Green heat with small-scale wood combustion

for agriculture, SME and industrial plants

Regulations for boilers up to 2 MW and guidelines to optimize combustion and reduce harmful emissions

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Biomass for Energy

TWECOM
Growing local energy

Investing in Opportunities

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Green heat with small-scale wood combustion for agriculture, small and medium-sized enterprises (SME) and industrial plants

Regulations for boilers up to 2 MW and guidelines to optimize combustion and reduce harmful emissions

1 Selecting the biomass boiler

2 Reducing emissions

3 Maintenance and management

Introduction

Ever since humans controlled fire, wood has been used for fuel. In developing countries, it is still the main fuel type. Western Europe saw a significant post-war decrease in the use of wood for energy. However, this recently changed, which is reflected in the current energy policy. Europe is committed to realising an energy mix with clear targets relating to expansion of using renewable energy resources. A key role is allocated to using biomass as a source of energy, and in particular to using wood and wood waste as fuel.

Between 1990 and 2010, the amount of energy extracted from wood and wood waste doubled (+110%). In 2010, wood and wood waste were the main sources of renewable energy in the EU. In absolute numbers, these contributed most to the mix of renewable energy resources in the gross domestic energy consumption of the EU-27. The reasons for the key role of wood and wood waste in Europe's energy transformation are:

- The energy transformation of wood takes place in an existing market: both in terms of suppliers of combustion technologies, maintenance, trade, logistics, etc.
- Wood can be stored during periods of limited demand, enabling seasonal production.
- This fuel, provided that the conversion technology is adjusted, can produce energy on demand, enabling a quick response to fluctuations in wind and solar power supply.
- Wood can generate high-calorie heat, which is not always possible for other forms of biomass.
- Local availability of wood in Europe contributes to realising energy independence.
- Increasing awareness of the value of wood encourages smaller-scale forest owners and farmers to actively and sustainably manage their forests or hedges, or by growing their own woody biomass, for example by short rotation coppice plantations.
- If sustainably produced and efficiently converted, wood has a major positive impact on reduction of greenhouse gases in comparison with fossil fuels.

THIS PUBLICATION IS A MANUAL FOR BEST PRACTICE IN WOOD COMBUSTION in small-scale (0-2 MW) incineration systems and falls within the scope of the European projects ARBOR and TWECOM. The manual contains guidelines for:

- Selecting an appropriate type of biomass boiler (Chapter 1);
- Making heat production in small-scale wood combustion systems more efficient (Chapter 2);
- Limiting the impact of wood combustion on the air quality (Chapter 2);
- Managing and maintenance of the biomass boiler (Chapter 3).

THIS MANUAL IS SUITABLE FOR THE FOLLOWING TARGET GROUPS:

1 Producers of green thermal energy through wood combustion systems with a thermal input up to 2,000 kW who intend to improve the efficiency of the existing combustion system, and/or intend to reduce the air emissions generated by the combustion process.

2 Companies and SME's interested in generating heat through wood combustion in small-scale combustion systems aiming to make an informed decision.

The ARBOR project aims to develop regional strategies for optimising the energy potential of biomass. For example, demand for wood as a fuel for operational applications in the Province of West-Vlaanderen has been charted/described in detail and the potential of short rotation coppice has been tested in pilot projects on agricultural land and unused commercial plots in West-Vlaanderen.

http://arbornwe.eu/

arbor Biomass for Energy

The TWECOM project aims for sustainable valorisation of woody biomass derived from landscape management for local-scale energy production.

http://www.twecom.eu/

TWECOM Growing local energy

1 Selecting the biomass boiler

1.1. TYPES OF BIOMASS BOILERS

Biomass boilers should not simply be regarded as an equivalent for conventional boilers on fossil fuels. These technologies have some important differences in their application, and the user's awareness of these is essential.

For small-scale combustion, the current used types of biomass boilers are underfeed stokers and grate furnaces. Depending on the specification of the grate design, the incinerator type can be either a flat grate incinerator or a stepped grate furnace. These systems are illustrated in Figure 1. The rated output of each furnace type is listed in Table 1.

There are also other types of biomass boilers, such as log wood boilers. Such boiler types are not within the scope of this publication as they are not for non-household applications, and will therefore not be further discussed.

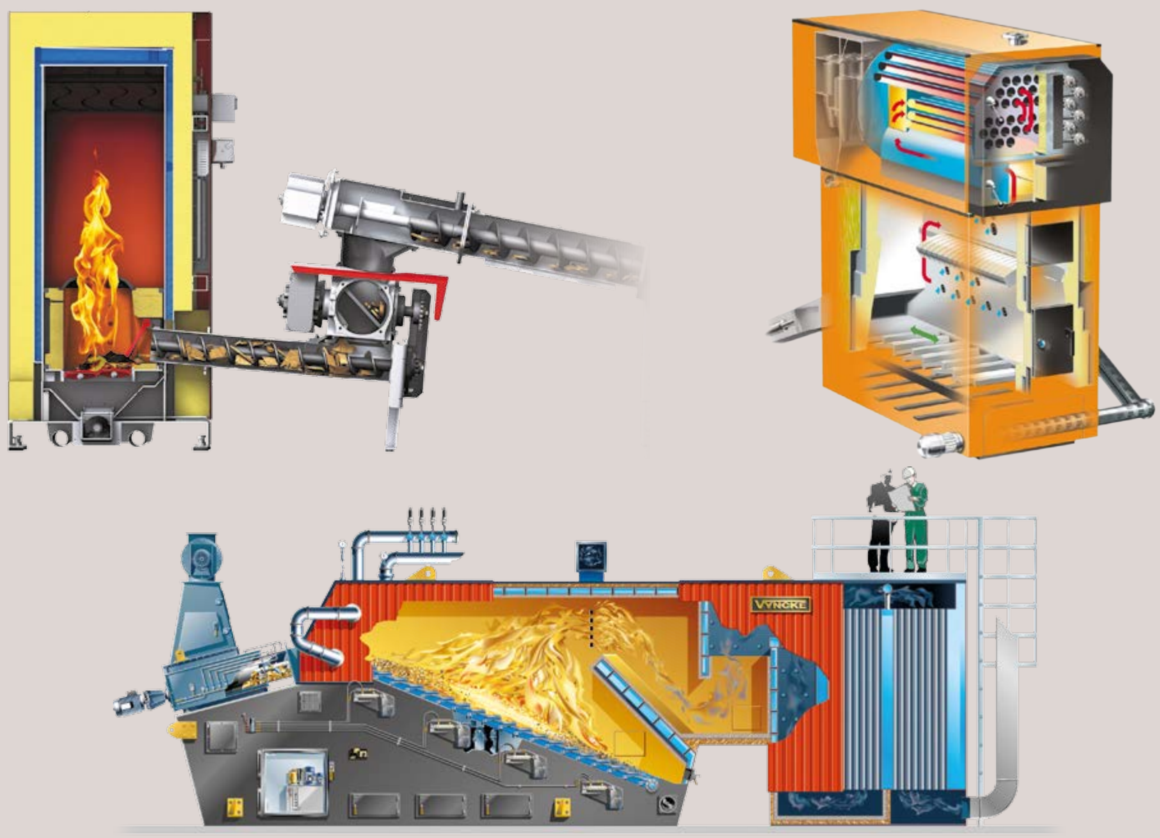


Figure 1: **Diagram representing an underfeed stoker furnaces (Hargassner, left), a flat grate furnace (Schmidt, Compte R., Uniconfort, right) and a stepped grate furnace (Vyncke, bottom).**

Underfeed stoker furnaces

This type of boiler is also referred to as an underfeed stoker.
It is based on an auger screw lifting the fuel from the bottom into the combustion chamber. After the fuel is burnt up, the ashes are carried to an ash container by an ash removal screw. This type of boiler performs well for high-end homogenous fuel types with limited fuel particle sizes and low ash content.
An underfeed stoker furnaces is generally used for boilers with a lower rated output. Boiler feeding is fully automated with autonomous operation from several days to several weeks, depending on the dimensions of the storage system. The cost of such systems is generally significantly lower than that of a grate furnace.


Figure 2: **combustion chamber in an underfeed stoker furnace**

Flat or horizontal grate furnaces

In a flat grate furnace, the fuel is conveyed from the side into the furnace with a horizontal motion of diagonally slanted grate elements. This motion allows for burning out the fuel in phases, allowing the fuel to be spread very homogeneous on the grate. Flat grate furnaces are slightly less flexible than the stepped grate furnace because of the requirements this imposes to the fuel, and are generally also used for smaller outputs. As with stepped furnaces, flat grate furnaces are capable of burning fuels of lower quality and higher ash content as the ashes are discharged quicker through the moving grate.


Figure 3: **combustion chamber in a flat grate furnace**

Stepped or diagonal grate furnaces

The fuel enters through the side of the furnace on a grate consisting of grate components in a stepped configuration. This mixes unburnt and burning particles, resulting in a homogeneous fuel bed on the grate. At the end of the steps, a de-ashing screw removes the ashes from the furnace. Due to the stepped grid, this furnace is less sensitive to particle size of the fuel in comparison with the flat grate furnace.
Generally, stepped grate incinerators are more expensive systems and are therefore often applied for larger outputs (> 500 kW).
The initial investment is high, but the fuel cost is lower as quality and calibration requirements of the fuel are not so high.
Grate furnaces are also fully automated with autonomous operation from several days to several weeks, depending on the dimensions of the storage system.


Figure 4: **combustion chamber in a stepped grate furnace**

Table 1: **Rated output and efficiency relating to the type of biomass boiler**

Boiler type	Characteristics of the biomass boiler	
	Rated output	Efficiency
Underfeed stoker furnace	25 kW - 25 MW	± 90%
Flat grate furnace	25 kW - 5 MW	± 90%
Stepped grate furnace	150 kW – 25 MW	± 90%

Which boiler to select?

The basic requirements that must be considered in selecting a biomass boiler are the required output, the resources available and the fuel characteristics. The specification of the basic requirements are different for each situation. Figure 5 shows the factors that influence the choice of incinerators.

Figure 5: **Factors determining the choice of biomass boiler** >

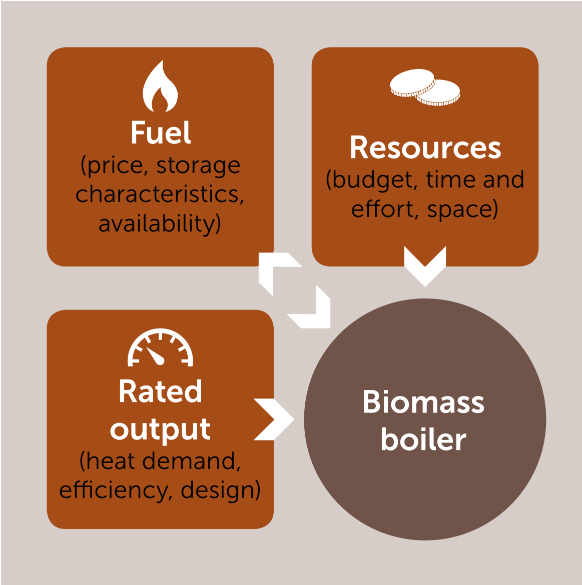


Figure 6: **Biomass boilers are available in many types and sizes**

Figure 7: **The boiler room can be combined with the storage room in a single or multiple heating container. This saves costs and space and is specifically designed for public and industrial buildings.**

1.2. RESOURCES AVAILABLE

The main resources required are the budget available, time and effort you are willing to invest to operate the biomass boiler and the space available for a boiler room.

Time and effort

Generally, a biomass boiler requires more monitoring than a fossil fuel boiler. The fuel silo must be filled from time to time, the furnace must be cleaned and the ashes must be extracted. The owner should decide on the time and effort that can be invested for operating the system.

Suitable place for the boiler

The space where the boiler will be set up can be determined in advance if there is an existing heating system. In such a situation, the space or utilities (pipes, cables) may have to be altered in order to ensure their suitability for the biomass combustion system. In the case of a new boiler room, other aspects can be taken into consideration, such as safety, accessibility, inserting a flue or chimney, fuel supply and storage.

THE FOLLOWING ASPECTS SHOULD BE CONSIDERED when selecting a suitable place for the system:

- The boiler is best placed as closely as possible to the fuel reservoir. This limits the distance to be covered by the supply system. The maximum distance is 6 to 8m. It also saves on cost and allows for less complex operations.
- The storage reservoir next to the furnace should be easy to refill (see 1.3 'Supply and storage')
- A ventilation shaft must be provided as an inlet of incineration air and as an outlet of residual heat and to guarantee a healthy and safe working climate. Furthermore, the ventilation system also serves to control the temperature in the boiler room (max 40 °C). The ventilation in the boiler room is subject to the same standards relating to technical and safety requirements as for conventional systems.
- The supply system carrying fuel to the incinerator and the system itself may make noise. If this is the case, noise protection measures must be implemented in order to prevent noise.
- The fire safety of the boiler room must be guaranteed. For more information relating to statutory requirements, please refer to the municipal authorities or the fire brigade.

Budget

Wood incinerator systems require a higher initial investment than analogous heating systems on fossil fuels. Sometimes, the additional cost can run up to four times the cost of a regular fuel oil-based boiler. When budgeting for a biomass boiler, also take the following aspects into consideration in addition to the initial investment:

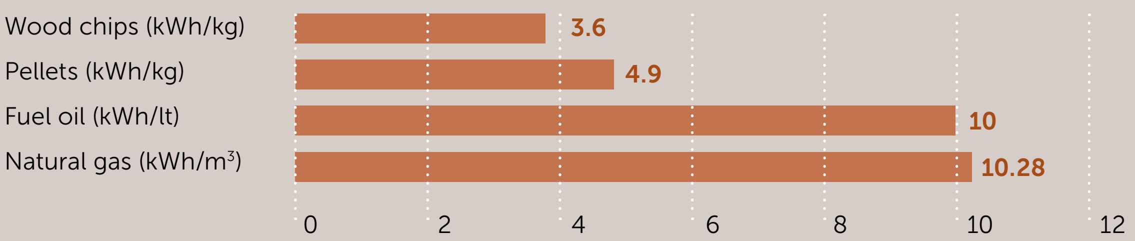
- fuel cost;
- subsidies;
- interior of the boiler room;
- cost of managing the system, including working hours and the cost of any emission measurements;
- cost of ash discharge.

1.3. BIOMASS FUEL

In general, by volume, the woody biomass has a thermal energy value (in calories) about 1/3 of fossil fuels (see Figure 8). This means a higher volume of fuel is needed for producing the same amount of heat. The biomass fuels that are suitable for combustion in a small-scale incinerator are wood chips, wood pellets and untreated and non-polluted wood waste. The main properties of these types of woody fuel are summarised in Table 2. In terms of their thermal energy value, wood pellets have a higher score than wood chips due to their higher density and lower moisture content. In turn, the thermal energy content of waste wood, for example from palettes or demolition wood, is generally lower than that of wood chips from the forest industry, for example. This is due to a significant amount of dry matter having been lost during the life span of the wood as a building material.

Figure 8: **Energy content of woody biomass compared with fossil fuels**

Value in calories



The energy content of 1,000 m^3 of natural gas or 1,000 of fuel oil is equal to that of 2 tonnes of pellets or 12 m^3 of wood chips.

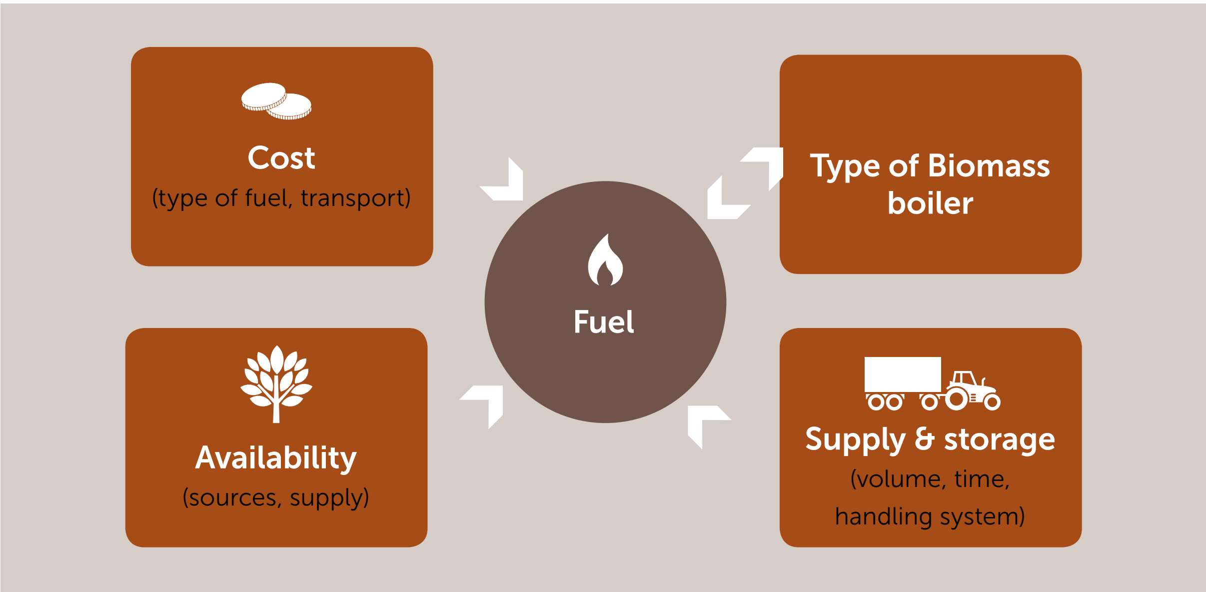
Figure 9: **Various types of biomass fuel:** (A) forestry chips without bark, (B) wood pellets, (C) forestry chips with bark (full chipped trees) and (D) untreated, non-polluted wood waste

Table 2: **Moisture content, bulk density and energy content of the various biomass fuels** (source: ISSO-Publication 108)

Wood type	Moisture content (%)	Bulk density (kg/m^3)	Energy content (kWh/m^3)
Wood chips	30	160 - 330	600 - 1100
Bark	50	320 - 500	750 - 1000
Sawdust	40	150 - 270	450 - 750
Sanding dust	15	170	717
Wood shavings	15	90	380
Pellets	<10	670	3000 - 3500

In the decision process, you are required to select a fuel type at an early stage. Figure 10 provides a flow chart showing the factors affecting the choice of fuel. The key factors to be considered are the cost and the requirements regarding supply and storage. Furthermore, the choice of fuel is also dependent on the choice of boiler type.

Figure 10: **Factors determining the choice of fuel**



Availability of biomass

It is important for the fuel to be readily available and to assure continuity in providing fuel supply. You may opt to select fuels from a sustainable origin, or fuels that can be derived directly from the environment.

Figure 11: **For planting short rotation coppice, frequent choices include poplar (left) and willow (right)**

Short rotation coppice

Short rotation coppice is the name for densely planted, fast-growing tree species, allowing for harvesting of all above-ground biomass every 3 to 5 years for energy production. The trees are harvested in winter, allowing for new shoots to grow in the following spring.

Willow and poplar are highly suitable for this purpose, as these are easy to plant as a cutting and grow quickly, although regional tree species can also be considered for use as short rotation coppice.

Cost of biomass

The cost of the fuel is determined by the fuel type and the transport. The effective thermal energy value (and thus the water content), together with the granulometry and the purity of the chips will determine the price.

The regular price of wood pellets is about € 145 to € 260 per tonne, which equals € 29 to € 52 / MWh. The prices of wood chips fluctuate between € 30 and € 120 per tonne depending on quality and moisture content, which equals about € 10 to € 30 MWh.

Figure 12: **Filling system with screws for supply of wood chips to the silo.**

Know what you buy

The thermal energy value in calories is determined by the moisture content and the density of the wood. There is little difference in the energy content per kilo between hard and soft wood types with similar moisture contents. However, the density between the wood types makes a major difference. This means that the energy content per volume unit can differ significantly. If the wood is sold per tonne, first ask about the moisture content. If the wood is sold per m^3, check the density of the wood you are buying. This way, you avoid buying water.

Supply and storage

Filling the reservoir can be done in various ways. If you have a basement silo, the chips can be unloaded directly into the reservoir with a cart or a walking floor. If the silo is at ground floor level or above, then the chips can be unloaded into a hopper with a horizontal and a vertical feed screw (Figure 12) to gradually transport the chips into the silo. If you have an articulated or telescopic loader, shovelling the chips over into the silo after unloading is also an option.

The required reservoir volume is mainly determined by the predicted wood consumption and the fuel delivery method. This means that there should at least be enough space for a single fuel delivery (generally 90 m^3) plus the maximum fuel consumption for one week. Depending on the

bulk density of the biomass, a bigger or smaller reservoir space will be required. Wood pellets are harder and denser than wood chips and therefore require less storage space (3 m^3 pellets = 10-12 m^3 wood chips). Sometimes, a second storage space is required to supply the main supply silo to the boiler, for example if the volume of a single delivery is larger than the silo volume.

In addition to the storage volume, the time required to fill this space is also a factor. Depending on the situation, you may select walking floor supply, a filling system with feed screws (wood chips) or blow-in system (pellets).

When designing the storage space, the following points of attention are relevant:

- Provide enough space for maneuvering to enable the desired supply method (for example tractor and trailer (30 m^3), walking floor (90 m^3), pneumatic delivery wood chips, etc.) when selecting the location of biomass storage. Some target values are set out in Table 3. The selection of ground level or basement storage is mainly dependent on the space available and the location of the boiler system.
- The requirements relating to fire safety of the storage space must be guaranteed. For more information relating to statutory safety requirements, please refer to an expert installation company.

Figure 13: **The biomass fuel can be stored in a basement reservoir or a silo at or above ground level.**

Table 3: **Guidelines for volumes supplied and the required maneuvering space to allow for the chosen supply method**
(source: Bioénergie promotion 2013)

Supply method	Total length (m)	Height (m)	Radius (m)	Load capacity (tonne)	Volume (m³)
Tractor and trailer	8 - 10	2 - 3.5	8	10 - 15	6 - 30
Rigid truck	7 - 9	3.8	8 - 10	19	30 - 40
Rigid truck with trailer	13	4	15	40	60 - 80
Trailer (walking floor)	11 - 15	3.8 - 4.4	15	38	70 - 100

Fuel required for the type of biomass boiler

The main characteristics to be considered when selecting a fuel type are:

- *Type of biomass:* most biomass boilers allow for some flexibility in the choice of fuel type [(1)]. For example, if you choose an underfeed stoker or flat grate furnace, you can use both wood chips and wood pellets subject to minor adjustments to the system.
- *Particle size:* Most small-scale biomass systems specify the use of biomass with a maximum particle size of G30 or G50 (see Table 4). The right particle size is important to assure smooth automatic feed of the boiler. The permitted variation in particle size depends on the feed system and the boiler type. In particular for underfeed stokers, the particle size of the biomass may not exceed the maximum dimensions, as the boiler is supplied with a feed screw, where the dimension is dependent on the boiler's rated output. If the fuel contains particles larger than the screw diameter, this can cause problems in the supply system. Also when the particles are the wrong shape, for example wedge shaped, the reservoir system may get blocked. Grate furnaces (in particular with a large rated output), on the other hand, are less sensitive to the particle size of the fuel due to a supply system with larger dimensions, and a walking floor and hydraulic hopper rather than a screw.

Table 4: **Composition and class limits of particle size in accordance with the Austrian standards (Önorm)**
(the fraction is always expressed as a percentage of weight)

	Fine fraction Max. 4%	Fine fraction Max. 20%	Main fraction 60-100%	Coarse fraction Max. 20%
G30	< 1 mm	2,8-1 mm	16-2,8 mm	> 16 mm
G50	< 1 mm	5,6-1 mm	31,5-5,6 mm	> 31.5 mm
G100	< 1 mm	11,2-1 mm	63-11,2 mm	> 63 mm

[(1)]Often it is technically feasible to use different types of biomass in biomass systems subject to minor adjustments. In theory, it is possible to switch over from pellets to wood waste. However, in practice, you will need to consider the fuel for which the environmental permit was granted, and any required technical modifications to the system due to any differences in the combustion pattern of the various fuels.

Table 5: **Composition and class limits of particle size in accordance with the European standards (EN 14961)**
(the fraction is always expressed as a percentage of weight)

	Fine fraction < 3.15 mm	Main fraction Min. 75%	Coarse fraction
P16A	≤ 12%	≥ 3,15 and ≤ 16 mm	100% < 31,5 mm and ≤ 3% > 16 mm
P16B	≤ 12%	≥ 3,15 and ≤ 16 mm	100% < 120 mm and ≤ 3% > 45 mm
P31,5	≤ 8%	≥ 8 and ≤ 31,5 mm	100% < 120 mm and ≤ 6% > 45 mm
P45A	≤ 8%	≥ 8 and ≤ 45 mm	100% < 120 mm and ≤ 6% >63 mm
P63	≤ 6%	≥ 8 and ≤ 63 mm	100% < 350 mm and ≤ 6% >200 mm
P100	≤4%	≥ 16 and < 100 mm	100% < 350 mm and ≤ 6% >200 mm

- *Moisture content:* burning wet wood has a negative impact on the thermal energy value of the fuel and we strongly advise against it. The heat used to evaporate the moisture in the wood will be lost. Every 5% of moisture content in wood will will give loss to a similar quantity of energy. If wood is combusted at 45% moisture content, 15% to 20% of the energy is lost to evaporate the water compared to burning dry wood (see Figure 14).
- *Ash content:* if the furnace has a continuous discharge mechanism for ashes (such as grate furnaces), fuels with high ash content (up to 50%) can be used. If ash discharge is not continuous, the ash content should preferably be below 3% (such as for underfeed stokers). High-ash content flows (ash content above 25%) such as bark or root wood cannot be combusted in an underfeed stoker furnace because the ashes reach too high temperatures, with slag formation as a result. In a grate furnace, these can be applied because the ash residues are discharged on time by the moving grate. The ash content of wood chips from forestry and landscape management, and short rotation coppice, is generally around 1.5%, which makes them more suitable for application in underfeed stokers.

The requirements of fuel for use in the various furnace types are summarised in Table 6.

Figure 14: **Impact of the moisture content on the value in calories of woody biomass**

Table 6: **Fuel types for different furnaces**

	Fuel type	Moisture content (%)	Ash content	Particle size
Underfeed stoker furnace	Wood chips, dry untreated wood waste, wood pellets	20 - 30%	< 3%	> 3 x 3 x 1 cm [2]
Flat grate furnace	Wood chips, dry untreated wood waste, wood pellets	25-35%	< 10%	3 – 5 cm
Stepped grate furnace	Wood chips, fresh untreated wood waste (for example branches, bark)	25 - 50%	Not limited	3 - 30 cm

[2] The specifications of the biomass system are based on either the Austrian Önorm or the European standard for solid biofuels EN14961. For underfeed stokers generally P31,5 (EN14961) or G30 (Önorm 7133).

1.4. RATED OUTPUT OF BOILER

The dimensions of a biomass boiler must be determined very precisely depending on the existing or forecasted heat demand. Oversizing leads to higher initial investment costs and increased emissions of hazardous substances. To correctly determine the required nominal capacity, it is best to ask an expert installation company or supplier.

Heat demand

The total heat demand consists of simultaneous demand for heating spaces, hot water, process heat and unintentional heat loss during transport and distribution. Heat demand can be determined based on statistics relating to energy consumption or performing a heat loss calculation.

- *Heating of spaces:* This is the heat required for heating offices, housing units and buildings or greenhouses. The intention of the heating system is to compensate the heat loss in the building in order to achieve the required indoor temperature. Heat losses are incurred due to transmission of heat through the shell of the building, due to ventilation of the building and infiltration (i.e. unintentional ventilation through holes and gaps).
- *Sanitary hot water:* demand for heat is determined by the required hot water volume.
- *Process heat:* For agricultural firms and companies, the biomass boiler may also have to provide heat for the production process, for example heating water to dissolve milk powder for calves and piglets. This type of heat demand must be considered individually.
- *Unintentional heat losses:*Heat losses can be incurred due to poorly insulated piping or radiation and convection losses near the furnace. *Additionally, some heat losses may be incurred that are specific to the sector, for example dust and mist extraction in sawing mills and spraying plants respectively.*

In addition to total heat demand, the dynamics in heat demand are important to consider. These are caused by:

- variations in solar radiation (winter versus summer);
- equipment or animals producing heat;
- presence of persons or animals.

In order to allow for these dynamics, it is important to match the heat transport and heat outlet system to the biomass boiler's characteristics as closely as possible.

Output

The optimal size of the boiler must be determined individually. The reasoning is often incorrectly, when parties want a bigger size boiler than required in order to always be certain to produce enough heat when heat demand is high. The risk is, however, that if less heat is required frequently, the required output will fall below the minimum partial load. This means the boiler will switch off. As the number of full load hours of the system are low in such a scenario, the capital cost will be high compared to the total annual cost of the system. A smaller system is generally more expensive per kW of installed rated output, but will produce more full output hours and can also be used during times of lower heat demand, optimising the system output.

For optimal economic return on investment, the rule of thumb is that the boiler should run at least 3,500 full rated output hours under central European wheather conditions, i.e. being operational 1/3 of the year. This corresponds with a boiler with a rated output of about 65% of peak demand. For example for a 100 kW boiler, consumption should at least be 350,000 kW. If you need less, your profit on fuel oil saved is too low and the pay-back period is too long.

Bivalent configuration

In order to avoid the boiler from often running partial load, the boiler can be placed in a bivalent configuration with a heat buffer. Read more about the application of a buffer vessel under 2.3 'Configuration of the heating system' (p. 29).

Figure 15: **Buffer vessel in bivalent configuration with the biomass boiler.**

Cascade configuration

Heat demand does not necessarily have to be covered by a single boiler. If heat demand shows strong fluctuations or a discontinuous profile, you may choose to install a combination of boilers. This means you have a choice of combining biomass and fossil fuels, or a combination of more than one biomass boiler. If heat demand is fairly continuous and sufficiently high throughout the year, most will chose a combination of biomass boilers. Only in the event of fairly continuous heat demand combined with short-time peak demand, or in the event of very limited discontinuous demand outside the heating season, or where sanitary hot water should also be produced, the obvious choice would be a combination of biomass and a fossil fuel boiler.

Deploying a parallel combination of boilers has the following benefits:

- The minimum rated output supplied is lower for a combination of more than one biomass boiler with a lower capacity than when using a single large biomass boiler. This allows you to cover smaller heat demands, avoiding partial load performance.
- The combination with a fossil fuel system can significantly decrease the investment cost in some cases, as the cost per kW for such systems is far below biomass systems, and the additional cost of fuel oil is limited due to short-term use during peak demand;
- The second boiler can serve as a back-up system, increasing operational continuity and limiting downtime and losses when the other boiler breaks down.
- Outside the heating season, when heat is only sporadically required, using a fossil fuel system is easy to supply heat or sanitary hot water.

Figure 16: **Configuration of biomass boilers in cascade configuration.**

DECISION: **WHICH TYPE OF BOILER TO CHOOSE?**

Making the right choice of biomass boilers is a complex process, and a range of factors must be considered. The optimal system is different in each situation. The main issue is to ensure the correct dimensions of the system (i.e. not too large in order to avoid running at partial load) and to ensure a perfect match between biomass, supply system and furnace. If using unsuitable biomass, the system will never show optimal performance.

2 Reducing emissions

2.1. THE COMBUSTION PROCESS

In order to understand how emissions arise and how to avoid these, it is essential to understand the combustion process in a biomass boiler.

Combustion consists of a number of consecutive phases, during which complex chemical and physical reactions take place. Essentially, a solid substance is combusted by adding oxygen, releasing carbon dioxide (CO_2) and water (H_20). The different phases are explained in further detail in Figure 17.

Optimising the different steps in the combustion process allows for limiting the emissions and achieving optimal boiler output. For wood combustion, the net CO_2 emissions are significantly lower than fossil fuel furnaces (Figure 18).

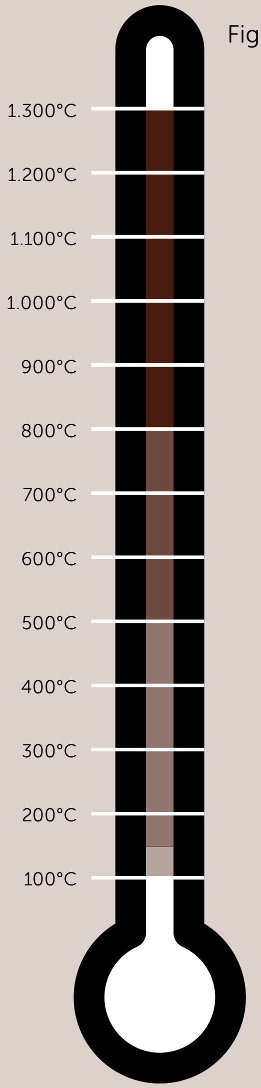


Figure 17: **Various phases in the combustion process of a biomass boiler**

4 **Combustion of gases**

When temperatures are even higher (400-1,300 °C) and in the presence of oxygen, full oxidation of the biomass ensues, in which the carbon chains are fully converted into carbon dioxide (CO_2) and water (H_2O). During this process, heat is released with combustion of the volatile components (at a temperature of 500-600 °C), and subsequently the solid carbon will oxidise (at a temperature of 800-900 °C) until only ash residues remain.

3 **Gasification of biomass**

At higher temperatures (500 - 800 °C) and in the presence of oxygen, further thermal degradation of the biomass ensues, in which the carbon chains are converted into carbon oxide (CO), carbon dioxide (CO_2) and water (H_2O), CH_4 and other hydrocarbons.

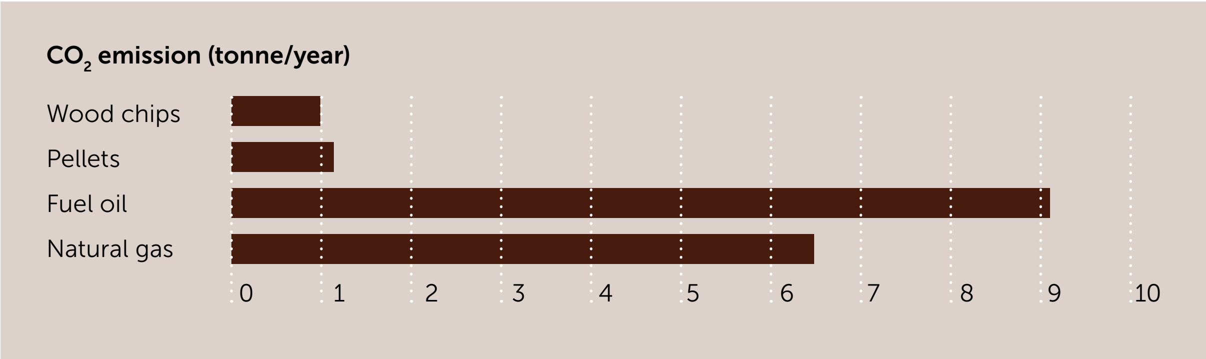
2 **Pyrolysis of biomass**

At higher temperatures (150 - 500 °C) and in the presence of oxygen, further thermal degradation of the biomass follows, in which the long carbon chains decompose into tar, charcoal, CO and CO_2.

1 **Drying of biomass**

The moisture present in the biomass evaporates at low temperatures (100 - 150 °C). The evaporation of water uses energy derived from the heat in the combustion chamber. Depending on the moisture content, the incineration process is slowed to some extent.

Figure 18: **Net CO_2 emissions**
on the full fuel life cycle at an annual energy consumption rate of 27,000 kWh (this is equal to heat demand for a liveable surface of 220 m^2).



Complete combustion

A complete combustion process mainly forms CO_2 and H_2O, converted a maximum of fuel into thermal energy. Incomplete combustion converts only some of the fuel into thermal energy. Furthermore, in addition to CO_2 and H_2O, other undesirable gases arise that are hazardous both to humans and the environment. The emission of black smoke from a chimney is a visible sign of incomplete combustion. Proper configuration of the incineration process is therefore a key requirement to maximise the thermal output of the biomass.

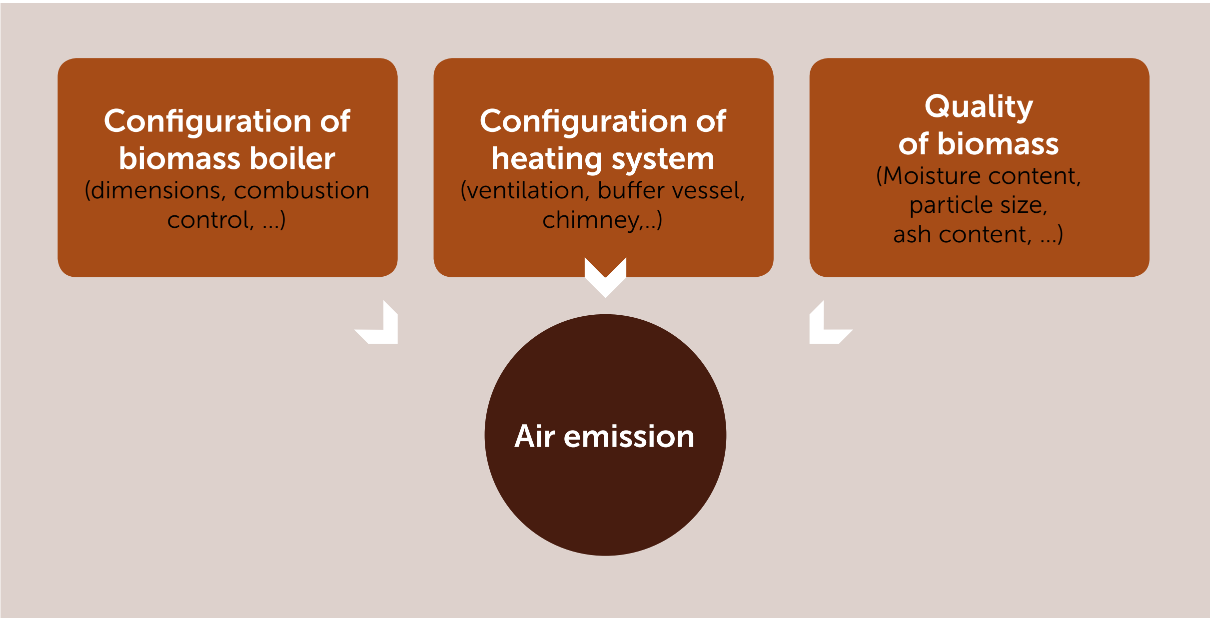
Oxygen supply is the key factor in the incineration process. Once oxygen is sufficiently present, temperature is the key factor. Furthermore, the mixture of the fuel and oxygen and the processing time of the combustion gases in the furnace chamber are important factors.

Hazardous substances

Wood combustion causes besides water vapour (H_2O) and carbon dioxide (CO_2), and emissions of fine dust particles, nitrogen oxides (NO_x), dioxins and other hazardous substances. However, if combustion is incomplete, or if the fuel is of inferior quality, some of these hazardous substances may arise in higher concentrations, and the flue gases may then also contain carbon monoxide (CO), volatile organic compounds (VOC) and polyaromatic hydrocarbons (PHC). Some of these substances are very harmful to the environment (acid rain, greenhouse effect) and human health (carcinogens).

In order to limit emissions of such hazardous substances, complete combustion must be the goal. Both the configuration of the full heating system and the individual furnace and the biomass quality play a key role in this respect. This is indicated in the flowchart of Figure 19.

Figure 19: **Factors determining the emissions of a biomass boiler**



2.2. CONFIGURATION OF THE BIOMASS BOILER

Taking into account some straight-forward guidelines, emissions can be limited by selecting the right biomass boiler:

- *Correct dimensions* for the relevant heat requirement is very important. As stated previously in 1.4, oversizing the boiler results in having the boiler running on partial loads, increasing emissions of fine dust particles and CO.

- As the quality of woody biomass is less constant than standardised fuels such as fuel oil or natural gas, it is important for the system to be equipped with an *electronic lambda sensor* (see Figure 20) .This serves to adjust the supply of air and fuel to the fuel quality. Not enough oxygen results in incomplete combustion, leaving a mixture of hydrocarbons still to be burnt. This is why every controlled combustion process is adjusted with excess oxygen. For this control, an oxygen meter is placed in the gas flue to measure a few percent of residual oxygen. If the oxygen percentage is too low, air is added. If the oxygen percentage is too high, the quantity of air is decreased. If the percentage of residual oxygen is sufficient, excess CO and therefore extra soot are avoided.

Figure 20: **An electronic lambda sensor controls the quality of the combustion process.**

The additional benefit is higher energy efficiency. If there is too much air, the excess air must be heated, which is wasting energy. This way, the boiler is always running on the required output with optimal combustion.

- Choose for *staged combustion* (primary and secondary air supply). A biomass boiler equipped with a two stage combustion process with injection of primary air in the fuel bed and secondary air in the combustion chamber ensures 30 to 40 percent less NO_x emissions. Due to the lower flame temperature and with limited presence of O_2 in the fuel bed, the NO_x that forms is reduced

Figure 21: **Automatic cleansing of the heat exchangers based on spirals (left) or compressed air (right).**

into N_2 gas. The higher temperatures and excess oxygen due to secondary air supply ensures complete combustion.

- *Forced ventilation* guarantees adequate mixing of fuel and oxygen, as air circulation is not dependent on weather conditions this way. Adequate mixing results in complete combustion, preventing undesirable harmful emissions from arising.
- An *automatic cleaning system* of the heat exchanger ensures that the boiler stays cleaner, which means less fly ash is carried on the flue gases (Figure 21).

2.3. CONFIGURATION OF THE HEATING SYSTEM

Taking into account some straight-forward guidelines during the configuration of the heating system, emissions can be limited by selecting the right biomass boiler.

- Check if the biomass boiler should be equipped with a *buffer vessel*, taking into account a turn-down ratio of 3:1 (see text box). A buffer vessel can be used for storing excess heat from over-production if heat demand is smaller than one third of the rated output of the boiler, or for covering for a short-term peak in heat demand exceeding the boiler's rated output. The following example is for a boiler with a rated output of 300 kW. For this boiler, the minimum partial load is 1/3 x 300 kW = 100 kW. If heat demand drops below 100 kW, the boiler will either switch off or store excess heat in a buffer vessel. Some or all of the stored heat can then be released depending on subsequent heat demand. This avoids having the boiler run on partial load for a long time. On the other hand, if heat demand increases, exceeding 300 kW, for example 350 kW, this extra 50 kW can be supplemented using the excess heat stored in the buffer vessel. This way, a higher output than the rated output of the biomass boiler can be delivered for a short time.
- Additionally, there are various serial connection methods for *flue gas cleaning*. These methods are used to remove the hazardous substances from the flue gases before being blown into the environment. Depending on the substance to be removed, other methods can be deployed. In order to remove fine and coarse dust particles from flue gases, cyclones or multi-cyclones (efficiency 60-90 %), cloth filters (efficiency 99%) or electrostatic filters (efficiency 95%) are often used. The two latter methods are very expensive and are applied only for combustion systems with a rated output of 5 MW. Please note that flue gas cleaning is not normally necessary if burning wood pellets or wood chips.

Turn down ratio

The minimum partial load under which acceptable combustion output can be realised is determined using the ratio between the lowest and highest rated output. This is referred to as the turn down ratio. For wood chips systems, this is generally 3:1 or 33%; for pellet-based boilers this is generally 4:1 or 25%. This means that the biomass boiler switches off automatically when heat demand drops below this critical value.

2.4. FUEL QUALITY

Fuel quality has a clear impact on performance of the system (certainly relating to fuel supply to the furnace), the combustion process efficiency and emission of hazardous substances. A biomass boiler is not a multi-burner. Burning fresh organic waste will give rise to higher emission of NOx, dioxins etc., and corrosive flue gases that may significantly reduce the economic life of the system.

A number of quality standards are being developed for biomass quality (for example EN14961). However, application of these standards is not yet mandatory when trading biomass fuel. Actually these standards are rather used by biomass suppliers to indicate the quality. As a customer / buyer, you can apply these standards for assessing the quality of the fuel supplied. The key criteria of the biomass fuel defined based on this standard that have an impact on the emissions are: particle size, moisture content, ash residue content and the presence of impurities.

Particle size

If the fuel consists of too many fine dust or particles, this will cause high emissions of fine dust. For more information relating to the various particle size classes, please refer to Tables 4 and 5.

Moisture content

It is recommended to use biomass with a moisture content within the limits of the specifications indicated by the biomass boiler manufacturer. The fuel may not be too wet or too dry. If moisture content is too high, this will lead to *incomplete combustion*, causing hazardous substances and tar to be generated. The tar will come settle the heat exchangers, reducing efficiency of the biomass system.

On the other hand, combustion of wood that is too dry will also have a negative impact on the combustion process. If moisture content is too low, this will lead to accelerated combustion, raising the temperature in the furnace chamber too high. A possible result is higher emissions of NO_x and melting ashes (developing slag). If wood that is drier than 20% moisture content is frequently burned, you are advised to select a boiler with flue gas recycling in order to decrease the flame temperature.

Ash content

The ash content affects the emission of hazardous substances, and also the efficiency of the incineration process. The quantity of ash is a factor (2-4% ends up in the chimney) and also the ash composition. The composition also determines the melting point of the ash. Fuel with a low ash melting point increases the risk of break-downs of the system, causing a sub-optimal incineration process.

Nitrogen content

NO_x emissions for biomass combustion in small-scale systems are mainly dependent on the nitrogen content in the fuel and are generally between 300 and 500 mg/Nm^3 (Table 6). This is why it is sensible to use woody biomass with low N content and frequently monitor the nitrogen content of the fuel. If the biomass is derived from in-house biomass crops such as Miscanthus and short rotation coppice, extra attention of the N content is recommended. This can be taken into account by limiting fertilisation.

Table 7: **Connection between the nitrogen content in the biomass and NO_x emissions.**
(source: bioénergie international n° 31 May-June 2014)

N-content of biomass	NO_x emissions
< 0,1 - 0,2%	208 - 375 mg/Nm^3
0,2 - 0,4%	375 - 525 mg/Nm^3
0,4 - 0,6%	< 600 mg/Nm^3

Impurities

Sulphur oxides (SO_x) can also be created during the incineration process. SO_x emissions are directly related to the sulphur concentration of the fuel. In pure wood, these concentrations are often very low. Combustion of treated wood can result in increased SO_2 emissions. Other impurities in biomass, such as heavy metals, are usually found in very low concentrations in natural wood, and are therefore not a problem in the incineration process and emissions.

DECISION: **HOW TO REDUCE EMISSIONS**

Limiting emissions is a combination of correctly selecting and configuring the combustion boiler and selecting high-quality biomass. The emission of hazardous substances is often a result of incomplete combustion, affecting both the environment and the boiler. The lower the combustion level, the quicker the boiler is polluted and the shorter its life span.

3 Maintenance and management

3.1. PROCESS CONTROL

The following process parameters can be monitored in order to detect any break-downs in due time:

- *Flue gas temperature:* an indicator of pollution of the heat exchangers due to ash sediments is the flue gas temperature running high due to reduced heat transfer. If this is the case, the boiler should be switched off in order to manually remove the ashes from the furnace chamber and the heat exchanger.
- *Excess air ratio:* this is a measure of the quantity of air that is supplied to the combustion process in comparison with the minimum quantity of air required for full oxidation of the fuel. If too low, not enough oxygen is available for incineration. Ideal values for excess air ratio are 1.4 to 1.6. The secondary air supply to the furnace chamber must be increased. The excess air ratio for primary supply should ideally be 0.7.
- *Rounds per minute of flue gas fan:* if the RPM are higher than usual, the vacuum in the boiler is not adequate. This may be a result of blockage in the furnace, the chimney or measuring sensor, a broken seal or ash piling up in the heat exchanger.
- *Rated output of the boiler:* if the output is too low, there are probably problems with the hydraulic system (for example circulation pump), the fuel's moisture content is too high or the energy content is too low. It may be necessary to replace the circulation pump or to buy a higher quality biomass.
- *Slag formation:* if excess slag is developing, this indicates that the incineration system is not properly adjusted to the biomass used, for example if the system is adjusted to wood chips with a higher moisture content than effectively used, or if biomass with a low ash melting point is used. The furnace temperature is often also too high (above 900°C) and the ratio between primary and secondary air is often not adjusted properly.

Figure 22: **Slag formation**

- *Emissions of flue gases:* if the emissions have significantly increased or if excessive smell is detected, the combustion is inadequate. This can be resolved by readjusting the incineration process, cleaning the boiler and checking the fuel quality.
- *Supply and return temperatures:* if the heat demand suddenly decreases, the boiler is unable to release the residual heat and the boiler will start overheating. Eventually, the thermostat will set to safety. This can be resolved by reducing fuel supply or storing the excess heat in a buffer vessel.

3.2. DISCHARGE OF COMBUSTION ASHES

Ashes generally arise in two places in the incinerator system, so that we can discern the following types of ashes:

- *Bottom ash:* arises in the furnace and comprises 60 to 90% of the total ashes in the biomass. This ash can pile up under and around the combustion grate.
- *Fly ash:* these are combustion ashes that pile up near the heat exchanger, reducing heat transfer.

Discharging these combustion ashes is a key component of biomass boiler operations, as excess combustion ashes can lead to break-downs of the incineration boiler and to increased operational cost. If the boiler is equipped with serial flue gas cleaning systems, ashes may pile up here too. Depending on the technologies used, we discern:

- *Cyclone fly ash:* if a pre-separator for dust particles is built in, ashes can develop at the end of the furnace near this multi cyclone and may comprise 10-35% of the total ashes in the biomass.
- *Filter fly ash:* if an electrostatic filter or cloth filter is present, ash drop out will develop near this filter. The quantity of filter fly ash can run up to 1 -10% of the total ash in the biomass.

In most boiler systems, automatic de-ashing of the furnace takes place through a feed screw system and automatic cleaning of the heat exchangers. If this concerns vertical heat exchangers, turbulators or spirals are used; compressed air is used to clean horizontal heat exchangers (Figure 21). The ashes then enter one or more (dust-tight) ash containers that are located in the immediate vicinity of the boiler or boiler room. If both bottom ash and filter ash are collected, it is important to check if these ash fractions can be discharged together or not.

Figures 23 and 24: **Ash container and discharge of ashes through a feed screw.**

3.3. MAINTENANCE SCHEDULE

A biomass boiler requires more attention than a boiler running on fossil fuels in terms of maintenance and management as these boilers are more prone to break-downs. Steps for inspection, maintenance and resolving breakdowns can normally be found in the manual supplied by the manufacturer of the boiler. In order to prevent and detect problems with the system in due time, it is recommended for the owner to personally inspect and maintain the incineration process frequently. Furthermore, the owner should also have the boiler maintained as set out in legislation, observing the supplier's instructions.

What to look for when selecting your installation company?

Biomass is not a standardised fuel such as fuel oil or natural gas. This is a demanding fuel, both in relation to handling and the combustion process. If this is duly considered, you will be rewarded with a system providing optimal efficiency, low ash development and long life span. Please consider that you will have to carefully control the operation of the incineration systems, and that the system will have to be adjusted frequently. Support by an expert installation company is highly recommended, and this is best duly considered when selecting your supplier / installation company. Verify if a certification system for installation companies, proving the necessary competences to design and realise wood boilers, is applicable in your country or region. Anyhow, it is advised to approach an installation company with extensive experience in installing biomass boilers.

Maintenance schedule	
Weekly	Inspection of the quality and quantity of the fuel Inspection of the process parameters as listed in 3.1 Inspection of the ash discharge, replace the ash containers in due time Inspection of the furnace chamber for any irregularities Inspection and cleaning of the sensors (among others to measure the pressure) Cleaning the boiler to remove any piled-up ashes and dust. Depending on the system and intensity of use, the ash is automatically discharged from the combustion chamber. If this is not the case, the ashes must be manually removed from on and under the grate and in the furnace chamber. Cleaning the optic detectors in the fuel supply (if supplied by a walking floor)
Monthly	Cleaning the heat exchangers It is also possible to equip the boiler with automated outlet pipe cleaning of the heat exchanger, allowing for a significantly lower frequency of manual cleaning.
annually or every 6 months	Maintenance of the boiler by the supplier / installation company. This concerns a general inspection of the system and if necessary replacement of parts sensitive to wear and tear, such as the lambda sensor, pressure sensors, screws, filters and seals.

DECISION: **HOW TO MAINTAIN AND MANAGE THE BOILER?**

If the system is working properly and is equipped with a lambda sensor, manual adjustment of the boiler is generally not necessary. The boiler must, however, be cleaned in order to ensure continued optimal performance. Based on some simple checks, you can monitor the quality of the incineration process. In the event of any irregularities, please notify your installation firm.

Thank you

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[3] ARBOR's mission is encouraging an innovative, sustainable plan for generating energy from biomass in North Western Europe (NWE). The regions in which the partners are active are: Flanders, German, Luxembourg, United Kingdom, Ireland and the Netherlands. Arbor receives support from the European Fund for Regional Development through Interreg IVb, the Flemish Energy Agency (VEA), Business Agency and the Provinces of West-Vlaanderen, Oost-Vlaanderen and Vlaams-Brabant.

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