed in each building, and the district network producer can offer more efficient energy services to the consumer.

District networks also facilitate competition between different heat sources and fuels. For this reason, it can become an important element in a liberalized energy market.

There are other factors to consider, for instance, district networks facilitate the provision of a range of efficient energy services throughout the community. They provide fuel flexibility for the future, boosting the use of new renewable sources, and due to the low CO_2 emissions achieved they can be integrated more easily than individual installations, whether they are detached houses or buildings, where the grid quickly provides an easy route for supply to a large number of consumers.

Finally, it should be remarked that there is another catalogue addressing direct heating (chapter 3 and Annex I) that should not be confused with district heating. The district heating catalogue, as previously mentioned, focus on a central installation covering the energy demands of different buildings (physically separated) while in the direct heating the central installation covers the energy of a single building.

3.Technical considerations

3.1 Main elements of a district heating installation

The main goal of this chapter is to provide a general overview of the main technical elements of a district heating in order to facilitate the conversation and the agreements with the energy service/engineering company in charge of the design and development of the district heating installation. The main elements to consider are:

- Generation plant: heat production in these systems is carried out centrally to meet the demand of the several consumers. This way, individual equipment that should be placed otherwise at the points of consumption (houses or buildings) can be avoided, while it is possible to have more energy-efficient technologies installed at the generation plant (more efficient equipment and operation & maintenance are carried out by professional staff in order to avoid operational problems).
- Distribution piping network: the piping network allows the distribution of fluids (normally water) through insulated pipes to minimize thermal losses. By means of a thermal fluid, the energy is transported to the users, where the heat is transferred to the consumption points by cooling the fluid. The network also has a return circuit to the plant. The pipes are usually distributed in subway trenches that follow the layout of streets in urban areas.
- Substations: the heat transfer between the distribution network and the consumers (buildings or houses) is carried out through a substation consisting of a heat exchanger and the elements that regulate, measure and control the correct operation of the installation.
- Control and management of district heating networks

3.1.1 Generation plant

When establishing the technical requirements to be met by the installation to be able to use biomass, it is important to focus not only on the boiler, but also on the entire feeding and storage system, since many times it is where the greatest source of clogging occur.

3.1.1.1 Storage area

Next to the generation plant, it is essential to have enough space to store at least the amount of material necessary to supply the boiler for a minimum period of time (a minimum period of at least 2 weeks is recommended). This storage must be located adjacent to the room where the boiler is located but cannot be located together according to the regulations.

The volume of the storage area will be defined considering the following aspects:

- Amount of biomass to be stored, where it has to be considered the self-sufficient target of the plant for a certain period of time.
- Bulk density of the biomass to be stored, it will depend on the biomass selected and the size distribution of this biomass. In order to have an estimative value of the bulk density of different biomass, the BECoop Factsheet "Solid Biomass for Small-Scale Heating Applications" (Annex IV) can be consulted.
- Average consumption of biomass per day.

Taking into account the previous considerations, the approximate storage area can be calculated by means of the following formula:

$$\text{Usable volume needed} = \frac{\text{consumption of biomass per day}\left(\frac{\text{kg}}{\text{day}}\right) \times \text{ number of days to be self} - \text{sufficient (days)}}{\text{bulk density of the biomass }(\frac{\text{kg}}{m^3})}$$

Even though, the final surface needed will depend upon the equipment selected for biomass storage. It is possible to choose between a vertical silo, a feeding chamber or pit, a top loader or even a mobile floor. This final decision must be made by the energy services company that carries out the installation, taking into account the final location of the generation plant, the biomass selected and the available space.

3.1.1.2 Feeding systems

The feeding system is also usually a critical point for three reasons:

- Biomass is sometimes heterogeneous (which makes its flow very difficult in certain systems) and can cause clogging, therefore it is necessary to ensure a homogeneous particle size.
- Possibility that the shredded material contains exogenous materials of non-negligible size (stones, wires, ...), it is not very common in the case of forestry woody biomasses, although in the case of agricultural resources it can occur.
- High inorganic content in the fines (soil, sand, dust) that can affect the accelerated wear of the feeding systems, this will be influenced by the collection system used on the field and the pre-treatments carried out to obtain the final biomass product.

Generally, the most common feeding system (in small installations) used is by means of screws conveyors (in this sense, it should be noted that normally the lower the angle of inclination, the lower the probability of clogging). Even though, the standard screws conveyors are not compatible with the presence of exogenous material, that is why this external contamination should be avoided. If this is not possible, or if you want to opt for a more robust system, some alternatives that should be required in the installation would be:

- There are other screw conveyors capable of handling the transfer of heterogeneous material. Reference and evidence of operation of the system in other installations should be requested. Some key points are:

  a) use of screw conveyors oversized and robust.

b) screw conveyors with sharp cutting edge.

c) control system that avoids blockage; motor with variable pitch.

d) Screws with thread angle changeability

e) rotary shearing valves (in case of a long woody sticks, it does not jam the valve, but it cuts the stick).

- There are other feeding systems such as redlers and pneumatic conveying systems, but normally this imply higher costs and space that are possibly not compatible with medium/small thermal power installations (eve though, each case should be independently analysed).

3.1.1.3 Thermal power plant

The generation plant is the core element of a district heating network and where the thermal energy is generated and distributed to the buildings through the distribution network.

The generation plant is located inside a building built for this purpose, exclusively for the production and pumping of hot and cold water. The power generating elements (boiler room), as well as the main pumping units, which drive the heat transfer fluid to the different consumption points, are located inside this building.

The thermal power plant operates automatically, depending on demand, regulating its operation with a control system that takes data from the consumption points and from the plant itself. The operating time of the generation equipment depends on the installed power compared to the thermal demand and the capacity of the existing accumulation systems (water accumulators, buffer tanks, etc.).

The connection of the water supply network supplied to the boiler room will consist of valves, pipes and manholes that allow the cutting or isolation of sections in case of failure of any of them.

The boiler room site (but also the storage area) should be equipped with:

- Low voltage electrical network and its corresponding protections.
- Interior and exterior lighting.
- Fire protection installations.
- Rainwater drainage, especially important in the storage area.

The main thermal generation equipment used are listed below:

- The boilers used in urban heat networks are water-tube or pyrotube boilers (with efficiencies around 85-90%) that use local energy resources such as biomass as fuel.
- Cleaning system, as for instance cyclones and/or bag filters, sometimes are needed in order to fulfil with the emissions directive. In this sense, two directive should be taking into account, the Ecodesign regulation 2015/1189 for boilers lower than 500 kW and the directive 2015/2193 for biomass boilers lower than 50 MW.
- The accumulation systems of the heat networks allow to dimension the plants in a way more adjusted to the needs, achieving that they work during more time at full load and improving, in this way, the energetic performance of the installation. The main drawback is the necessity of space for the storage tanks and the auxiliary systems.

- As safety measure, the installation should account with a the tank or expansion vessel that absorbs the increase in pressure of the fluid when its temperature rises.
- The pumping system (pumping groups) that drive the heat transfer fluid from the power plant, through the distribution network, are used to regulate the flow.
- Other auxiliary equipment can be used in an installation such as compressors for the air supply of pneumatic drives, shut-off valves, hydraulic distributors, regulating valves, etc.
- A first number to be considered for the space needed for this generation plant, could be the ratio 30-200 m^2 per MW_{th} heat output [3].

Focusing on the "heart" of the thermal generation plant, the boiler, there are different technologies, but for small-medium heating capacities, the most frequently used are:

Underfeed biomass boiler

The fuel is fed through a vertical duct, by means of a screw conveyor, and it is burnt in a fixed grate. This is an appropriate technology when a small-medium power installation is required, with power in the range from 20 kW to about 2 MW. Regarding the fuels to be consumed, it is appropriate when they have a medium size (up to 100 mm), a low percentage of ash (<1 %) and a medium moisture content (up to 30 %).

Biomass boiler with fixed grate

In these boilers, the material descends/advances through a grate as the new fed material enters in the boiler and causes the inner material to advance. It is usually set in small power as an inclined grate in steps or in a grate. Even though they may be more robust than underfeed biomass boiler, it is difficult to guarantee good combustion with some fuels given the limited regulation over the material and the bed. This can cause low efficiency, and thus loss of economics, and visible smoke in the stack.

It is an appropriate technology when a small-medium power installation is required, with power outputs in the range from 20 kW to about 2 MW. Regarding the fuels to be consumed, it is appropriate when they have a medium size (up to 100 mm), a low percentage of ash (1-3 %) and a medium moisture content (up to 30 %).

Biomass boilers with mobile grate:

Regarding to mobile grates, these can be used for a wide variety of biomass resources. This is due to the high flexibility of the system to handle heterogeneous fuels in terms of particle size, moisture and ash content.

In general, existing mobile grate systems can operate with chips up to 55% moisture and particle sizes up to G100 (although such moisture contents and particle sizes are generally not recommended). Depending on the ash content and the melting temperature of the ash, it is also possible to install water-cooled mobile grates, which prevent the possible sintering of the solid residues (ashes) in the grate.

It is a robust, reliable technology suitable for processes where higher plant availability it is required. Normally it is recommended from power ratings from 200 kW to 200 MW. The main disadvantage it is the higher price of this technology compared with the other previously mentioned.

Also, according to the size distribution of the biomass to be used some modifications should be considered in these technologies, in the point 3.1.1 of the BECoop technical catalogue “Direct heating” some considerations are mentioned according to the size distribution (pellet, woodchips, briquettes and log) of the biomass fuel to be consumed.

Additionally, since it is necessary to cover the needs of a certain number of buildings, whose demands may vary from one building to another at different times and days, it is possible to opt for an installation that allows modularity in the production of energy. For example, the installation of two boilers of less power, instead of one that covers all the power, would allow a more efficient work of the installation.

3.1.2 Distribution piping network

The distribution network is a network of insulated pipes that distributes the thermal energy (thermal fluid) from the generation plant to the different buildings.

The heat transport line consists of two pipelines (with their corresponding collectors), one for the supply and one for the return. In the case of centralized heating and cooling networks, the line consists of four pipes.

There are three main factors to be considered to design the distribution piping network:

- Where the pipes should be located? The current trend is to install underground installations for visual and safety reasons, even though the investment cost is lower in surface installations.
- Type of material to be used. Larger pipes are usually made of carbon steel and for smaller diameter pipes plastic materials are being used, such as cross-linked polyethylene.
- The selection of the type of insulation is quite relevant since it has an influence on the overall efficiency of the system. It should be taken into account that in the distribution networks is where the greatest performance losses occur in this type of installations, which can range between 5 and 10 % (taking the latter as a very conservative value).

In addition to the pipes, the distribution network incorporates other elements necessary for its proper and optimum operation: fixed points for expansion control, pre-insulated sectioning valves, air trap located at high points, discharge or emptying points (valves) located at low points, expansion elements, branches for service connections, manholes, junctions with existing services, filters, pressure and temperature gauges, etc.

3.1.3 Substations

The thermal energy produced in the generation plant is transported through the distribution network and finally reaches the consumer through substations located near the consumption points. At the substations, the pressure and temperature of the network are adapted to the conditions of consumption.

In each building there is a heat transfer substation, consisting of a heat exchange system, without fluid or pressure exchange, through which heat is transferred to the terminal elements for heating, cooling and domestic hot water service.

In the substations, in addition to the heat exchanger, there are regulation and control elements and metering equipment for billing the thermal energy supplied from the network to each end user.

A list of the minimum components would be as follows:

- Shut-off valves at the inlet and outlet of each individual installation.

- Approved energy meters.
- Differential pressure regulation valves.
- Power regulation valves.
- Water treatment system for internal circuits.
- Sieve filter.
- Electrical and control panel including regulation and communication devices with the control panel.

In the buildings/houses, where currently are being heated with other fuel, normally they account with the majority of these equipment and can be reutilised for the new district heating network with minor investment in most cases.

3.1.4 Control and management of district heating networks

The main aim of the control of the district heating networks entails the regulation between the generation of energy and the real demand in the network in each moment. Another important variable to regulate is the control of the supply and return operating temperatures, which is usually based on the outside temperature.

In order to adjust the supply of the thermal energy, the most common solution is to regulate the supply temperature and the flow of the thermal fluid.

This control is usually managed through a "supervisory control and data acquisition" (SCADA), this supervision will allow the optimization of the operation of the network and will increase the safety of its operation. The control and monitoring of the installations include the elements of the power plant and, in some cases, the regulation and measurement substations of the consumption points.

3.2 Power of the District heating

The real power of the installation should be calculated by an expert company in this field, as for instance an energy service company with expertise in biomass district heating, even though in order to assess this profitability the user should provide some input information.

3.2.1 Buildings

It is necessary to identify the buildings to be covered by the district heating network, here two stages can be differentiated:

- 1st stage: This step refers to the buildings, which the current energy demands should be covered at the moment of the implementation of the district heating.
- 2nd stage: Additionally, it is often the case, where there is a possibility that other buildings will join in the future. If possible, an estimation of these building should be also done at the initial stage, since this could be also considered at the moment of the design of the district heating, but without making the mistake of greatly oversizing or downsizing the installation from the beginning.

The location of the buildings should be indicated along with their distance to the plant. If possible, a map considering the roads, buildings, and so forth will facilitate this information and the future steps regarding the design of the piping network.

3.2.2 Energy demand

From the buildings previously identified, the energy demand of each of them should be known in order to determine the power of the installation. To obtain this data, the invoices can be checked and reported. It is recommended to provide the data from, at least the last three years, in order to have a representative energy demand of each building.

Additionally, if possible, the power of each individual installation should be provided along with a consumption curve of each building. This will allow to know when the power consumption is carried out in each building throughout the day.

Sometimes, the previous data cannot be obtained. In that case, it could be useful to provide information about the building to be heated, as for instance:

- What type of building is it? Residential? Office? Sports centre? Swimming pool?
- Year of construction of this building? What type of insulation?
- Useful surface to be heated in each building?
- Are people living/working all the time?
- Number of hours that it is heated along the day.

The same information should be provided about the domestic hot water (DOC) and cooling (if cooling wants to be covered in the DH), if possible.

Summarizing, an example of the data to be provided are indicated in the following Table 1:

Table 1. Necessary data to be fulfil by the user to know the energy demand of each building

Stage 1 or 2	Name of the Building	Heating/ Cooling/ DOC	Useful surface to be covered (m^2)	Final energy consumption (kWh/year)	Number of hours of operation (h)	Additional information
1	City Council	Heating	1.000	100.000	1.500	-
2	Nursing home	Heating	1.500	200.000	2.000	-

In case, that cannot be provided the energy demand of each building, there are different tools that allow have a first number regarding the energy density of the area selected, some of them are: Hotmap (https://www.hotmaps.eu/map), S-EEnerrgies Dataset (https://s-eenergies-open-data-euf.hub.arcgis.com/apps/417665ed989a4319acfbec2b92a08332/explore), and THERMOS (https://www.thermos-project.eu/thermos-tool/tool-access/). All these tools can be found in the BECoop toolkit (https://becoop.fcirce.es/toolkit/), where at least a summary can be found, and in some cases a guideline about how to use it.

Also, other option about how to do a first estimation of the final energy consumption from a simple way (but less accurate), can be found in the point 3.2 of the BECoop catalogue "Direct Heating", based on the energy class of the building to be heated and the useful surface area to be heated.

3.2.3 Power of the installation

Taking into account the buildings to be covered, where they are located, and the energy consumption of each building, a first estimation about the power needed of the installation can be done. In order to do so, these main considerations should be taken into account:

- Final energy consumption: it means the sum of all the useful energy of each building, this will imply the average thermal demand to be consumed and therefore the minimum amount to be generated each year.
- Maximum power to be supplied: since there are moments where the heating demand will be higher than the average, this should be assessed to calculate the power of the installation, normally through the consumption curve. In this sense, the accumulation systems can mitigate these punctual moments, and therefore an appropriate design of the volume of this equipment and the power of the installation should be properly established.
- Heating losses in the network: as mentioned, there will be energy losses in the distribution of the thermal fluid to the different substations. These energy losses will depend on the parameters indicated in the section 3.1.2 of the Annex II. As starting point, 5 and 10% of energy losses could be considered (taking the latter as a very conservative value). This mean, that 5-10 % more of energy should be generated in the output of the biomass boiler.
- Yield of the biomass boiler: biomass boiler doesn´t have a yield of 100 % (although in the case of condensation biomass boiler this can happen), normally the yield ranges between 85-90 %. This fact should be considered in order to assess the real power of the installation.
- Additionally, more specific aspects should be considered as for instance the climate conditions of the area where the district heating is going to be located.

Figure 2 provides a basic estimation of the energy that should be provided in the different elements of the district heating network, even though this calculation is more complex, and therefore should be carried by an expert in this field.

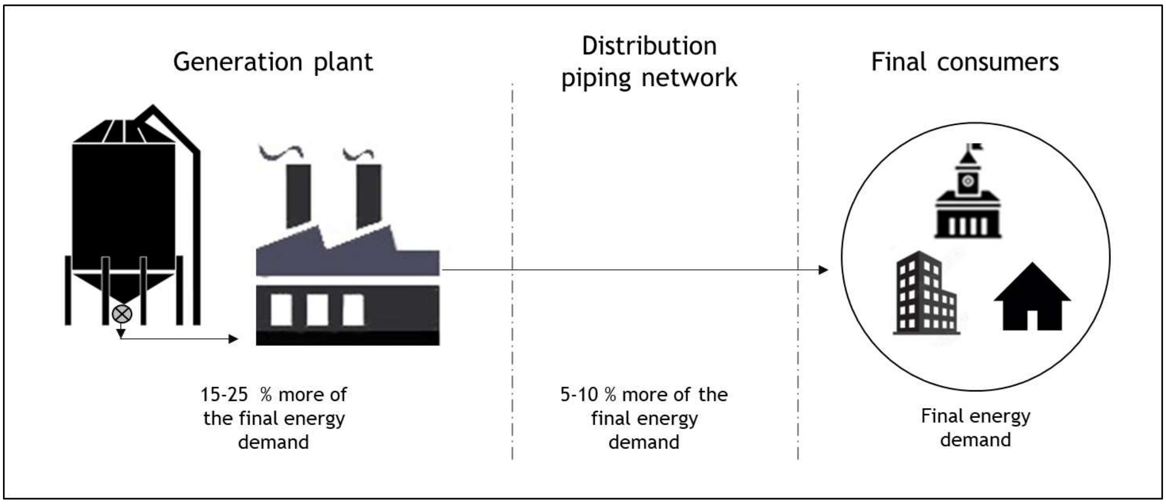


Figure 2. Basic scheme of the energy to be supplied in each part of the district heating system.

3.2.4 Amount of biomass needed

At the same time, once the amount of energy to be produced in the generation plant is obtained, an estimate number of the amount of biomass required can be assessed. In order to do so, the low calorific value and the moisture content of the biomass selected should be obtained. If these parameters are unknown the BECoop factsheet "Solid biomass for small-scale heating applications" can be consulted where average values are provided.

$$Energy\ to\ be\ produced\ in\ the\ generation\ plant\left(\frac{MWh}{year}\right) = \frac{Final\ energy\ demand\ of\ the\ consumers\ (\frac{MWh}{year})}{Efficiency\ of\ the\ piping\ network\ (\%)}$$

$$Energy\ to\ be\ covered\ by\ biomass\ (\frac{MWh}{year}) = \frac{Energy\ to\ be\ produced\ in\ the\ generation\ plant(\frac{MWh}{year})}{Efficiency\ of\ the\ generation\ plant\ (\%)}$$

$$Amount\ of\ biomass\ needed\ (\frac{t}{year}) = \frac{Energy\ to\ be\ coverd\ by\ biomass\ (\frac{MWh}{year})}{Low\ heating\ value\ of\ the\ biomass\ (\frac{MWh}{t})}$$

3.3 Operational and maintenance of the installation

Although biomass is a cheaper fuel than fossil fuels (natural gas, heating oil, propane, etc.), its operation and maintenance cost are slightly higher, considering that more frequent maintenance operations should be carried out due to the significant amount of ash generated during the combustion of the biomass in order to guarantee the correct operation (and therefore do not decrease the yield of the installation) and to guarantee the service life of the installation:

- The frequency of the bottom ash accumulated removal will depend upon the installation characteristics and the biomass to be consumed, but it is recommended to perform it at least once each two weeks.
- Removing the fly ash, that can be located in the heat exchangers tubes and other auxiliary/cleaning emissions systems, can be done automatically by means of a pneumatic system (or other technologies). It is also recommended to be performed at least once per year, (normally after the winter season) and invest additional time to deeply clean all the installation.

Normally these operations are carried out by the company in charge of the operation of the installation.

If these maintenance operations are being done and the design of the installations is based on the energy to cover and the biomass resource to be fed, no malfunctions should arise.

Sometimes the bad experiences associated to the use of biomass, it is because:

- The district heating has been oversized and therefore the installation usually operates at very low capacity.

- The biomass fed it is very different for which the installation has been designed, as for instance: (i) different moisture content, (ii) size distribution (this can cause problems in the combustion but also in the feeding system), (iii) chemical composition (be careful with that since it cannot be visually identified, high alkali and chlorine content, if the boiler it is not designed properly, can considerable decrease the service life of the installation), (iv) low heating value, (v) ash content, etc. There are different quality schemes in order to guarantee the quality of the biomass (ENPlus, DINPlus, BIOmasud, etc), so this should be taking into account when the biomass it is purchased.

4.Profitability of a biomass direct heating

Profitability should be measured in economic, social, and environmental terms, since all of them are important, even though, it is well known that economical aspects are one of the main considerations in order to carry out the final decision. So let´s focus on how to assess the economical profitability of a biomass district heating.

The first aspect that should be addressed is related to the information previously mentioned in section 4.2, regarding the energy demand to be covered annually. Additionally, information should be retrieved regarding the current fuel used in these installations/buildings and the annual price that is paid. With this input data, the annual cost to cover the heating demands for all the buildings will be calculated, without taking into account the amortization of the installations, since it is understood that the installations are currently amortized.

At this point, it could be considered not just the current annual price, but also the tendency in the future years, since the stability of the prices will not be the same for all the fuels. Also, if the current fuels used are fossil fuels, it should be considered that in the coming years fossil fuels are expected to have an extra tax according to the specific emission factor of the fuels used. The same is currently happening in the industry sector (Figure 3), which can lead to a significant increase of the final price of the fossil fuels used.

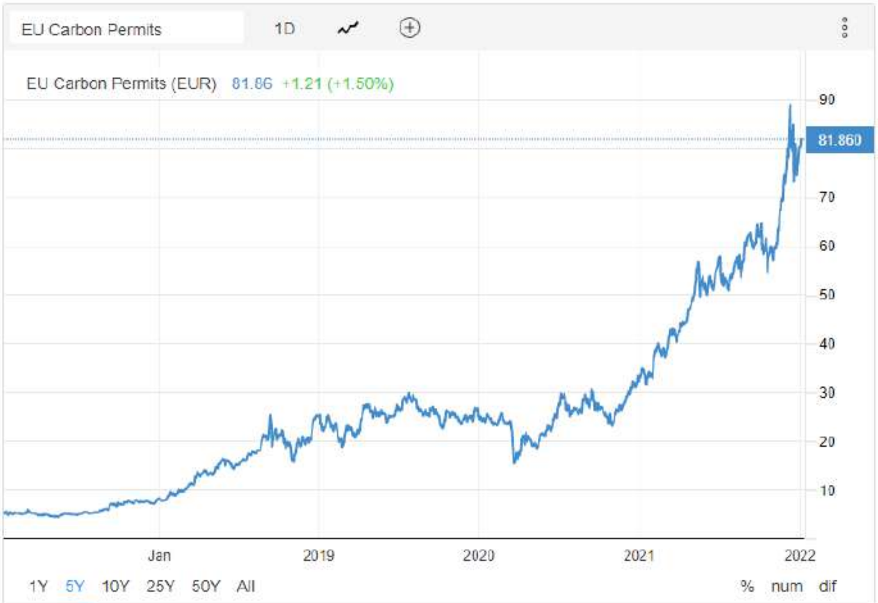


Figure 3. Evolution of the price of CO_2 emission in the last 5 years [4].

Complementarily, in order to have a good overview of the current and future scenarios with the current fuels, a sensitive analysis (final price and emission prices of the current fuel) can be done in order to have more information to take the final decision.

Once the current situation is well analysed, it should be compared with the future installation, and thus, two main aspect should be considered:

- Investment (CAPEX) of the new biomass district heating installation: it includes the investment cost, the assembly and the transportation of all of the equipment required, together with the civil engineering costs (installations necessary for the operation of the DH, as for instance the building of the generation plant, and the civil engineering of the piping network). This number is very sensitive to the specificities of each case (location where the initiative will be implemented, expertise of the company in charge of the operations, the equipment selected, the biomass fed, the linear meters of the piping network, etc.). An initial estimation with uncertainty ranges for heat biomass plants based on DH is provided by the Danish Energy Agency [5] for a power of 6 MW fed with different biomasses, Table 2.

Table 2. Investment costs according to the Danish Energy Agency for a DH of 6 MW fed with different biomasses [5].

CAPEX (€/kWth – heat output)	Woodchips	Pellets	Straw
Equipment	410 (350-470)	440 (380-510)	460 (370-550)
Installation	300 (250-340)	290 (240-330)	460 (390-530)
Nominal investment	710 (600-810)	730 (620-840)	920 (760-1,080)

- Operational and maintenance cost (OPEX): considers the actions mentioned in the section 4.2.3, and it can be divided in two groups: fixed cost (biomass cost, periodic maintenance, etc) and variable cost (electricity, etc.). According to the Danish Energy Agency Table 3 depicts some reference figures.

Table 3. Operational and maintenance cost according to the Danish Energy Agency for a DH of 6 MW fed with different biomasses [5].

OPEX (referred to heat output)	Woodchips	Pellets	Straw
Fixed O&M (€/MW_{th}/year)	27,800-37,700	28,000-37,900	43,900-59,600
Variable O&M (€/MWh)	2,34-3,71	1,81-2,30	1.92-2.59
- of which is electricity costs (€/MWh-heat)	1,51-1,99	1,40-1,61	1.43-1.71

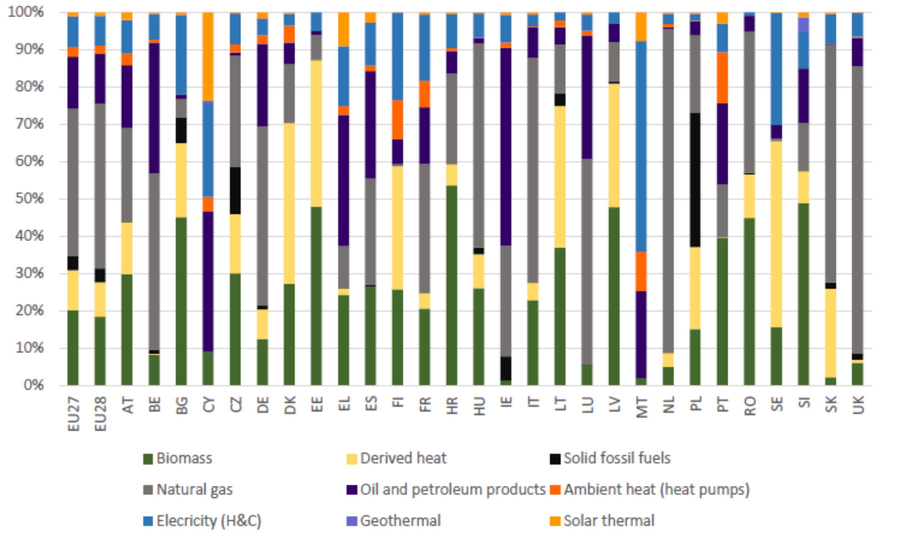
- of which is other O&M costs (€/MWh-heat)	0,83-1,72	0,41-0,69	0.49-0.88

Once, the CAPEX and OPEX of the new installation are estimated, in order to assess the economic profitability, the annual savings regarding the OPEX of the new installation should be calculated. After having estimated all the investment and operating costs along with the potential savings/ revenues, a simple way to calculate the payback period (this parameter indicates the necessary years to obtain the return of the investment carried out), is obtained through the division of the CAPEX and the annual savings associated with the new installation. The lower the payback, the lower the risk associated with the new installation. It should always be lower than the service life of the new DH installation (an average service life is between 20-30 years) for being economically profitable.

$$Payback = \frac{CAPEX\ (€)}{Annual\ savings\ (\frac{€}{year})}$$

As mentioned, this is a simple way of doing a first estimation, but to be more accurate other parameters should be considered as the inflation or the tax rate. If the CAPEX is covered by own or external resources, loans, etc., in order to obtain more information about business and financial considerations, the BECoop Catalogue for the provision of business and financial support services can be consulted.

Nowadays, due to the high percentage of the fossil fuels used to cover the energy demands of the residential sector (Figure 4), supporting financial mechanisms are available to accelerate and mitigate the risk of new investments in renewable energies, as in this particular case of biomass district heating. If this happens, the payback period will be lower than the one initially calculated (without financial support), since the CAPEX will be lower.



Note: Ambient heat is the energy in form of heat captured by heat pumps, the electricity used to fuel the heat pumps is included under "Electricity (for H&C)".
Source: Eurostat

Figure 4. Shares of energy used for heating and cooling in the residential sector by Member States in 2018 (%) [6].

Table 4 summarises the information mentioned in this section, through an example of investing on a new biomass DH and replacing the current consumption of a total of 250,000 litters of heating oil in all the buildings. In this example an inflation rate of 2 % has been considered for the case of heating oil and 1 % for the case of the biomass (since the price it is more stable, as previously mentioned), as a result a 10 year payback period is obtained.

Table 4. An example of a breakdown of savings, expenses and investment obtained for a DH.

Items	Unit	Data year 1
Savings (current situation)		
Consumption of heating oil	Litter/year	250,000
Price considered of heating oil	€/l	0.8
Annual heating cost	€/year	200,000
LHV heating oil	kWh/l	9.98
Yield of the oil boiler	%	85
Useful heating consumption	MWh/year	2,120
Expenses (future situation)		
LHV woodchips (at 30-35 moisture content)	kWh/kg	3.1
Yield of the district heating	%	75
Amount of the biomass needed	t/year	911
Nº of hour of operation	h/years	1,400
Power of the installation	MW	2
CAPEX cost (taking into account the average value of the **Error! Reference source not found.**)	€	1,443,887
OPEX cost (taking into account the average value of the Table 7)	€/year	70,488
Financial considerations		
Inflation of heating oil	% of inflation per year	2
Inflation of biomass	% of inflation per year	1
Grant	%	0
Loans	%	0
Payback		
Payback	Years	10

Environmental and social aspects, that sometimes are forgotten, should be also considered. In the case of biomass, these aspects are very relevant, since in order to develop new initiatives, these resources should be collected and consumed in the nearby areas in order to be economically profitable. This implies that employment is generated locally and normally in rural areas since it is where the biomass is located. Also, the use of biomass, can contribute to a good forest management that can prevent forest fires, avoid uncontrolled pruning burning on the fields, contribute to pest control, etc. And, of course, the mitigation of the dependence of fossil fuels, keeping in mind that the EU has a clear commitment to achieve carbon neutrality in 2050, and to contribute to the development of rural areas. Both goals are properly addressed with the promotion of district heating based on local biomass resources.

5.Stakeholders needed

In order to develop a district heating unit, the users, in the majority of the cases, would most likely need the support from other stakeholders, that sometimes can be integrated inside the community/RESCoop or in other cases they will provide external support by subcontracting. Some of the stakeholders that could be necessary are listed below:

Biomass producers/suppliers

It is very important to guaranty the supply of the raw material (biomass) that should feed the district heating installation. There are a huge range of biomass with different composition and size distribution, therefore the biomass purchased should guarantee the same range of properties since the installation it is designed for a specific biomass. It is recommended to consume local biomass, because it is more sustainable, and the transportation cost it is lower. These biomasses can be purchased from the biomass producers or from biomass suppliers, in any case it is important to carry out supply contract specifying who is in charge of transportation, the frequency of supply, and the quality of the biomass supplied.

Energy Services/Engineering Company (ESCO)

A district heating installation, it is an industrial plant, so therefore it is important to account with an expert company that will be in charge of the proper design of the installation. This step it is critical, since a bad design of the installation can jeopardise the viability of the project. It is recommended that these companies have a general overview of all the project, as for instance the energy demand to be covered at the initial stage, and the future stakeholders that can join in the future, also to have a clear idea of the biomass to be consumed, since the installation should be designed accordingly. Sometimes this lack of information entail problems in the future, so dedicating efforts to making the project fully understood is highly recommended.

Normally, this stakeholder can be in charge of the operation of the installation selling the energy to the final consumers, this fact it will depend on the business model selected by the community. In any case, which is not usually recommended, it is that one company it is in charge of the design, and other of the operation, since if problems happen, they can blame each other, this does not always have to be the case, but unfortunately it sometimes happens. Also, it is also frequently, that this stakeholder could be in charge of the biomass supply of the installation if they are in charge of the operation.

Some energy services/engineering companies have in their business model to be part of an energy community while others do not, this fact should also be taken into account depending on the business model to be selected by the energy community to be formed.

Equipment manufacturers

The selection of the proper equipment for the installation to be designed it is important, even though this process normally it is being done by the previous stakeholder (energy services/engineering companies), since they have agreements with several equipment manufacturers, and they choose the best technology for each particular case.

Public/Local institutions

To develop district heating installation, generally, it implies the use of public resources, as for instance administrative license and the use of urban ground where the piping network should be allocated (buried), for this reason it is fundamental the involvement of the administration (regional and state) and local bodies (town councils), and also to account with an urban development plan that allows the permits processing for the occupation and use of urban ground in order to speed up the development of the project for the implementation of the heat network. As well as coordination between the different administrations for the processing of permits (e.g. the licence from the Department of Industry for the construction and operation of the generation plant) and the optimisation of the system in the case of supply to buildings under different public ownership.

These public institutions can be also the final consumers of the heat, or even the promoters of the idea of carrying out a district heating in the area to supply the public buildings and the homes and businesses of local residents who want to be part of the community.

RESCoops

Current RESCoops already account with the expertise in community models, and they can expand its services lines through the promotion of district heating in the areas where they account with associate and the project it will be feasible, so therefore they can be promoters of new district heating installations. But, also, if the promoters are other stakeholders, they can be an interesting stakeholder to be contacted and communicated the idea since they can help you in the development of the community model, disseminate the initiative, or even they can be interested and being involved in this new local community.

Consumers

Final consumers can be a wide variety of different stakeholders as: individual houses, community of neighbours, commercial premises, local industries, or even some of the stakeholders previously mentioned as RESCoop and buildings of public institutions. They will be the “clients” of the DH, and therefore, they will expect to achieve financial savings, and to contribute to the environmental and social aspects in the area by being part of this community based on DH.

They should be open to adapt its current substations (if they already account with that) for being connected to the district heating network.

Transversal stakeholders (as research centre, biomass associations, investors)

In addition to the stakeholders previously indicated, which are the most necessary in this value chain, there are others, that in some cases, could help to assess/give advice/finance/etc the development of bioenergy communities based on biomass district heating, some of them are:

- Research centres: it could be interested to contact with this stakeholder if the promoter of the idea doesn´t account with the necessary technical information to assess if it could make sense to go further. The research centre can carry out a first feasibility study (being completely impartial) and if it is feasible to facilitate the contact with energy service companies or even being the technical expert (as representative of the promoter) in this communication with the ESCO.

Additionally, it can provide support to prepare some documentation in order to obtain financial grants to develop the project.

- Biomass association/local action groups: this stakeholder can inform to the promoter about stakeholders that can help them in order to develops its initiative, can inform them about other success cases based on biomass DH, open financial grants, etc.
- Investors: a DH it required a huge initial investment as was mentioned in the point 4, so it is frequently to some external funding, so in this case investors can provide support. Before contacting the investor, it is important to have a feasibility study, and the idea of the project well organized in order to capture its attention from the beginning.

In case the promotor of the idea needs to contact or find out a specific stakeholder, it is advisable to visit BEcoop e-market platform where you can find useful information in this regard.

6.Steps to be followed

This section aims to summarize and establish a chronology order of general steps to be performed by the promoter of the idea of a biomass district heating unit starting from the beginning.

Table 5. General steps to be followed to develop a biomass DH from the beginning.

Order	Action	Description	Stakeholders that can help
1	To define the buildings to be covered by the district heating and the energy demand to be covered	Should be considered to understand the capacity of the district heating to be developed. See chapter 3.2.1.	All the final consumers of the DH, as individual homes, commercial buildings, public institutions, RESCoops, etc.
2	Current energy demand of these building	It is needed to assess the current situation and to compare with the future DH. See chapter 3.2.2 about the information required	All the final consumers of the DH should provide this information. If support is needed, they can contact Research centres or ESCOs to carry out an energy audit or doing some estimations.
3	To do a pre-feasibility assessment about the implementation of a DH unit	Based on the information described in chapters 3 and 4. It is needed in order to decide whether go further with this idea or not.	It should be done by an expert in this field, it could be a Research centre or even the ESCO that if feasible will be in charge of the design and implementation.
4	To identify and contact different ESCOs and	Preliminary contact with ESCOs should be done with the goal of communicating the project and investigate if	It can be done by the promoter of the idea with the support of the company that carried out the pre-feasibility assessment (if

	communicate the initiative	they are interested to collaborate.	previously wasn't done by an ESCO)
5	To start with the definition the business model and to identify the members of the community	Who will design and implement the DH? Who is in going to be in charge of the operation of the DH? Which is the business model selected? In the case of public institutions these are the more frequent models: - Concession model (by public tender) by the city council for the operation and maintenance of the facility ceded to a private company. - Public company operating model, with the council's own resources (subcontractors). - Operating model with a company or investee company. - Mixed public-private operation model. Who will be in charge of the investment? What stakeholders are interested in being part of the energy community? Etc. See chapter 5 about stakeholders than can be needed and the main role that of each of them can provide, and the BECoop "Business and Financial Catalogue"	The previous conversation with the ESCOs can help, but also RESCoop can provide support about community business models.
6	To select the business model and the company in	According to the information previously indicated, the final decision about the	It should be done by the promoter and/or stakeholders currently involved in the

	charge of the design and the implementation	stakeholders selected and role of each of them should be defined. In the case of public institutions, public tenders are needed.	community. Also, if needed, the company in charge of the pre-feasibility assessment can provide support about technical support to facilitate the decision-making to the promoter.
7	To carry out the design and the implementation of the DH	To develop the project of the biomass DH and the implementation, selecting the biomass to be fed, the equipment needed, to obtain the administrative licenses, etc.	By the ESCO selected.
8	To guarantee the supply of the biomass	Biomass should be guaranteed with the proper quality for the design of the installation carried out.	It depends of the business model selected, and the role of each stakeholder of the community. Normally, the agreement with the biomass supply it is carried out by the same stakeholder that is in charge of the operation and maintenance of the DH.
9	To star with the operation of the DH and distribution of the energy to the final consumers	To guarantee the correct operation of the installation, securing the energy supply to the final consumers and the correct maintenance of the installation to ensure its useful life.	ESCO or the stakeholders selected to be in charge of the operation and distribution of the energy.

7.Success cases

In this section some initiatives already implemented will be described seeking to raise awareness regarding the possibility to successfully develop a biomass district heating and get a better idea of the average cost. This section will be updated in the second version of this catalogue in January 2023.

7.1 Vilafranca del Penedés, Spain (500 kW_{th})

Vilafranca del Penedés is a town located in Catalonia (Spain), in which the project VinyesXCalor (http://vineyards4heat.eu/es/) was developed. The initiative was promoted by the municipality of Vilafranca del Penedés as a political commitment to set an efficient low carbon economy through the use of an abundant source of biomass in the area (vineyard prunings), currently underused with the goal of covering the energy demands (heating and hot water) of four buildings (one more is expected to be connected to the network in the near future), Figure 5. For this purpose, multiple local public and private actors have been involved to create a new and sustainable value chain guaranteeing the profitability of the energy production from vineyard prunings: farmers, a harvesting service company, an energy service company, several consumers and the municipality. This value chain starts from the collection phase of the resource until the generation and distribution of the energy.

Figure 5: Scheme of the District Heating in Vilafranca del Penedés.

Part of the motivation came from the subscription of the Municipality to the Covenant of Mayors for Climate & Energy (EC initiative) in which several Sustainable Energy Action Plans were promoted. The rest of the motivation was triggered: (1) by the reality of the pruning residues management, which needed to be improved; (2) by the willingness to increase the competitiveness of the county economy; and (3) following the wine tourism local initiatives in the area, promoting sustainability and a zero km economy as a flag.

The selection of the equipment was performed according to the biomass to be consumed, average moisture content of 20 % on wet basis, an ash content of 6 % on dry basis, a low heating value of 14.8 MJ/kg and a particle size distribution classified as G50. The low density and irregular shape make the hog fuel required an adaptation of the boilers feeding system: the silo was designed to avoid bridges and the feeding screw is prepared for particles with longer size. Regarding the combustion system, the higher ash content and lower density compared to regular forest wood fuels, was taken into account in the selection of the system and in the operational parameters. As a result, a Heizomat RHK-AK-500 boiler of 500 kW was installed. It fully runs on vineyards pruning wood hog fuel. The saving in natural gas and electricity are up to 153 and 13 MWh, respectively, thanks to the use of biomass.

The total investment of the installation was 600.000 €, the consumption of biomass from vineyard pruning it is of 225 t/y (on average during the project although the potential can be up to 30,000 t/y in the area) that comes from 375 ha in a radius lower than 15 km. The emissions avoided are 125 t CO_2/y, and 4 permanent jobs were created in the entire value chain.

This information was obtained from uP_running project [7].

7.2 Sabando, Spain (400 kW_{th})

Sabando it is a small village of 40 houses that belong to the town of Arraia-Maeztu located in Euskadi (Spain). The village of Sabando, with 89 inhabitants, is situated in a hidden valley, surrounded by mountains, beech and oak forests.

One of the residents of the villages, had the idea of taking advantage of the existing resources seeking to (i) use the local biomass, (ii) reactivation of the rural environment, (iii) generation of local employment, (iv) reduction of carbon dioxide emissions. In order to achieve these goals, the decision focused on the creation of a small district heating to supply sanitary hot water and heating through micro heating networks in the municipality (all the houses), optimising the performance of these common systems with respect to the individual ones, generating local work and contributing to cleaning the forest, with all that this implies in terms of fire prevention.

In 2013, the installation and undergrounding of networks was undertaken (Figure 6) and the appropriate tests were carried out prior to paving. Two biomass boilers of 200 kW each, were installed with an accumulation vessel of 5.000 liters. For this installation, 300 t/y of local forestry biomass was consumed (with an average of 35-45 % of moisture) and stored in the village.

Figure 6. Civil engineering carried out to develop the district network in Sabando.

Regarding the economic data, the investment reached 582.128 €, with 80 % funded by the Basque Government and 20 % by the Sabando Administrative Board. Furthermore, the inhabitants had to pay 1,000 € for connecting to the district network and 300 € for maintenance. As a result, the final price of kWh_{th} was at 0.025 €/ kWh_{th}. Taking into account these data, the annual savings obtained were around 40 % per habitant, the average heating cost was of around 2,500 €/year (using heating oil) and now is around 1,500 €/year (with the DH, and taking into account the heating but also the hot water).

This information was obtained from Promobiomasse Interreg project [8] and REHAU [9].

8. Conclusions

This catalogue intends to provide the user with a better idea of what a district heating is, the information that should be retrieved in order to carry out an economic assessment such as the energy demands of the building to be covered by the DH, how to assess the power of the installation, the amount of biomass needed, and how to calculate the economic profitability based on simple equations. Additionally, it provides a guideline of the common steps to be followed and the group of stakeholders than can provide support if necessary.

Taking into account all this information, this report can serve as general guidelines/ handbook for a stakeholder willing to promote a district heating unit, but who lacks of technical knowledge or a general overview of the steps that need to be followed prior to investing.

9. References

[1] Climatización Urbana en las Ciudades Españolas. Red Española de Ciudades por el Clima.

[2] https://www.efidistrict.eu/en/new-district-heating-network/application-to-district-heating-systems/

[3] WEDistrict H2020 Project (857801). D3.12: technologies for DHCs (2021)

[4] https://tradingeconomics.com/commodity/carbon

[5] Danish Energy Agency, "Technology Data for Energy Plants Updated chapters," Danish Energy Agency, 2016.

[6] Bioenergy Europe Statistical Report 2020

[7] uP_running (691748): Take-off for sustainable supply of woody biomass from agrarian pruning and plantation removal, D6.3: Flagship success cases update v1, Annex II: Vineyards4heat flagship report, 2017

[8] Promobiomasse Interreg project. https://promobiomasse.eu/tag/plan-de-gestion/.

[9] REHAU. https://www.rehau.com/es-es/pueblo-de-bioenergia-en-sabando-alava.

Annex III: Technical catalogue on biomass co-generation for small scale applications

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].

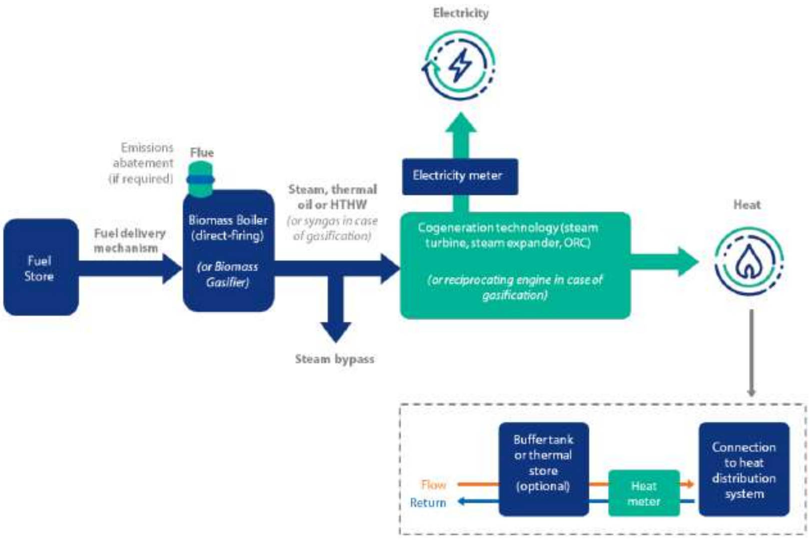


Figure 1: Typical biomass CHP components [1]

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].

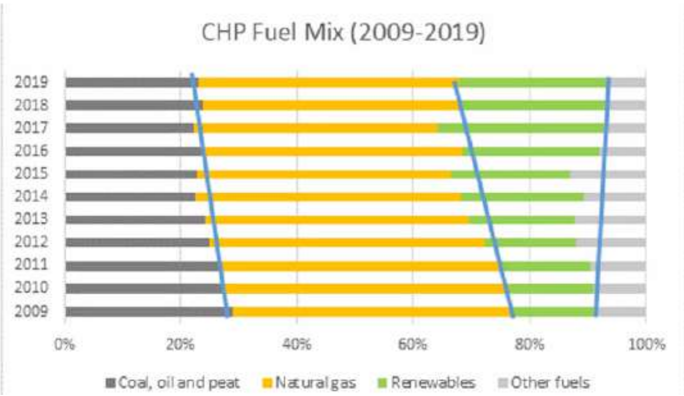


Figure 3: CHP Fuel mix in EU-27 [2]. Data based on Eurostat (2021)

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.

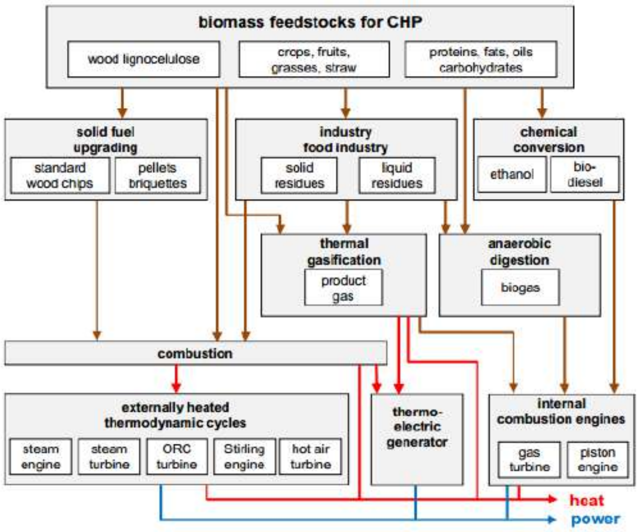


Figure 4: Most relevant paths of biomass feedstocks for CHP [9]

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 1 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 1: 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].

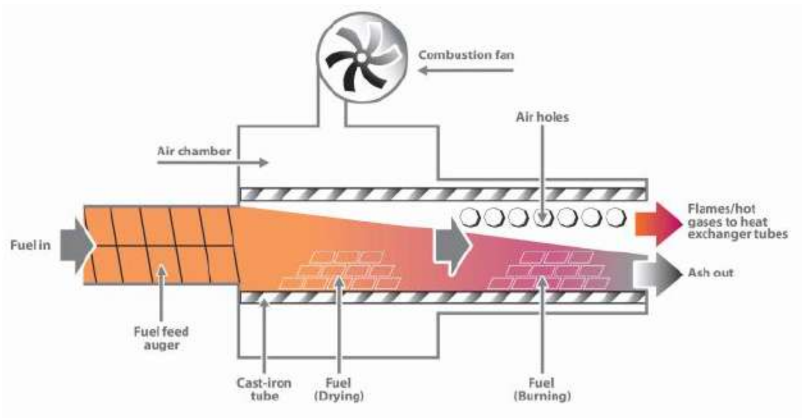


Figure 5: Fixed grate boiler [13]

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.

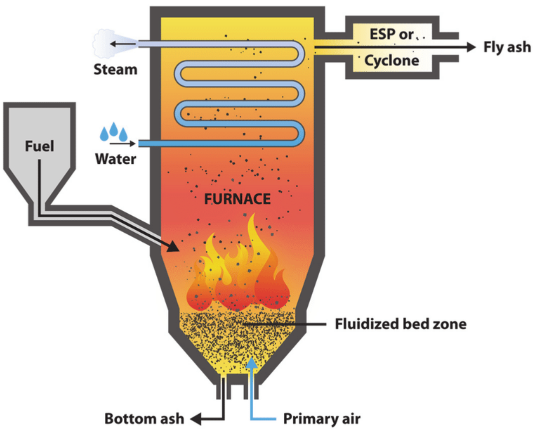


Figure 6: Fluidized bed boiler [14]

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].

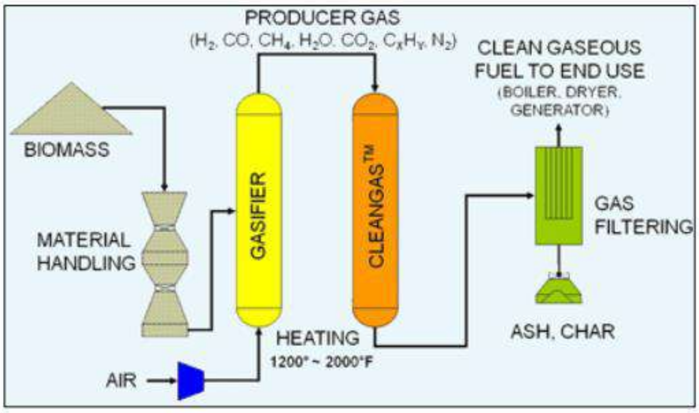


Figure 7: Example of two-stage gasification [16]

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 **Error! Reference source not found.**. 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].

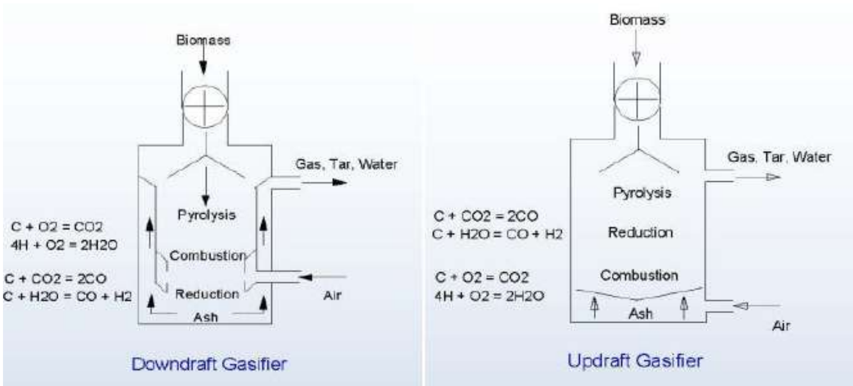


Figure 8: Fixed-bed gasification systems [17]

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].

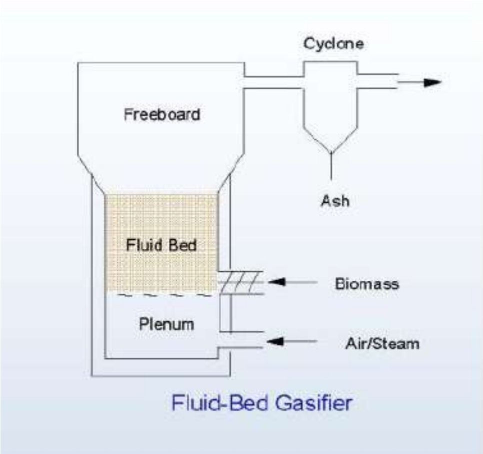


Figure 9: Fluidized-bed gasification systems [17]

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].

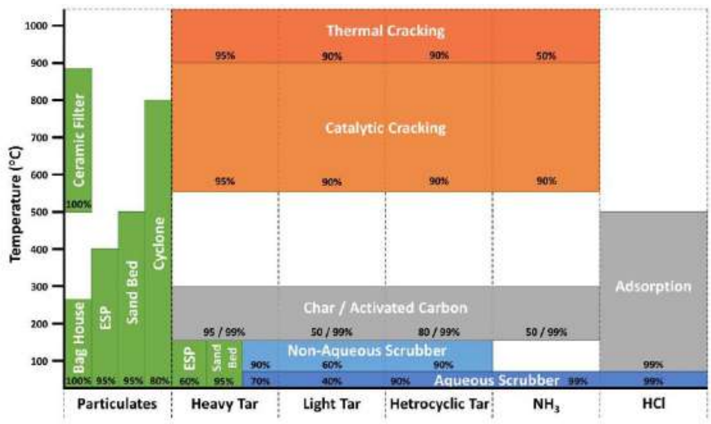


Figure 10: Syngas cleaning technologies including their applicable temperature range and efficiencies [23]

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].

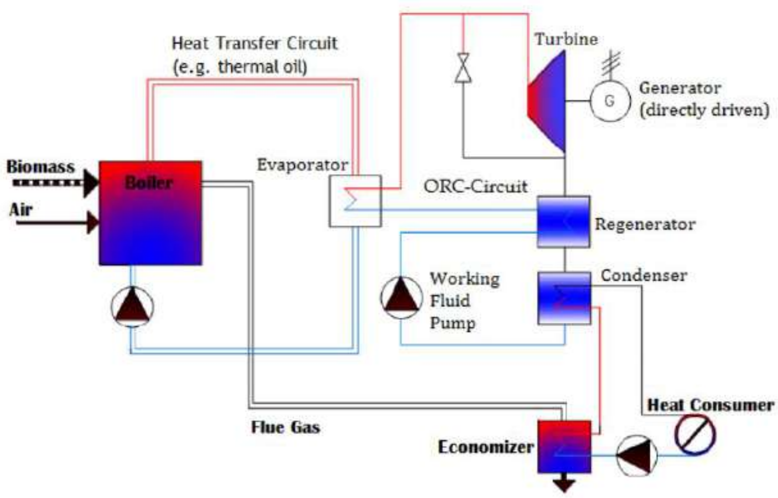


Figure 11: ORC process scheme [26]

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].

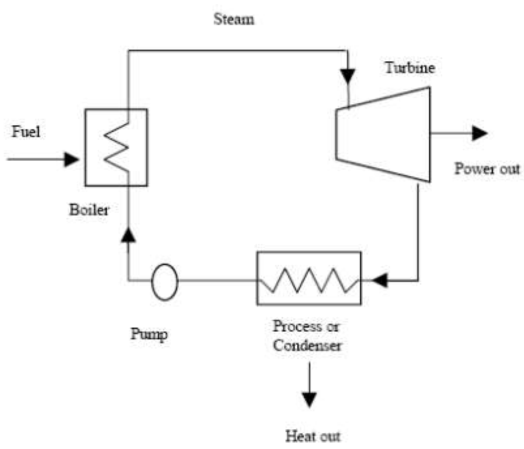


Figure 12: Steam turbine CHP system [27]

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].

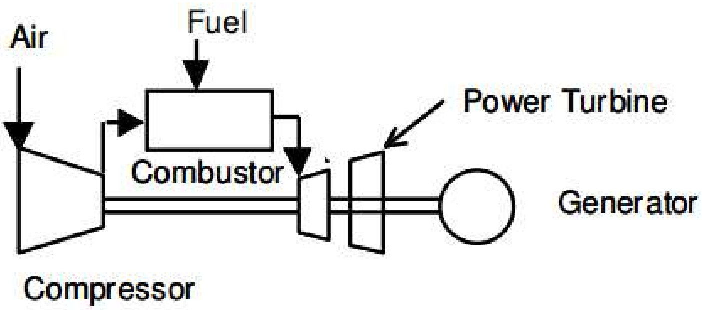


Figure 13: Components of simple-cycle gas turbine [28]

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].

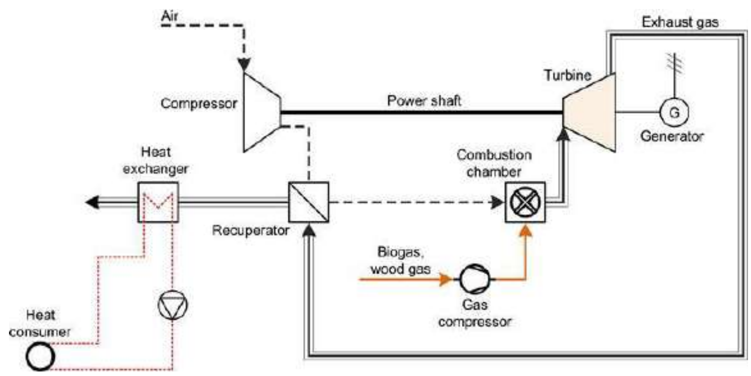


Figure 14: Microturbine-Based CHP System [30]

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].

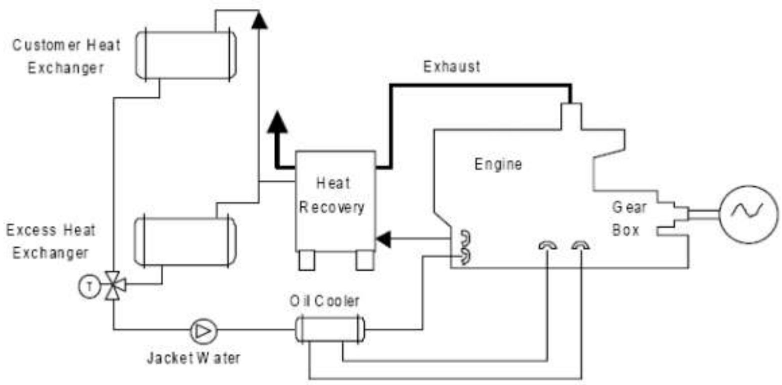


Figure 15: Closed-Loop Heat Recovery System for a Reciprocating IC Engine [27]

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 by-product. 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].

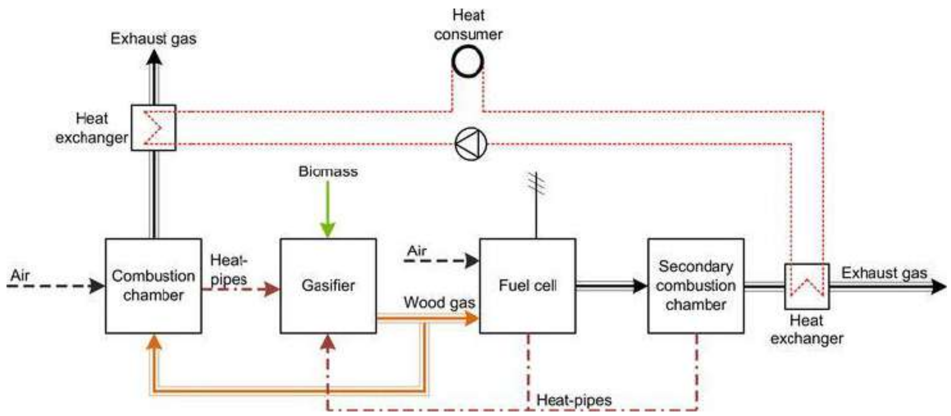


Figure 16: System diagram for a biomass CHP unit with fuel cell [29]

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].

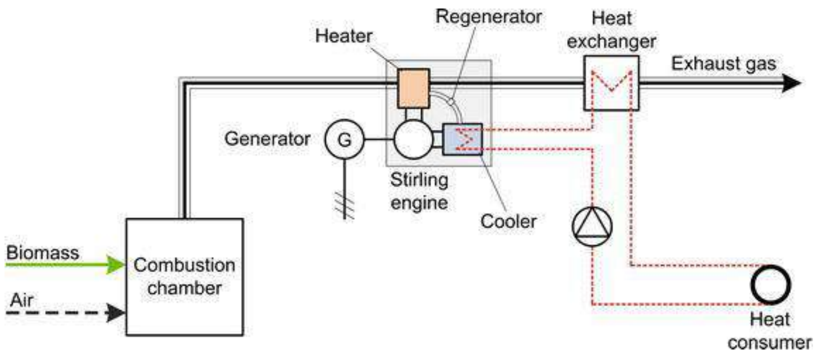


Figure 17: System diagram for a biomass CHP unit with a stirling engine [32]

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.

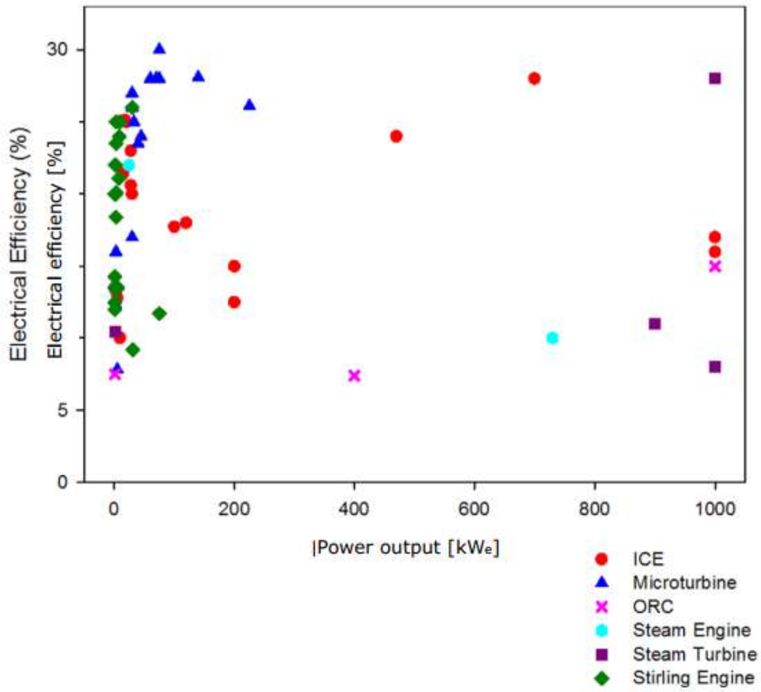


Figure 18: Electrical efficiencies of biomass conversion technologies based on power output [15]

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[18]. 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

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

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 2 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.

Table 2: 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%

Characteristic	CHP technology					
	Steam Turbine	Gas/ Combustion Turbine	Micro turbine	Reciprocating IC Engine	Fuel Cell	Stirling Engine
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
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[19] 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[20] (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[21]), the Energy

[19] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32004L0008
[20] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=celex:32012L0027
[21] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32018L2001

Performance of Buildings Directive (EPBD 2010/31/EU[22]) and the Ecodesign Directive (also referred as Energy related products/ ErP 2009/125/EC[23]).

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 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[24]) 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

[22] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02010L0031-20210101
[23] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02009L0125-20121204
[24] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32015L2193

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.

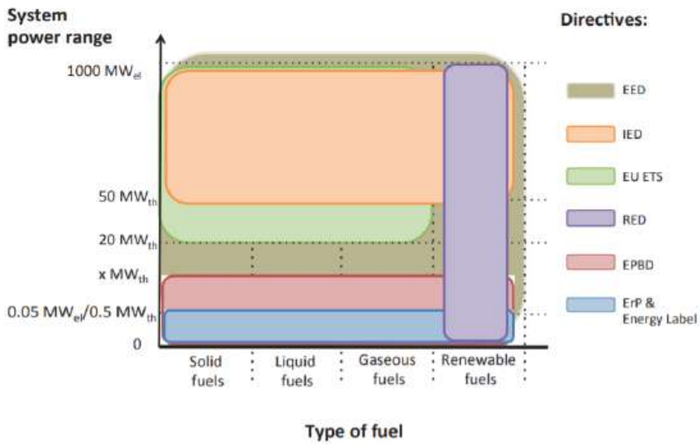


Figure 19: EU policies relevant for CHP based on fuel type and nominal power range [42]

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 2) 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.

6.1Volter 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.

8.References

[1] Sustainable Energy Authority of Ireland, Biomass CHP: Implementation Guide, (2020). https://e-rational.net/applications/biomass-chp.html.

[2] COGEN Europe, "Cogeneration in the Fit for 55 strategy" from webinar: Biomass CHP in the clean energy transition, organized by BIOCOGEN 2030, (2021).

[3] European Commission, EU energy statistical pocketbook and country datasheets, (2019). https://ec.europa.eu/energy/data-analysis/energy-statistical-pocketbook_en?redir=1.

[4] Eurostat, Combined Heat and Power (CHP) data 2005-2019, (n.d.). https://ec.europa.eu/eurostat/web/energy/data.

[5] SmartCHP H2020 project (815259), D6.1 Market Assessment, (2019).

[6] I. Obernberger, A. Hammerschmid, M. Forstinger, Techno-economic evaluation of selected decentralised CHP applications based on biomass combustion with steam turbine and ORC processes, IEA Bioenergy Task 32 Proj. (2015) 1–75. http://task32.ieabioenergy.com/iea-publications.

[7] ETIP Bioenergy European Technology and Innovation Plattform, Biofuel fact sheet, Biomass CHP facilities, (2018) 1–3. http://www.etipbioenergy.eu/images/ETIP_Bioenergy_Factsheet_Biomass_CHP_facilities.pdf.

[8] E. Elsarrag, Y. Alhorr, Green building practices: Optimisation of CCHP and biomass heating for maximum CO2 reduction in a mixed-use development, Int. J. Sustain. Built Environ. 2 (2013) 99–108. https://doi.org/https://doi.org/10.1016/j.ijsbe.2013.11.003.

[9] ETIP Bioenergy European Technology and Innovation Plattform, Biofuel fact sheet, Biomass CHP facilities, (2018) 1–3.

[10] R. Padinger, S. Aigenbauer, C. Schmidl, J.D. Bentzen, Best practise report on decentralized biomass fired CHP plants and status of biomass fired small-and micro scale CHP technologies, IEA Bioenergy. 32 (2019) 1–83.

[11] IEA-ETSAP and IRENA, Biomass for heat and power, (2015).

[12] AgroBioHeat H2020 project (818369), D4.2: Agrobiomass fuels and utilization systems, (2020).

[13] Sustainable Energy Authority of Ireland, Biomass Boilers - Technology Guide, (2019) 1–14. https://www.seai.ie/publications/Biomass-Boilers-Technology-Guide.pdf.

[14] J. Yliniemi, Alkali activation-granulation of fluidized bed combustion fly ashes, 2017.

[15] U. S. Environmental Protection Agency, Biomass Combined Heat and Power Catalog of Technologies, Biomass. (2007) 122. http://www.epa.gov/chp/documents/biomass_chp_catalog_part1.pdf.

[16] D. Peterson, S. Haase, Market Assessment of Biomass Gasification and Combustion Technology for Small- and Medium-Scale Applications Market Assessment of Biomass Gasification and Combustion Technology for Small- and Medium-Scale Applications, Contract. (2009).

[17] R. Bain, "Biomass Gasification Presentation." Presented at the USDA Thermochemical Conversion Workshop. NREL Biorefinery Analysis and Exploratory Research Group, in: 2006.

[18] T.B. Reed, A. Das, Handbook of Biomass Downdraft Gasifier Engine Systems, SERI . U.S. Dep. Energy. (1988) 148.

[19] T.A. Milne, R.J. Evans, N. Abatzaglou, Biomass Gasifier "'Tars'": Their Nature, Formation, and

Conversion, United States, 1998. https://doi.org/10.2172/3726.

[20] M. Asadullah, Biomass gasification gas cleaning for downstream applications: A comparative critical review, Renew. Sustain. Energy Rev. 40 (2014) 118–132. https://doi.org/10.1016/J.RSER.2014.07.132.

[21] M. Baratieri, P. Baggio, B. Bosio, M. Grigiante, G.A. Longo, The use of biomass syngas in IC engines and CCGT plants: A comparative analysis, Appl. Therm. Eng. 29 (2009) 3309–3318. https://doi.org/10.1016/J.APPLTHERMALENG.2009.05.003.

[22] P. Hasler, T. Nussbaumer, Gas cleaning for IC engine applications from fixed bed biomass gasification, Biomass and Bioenergy. 16 (1999) 385–395. https://doi.org/10.1016/S0961-9534(99)00018-5.

[23] J. Butler, J. Littlejohns, L. Luque, M. Hernandez, W. Skrivan, Handbook for Small Biomass Gasification CHP in Canada Hazard Mitigation, Emissions and the Regulatory Landscape for Small Scale Biomass Gasification Combined Heat and Power Systems, (2018).

[24] Mühlstein Jan, Mühlstein Jan; Unternehmen – SteamCell geht Dampf aus; Energie & Management GmbH; 25.11.2005, (n.d.). https://www.energie-und-management.de/free-archive/feview3/10901.

[25] Mühlstein Jan, Mühlstein Jan; Unternehmen – SteamCell geht Dampf aus; Energie & Management GmbH; 25.11.2005, (n.d.).

[26] G. Zweiler, R.; Doczekal, Ch.; Paar, K.; Peischl, Energetisch und wirtschaftlich optimierte Biomasse-Kraft-Wärmekopplungssysteme auf Basis derzeit verfügbarer Technologien – Endbericht; Projektnr. 812771; 2. Ausschreibung Energie der Zukunft; Bundesministerium für Verkehr, Innovation und Technologie (BMV, (n.d.).

[27] U.S. Environmental Protection Agency, Catalog of CHP Technologies, 2004. www.epa.gov/chp/documents/catalog_of_ chp_tech_entire.pdf.

[28] I. Energy and Environmental Analysis, Gas-Fired Distributed Generation Technology Characterization: Microturbines, (2003).

[29] D. Büchner, V. Lenz, Biomass Energy Small-Scale Combined Heat and Power Systems BT - Renewable Energy Systems, in: M. Kaltschmitt, N.J. Themelis, L.Y. Bronicki, L. Söder, L.A. Vega (Eds.), Springer New York, New York, NY, 2013: pp. 432–458. https://doi.org/10.1007/978-1-4614-5820-3_249.

[30] Thimsen D, IR250 Micro-turbine case study – technical update. Electric Power Research Institute, Palo Alto, CA, (2008).

[31] Resource Dynamics Corporation, Combined Heat and Power Market Potential for Opportunity Fuels, (2004).

[32] H.H. Kaltschmitt M, Hartmann H, Energie aus Biomasse: Grundlagen, Techniken und Verfahren. 2. Auflage. Springer, Berlin, (2009).

[33] I.J. Fischer, Technologies for small scale biomass CHP – plants – an actual survey, 2003. http://www.risoe.dk/rispubl/presentations/%0Afischer.pdf.

[34] D. Pritchard, Biomass Combustion Gas Turbine CHP, 2002. http://www.dti.gov.uk/files/file14922.pdf.

[35] H. Kopetz, Present Development in Small Scale Combined Heat and Power (CHP), n.d. http://www.svebio.se/attachments/33/293.pdf.

[36] P.A. K. Sipila, E. Pursiheimo, S. Tuula, C.J. Fogelholm, I. Keppo, Small-Scale Biomass CHP Plant

and District Heating, 2005.

[37] A.D. Hawkes, M.A. Leach, Cost-effective operating strategy for residential micro-combined heat and power, Energy. 32 (2007) 711–723. https://doi.org/10.1016/j.energy.2006.06.001.

[38] L. Dong, H. Liu, S. Riffat, Development of small-scale and micro-scale biomass-fuelled CHP systems - A literature review, Appl. Therm. Eng. 29 (2009) 2119–2126. https://doi.org/10.1016/j.applthermaleng.2008.12.004.

[39] CPC, (n.d.). http://www.gocpc.com.

[40] A. Malmquist, Swedish Micro-CHP Solution – Externally Fired Microturbine System, n.d. http://www.svebio.se/attachments/33/306.pdf.

[41] ÖkoFEN, Pellematic Smart_e 0.6, Electricity and heat for single family homes, n.d. https://stroomop.eu/data/documents/okofenefolderen.pdf.

[42] W. Götz, Thomas ; Saurat, Mathieu ; Tholen, Lena ; Adisorn, Thomas ; Obernberger, Ingwald ; Brunner, Thomas ; Kerschbaum, Michael ; Purushothaman Vellayani, Aravind ; Makkus, Robert ; Megel, Stefan ; Hauth, Martin ; Zappa, Green on-site power generation : environmental considerations on small-scale biomass gasifier fuel-cell CHP systems for the residential sector, Proc. 9th Int. Conf. Energy Effic. Domest. Appliances Light. (EEDAL '17). (2017) 909–921. https://doi.org/10.2760/113534.

[43] U.S.E.P.A. EPA, CHP Benefits, (n.d.). https://www.epa.gov/chp/chp-benefits.

[44] RED II (Renewable Energy Directive) 2018/2001/EU, (2018). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC.

[45] COGEN Europe, Delta Energy & Environment, The benefits of micro-CHP, (2016) 24.

[46] A. Proka, M. Hisschemöller, E. Papyrakis, The scale of transition: an integrated study of the performance of CHP biomass plants in the Netherlands, J. Integr. Environ. Sci. 11 (2014) 225–241. https://doi.org/10.1080/1943815X.2014.966113.

[47] Volter, Datasheet of Volter 40 Indoor, (n.d.). http://www.bkvab.se/downloads/Volter 40 Indoor_Datasheet.pdf.

[48] Anton Gissek, OPERATIONAL ENVIRONMENT FOR BIOMASS-BASED SMALL-SCALE CHP UNIT, Lappeenranta University of Technology, 2017.

[49] Small-scale CHP Life+ Project, Emå Dairy Lessons learned Factsheet, (n.d.).

[50] College on tap to receive gasifier, article on WhiteHorse Daily Star, Canada, (n.d.). https://www.whitehorsestar.com/News/college-on-tap-to-receive-gasifier.

Annex IV: Technical catalogue on biogas plants

1.Introduction

Biogas production plants are the match between bioenergy production and waste management strategies, where organic waste streams or feedstocks undergo anaerobic digestion (biochemical reactions of microbial metabolism) to be transformed into biogas and other added-value by-products, contributing in an increasing degree of decarbonization through circular economy perspective. Biogas is a gaseous mixture mainly composed by methane (CH_4) and carbon dioxide (CO_2) which exhibits good heating values and potential to stablish renewable substitute to conventional natural gas when upgraded to enhance its methane content and injected to the grid. It can also supply electricity and heat when used along with co-generation units. Due to its production, biogas generation facilities offer great opportunities for rural and country-side areas as well as for small-scale and self-consume energy production, thus suiting energy communities visions. Taking into account the BECoop audience (residential sector), these consumers could be municipalities, farmers, food-processing companies, community of neighbours, houses, swimming pools, local business, nursing home, hospitals, etc.

This specific catalogue will be focused on biogas production plant facilities, highlighting its main elements, CAPEX and OPEX trends, features, and profitability, as well as a brief roadmap for its assessment. To assess this goal, the information that can be found in this report are the following.

- A general overview of what an anaerobic digestion is in order to guarantee that this is the project that you want to promote.
- Technical considerations that should be known before contacting with stakeholders that can help you to develop your initiative. It should be known the main elements of the biogas plant, the information necessary to assess the power of the biogas plant, and the operational and maintenance requirements for this type of installation.
- Although, the best option (if you don´t have technical experience) is that an expert carried out a feasibility study, the point 4 explains how to assess a first estimation of the economic profitability of a biogas facility, but as indicated, this is just a starting point and then needs to be studied in more detail by an expert. Also, environmental and social benefits are mentioned in point 5.
- The point 6 indicates the group of stakeholders that can help you in the development of your initiative, and what kind of activities can be expected for each group of stakeholders. Not all of the stakeholders should be involved to develop a biogas production plant, it will depend of each particular case according to your necessities.
- The point 7 gives the general steps that should be carried out from the idea to the final implementations, with suggested stakeholders that can provide support if needed.
- Finally, some success cases are mentioned to provide some real examples of biogas plants owned by energy communities that are properly working or successful projects.

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.Anaerobic digestion concept

The concept of "anaerobic digestion" is related to the compilation of biochemical reaction (methane fermentation) that bacteria and several microorganisms carry out to degrade organic matter into simpler compounds and by-products for its metabolism [1]

Organic matter is decomposed into two different main fractions: a gaseous phase named **biogas** and a solid phase named **digestate**. Both fractions have been reported to offer various applications and both material and energetical valorisation as shown in Figure 1.

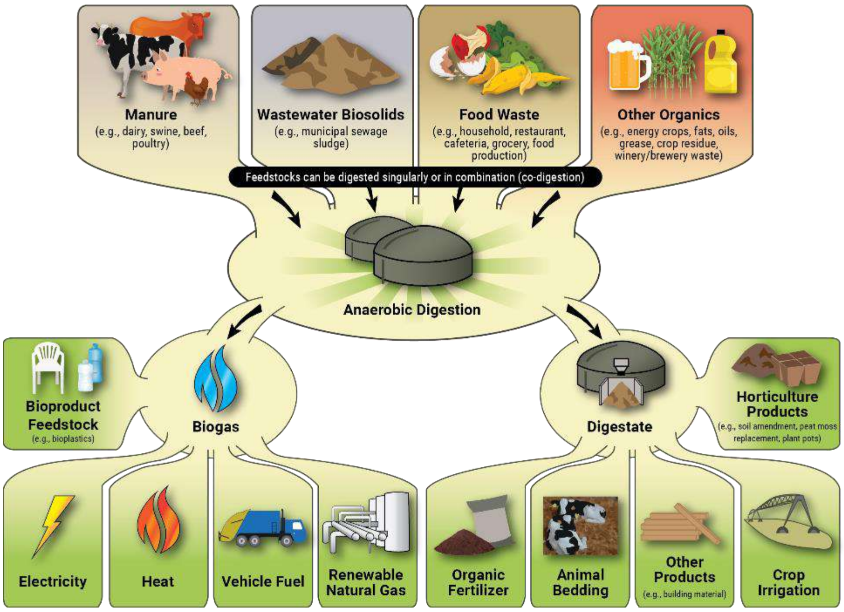


*Figure 1: Anaerobic Digestion for waste valorisation. Source: EPA, **[2]***

Biogas is a mixture of gases like natural gas which exhibits high heating values ranging 16-28 MJ/m^3. Methane (CH_4) is the main compound with near 45-75% share of overall biogas content, whilst carbon dioxide is the second main product holding a 20-30% share. Carbon monoxide, hydrogen sulfide and other trace compounds/elements are also found in biogas.

Because of its similarities with natural gas, biogas thus shows great potential to directly substitute natural gas as an environmental-friendly fuel solution for heating and co-generation applications. On the other hand, biogas production also offers a promising opportunity for waste valorisation, landfill management and processes decarbonization. Table 1 shows main similarities between biogas and natural gas properties.

*Table 1: Biogas and natural gas properties comparison **[1,3–5]***

Components	Units	Natural gas	Standard Biogas
CH_4	% vol.	70-90	45-75
CO_2	% vol.	0-8	47-25
N_2	% vol.	4-0	3-0

O_2	% vol.	0	< 0.5
H_2S	mg/m^3	2-20	3,000-10,000
NH_3	mg/m^3	-	50-100
HHV	kWh/m^3	11.3	6.6-7.5
Density	kg/m3	0.85-0.93	1.15-1.25

Biogas production enables efficient energy recovery from organic waste streams generated by domestic and/or industrial processes, producing carbon-neutral fuels that can be used to generate heat and/or electricity in facilities. Biogas is particularly promising as an energy solution for communities, as it allows for direct valorisation of community biomass waste streams.

Biogas production facilities may not be economically feasible unless they undergo a thorough assessment. The processes that involve biological reactions and microorganism, are susceptible to suffer from various difficulties, such as unaffordable capital expenditures and technical barriers that may hinder the techno-economic viability. Furthermore, while anaerobic digestion parameters can be optimized to maximize biogas potential within feedstocks, the supply of biomass may be subject to intermittent availability throughout the year or changes in chemical composition over time. In consequence, biogas production performances are usually very sensitive to feedstock (batch) changes, hindering its viability. As result, it is important to assess the supply chain, as well as the biomass providers and storage units, when proposing a project.

The use of biomass, waste streams and biogas facilities installation enable the use of autochthonous and renewable energy resources while contributing to create local employment in the municipalities where the valorisation initiative is implemented. From an economic perspective, organic waste streams usually have a lower price than conventional fuels and, additionally, environmental benefit derived in terms of forest cleaning, contributing to reduce forest fire risk, prevention of open-fires (as for instance of agricultural pruning) and the reduction of CO_2 emissions, due to the substitution of conventional fuels by biomass.

From the users' point of view, biogas production facilities could offer economic and technical benefits. It could contribute to reducing fossil fuel dependence, local energy safety, raising energy savings as well as solving domestic and industrial waste management issues.

3.Technical considerations

3.1 Main elements of a biogas production facility

The main goal of this chapter is to provide a general overview of the main technical elements of a biogas production plant in order to facilitate the conversation and the agreements with the energy service/engineering company in charge of the design and development of the installation. The main elements to consider are:

- Feedstock: The feedstock is the organic material that is fed into the biogas plant. It can be a variety of organic materials, such as agricultural waste, food waste, and animal manure.

- Anaerobic digester: The anaerobic digester is the main vessel where the anaerobic digestion process takes place under controlled conditions. It is a sealed tank that is designed to create an environment where microorganisms can break down the organic matter and produce biogas.
- Storage or Gas holder unit: The gas holder is a tank that stores the biogas produced by the anaerobic digester. It is designed to hold the gas at a constant pressure so that it can be used as a fuel whenever there is a high energy demand.
- Sludge treatment: The sludge treatment system is used to process the sludge that is produced as a by product of the anaerobic digestion process. The sludge is treated and stabilized, and then it can be used as an organic fertilizer or a soil conditioner.
- Upgrading unit: Such as gas scrubber units, devices that removes impurities from the biogas, such as hydrogen sulphide and moisture.
- CHP unit: The gas engine is a device that converts the biogas into electricity and heat. It is typically fuelled by natural gas or propane, but it can also be fuelled by biogas.
- Control and management of biogas plant.

3.2 Biogas plant

Biogas plant main features different elements to perform acceptable production efficiencies. When establishing the technical requirements to be met by the installation to optimise its production, it is important not to focus only on the digester unit, but also on the entire biomass and biogas storage system as well as the further biogas application since many times it is where the greatest source of oversizing issues.

3.2.1 Biomass storage

The properties, nature, and mass flow of the feedstock are key parameters for the proper operation of biogas plants. For this reason, it is essential to ensure a continuous, safe, and homogenous supply. One way to address this issue is through biomass storage, which can provide a direct solution. More information about feedstock's importance will be assessed on following sections.

Next to the biogas plant, it is essential to have enough space to store at least the amount of material necessary to regularly supply the digester needs. Indeed, the storage technology will depend on biomass' properties, especially its water contents. In biogas applications, target biomass is usually with a high moisture content, as livestock manure. Hence, wet storage systems are commonly employed. However, special measures must be ensured with storage times control, as possible fermentation and excessive degradations could take place, reducing its biogas potential. On the other hand, dry biomass must be protected from combustion and decomposition effects (see Figure 2).

Anyway, the cost of storage is also one important parameter to assess the overall economic viability of the plant. Additionally, the storage is often necessary due to stationary characteristic on the feedstock or to avoid any possible intermittence of supply during the year.

Figure 2: Biomass storage options for different types of biomass: Solid crop waste (top left), sludge (top right) and liquid live stock (bottom)

In conclusion, biomass storage units may be assessed to protect the biogas production from uncontrollable or seasonal issues, but its required investment may increase with capacity, for that reason a proper size must be estimated.

The volume of the storage area will be defined considering the following aspects:

- Amount of biomass to be stored, where it has to be considered the self-sufficient target of the plant for a certain period of time.
- Bulk density of the biomass to be stored, which depends on the biomass selected and the size distribution of this biomass.
- Average consumption of biomass per day. For this, digester retention times must be assessed.

Taking into account the previous considerations, the approximate storage area can be calculated by means of the following formula:

$$\text{Usable volume needed} = \frac{\text{consumption of biomass per day} \left(\frac{\text{kg}}{\text{day}}\right) \times \text{ number of days to be self} - \text{sufficient (days)}}{\text{bulk density of the biomass} \left(\frac{\text{kg}}{m^3}\right)}$$

Even though, the final surface needed will depend upon the equipment selected for biomass storage. This final decision must be made by the energy services company that carries out the installation, considering the final location of the generation plant, the biomass selected and the available space.

3.2.2 Digester

The digester represents the core of the biogas production plant. It is the main unit where biochemical anaerobic digestion processes take place, which involves the action of different microorganisms that decompose and break down the organic matter (in an oxygen-free atmosphere) to produce methane (CH_4) and carbon dioxide (CO_2) as primary products and main components in biogas. Furthermore, solid residue is also obtained - commonly named digestate - which can offer several further applications. The configuration of a digester, which is essentially a chemical reactor, depends on the feedstock and operation conditions, and can impact the particular purposes for which the produced biogas is used [6]

One of the most important parameters for digester operation regards its temperature. As anaerobic digestion comprehends a multi-step and multi-phase biological reaction system, biogas production is greatly dependent upon temperature. Two main broad categories of methanogens bacteria are found: Medium-temperature, mostly identified as **mesophilic**, which thrive anaerobic digestion between 30-38ºC; and high temperature bacteria, mostly known as **thermophilic**, which find optimum gas-producing temperatures ranging 49-57ºC. Furthermore, there are recent studies suggesting that psychrophilic bacteria operating in a temperature range of 5-15 ºC can bring an efficient as well as an economically positive imprint on the anaerobic digestion processes [7].

Moreover, different configurations design can be found in Figure 3, highlighting their main features:

- **Batch technologies:** These are the most common and simple ones, often used for small-scale plants. It is the most economical option as its construction and operation is simpler, able to suit different type of feedstocks. However, it is also the least sophisticated one. Batch digester usually need of mechanical mixing and lacks proper control of fermentation process, thus yielding lower biogas rates. Regarding its operation, feedstocks are introduced at the beginning into the reactor and remains closed for the overall duration of digestion process.
- **Plug flow technologies:** These types of digesters are usually long tube tanks in which waste flows through. They are typically used for industrial and large-scale, as they are highly efficient regarding biogas production yield, but its construction is quite complex, thus requiring high initial investments.
- **Complete mix:** Enclosed heated tanks with mechanical or gas mixing systems that are more suitable for highly wet feedstocks.
- **Hybrids:** There are also some hybrid technologies that combine features from both batch or continuous digester reactor, making them suitable for wider ranges of applications, but they still may require skilled operators and higher maintenance costs.

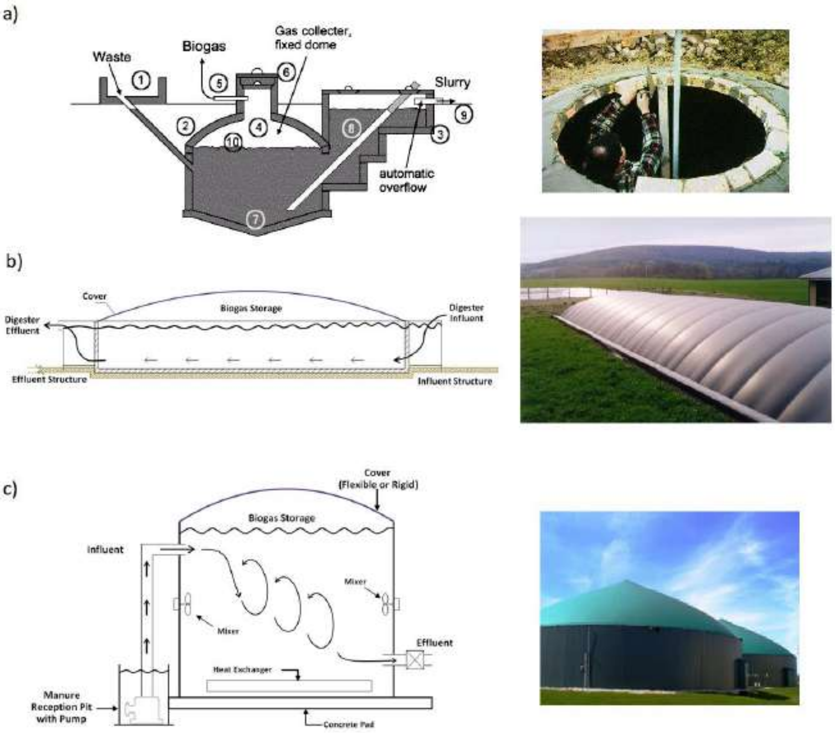


Figure 3: Biogas digester main technologies: a) Batch overflowing digester b) Plug-flow digester c) Gas mixing system digester. Source: U.S. Environmental Protection Agency

Table 2 summarizes the main features of most common digesters.

Table 2: Main digester operational features and characteristics [6]

Factors	Fixed dome	Floating drum	Tubular design	Plastic containers
Gas storage	Internal Gas storage up to 20 m³ (large)	Internal Gas storage drum size (small)	Internal eventually external plastic bags	Internal Gas storage drum sizes (small)
Gas pressure	Between 60 and 120 mbar	Up to 20 mbar	Low, around 2 mbar	Low around 2mbar
Skills of contractor	High	High	Medium	Low
Availability of Material	yes	yes	yes	yes
Durability	Very high >20 years	High; drum is weakness	Medium; Depending on chosen liner	Medium
Agitation	Self agitated by Biogas pressure	Manual steering	Not possible; plug flow type	Evtl Manual steering
Sizing	6 to 124 m³ digester vol	Up to 20 m³	Combination possible	Up to 6 m³ digester vol
Methane emission	High	Medium	Low	Medium

It is important to carefully consider the main purpose of biogas application, as well as the daily amount of biomass entering the process and the acceptable range of biogas yield. These factors are key to estimating the sizes of other units, such as biogas storage and use facilities, and should be taken into account by both the constructor and the designer.

3.2.3 Biogas storage units

After anaerobic digestion, the produced biogas will likely be stored in the short or medium term for further application. This may include direct use for on-site cogeneration or transport to an off-site application or distribution point.

The storage tank for biogas can either be located inside the digester or downstream as an independent unit. Additionally, it is important to consider the pressure ranges for the storage system, which will depend on the expected production outcome and storage needs [8]:

- Low-pressure Biogas Storage: The most common are flexible membrane materials which offer the least trouble with H_2S corrosion under less than 2 psi pressure (Figure 4).

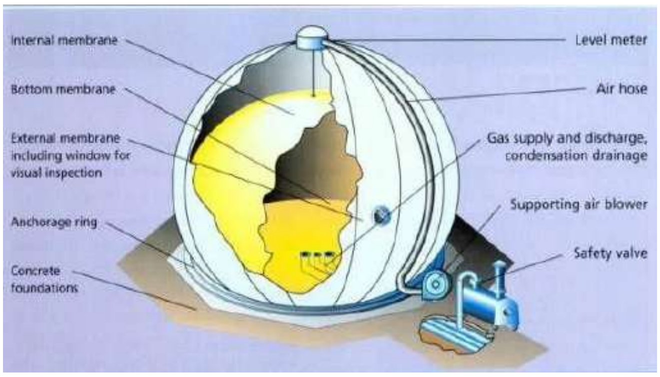


Figure 4: Low pressure storage system. Source: BioEnergy Consult [4]

- Medium-pressure Biogas Storage: Prior to its storage, biogas should be cleaned and compressed to assess these types of units and to ensure operation and avoid corrosion In this case biogas is stored in 2 – 200 psi pressure range.
- High-pressure Biogas Storage: This type of unit is mostly assessed for higher applications as biogas upgrading and biomethane off-site uses, where biomethane must be compressed or liquefied to save space and facilitate its further transportation. The gas is stored in steel cylinders or bottles as for other commercial gases. Storage facilities must be adequately fitted with safety devices such as rupture disks and pressure relief valves. Pressure is compressed between 2,000 and 5,000 psi, which cost is much greater than other storage units (Figure 5).

Figure 5: High pressure biogas storage system. Source: AtmosPower Pvt. Ltd. [9]

3.2.4 Sludge Treatment

Sludge treatment refers to the processes that involve the treatment of solid by-products of anaerobic digestion. With these, different purposes might be considered, as simply as its volume reduction, weight, or toxicity. As expected, the treatment will be different depending on the characteristics of the sludge, the desired end-product and the available possibilities. Summing-up, the purposes for sludge (or digestate) semi solid by-product are:

- Volume reduction: easing transport, handling or storing.
- Pathogen reduction: the disposal of anaerobic digestion sludge increases risks for health due to elevated potentials of pathogens, thus its treatment is mandatory to reduce those risk when disposed or handled.
- Nutrient recovery: sludge or "digestate" is a promising strategy for recovering phosphorus and nitrogen inorganic compounds, which can be potentially used as fertilizers. In fact, currently most potential application of digestate pathway is its processing as fertilizer or soil amendment.
- Energy recovery: as any other end-waste, sludge and digestate can be energetically valorised by incineration to produce heat and electricity when coupled to a combined cycle plant.

Figure 6 shows various strategies and treatment methods that can be taken into account for the sludge treatment. While composting is currently the preferred method for converting digestates into a soil amendment product that benefits soil structure, other less effective methods focus on decreasing the amount of digestate generated rather than producing valuable by products. Drying and thickening digestate streams are simpler and more cost-effective ways to reduce the volume of solid or liquid digestate after anaerobic digestion, making it easier to dispose of. Lastly, the least efficient and ecological route followed by biogas producers is incineration of residual digestate streams. However, it is still the most common pathway after biogas production when no market or further application is assessed.

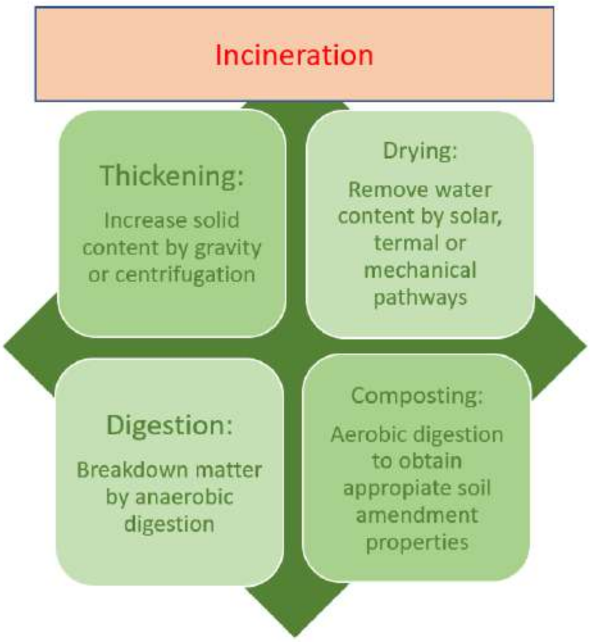


Figure 6: Anaerobic digestion sludge by-product treatment strategies

3.2.5 Biogas use: Boiler, CHP or upgrading unit

After production, biogas may be converted into other useful forms of energy as heat, electricity or upgraded into biomethane to applicate as natural gas substituent. The design of a biogas production plant should take into consideration the intended application of the produced biogas prior to construction, in order to ensure that all necessary units are incorporated into the design. For this, different units and strategies for valorisation are considered:

- **Combustion engine**: Most direct biogas application is as fuel for combustion engines or boilers with the goal of producing heat, mechanical power for any vehicle or equipment, or electricity when integrated into CHP unit (for more information about CH units, you can consult the BECoop technical catalogue "co-generation").
- **Upgrading units:** Some upgrading units can convert biogas into biomethane by removing impurities as sulphur compounds and CO_2 and adding hydrogen. This biomethane can be injected into natural gas grid and sold as renewable fuel.
- **Fuel cell:** Biogas can be used as a fuel source for fuel cells, which convert the chemical energy of the gas into electricity through an electrochemical process. This application is rarer than the previous ones explained, as its economic feasibility remains much lower.

3.2.6 Control and management of biogas plants

The main objective of controlling a biogas plant is to regulate the generation of biogas, the feedstock stream fed into the digester, and the distribution, application, or storage of the produced biogas. Another important variable to regulate is the control operating temperatures, digestion retention times and/or pressures, which is usually based on the technical specifications of the different units.

Temperature is a defining parameter for the biogas plant and production. A biogas plant can operate at a range of temperatures, depending on the specific microorganisms used in the digestion process. These microorganisms and commonly classified as thermophilic (relatively high temperatures) and mesophilic (mild temperatures).

Mesophilic systems, which use microorganisms that thrive at moderate temperatures, can operate between 25-35°C. The optimal temperature range for most types of anaerobic digestion is between 35-40°C. However, some thermophilic systems, which use microorganisms that thrive at higher temperatures, can operate at temperatures between 55-60°C.

The control of the different parameters as digester temperature, feeding rates, biogas pressures and feedstock retention times are usually managed through a "supervisory control and data acquisition" (SCADA), this supervision will allow the optimization of the operation and will increase the safety of its operation. The control and monitoring of the installations include the elements of the biogas generation and power plant.

3.3 Power of Biogas Plant

To assess the power of the installation, the user should provide some preliminary input data such as their energy requirements, biomass potential, and availability.

Biogas plant facilities represent a remarkable investment whose margins shall be properly calculated. Once the primary energy potential is defined, it is possible to start considering its supply format (heat and/or power). However, results must be compared to match energy requirements and investment capacities. It should be considered that any overestimation may arise the risk of expensive project payback rates, threatening the economic feasibility of the project.

For these reasons, it is important to perfectly acknowledge community energy demands and necessities to avoid overestimated plant volumes and facilities leading to unaffordable projects. It is recommended to address the aid of expert companies to satisfy those calculations.

3.3.1 Feedstock's biogas potential and performance efficiency

The maximum power output of a biogas plant can be estimated using several methods. One common method is to use the amount of feedstock that will be used by the plant as a starting point. By knowing the composition of the feedstock, you can estimate the potential amount of biogas that will be produced by the plant.

The biogas potential of feedstocks is an important factor when considering biogas production activity. A proper biogas production rate can be assessed through feedstock's biogas potential, which results will also impact on other considerations, such as economics, regulatory issues, feedstock availability on and off the facility, and end use of the biogas, that should also be evaluated. This data can be easily collected online, whereas expert companies are used to manage these technical concepts.

It is necessary to identify the biogas potential range that our chosen feedstocks can offer. For these:

- 1st stage: This step refers to the potential and availability of all suitable feedstock in the surrounding area that may be applied to biogas plant (e.g. manure, crop residues, organic waste etc.) and its biogas potential. Feedstocks from outside purchases or supplies may suffer from intermittences or supply issues. It should be ensured to have the most homogeneous feedstock supply to ensure anaerobic digestion stability.
- 2nd stage: Once the overall annual feedstock capacity is defined, it would be possible to estimate the overall maximum biogas potential for the available feedstock. For example, after considering a total available amount of 300 tons of pig manure per year, and considering pig manure BMP[25], a maximum annually biogas potential of 6,000 m^3 could be estimated.

Another important factor that can be used to estimate the maximum power output of a biogas plant is the efficiency of the plant's anaerobic digestion process. The efficiency of the process can be affected by a number of factors, including the temperature, pH, and pressure of the digester, as well as the type of microorganisms that are used. If an efficient coefficient of 60% is considered for the previous examples, a total annual biogas potential of 3600 m^3 should be finally inferred.

[25] *BMP, Biomethane Potential test: The biomethane potential (BMP) test is a laboratory analysis used to determine the potential amount of methane that can be produced from a given organic substrate, such as agricultural waste, sewage sludge or manure.*

Table 3: Various feedstock's biogas potential.

Feedstock Type	Biogas Potential (m^3/ton)
Industry waste	457
Wood residues	225
Food organic waste	281
Sugar beet	321
Wheat	202
Soybeans	229
Rice	229
Sugar cane	202
Pig slurry	20
Sewage Sludge	15

Once you have an estimation of the potential biogas production and the efficiency of the anaerobic digestion process, you can use that information to estimate the maximum power output of the plant. It's important to keep in mind that these are just estimates and that actual performance may differ. Many site-specific factors like feedstock quality, digester design, and process monitoring and control also have a large impact on the performance of the plant. It is always recommended to consult with experienced biogas plant designers or operator for accurate estimation and effective plant operation.

3.3.2 Biogas end-use application

During the conception phase of any biogas production facility, it should be addressed which would be the final application of the produced biogas based on the community's objectives.

Some of the most common applications for biogas production include:

- Energy generation: Biogas can be used as a source of energy for heat and electricity production in power plants. It is often used to fuel internal combustion engines or gas turbines to generate electricity.
- Off-grid or on-grid: Most biogas production facilities are aimed to satisfy off-grid energy requirements as for self-consumption heating and electricity production. However, bigger anaerobic digestion projects also aim the conversion of organic waste into electricity with selling purposes to the electrical grid system. Biogas production applications could also aim both in-site heating and to-grid electricity sells.
- Biomethane upgrading: Biogas can be purified to remove carbon dioxide and other impurities to produce biomethane, which is almost pure methane, it can be used as fuel for natural gas vehicles (NGV) and for injection into the natural gas grid.

It is crucial to define the intended application of the produced biogas, as it will impact the design and estimation of output power and capital expenditures. For instance, if the final application is electricity generation, there may be a need to purchase biogas upgrading units or combined heat and power (CHP) units. Many small-scale biogas plant facilities are designed for off-grid applications to increase energy savings for heating or other uses.

3.3.3 Power output estimation

There are several ways to estimate the maximum power output of a biogas plant, but the most common method is to use the lower heating value[26] (LHV) of the biogas and the maximum biogas production potential. This estimation allows to identify the highest theoretical power that the plant could produce taking into account that all the energy contained in feedstock is transformed into biogas. It needs to be highlighted then, that anaerobic digestion performance will define real conversion rates and biogas yields.

As LHV may vary from one biogas to another, due to possible differences on their composition and from different feedstocks, typical average values can be used for estimating the total primary energy of the biogas potential input. The following formula may help to estimate the primary maximum power output of the biogas plant depending on the amount of feedstock used:

$$Maximum\ Power\ Output\ (kW) = \frac{V_{biogas\ (m^3/year)} \times LHV_{(MWh/m^3)}}{h} \times C_i$$

Whereas:

- V_{biogas} refers to estimated annual maximum biogas potential for the specific case
- LHV refers to chosen standard or specific biogas lower heating value
- *h* refers to the expected annual total running hours for the plant
- C_i refers to the different efficiency coefficients that must be applied for the boiler, co-generation or other biogas application unit.

  **E.g. Biogas used for heat production by boiler unit shows typical efficiencies C_{boiler}=0.75 for most commercial equipments. Biogas used for electricity production by co-generation unit shows typical efficiencies C_{boiler}=0.45 for most commercial equipments*

It should be noted that this method is just a rough estimation and real power output performance will depend on many factors including the design and operation of the biogas plant.

Additionally, you may also refer to other inputs and outputs of the plant such as feedstock, digester volume, and type, mixing method, temperature control, pre-treatment, etc; to get a more accurate estimation.

3.4 Operational and maintenance of the installation

Even though biomass and waste feedstocks are more cost-effective than fossil fuels, the operation and maintenance costs of biomass valorisation technologies are slightly higher to ensure proper operation and service life of the installation. This is due to the significant amount of inorganics and impurities that remain after biomass digestion, necessitating more frequent maintenance operations:

- The frequency of sludge and digestate removal will depend upon the installation characteristics and the biomass to be consumed. Biogas plant constructors and operators are expected to have experience and a background in maintenance of digesters and other units, particularly with regard to the retention and digestion times specified in the technical specifications of the units.

[26] *The lower heating value (LHV) of biogas is the amount of energy released when the biogas is burned and is typically measured in units of energy per volume. LHV of biogas can vary depending on the composition of the biogas, but it is typically around 55 MJ/m³*

- When considering boilers or CHP for biogas use, removing the contaminants that can be located in the heat exchangers tubes and other auxiliary/cleaning emissions systems, can be done automatically by means of a pneumatic system (or other technologies). It is noteworthy to remark that biogas may contain small quantities of sulphurous compounds and other contaminants that may produce corrosion of the units, thus it is also recommended maintenance to be performed at least once per year, (normally after the winter season) and invest additional time to deeply clean all the installation.

Normally these operations are carried out by the company in charge of the operation of the installation. If these maintenance operations are being done and the design of the installations is based on the biomass resource to be fed, no malfunctions should arise.

Sometimes the bad experiences associated to the use of biomass, are due to the following issues:

- The biogas plant has been oversized and therefore the installation usually operates at very low capacity.
- The installation may encounter issues when the biomass fed is significantly different from the design specifications, as for instance: (i) different moisture content, (ii) size distribution (this can cause problems in the feeding system), (iii) chemical composition (be careful with that since it cannot be visually identified, high alkali and chlorine content, if the digester it is not designed properly, can considerably decrease the service life of the installation), (iv) low biomethane potential, (v) ash content, etc.

4. Capital expenditure and Operational Costs

4.1 CAPEX Estimation

Estimating the capital expenditure (CAPEX) for a biogas production plant can be a complex process, as it will depend on a variety of factors such as the size and location of the plant, the type of feedstock and digester to be used, and the desired rate of biogas production. As commented on previous section, once defined the main parameters that match feedstock's availability, biogas end-use application and the specific circumstances for the case scenario, the following tips could be followed to have preliminary estimations of capital expenditures (CAPEX).

A common approach to estimate the CAPEX is to break it down into different component costs. These costs can be broadly categorized into four main areas: land, construction, equipment, and contingencies:

$$CAPEX = Land\ costs + Constructions\ Costs + Units\ Purchases + Contingencies$$

Where:

- **Land cost:** This will include the cost of acquiring or leasing the land on which the plant will be built, as well as any site preparation or development costs.

- **Construction cost:** This will include the cost of building the structures and facilities required for the plant, such as the digester, gas storage unit, and power generation equipment. It also includes costs of installation and commissioning of the equipment and civil work like excavation, foundation, and building.
- **Equipment cost:** This will include the cost of purchasing and installing the equipment required for the plant, such as the digester, gas storage unit, gas treatment and compression equipment, pumps, and control systems. As explained, a previous estimation has been developed to properly sized the volumes and capacities of these units. Here is the key to the project successful achievement, as overestimation of these units could lead to unoptimized biogas production performances and thus to unaffordable projects.
- **Contingencies:** This will include any additional costs that may be incurred during the project, such as permitting fees, legal fees, and unforeseen contingencies that may arise during the construction process.

The cost of building a biogas production plant, also known as an anaerobic digestion plant, can vary significantly depending on a number of factors, including the size of the plant, the type of feedstock it will use, the location of the plant, and the specific technologies and equipment that are employed. In general, the cost of building a biogas production plant is primarily driven by the cost of the anaerobic digester, which can be a significant portion of the total nearly 40-50%, as well as the cost of other equipment such as gas engines, gas holders, and sludge treatment systems. In addition, there may be costs associated with site preparation, utility connections, and other infrastructure work. A common estimation of Capital Expenditure breakdown for off-site cogeneration is referred to in Figure 7 [10]

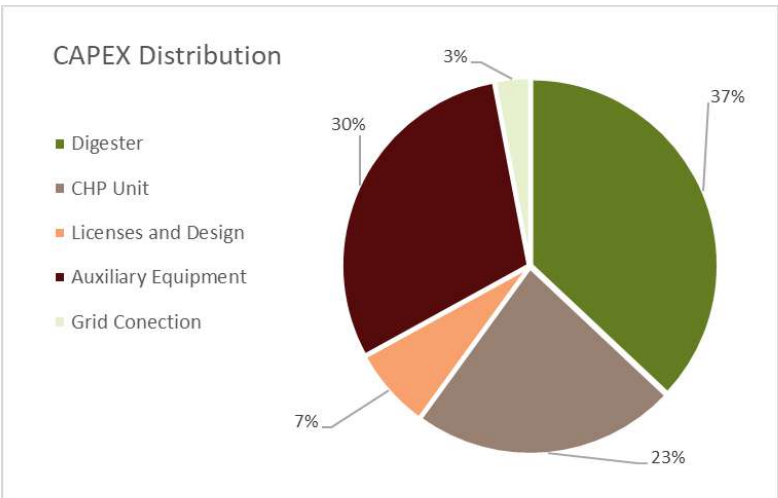


*Figure 7: CAPEX Distribution **[10]***

The costs for each of these categories will depend on a variety of factors specific to the project, and estimates can be made using historical data, industry standards and guidelines, and consulting with experienced engineers. It's also important to consider any government subsidies or tax breaks, which may be available to support a biogas project.

Once the costs have been estimated, they can be grouped together to give an overall estimate of the CAPEX for the project. It's important to remember that this is just an estimate, and the actual costs may differ based on a variety of factors. It's also a good idea to consult with experienced engineers and financiers to ensure that the estimate is accurate and to help with the planning and execution of the project.

4.2 OPEX Estimation

Operational expenditure (OPEX) refers to the ongoing costs associated with operating and maintaining a biogas production plant. These costs can vary widely depending on the size and location of the plant, as well as the type of feedstock and technology used.

Some of the most common operational expenditure items for a biogas production plant include:

- **Feedstock:** This is likely to be the largest operational expenditure item for a biogas plant, as it represents the raw material that will be used to produce the biogas. The cost of feedstock will depend on factors such as the type and volume of feedstock used, as well as any transportation and handling costs.
- **Labour:** This includes the cost of hiring and training employees to operate and maintain the plant.
- **Maintenance:** This includes the cost of regular maintenance and repairs to the plant and its equipment, as well as any spare parts that may be required.
- **Utilities:** This includes the cost of electricity, water, and other utilities that are needed to operate the plant.
- **Chemicals:** Some biogas plants may require the use of chemicals to optimize the anaerobic digestion process or to treat the biogas before it is used or sold.
- **Taxes and fees:** This include any taxes or fees that are required to operate the plant, such as property taxes, environmental fees, or permits.

Figure 8 shows a compilation of typical biogas production total cost (capital investment, operational and feedstock supply are inferred) correlating main factors: production capacity, feedstock, and biogas valorisation technology. Production cost for biogas co-generation are plotted for the range lower values whilst biomethane upgrading and grid-injection facilities are plotted for range higher values [11]

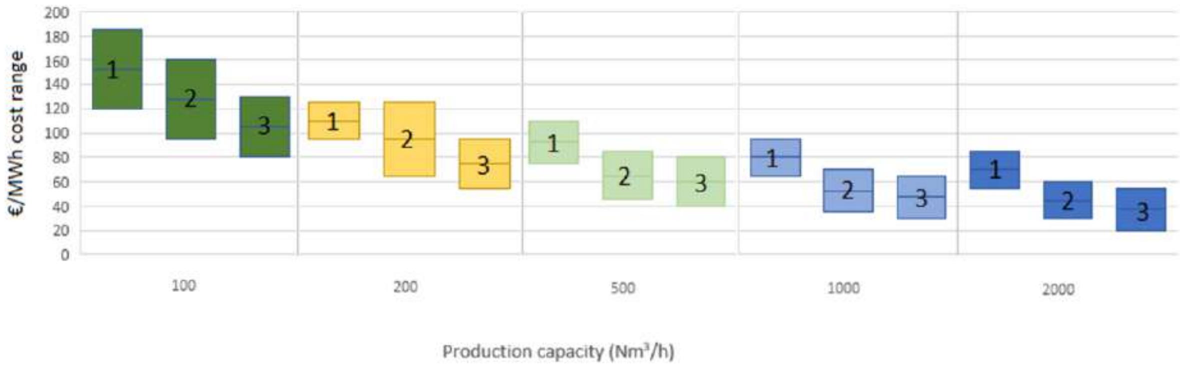


Figure 8: Range of total cost per energy produced correlation with production capacity and type of feedstock. 1: Energy Crops; 2: Manure; 3: Organic Waste

It's important to keep in mind that these are just some examples of common operational expenditure items, and the specific costs will depend on the project.

5.Profitability of biogas plants

Biogas plant profitability is greater than just economic issues. In first term, environmental challenges are roughly tackled by anaerobic digestion. Methane is one of the most contaminant greenhouse gases, thus its profitability as an energy carrier is further than only economic, but climate change mitigation. Moreover, anaerobic digestion emerges as a great application for the improvement of waste management strategies, otherwise, most waste streams end up disposed in landfills and contribute to pathogenic threats and environmental disasters.

In social terms, biogas plants also profit from great benefits regarding the economy and activities in rural areas, which are indeed the ones that hold the biggest potential for biogas explorations. Biogas plants create jobs that satisfy their construction, operation, maintenance, and supply, in addition to promoting local development, agricultural waste, and food waste management, reducing farm industry odours and health risks. In fact, rural areas may offer suitable symbiosis with biogas plants providing valuable local feedstock in exchange for cheaper and greener energy and waste management. All these facts result in cost savings for both the biogas plant and the agroindustry involved.

When biogas is involved in self-consumption or heat and electricity co-generation, savings on facility heating or electricity consumptions may have positive effects on the amortization of the installations and payback periods.

At this point, it could be considered not just the current annual price of fuels, but also the tendency in the future years since the stability of the prices will not be the same for all the fuels. Also, if the current fuels used are fossil fuels, it should be considered that they have an extra tax according to the specific emission factor of the fuels used, which can lead to a significant increase of the final price of the fossil fuels used. This price increase will make more and more attractive the potential savings from a biogas plant.

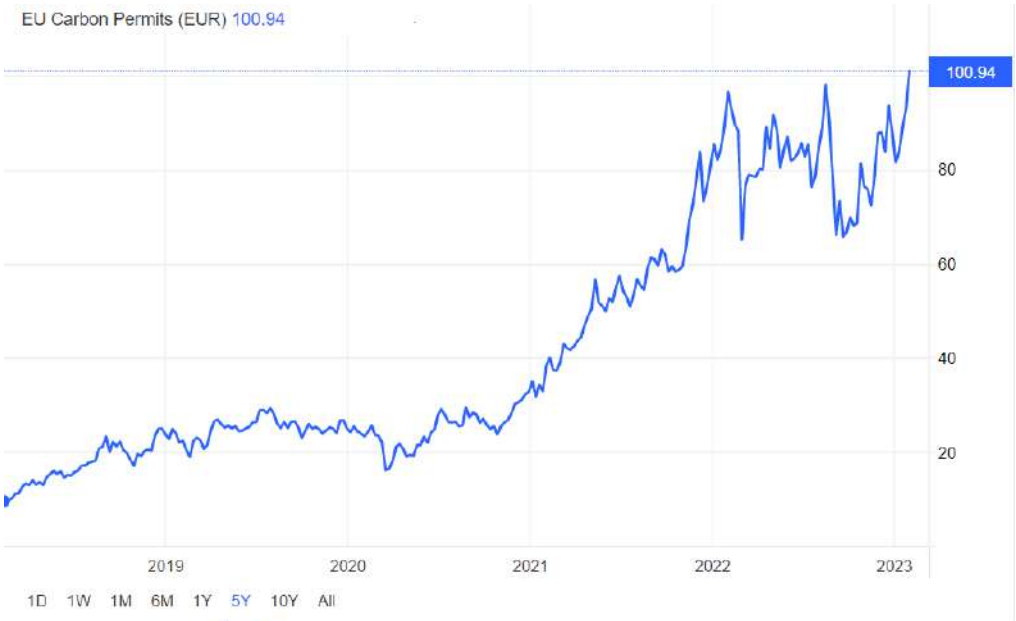


Figure 9: Evolution of the price of CO_2 emission in the last 5 years [12]

Once the current situation is well analysed, it should be compared with the future installation, and thus, two main aspect should be considered:

- Investment (CAPEX) of the new biogas plant installation: it includes the investment cost, the assembly and the transportation of all of the equipment required, together with the civil engineering costs. This number is very sensitive to the specificities of each case (location where the initiative will be implemented, expertise of the company in charge of the operations, the equipment selected, the biomass fed, etc).

- Operational and maintenance cost of the installation (OPEX): it includes the raw materials cost, labour cost, maintenance cost, energy cost, etc.

- Once, the CAPEX and OPEX of the new installation are estimated, in order to assess the economic profitability, the annual savings and/or energy sales of the new installation should be calculated. After having estimated all the investment and operating costs along with the potential savings or revenues regarding heat or power sales, a simple way to calculate the payback period (this parameter indicates the necessary years to obtain the return of the investment carried out), is obtained through the division of CAPEX and profit of the operation (the annual savings and/or revenues discounted with OPEX costs) associated with the new installation. The lower the payback, the lower the risk associated with the new installation. It should always be lower than the service life of the new biogas facility (an average service life is between 20-30 years) for being economically profitable.

$$Payback = \frac{CAPEX}{\left(Annual\ savings\ \left(\frac{€}{year}\right) + Energy\ Sales\ \left(\frac{€}{year}\right)\right) - OPEX}$$

- Annual savings refers to the substitution of heat and or electricity consumptions by biogas valorisation.
- Energy sales refers to the revenues obtained by biogas, biomethane, electricity, heat or by products sold to other consumers or injected to the grid.

As mentioned, this is a simple way of doing a first estimation, but to be more accurate other parameters should be considered as the inflation or the tax rate. If the CAPEX is covered by own or external resources, loans, etc., in order to obtain more information about business and financial considerations, the BECoop Catalogue for the provision of business and financial support services can be consulted.

Table 4 summarises the information mentioned in this section, through an example of investing on a new small-scale biogas plant production replacing electricity household consumption[27] of an average 10,000 population community (16,000 MWh_e) producing 5,000 tons of urban organic waste[28] (biogas potential of 0.280 m^3/kg as shown in section 3.3.1). In this example an inflation rate of 2% has been considered for household electricity consumptions and 1% for OPEX increase annually, as a result a 10-year payback period is obtained.

[27] Energy consumption per capita in the household's sector in the EU in 2020 was 1.6 MWh per capita

[28] When expressed in relation to population size, the EU generated, on average, 4 813 kg per capita of waste excluding major mineral waste in 2020, whereas household shares 9.15%. Thus, organic municipal waste is estimated on **500 kg per capita annually** [15]

Table 4. An example of a breakdown of savings, expenses and investment obtained for a biogas plant.

Items	Unit	Data year 1
	Savings (Current situation)	
Consumption of electricity	MWh/year	16,000
Price of electricity considered	€/MWh	150
Annual electricity cost	€/year	2,400,000
Biogas production	MWh/year	5,800
Yield of electricity production	%	35
Useful electricity production	MWh/year	2,030
Total energy satisfied by biogas		13%
Annual electricity savings	**€/year**	**304,500 €**
	Expenses (future situation)	
Power of the installation (see section 3.3.3) with 7920h of work per year	MW	0.30
CAPEX cost (taking into account investment trends in bibliography [13]	**€**	**1,845,900**
Annual total cost: amortisation of investment cost, electricity consumption of the plant, feedstock costs, transport of feedstocks, salaries and maintenance costs (see section 4.2)	€/year	121,800
Total earning (Savings – OPEX)	**€/year**	**182,700**
	Financial considerations	
Inflation of electricity	% of inflation per year	2
Inflation of OPEX	% of inflation per year	1
Grant	%	0
Loans	%	0
	Payback	
Payback	**Years**	**9,3**

6.Stakeholders needed

In order to develop a biogas installation, the users, in the majority of the cases, would most likely need the support from other stakeholders, that sometimes can be integrated inside the community/RESCoop or in other cases they will provide external support by subcontracting. Some of the stakeholders that could be necessary are listed below:

Biomass producers/suppliers

It is very important to guaranty the supply of the raw material (biomass) that should feed the biogas installation. There are a huge range of biomass with different composition and size distribution, therefore the biomass purchased should guarantee the same range of properties since the installation it is designed for a specific biomass. It is recommended to consume local biomass, because it is more sustainable, and the transportation cost it is lower. These biomasses can be purchased from the biomass producers or from biomass suppliers, in any case it is important to carry out supply contract specifying who is in charge of transportation, the frequency of supply, and the quality of the biomass supplied. Furthermore, energy communities shall be formed by biomass producers that are willing to valorise its resources.

Energy Services/Engineering Company (ESCO)

A biogas production plant, it is an industrial plant, so therefore it is important to account with an expert company that will oversee the proper design of the installation. This step it is critical, since a bad design of the installation can jeopardise the viability of the project. It is recommended that these companies have a clear idea of the biogas to be produced, since the installation should be designed accordingly. Sometimes this lack of information entail problems in the future, so dedicating efforts to making the project fully understood is highly recommended.

Some energy services/engineering companies have in their business model to be part of an energy community while others do not, this fact should also be taken into account depending on the business model to be selected by the energy community to be formed.

Equipment manufacturers

The selection of the proper equipment for the installation to be designed it is important, even though this process normally it is being done by the previous stakeholder (energy services/engineering companies), since they have agreements with several equipment manufacturers, and they choose the best technology for each case.

Public/Local institutions

To develop biogas plants, generally, it implies the coordination between the different administrations for the processing of permits (e.g. licenses for waste management, production of energy, etc.) and the optimisation of the system in the case of supply to buildings or other facilities under different public ownership. Furthermore, if electricity sales or biomethane injection to the grid is forecasted, then the administration will play a fundamental roll to enable and give the license of connection to the public grid.

Consumers

Final consumers can be a wide variety of different stakeholders as: individual farms, community of neighbours, local industries, or even some of the stakeholders previously mentioned. They will be the “clients” of the biogas use or energy, and therefore, they will expect to achieve financial savings, and to contribute to the environmental and social aspects in the area by being part of this community based on biogas production and usage.

Transversal stakeholders (as research centre, biomass associations, investors)

In addition to the stakeholders previously indicated, which are the most necessary in this value chain, there are others, that in some cases, could help to assess/give advice/finance/etc the development of bioenergy communities based on biogas production, some of them are:

- Research centres: it could be interested to contact with this stakeholder if the promoter of the idea doesn´t account with the necessary technical information to assess if it could make sense to go further. The research centre can carry out a first feasibility study (being completely impartial) and if it is feasible to facilitate the contact with energy service companies or even being the technical expert (as representative of the promoter) in this communication with the ESCO. Additionally, it can provide support to prepare some documentation in order to obtain financial grants to develop the project.
- Biomass association/local action groups: this stakeholder can inform to the promoter about stakeholders that can help them in order to develops its initiative, can inform them about other success cases based on biogas plants, open financial grants, etc.
- Investors: a biogas plant requires a huge initial investment as it was mentioned before, so it is frequent to acquire some external funding. In this case, investors can provide support. Before contacting the investor, it is important to have a feasibility study, and the idea of the project well organized to capture its attention from the beginning.

In case the promotor of the idea needs to contact or find out a specific stakeholder, it is advisable to visit BECoop e-market platform where you can find useful information in this regard.

7.Steps to be followed

This section aims to summarize and establish a chronology order of general steps to be performed by the promoter of the idea of a biogas production plant unit starting from the beginning.

Table 5. General steps to be followed to develop a biogas facility from the beginning.

Order	Action	Description	Stakeholders that can help
1	To define the available amount of biomass for anaerobic digestion and the potential of biogas than can be produced with it.	The first step is to understand the dimensions of the biogas plant to be developed, which relies on the estimated production of biogas. See chapter 3.3.1	Biomass suppliers and producers are important stakeholders in determining the available amount of biomass. Additionally, other community members can also be involved in the process. In cases where support is needed, they can reach out to research centers or ESCOs to carry out estimations and

Order	Action	Description	Stakeholders that can help
			provide guidance on the design and implementation of the biogas plant.
2	Biogas final use or application.	The way biogas is going to be valorised or used is very important to envision the type of technologies that will be implemented within the plant and its cost. See chapter 3.3.2 about the information required	Final consumers should provide the type of energy to be covered with the biogas (thermal, electricity, both, etc). Research Centres and ESCO can provide support for the selection of the technology.
3	To do a pre-feasibility assessment about the implementation of a biogas plant	Based on the information described in chapters 3 and 4, it is key to evaluate the economical KPIs in order to decide whether to go further with this project or not.	It is recommended that the design and implementation of a biogas plant be carried out by an expert in the field, such as a research center or an Energy Service Company (ESCO).
4	To identify and contact different ESCOs and communicate the initiative.	Preliminary contact with ESCOs should be done with the goal of communicating the project and investigate if they are interested to collaborate.	It can be done by the promoter of the idea with the support of the company that will carry out the pre-feasibility assessment (if it wasn't previously done).
5	To carry out the design and the implementation of the biogas plant.	To develop the project of the biomass anaerobic digestion for biogas production and its implementation, selecting the biomass to be fed, the equipment needed, to obtain the administrative licenses, etc.	Usually done by the ESCO selected and/or an engineering company.
6	To guarantee the supply of the biomass.	The proper quality of biomass is crucial for the successful design and operation of a biogas installation. See risks in Section 3.2.1	It depends on the business model selected, and the role of each stakeholder of the community. Normally, the agreement with the biomass supplier is carried out by the same stakeholder that is in charge of the operation and maintenance of the biogas facility.
7	To start with the operation of the biogas plant	Guaranteeing the correct operation of the installation, securing the energy (biogas, biomethane, electricity or heat) supply to the final consumers and the correct maintenance of the installation to ensure its useful life.	ESCO, the community or other stakeholder selected to be in charge of the operation and distribution of the biogas application products should be responsible of this.

8. Success cases

This section describes an initiative that has already been implemented with the goal of raising awareness about the potential benefits of successfully developing a biogas plant, as well as gaining a better understanding of its average techno-economic performance.

8.1. Combination of Anaerobic digestion with composting in Girona, Spain

Pla de l'Estany is a poblation of Girona province (Catalonia, Spain) designed as vulnerable zone according to Government. In order to improve land fertilization and minimize environmental pollution when applying manure, it is compulsory to farmers to establish Nutrient Managing Plans (NMP) which farmers had to design and validate according to the dosage of nutrients applicable to their crops. Enhancements in animal feeding, manure transportation and treatments may be also considered. [14]. In this context, the dairy farm SAT Sant Mer, decided to build a biogas plant to process the manure produced together with other organic wastes. The project of Apergas plant is the result of the synergy of three companies: SAT San Mer, EnErGi, and BIOVEC. The design of the plant was done in 2007, the construction during 2008 and the startup in 2009. It treated slurry from dairy farms of SAT San Mer altogether with organic wastes from other agribusiness facilities. A total of 18,771 m3 of cow slurry and 3,129 m3 of co-substrates were digested.

Figure 10: General view of Apergas biogas plant (left), anaerobic digesters (right)

Biogas at a flow rate of 322 ton per year was valorized in CHP unit of 500 kW with an electrical production of 4,000 MWh per year. A total of 1,100 tons CO_{2eq} per year savings were estimated for the operation of the plant during 2010 and 2011. Furthermore, CAPEX data were reported with a total of 1.4 M€, whereas main digesters and CHP units share a 50% of the investment. Also cost of operation (OPEX) were reported regarding electrical consumptions, salaries, maintenance, and other costs as a total of 200 k€ per year.

Table 6: CAPEX and OPEX of the project.

CAPEX	
Unit Description	Cost (€)
Equipment (stirrers, pumps, valves, CHP engine, etc.)	522,800 €
Concrete works (Anaerobic digesters, composting platforms and trenches, etc.).	292,000 €
Facilities (gas, water, electricity)	132,000 €
Grid connection	136,200 €
Mechanical separator	28,300 €
Hydrogen sulphite control	18,000 €
Soil movement, levelling, etc.	89,500 €
Other (roads, fees, contingency, etc.)	63,000 €
Toilets, landscaping, etc.	15,000 €
Project engineering	114,000 €
Total Investment	**1,410,800 €**
OPEX	
Concept	Cost (€)
Salaries	33,100 € / y
Operational control (sampling, analysis, etc.)	27,830€ / y
Maintenance	61,200 € / y
Electricity	12,976 € / y
Other	70,000 € / y
Total operational cost	**205,106 € / y**

9.Conclusions

This document establish the main terms and elements that must be understood and considered when thinking on implementing a biogas production facility. For such assessment, it is clearly defined which are the key- parameters to develop for these kinds of projects: available biomass in the area, biogas capacity and potential, and a clean economic assessment to ensure the feasibility of the facility. Moreover, it also offers several examples of stakeholder's groups that may enable and offer synergies for the implementation of biogas production and valorisation projects. Some steps to follow are also given. Finally, this catalogue may serve as a guide for promoters to enable their actions with stakeholders, energy communities and biomass owners. However, bioenergy projects require some technical knowledge and experience, thus it is highly recommended to further consult experts and engineering companies to facilitate the decision-making process prior to investing.

10.References

[1] An introduction to biogas and biomethane – Outlook for biogas and biomethane: Prospects for organic growth – Analysis - IEA n.d. https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane (accessed February 2, 2023).

[2] How Does Anaerobic Digestion Work? | US EPA n.d. https://www.epa.gov/agstar/how-does-anaerobic-digestion-work (accessed January 9, 2023).

[3] Rasi S, Veijanen A, Rintala J. Trace compounds of biogas from different biogas production plants. Energy 2007;32:1375–80. https://doi.org/10.1016/J.ENERGY.2006.10.018.

[4] BASIC DATA ON BIOGAS 2012.

[5] Jacob Jørgensen P, for Day R. Biogas-green energy. Process. Design. energy suPPly. environment Biogas-green energy Process • Design • Energy supply • Environment n.d.

[6] Anaerobic System Design and Technology | US EPA n.d. https://www.epa.gov/agstar/anaerobic-system-design-and-technology (accessed January 20, 2023).

[7] Akindolire MA, Rama H, Roopnarain A. Psychrophilic anaerobic digestion: A critical evaluation of microorganisms and enzymes to drive the process. Renewable and Sustainable Energy Reviews 2022;161:112394. https://doi.org/10.1016/J.RSER.2022.112394.

[8] Types of Biogas Storage Systems | BioEnergy Consult n.d. https://www.bioenergyconsult.com/biogas-storage/ (accessed January 19, 2023).

[9] Gas Plant & Biogas Manufacturing Company in Ahmedabad - Atmos Power Pvt. Ltd n.d. https://www.atmospower.in/ (accessed February 2, 2023).

[10] Biogas Plant Development Handbook | BiogasWorld n.d. https://www.biogasworld.com/biogas-plant-development-handbook/#economics_handbook (accessed February 2, 2023).

[11] El biogás. Actualidad y perspectivas de un gas renovable - Fundación Naturgy n.d. https://www.fundacionnaturgy.org/publicacion/articulo-el-biogas-actualidad-y-perspectivas-de-un-gas-renovable/ (accessed January 24, 2023).

[12] EU Carbon Permits - 2023 Data - 2005-2022 Historical - 2024 Forecast - Price - Quote n.d. https://tradingeconomics.com/commodity/carbon (accessed January 24, 2023).

[13] Biogas installations investments n.d. http://www.biogas-renewable-energy.info/biogas_installations_investments.html (accessed January 31, 2023).

[14] Foged R, Lyngsø H, Flotats X, Bonmati Blasi A, Martin Schelde K, Palatsi J, et al. Assessment of economic feasibility and environmental performance of manure processing technologies 2012.

[15] Waste statistics - Statistics Explained n.d. https://ec.europa.eu/eurostat/statistics-explained/index.php?oldid=503519 (accessed January 31, 2023).

Annex V: Factsheet of solid biomass for small-scale heating applications

BECoop
UNLOCKING THE COMMUNITY BIOENERGY POTENTIAL

FACTSHEET OF SOLID BIOMASS FOR SMALL-SCALE HEATING APPLICATIONS

Summary of the factsheet

Bioenergy – energy produced from biomass – is the most widely used renewable energy source in Europe as well as the most versatile, being able to provide heat, electricity or fuels for transport. The current factsheet focuses on the use of biomass as a solid biomass fuel, especially targeting small-scale heating applications.

KEYWORDS:
Biomass
Types of Biomass
Biofuel Characteristics
Certification of biomass

Types of biomass: The following main types of biomass can be discerned depending on the activity which produces them.

- **Agricultural biomass:** usually, the term refers to crops residues that are generated after the harvesting of the main product (e.g. straw) or from regular prunings of permanent crops (e.g. olive trees, vineyards, orchards), etc. The term can also apply to dedicated, non-food plant species, such as miscanthus, willow, poplar, etc. that are cultivated with the intend of being used as feedstock for energy purposes.
- **Forestry biomass:** a wide range of materials that derive from the sustainable management activities of forests (firewood, forest residues, etc.) and from the forest wood processing sector (sawdust, wood shavings, etc.). Most of the bioenergy in Europe is coming from forest biomass, especially in heating applications.
- **Agro-industrial biomass:** residues that are generated after processing a main agricultural crop in an agro-industry. They include olive stones, exhausted olive cake, almond shells, sunflower husks and others. Since they are generated in a specific point, they do not require harvesting operations and are thus a very cost-competitive option for energy generation.
- **Biomass from urban parks and gardens:** often referred to as "green waste", it mostly consists of tree prunings and other cuttings that are generated in an urban setting. They are typically handled in the framework of municipal waste management schemes.

Tradeable Forms of Biomass:

Bales	*Firewood*	*Chips or hog fuel (mixed shavings)*	*Granular material*	*Pellets*	*Briquettes*

Indicative fuel properties of various solid biofuels									
Property	Units	Wood Pellets A1	Vineyard pruning pellets	Sunflower husk pellets	Olive tree pruning (hog fuel)	Wheat Straw	Olive Stones	Almond shells	Miscanthus
Moisture content	w-%, a.r.	≤10	10	10	27	15	15	11	15
Ash content	w-%, d.b.	≤0.7	4.5	4.0	4.2	5.0	1.2	1.6	4.0
LHV	MJ/kg, a.r.	≥16.5	15.7	15.7	12.9	14.6	15.8	16.1	14.7
Bulk Density	kg/m^3, a.r.	600≤BD ≤750	710	550	230	200 (bales)/ 85 (chopped)	730	410	130 (chopped)
Nitrogen, N	w-%, d.b.	≤0.3	0.81	0.8	0.93	0.5	0.3	0.4	0.7
Sulphur, S	w-%, d.b.	≤0.04	0.07	0.1	0.08	0.1	0.02	0.01	0.2
Chlorine, Cl	w-%, d.b.	≤0.02	0.02	0.06	0.04	0.4	0.1	0.02	0.2

a.r: as received; d.b: dry basis; LHV: Low Heating Value; More information on biomass properties on D3.2 of the Biomasud Plus project and Annex B, EN ISO 17225-1; Solid biofuel composition can vary significantly. The given values are only indicative of typical values.

Biomass Fuel Quality Certification Schemes:

A biomass fuel quality certification scheme is meant to provide assurances to small-scale, i.e. domestic, biomass end-users that the fuel they purchase does indeed comply with specific quality parameters. Such schemes require that biofuel producers adopt specific quality control measures, which is then certified through third-party audits. The most widespread quality certification scheme is **ENplus®** for wood pellets. Other schemes, such as **BIOmasud®** allow for certification for more assortments, such as olive stones and nut shells.

What makes a solid biofuel suitable for small-scale heating applications?

Generally, all types of biomass can be converted to energy with the use of appropriate technology. However, in small-scale heating applications there are several technical and other limitations that influence the choice of the appropriate fuel. Some of the most important ones are:

- ✓ **Low moisture content**: increases the energy received from the fuel and helps maintain a clean and efficient combustion.
- ✓ **Low ash content**: reduces emissions of dust, while also minimizing the cleaning intervals.
- ✓ **Homogeneous / consistent particle size**: helps to avoid issues in the fuel feeding system.
- ✓ **High energy density**: minimizes storage requirements and transportation costs.

Ultimately, a consumer should never forget that in order to be **effective** and **low-emissions**, bio-heat should be produced in **properly installed and well-maintained** appliances and using the **appropriate fuel assortments**!

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Annex VI: Factsheet of biomass logistic supply chain

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FACTSHEET OF BIOMASS LOGISTIC SUPPLY CHAIN

Summary of the factsheet

The current factsheet tackles the topic of biomass supply chain providing: (i) some tips, (ii) logistic considerations to be taking into account according to resource selected and (ii) final recommendations that should be considered with other stakeholders of the value chain when developing an initiative.

KEYWORDS:

Biomass logistic
Supply chain
Collection system
Agreement with other stakeholders

What should be taken into account to properly select the supply chain?

Biomass logistic operation is a critical step of the solid biofuels value in terms of economic feasibility, quality and environmental performance. There are different possibilities when collecting these resources, some of them are better than others, the most suitable alternative will depend on a number of factors, such as:

- Amount of biomass to be mobilized yearly according to the availability and the market potential.
- CAPEX (investment) of the new machinery needed.
- Access and slope to the field/forest, since it could constrain the suitable machinery to be used and the supply chain to follow.
- Distribution and amount of biomass to be harvested from the fields/forest/urban parks
- Quality requirements of the client (it could be a final consumer or an intermediate stakeholder), for instance: moisture content, size distribution, etc.

Machinery*	Productivity (t/h)**	Investment. CAPEX (€)***
Collection integrated with shredding/chipping	1.5-4	20,000 – 40,000
Large shredding/chipping	10-25	200,000 – 500,000
Small chipping machines	2-10	10,000 – 50,000
Self-loader truck	10-15	150,000 – 350,000

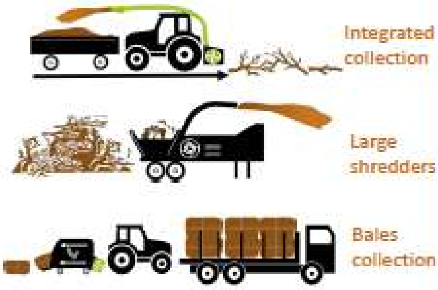
*There are many different types of machinery

**Productivity can change according to the biomass resource used

***CAPEX can vary according to the productivity and the brand selected

Agricultural biomass

- It is a biomass resource with high dispersion and low productivity per ha, so logistic operation is critical.
- Almost each year it is generated after pruning/harvesting operations. Collection should fulfil RED II criteria.
- Usually, the radius of operation should be lower than 30 km, if bales are produced it could be increased.
- Shredder machinery are more suitable than chipper machinery since it could contain sand and stones (contamination that should be avoided during the collection operations)
- Reference documents: Monographic uP_running, Straw to Energy



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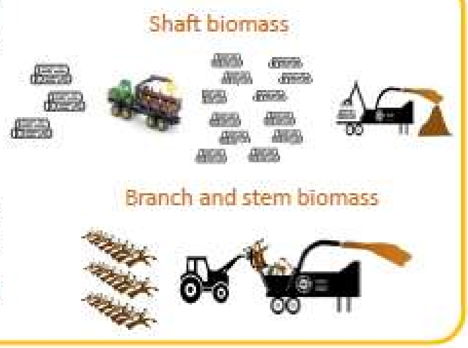
Forestry biomass

- There is a significant variability in terms of tonnes of biomass that can be obtained per ha (from 20 to more than 100 t/ha) according to the forest characteristics.
- Biomass logistic operations should fulfil RED II criteria.
- The average radius of operation could be of around 100 km.
- Large chipper machinery is usually preferable since the product obtained is more homogenous, and productivity reached is higher.
- Reference documents: Wood fuels handbook, Recovery of forest residues



Biomass from urban parks and gardens

- The amount of biomass will depend of the tree species, a first estimation could be around 15-30 t/ha.
- It is obtained when maintenance operations are performed and/or planned by the managers of these urban parks and gardens.
- Small chipper machinery (easily to move from one site to other) is usually preferable since the product obtained is more homogenous. It could be fed manually or with machinery.
- Reference document: Biomass supply chains

Recommendations to develop new biomass supply chains

Biomass owners
Don´t forget to obtain a successful agreement with the resource owner (farmers, forest management, municipalities, etc), sometimes intangible benefit could be enough.

Logistic operators
It will be easier if you already account with some machinery to avoid starting from scratch. Also, don´t forget that in some cases it could be more profitable to subcontract a service than investing on machinery or equipment.

Try to avoid the mobilisation of the biomass from one point to another if it is not necessary.

Clients
Supply agreements with your consumers will decease the risk of the OPEX and CAPEX of these collection operations. In this sense, it is key to reach an agreement regarding the quality, price and supply period requirements to ensure good cooperation and avoid misunderstandings.

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Annex VII: Factsheet of solid biofuels production

FACTSHEET OF SOLID BIOFUELS PRODUCTION

Summary of the factsheet

Production of pellets/woodchips/briquettes are characterized by high homogeneity as well as stable physical and chemical properties. These solid biofuels production can take place with different technologies and in a wide range of installation capacity. Various options of production lines (automatic, half-automatic with manual operations, etc) create possibilities to adjust properly the installation to the fuel requirements, producer's expectations, investment needed and final price of the solid biofuel.

KEYWORDS:

Installation capacity

Uniform shape

Stable quality

Investment cost

Why processing biomass?

- Production of good quality biomass fuel in the form of pellets, woodchips and briquettes is intended for achieving a homogenous biofuel with a stable quality. This fact will facilitate the following operations with high efficiency to produce heat in a controlled, maintenance-free, and environmentally friendly manner.
- Reference quality standards/certification:
  - Pellet: ENPLUS, DINPlus, ISO 17225-2/6
  - Woodchips: ISO 17225-4, Biomasud
  - Briquettes: ISO 17225-3/7

Parameter	Pellet	Woodchips	Briquettes
Moisture content, %, a.r.	8-12	15-35	10-20
Ash content, %, a.r.	<0.5	<3.0	<3.0
LHV, MJ/kg, a.r.	18-19	13-16	15-18
Bulk density, kg/m³, a.r.	600-750	150-350	350-550

a.r: as received; d.b: dry basis; LHV: Low Heating Value

Pellet production

- The pellets production technological line consists of the following units: (i) shredding/milling system, (ii) drying/mixing section, (iii) pelletizing (granulator) unit, (iv) pellet's cooling system, and (v) packing line.
- The expenditures related to the pelletizing line (without buildings and feedstock cost) depend on its capacity and automation rate. The approximate production cost of pellets is from 60-120 €/t (in dependance on the labor costs, electricity price etc.)

*Drying operations with herbaceous material is not always required

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Woodchip production

- The essential parameters of woodchips are proper particle size and moisture content. The wood chips production line is very simple, and its costs depends on the capacity and automation rate.
- The approximate production cost of wood chips is from 20 to 50 €/t (without feedstock cost).

Briquettes production

- In the briquette production process, it is very important to select the appropriate mill for the processed type of biomass and its form (logs, branches, straw, boards, chips) and the briquetting device that will produce a product of a specific shape.
- The production costs are in the range 45-150 €/t (without feedstock cost).

Investment costs

- The investment can highly change between EU countries, and the technology selected, but some ranges are:

Installation capacity, kg/h	Pellets Investment costs, k€	Woodchips Investment costs, k€	Briquettes Investment costs, k€
200	10-60	2-4	10-50
700	55-110	5-12	40-80
1000	110-600	10-15	55-120
2500	250-1,000	25-60	80-250

Market audience of these solid biofuels

- Pellets are recommended for fully automatic domestic boiler with a small amount of storage spaces.
- Wood chips are rather suggested for medium-sized and industrial boilers (above 50 kW) due to the storage conditions and higher moisture content (the volume of wood chips store is 3-4 times larger than that of pellets).
- Briquettes can be utilised in boilers/fireplaces of all sizes, but their feeding to the combustion chamber in small heating units must be done manually.
- The market price of these solid biofuels for a final consumer depends on many factors (biomass type, fuel accessabillity, alternative fuel prices etc.), and are, as follow: pellets (170-350 €/t), briquettes (150-400 €/t), and wood chips (50-100 €/t).

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Annex VIII: Factsheet of biomass feedstock evaluation

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FACTSHEET OF BIOMASS FEEDSTOCK EVALUATION

Summary of the factsheet

The current factsheet tackles the topic of biomass feedstock evaluation: (i) why it should be considered, (ii) how to assess the biomass potential (iii) from biomass potential to biomass availability and (iv) stakeholders that can provide support.

KEYWORDS:

Biomass potential

Biomass availability

Feedstock evaluation

Stakeholders support

Why feedstock evaluation should be considered?

One of the most important aspects to be taken into account when considering any activity around local biomass is to know if there is biomass potential in a nearby area and if it can be guaranteed in the future.

In this sense, it is necessary to differentiate between the potential biomass that may exist and the biomass that will be available and accessible.

How to assess the biomass potential?

A methodology to assess the biomass potential to follow could be:

- To *define the sourcing radius (km)* for assessing the biomass potential (normally should be lower than 100 km). It should be taken into account that a large part of the cost associated with the supply of biomass is due to the transportation of biomass.
- To consult the *agricultural and forestry statistical yearbooks*, in order to assess the amount of ha of each crop at least from the last 3 years.
- To identify the most representative crop in your local area and its corresponding *biomass productivity* that you can obtain *per ha*. This will depend on the type of biomass and:
  - the type of crop species
  - whether the biomass comes from whole tree or only from tops and branches (always respecting the criteria set by RED II)
  - if the biomass comes from pruning, plantation removals, maintenance operations, forestry fires, etc.
  - Frequency of horticultural practices
- In the case of agroindustrial biomass, it will depend on the amount of crops collected and processed each year during the treating/ refining processes in the agroindustries.

Other option if you want to do a first assessment is to consult *some open-source tools* described in the BECoop toolkit that provides a first estimation of the biomass potential, as: *BIORAISE, S2BIOM*. These online tools are very general but can provide a preliminary idea of the biomass potential.

There are *more advanced techniques* such as to create your *own geographical information system, remote sensing technologies* (as for instance LIDAR), etc but this are more complicated for an unexperienced user.

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FACTSHEET OF BIOMASS FEEDSTOCK EVALUATION

Biomass Productivity Ratios

Resource	Productivity per ha (t/ha, d.b.)	Comments
Forestry biomass	20-100	When maintenance operations are needed.
Agricultural biomass from pruning operations	0.7-4.0 (rainfed land) 1.5-8 (irrigated land)	It depends on the crop and the type of land (rainfed or irrigated). Pruning operations are carried once per year or every two years (mainly with olive crops).
Agricultural biomass from plantation removals	1.7-40	It is becoming more and more common to renovate plantations, either by changing variety, crop or to make the plantation more productive. It depends on the crops but between 10-60 years the plantations are usually renovated.
Agroindustrial resources (olive pit, exhausted olive cake, almond shells, etc)	-	Highly depends on the quantity of harvested crop collected each year and the type of agro-industry. It is usually derived as a by-product of refining/treating a crop product.
Biomass from urban parks and garden	15-30	When maintenance operations are needed.

From biomass potential to biomass availability

Once you know the biomass potential, you should consider other aspects in order to assess the biomass availability, as for instance:

- *Technical considerations for the harvesting of biomass* (access to the fields, slopes, distances between plantations etc.)
- To *get in contact with some local owners of biomass* (farmers, cooperatives, public and private forest owners) in order to obtain *information about the standard practices* that the owners of this biomass are doing in the area of interest.
- *Biomass logistic operators are needed*, if they do not exist, it can be a barrier.
- *Current consumers of biomass*. Is there other biomass consumers? Are they expected in the future? Such consumers could threaten the secured supply of the biomass.
- *Other current or future use* of biomass as for instance organic matter.

Once you collect all this information you can have a better picture of the biomass availability in your local area.

Stakeholders that can provide support

To carry out a feedstock evaluation can be a complicated task, so the following stakeholders can provide support:

- *Research Centers Universities*
- *Public Institutions Biomass associations*
- *Biomass owners/ agricultural/forest co-operatives*
- *Biomass suppliers*

Look for them in the BECoop e-market

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