Promoting the penetration of agrobiomass in European rural areas

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Agrobiomass fuels and utilization systems

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Abbreviations

a.r.	As received
CHP	Combined Heat and Power
d.b.	Dry base
ESP	Electrostatic Precipitator
SNCR	Selective Non-Catalytic Reduction
SCR	Selective Catalytic Reduction
SRC	Short Rotation Coppice
OGC	Organic Gaseous Compounds
PM	Particle Matter

Project consortium

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2	Fundación Centro de Investigación de Recursos y Consumos Energéticos	CIRCE
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10	Bioenergy Association of Ukraine	UABIO
11	White Research Sprl	W.R.
12	Agronergy	AGRONERGY
13	Association d'Initiatives Locales pour l'Energie et l'Environnement	AILE

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Executive Summary

Agrobiomass is widely available from various origins and in various forms all over Europe. For most of them, the fuel properties of agrobiomass are more challenging than those of woody forest biomass. As a result, their utilization require the use of specific, tailored made systems that take into account these peculiarities. Such systems are already market-available and can be used in modern agrobiomass heating applications.

Regarding the main components of a biomass heating plant, the following considerations for the main sub-systems should be taken into account for agrobiomass:

- Fuel feeding: automatic feeding is a significant feature for almost all modern biomass heating application. Depending on the physical form in which agrobiomass is delivered at the facility, different options, from feeding screws to moving floors and automatic lines for straw feeding / cutting can be set.
- Combustion: moving grate systems are the current state-of-the-art for agrobiomass combustion, enabling good mixing of air and fuel and ensuring high levels of burnout. Gasification concepts for small-scale agrobiomass systems is another upcoming technology.
- Heat exchanger: frequent and appropriate cleaning of the surfaces is required in order to deal with the higher level of deposits from agrobiomass combustion.
- Ash removal: higher levels of ash content require more frequent ash cleaning and appropriate ash disposal methods.
- Control systems: a novel feature of modern biomass heating solutions, an appropriate control system can lead to improved efficiency, reduced emissions as well as overall user experience and convenience.
- Flue gas cleaning: depending on the regulatory requirements and limits, appropriate solutions can be employed for control of dust, NOx or acidic gases emissions.

Introduction

The present document constitutes Deliverable 4.2 “Systems for agrobiomass utilization” of the AgroBioHeat project, prepared in the framework of Task 4.1 “Technological state-of-the-art and trends”.

The report summarizes in a condensed form information on modern, efficient, reliable and clean technologies for agrobiomass heating in small sized facilities.

The report has two main sections. The first one provides an overview of the technological systems and sub-systems used for agrobiomass heating applications: fuel feeding, combustion, heat exchangers, control systems ash removal and flue gas cleaning systems. The second one focuses on the most common agrobiomass fuels and provides information on their main tradeable forms, typical fuel properties and others.

The report is complemented by a series of nine factsheets - two on equipment components (state-of-the-art combustion systems, flue gas cleaning systems) and seven for different agrobiomass fuels (miscanthus, nut shells, olive stones, prunings, SRC, straw, sunflower husks). These factsheets further summarize the information contained in the deliverable for the benefit of external stakeholders and for use in communication purposes. The factsheets will be translated in the main project languages (Croatian, French, Greek, Romanian, Spanish and Ukrainian) depending on the market needs of each country.

A 2nd version of this report will be made available in the second half of 2021, providing additional information on both agrobiomass heating systems and fuels, based on feedback from equipment manufacturers, fuel producers, results from the AgroBioHeat project (e.g. combustion tests) and others.

1. Technologies for agrobiomass heating

Biomass combustion may be used to provide heat in a boiler, for heating and air conditioning at household or single building level, for larger scale applications (greenhouses, industries, district heating network) or in a power cycle for Combined Heat and Power (CHP). Whatever the application the general process is always the same; feedstock is burnt, flue gases flow into a heat exchanger providing heat to a working fluid, cooled gases are conveyed to the emission abatement section and finally reach the stack and are released to the atmosphere.

As it is further analysed in Chapter 2, solid agrobiomass fuels are in general considered to be more "difficult" in terms of their combustion behaviour compared to woody biomass from forestry. This poses a challenge for boiler manufacturers to achieve high efficiencies and low emissions with these fuels. Even though biomass boilers with more simple technologies like fixed grates for example may not be suitable for agrobiomass heating there are many modern state-of-the-art boilers that are designed taking into account agrobiomass fuel peculiarities from the fuel feeding system, over the combustion system to the flue gas cleaning equipment.

When choosing a suitable boiler for agrobiomass combustion each boiler subsystem – feeding systems, combustion system, heat exchanger, ash removal system, control system and flue gas cleaning system- has to be compatible with the specific biomass's properties.

1.1. Fuel feeding

Most modern biomass boilers include an automatic fuel feeding line. Depending on the form the agrobiomass is available in the market and how it is stored, different feeding systems may be required. The most common fuel feeding systems used in agrobiomass heating applicationsare presented below.

1.1.1. Feeding systems for granular fuels / pellets

Many agrobiomass fuels are marketed either as granular fuel, like olive stones, or as densified materials such as agropellets. The granularity of these fuels and the relatively homogeneous character makes feeding to the boiler a relatively simple job. The following options are available:

- Feeding screw either rigid or flexible. Feeding screws are recommended for relatively fine and clean biomass fuels with well-defined particle sizes as they are sensitive to metal and mineral impurities in the fuel. One of the main advantages of using a feeding screw is that it is an inexpensive solution. In order to completely empty the fuel storage rooms, side ramps are recommended.
- Feeding screw with agitator: used for a more efficient utilization of the storage room, without the need for sloping floor.
- Suction system and feeding screw: suitable for longer distances from the storage room to the boiler.

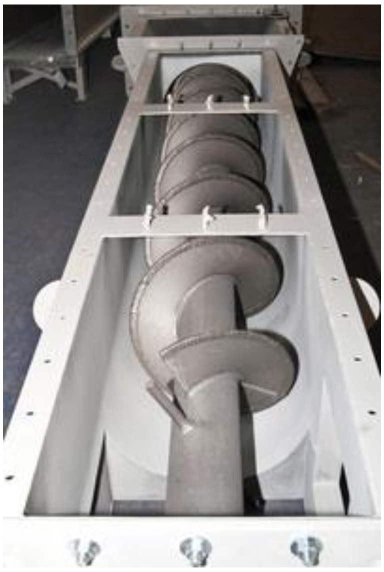

Figure 1: Feeding screw [Image source: BIOMASS MAGAZINE[1]]

1.1.2. Feeding systems for chips / hog fuel

Agrobiomass that is available in the form of wood chips or hog fuel – as is the case with Short Rotation Coppice or prunings – is still granular but less homegeneous and requires more robust feeding systems. The following systems may be applied:

- Discharge agitator with screw: a robust agitator with heavy duty gearing ensures reliable fuel transport.
- Hydraulic walking floor : robust and versatile system designed for transferring coarse material

Figure 2: Agitator system [Image source: HERZ[2]]

[1] http://biomassmagazine.com/articles/10845/all-the-right-moves
[2] https://www.herz-energie.at/

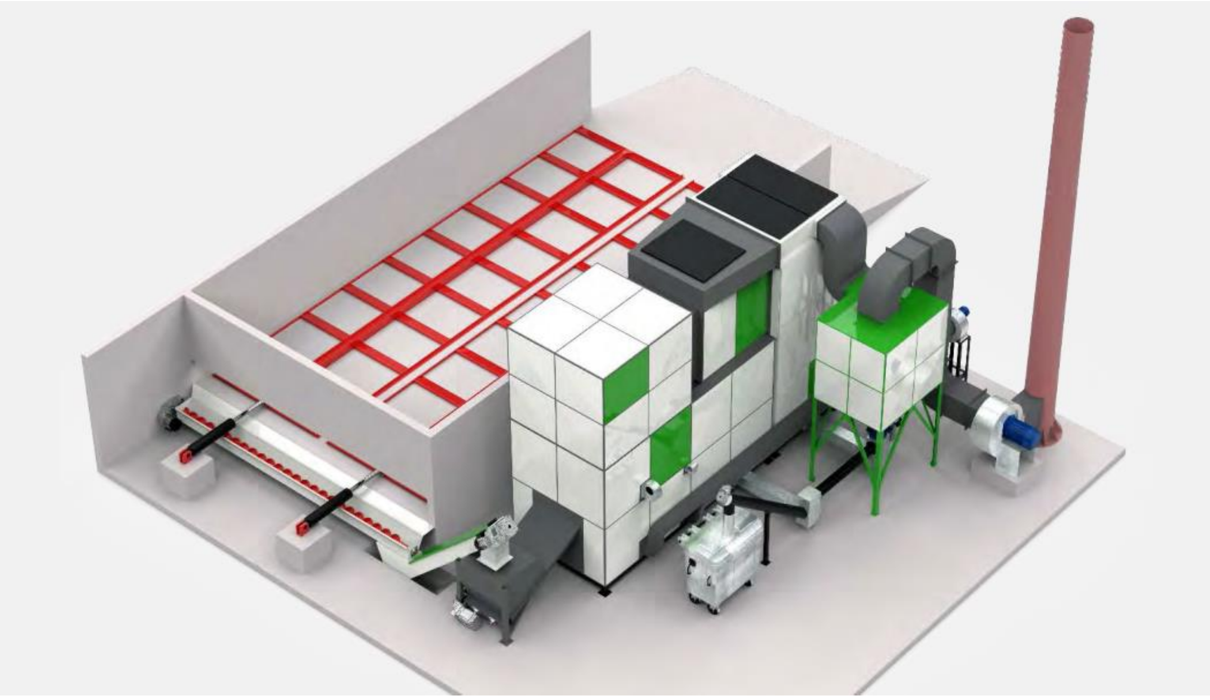

Figure 3: Biomass heating installation with walking floor feeding [Image source: Camino Design / PelleTech[3]]

1.1.3. Feeding systems for whole bales

If the agrobiomassis available in the form of bales (most commonly for herbaceous biomass like straw or miscanthus) one of the following solutions may be applied:

- Bale pusher with hydraulic piston, or
- Bales travel on a feed conveyor to a shredder and then to the boiler via a feeding screw.

Figure 4: Straw shredder [Image source: REKA[4]]

[3] https://www.caminodesign.gr/
[4] https://www.reka.com/

In semi-continuous systems, the bales are fed in a batch-wise operation into the furnace either with a bale pusher or manually. Such systems are usually suitalble for small-scale and usually exhibit temperature and CO peaks caused when a new bale is delivered.

For larger heating plants, cigar burners may also be used[5]. Cigar burners are a variant feeding method for straw bale combustion. Whole or sliced bales are delivered in a continuous process by a hydraulic piston through a feeding tunnel on a water-cooled moving grate. Upon entering the combustion chamber, the fuel begins to gasify and combustion of the charcoal follows while the unburned material is moved over the grate. By using cigar burners, the straw bales can be fed without prior shredding.

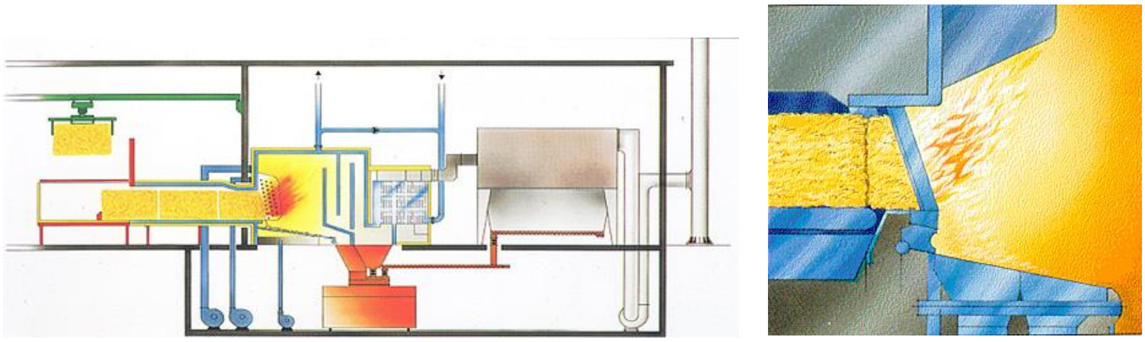

Figure 5: Cigar burner [Image source: Babcock & Wilcox Vølund[6]]

1.1.4. Fuel feeding system into furnace

Once the fuel is transported from the fuel storage to the boiler the fuel feeding system regulates the amount of fuel that is fed to the furnace. There are three fuel feeding options regarding how the fuel is fed to the combustion chamber: underfed stoker, top fed (overfed) and horizontal feed.

[5] For example, Danish manufacturer Linka offers the possibility of cigar burner systems for straw plants with capacities larger than 8,000 kW: www.linka.dk/en/products/straw-1000---15000-kw/

[6] www.volund.dk/Biomass_energy/Technologies/Combustion/Straw_and_stalks

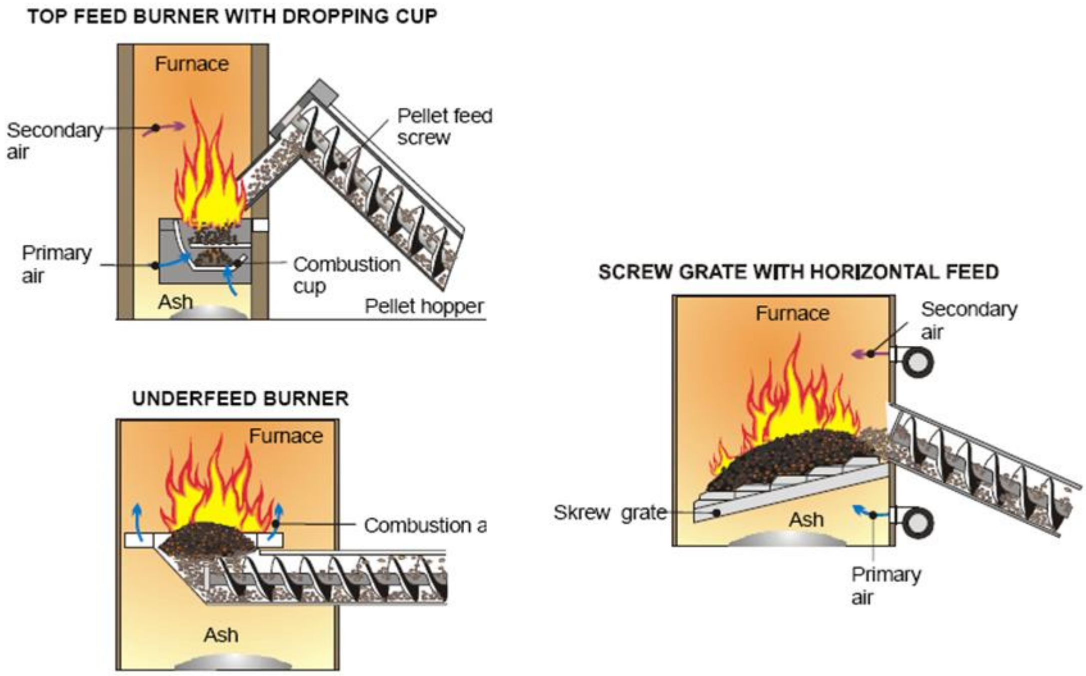

Figure 6: Overview of biomass feeding systems [Image source: (Alakangas, E., Paju, P., 2002)[7]]

1.2. Combustion systems

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. This separated primary and secondary air supply is called “staged combustion”.

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 NOx 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 water cooled or have refractory lining (with or without outside water or air cooling).

[7] Alakangas, E., Paju, P. (2002) OPET- Report 5: Wood pellets in Finland – technology, economy, and market

1.2.1. Fixed grates

Fixed grate systems are the simplest technology for biomass combustion and are only used in small-scale applications. Combustion is mainly surface driven therefore adequate radiation from the combustion chamber walls is necessary. Fuel distribution and movement over the grate cannot be controlled very well. Ash extraction is often manual, requiring either the removal of the bed as a draw or else the cleaning of the grate once the ash is cooled. When using agrobiomass fuels that have a high ash content, fixed grate systems often exhibit low efficiencies and high emissions of unburnt pollutants.

Figure 7: A fixed grater fed with underfed feeding (left), manual ash extraction from an operating fixed grate furnace [Image source: CERTH].

However, innovative variations of fixed grate systems may be applied for combustion of agrobiomass fuels with low ash content, for example using programmable tilting grates that can partially or fully discharge ash to a de-ashing screw below.

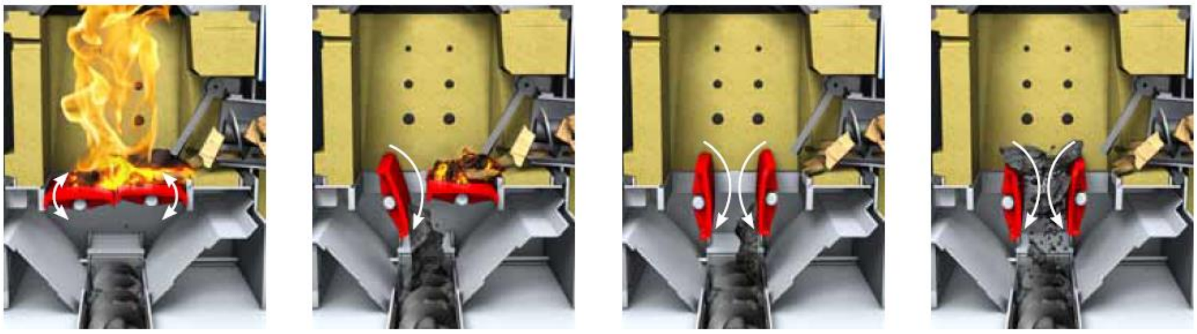

Figure 8: Tilting fixed grates [Image source: Hargassner[8]]

1.2.2. Moving grates

Moving grate systems can achieve a higher combustion velocity and efficiency, compared to fixed grate ones, because the solid fuel moves across the grate from the inlet section to the ash discharge section

[8] https://www.hargassner.be/fr/produits/chaudieres-a-granules/eco-pk-70-120-kw

and this allows a better mixing between air and fuel and facilitates the distribution of char, which then burns more quickly.

Moving grates show different configurations according to the different mechanical principles that move the grate. The main types of moving grates are:

- Travelling grates.
- Reciprocating grates.
- Vibrating grates.

1.2.2.1. Travelling grates

Travelling grate furnaces are comprised of grate bars forming an endless band moving through the combustion chamber. Fuel is supplied at one end of the combustion chamber onto the grate. The fuel bed itself does not move, but is transported through the combustion chamber by the grate. At the end of the combustion chamber the grate is cleaned of ash while the band turns around. On the way back, the grate bars are cooled by primary air in order to avoid overheating and to minimize wear.

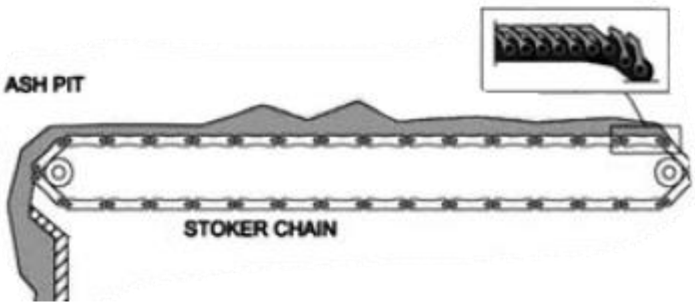

Figure 9: Travelling grate [Image source: (Dahlquist, 2013)[9]]

1.2.2.2. Reciprocating grates

Inclined reciprocating grates consist of fixed and movable rows of grate bars. By alternating forward and backward movements of the movable sections, the fuel is transported along the grate. Thus, unburned and burned fuel particles are mixed, the surfaces of the fuel bed are renewed and a more even distribution of the fuel over the grate surface can be achieved. Usually, the whole grate is divided into several grate sections, which can be moved at various speeds according to the different stages of combustion.

Horizontal reciprocating grates have a completely horizontal fuel bed that is achieved by the diagonal position of the grate bars.

[9] Dahlquist, E. (Ed.) (2013). Technologies for converting biomass to useful energy - combustion, gasification, pyrolysis, torrefaction and fermentation. Sustainable Energy Developments, Volume 4. https://doi.org/10.1201/b14561

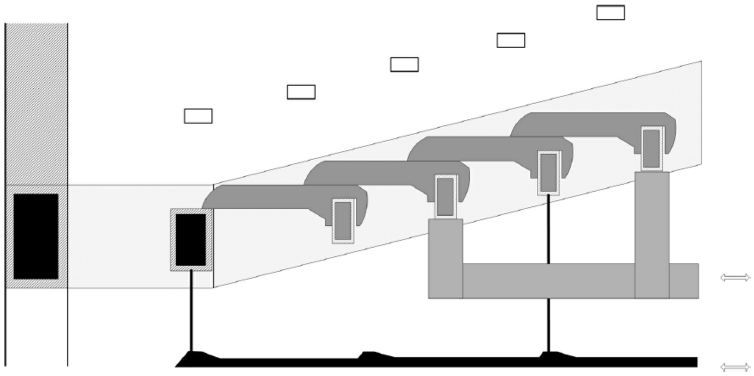

Figure 10: Inclined reciprocating grate [Image source: (van Loo, S. & Koppejan, J., 2008)]

1.2.2.3. Vibrating grates

Vibrating grate furnaces consist of an inclined finned tube wall placed on springs. Depending on the combustion process, two or more vibrators transport the fuel and ash towards the ash removal, while primary air is fed through the fuel bed from below through holes located in the ribs of the finned walls.

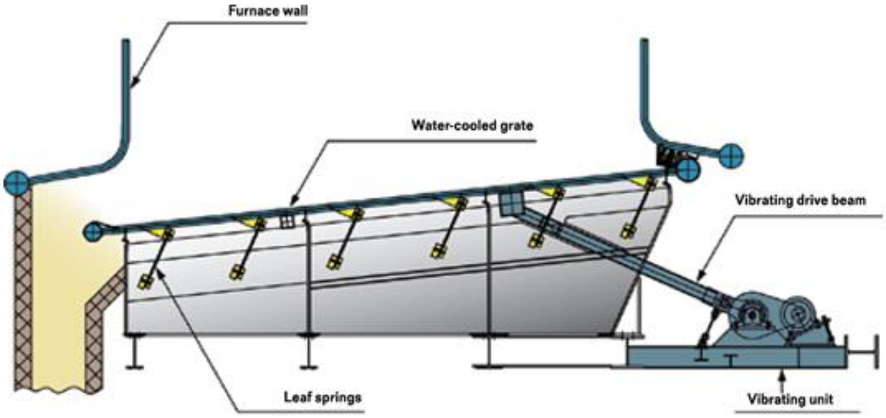

Figure 11: Vibrating grate [Image source: Babcock & Wilcox Vølund[10]]

1.2.3. Through-screw systems

The through-screw system can be used for larger fuel pieces (approximate length of 100 mm and diameter of 50 mm). The fuel is burned while being screw-fed through the combustion zone. The remaining ash is dropped into the ash deposit. This type of system is especially suitable for dealing with fuels that have a high ash content[11].

[10] www.volund.dk/Multi_fuel_energy/Technologies/Combustion_grates
[11] Quaak, P. (1999). Energy from Biomass - A Review of Combustion and Gasification Technologies. World Bank Publications.

Figure 12: Through-screw combustion chamber [Image source: Ökotherm[12]]

1.2.4. Gasification boilers

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. Such systems can achieve almost zero CO and OGC emissions, significantly reduced NOx emissions (in comparison to conventional fixed-bed combustion technologies) and very low particulate matter emissions.

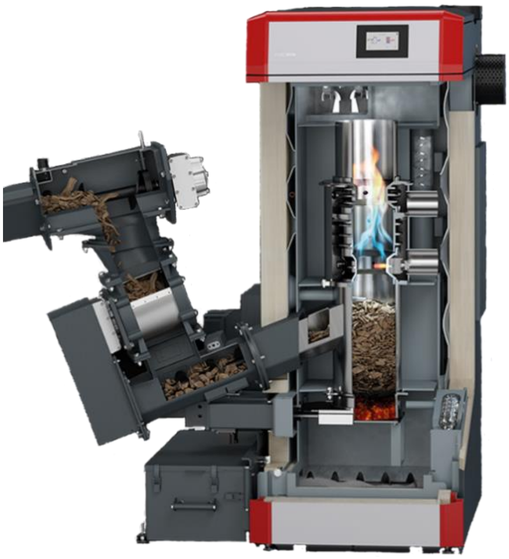

Figure 13: Gasification boiler by Windhager [Image source: Windhager[13]]

1.3. Heat exchangers

Heat exchangers may be positioned either vertically or horizontally. Usually, in small and medium-scale biomass boilers, gas tube heat exchangers are applied (hot flue gas flows inside the tubes while the water flows outside the tubes). Clean inner surfaces of the heat exchanger tubes are crucial for the

[12] www.oeko-therm.net/en
[13] https://www.windhager.com/int_en/products/wood-chip/purowin/

lifespan and efficiency of an agrobiomass boiler. There are two main technologies for automatic heat exchanger cleaning:

- based on mechanical means. Heat exchanger cleaning systems with automatic periodic reciprocating movement of turbulators, which ensures maximum heat transfer to the water.
- based on pressurized air. The pneumatic heat exchanger pipe cleaning system regularly removes the deposited ashes from the heat exchanger surfaces with short bursts of compressed air.


Figure 14: Pneumatic [Image source: Viessman[14]] (left) and mechanical [Image source: GUNTAMATIC[15]] (right) heat exchanger cleaning systems.

Other technologies may also be applied, for example, BioCurve[16] has developed a patent granted automatic heat exchanger cleaning system by water jets.

1.4. Ash removal systems

Ash removal is often considered to be a main issue with regard to the ease of use in biomass boilers. This is why the de-ashing system is of great importance. Grate ash and ash resulting from the heat exchanger cleaning process are collected in the ash box. De-ashing is typically carried out automatically by a de-ashing screw that conveys the ash into a sufficiently large-sized container. In order to lengthen the emptying intervals, ash compaction systems are sometimes applied. Compaction is achieved by an up-and-down moving grate. Even longer emptying intervals can be achieved by fully-automatic de-ashing systems that convey the ash to an external ash box with a de-ashing screw.

[14] www.viessmann.com/com/en.html
[15] www.guntamatic.com
[16] www.biocurve-heating.com/?lang=en

Figure 15: Ash compaction system (1-grate for ash compaction, 2-ash box) [Image source: (Obernberger & Thek, 2010)[17]]

1.5. Control systems

A state-of-the-art automated process control system of a modern biomass combustion plant usually consists of the following:

- Load control.
- Combustion control.
- Furnace temperature control.
- Furnace pressure control.
- Control loops needed for operation safety aspects.

The load control in biomass boilers is usually guided by the feed water /steam/ thermal oil temperature (depending on the heating medium) and determines the fuel and primary air feed.

In very simple applications, combustion control and CO emission reduction is achieved through a fixed set point for the excess air ratio (λ). However, if the moisture content of the fuel and/or load conditions change a combined CO/λ control provided best results.

Furnace temperature control should be achieved by flue gas recirculation and/ or water cooled furnace walls, while the negative pressure in the furnace is usually measured by appropriate pressure sensors and is controlled by an induced draught fan (Loo & Koppejan, 2008).

Most manufacturers offer as peripheral equipment suitable control applications that allow end-users to keep track of various functions of the heating plant, adjust its settings, or even receive remote support during disruptions.

[17] Obernberger, I., & Thek, G. (2010). The pellet handbook: The production and thermal utilisation of biomass pellets. Earthscan Ltd.

Figure 16: Example of a heating plant control and monitoring application (Image source: Linka[18]).

1.6. Flue gas cleaning systems

Even though modern boilers aim to achieve not only high combustion efficiency but low emissions as well when using agrobiomass, compliance with the emission limits of various regulations without the use of additional flue gas cleaning equipment is not always possible.

Depending on the application, there are multiple solutions available in the market for the abatement of pollutants such as particulate matter (dust), acidic gases and nitrogen oxide emissions.

1.6.1. Dust control

For dust emission abatement, cyclones, electrostatic precipitators (ESP) or bag filters may be used.

1.6.1.1. Cyclones

Cyclones are conical containers that remove particulates from high-speed rotating flue gas flows through vortex separation. Flue gas flows in a helical pattern before exiting the cyclone in a straight stream through the centre of the cyclone and out the top. Particles in the rotating stream have too much inertia to follow and thus strike the outside wall and then fall to the bottom of the cyclone, from where they are removed.

[18] https://www.linka.dk/

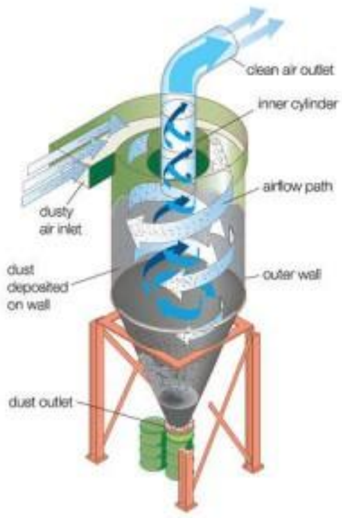

Figure 17: Flow pattern through a typical cyclone separator [Image source: baghouse.com]

Figure 18: Example of cyclone [Image source: Indiamart.com]

1.6.1.2. Fabric filters

Fabric or bag filters use filtration to separate dust particulates from dusty gases. They are one of the most efficient types of dust collectors available and can achieve a collection efficiency of more than 99 % for very fine particulates. However, fabric filters are not applied in small-scale applications due to their demand for compressed air for cleaning, the high space demand and the fact that condensation of water vapours in the filter has to be avoided, which cannot be guaranteed during partial load operation of small-scale boilers.

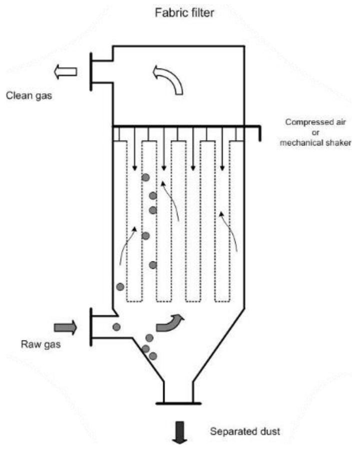

Figure 19: Fabric filter diagram [Image source : EMIS[19]]

Figure 20: Example of baghouse [Image source: www.baghouse.com]

1.6.1.3. Electrostatic precipitators (ESP)

ESPs use electrostatic forces to separate dust particles from flue gases. One or more (depending on filter size) high-voltage discharge electrodes are placed between grounded collecting electrodes.

[19] https://emis.vito.be/nl/node/19440

Particles receive a negative charge as they pass through the ionized field between the electrodes and are then attracted to a grounded or positively charged electrode and adhere to it.

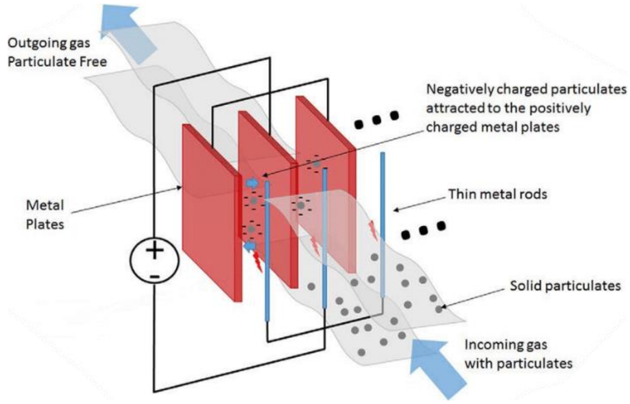

Figure 21: ESP conceptual diagram [Image source: (Becker et al., 2016)[20]]

Figure 22: Example of ESP for up to 100 kW [Image source: OekoSolve[21]]

1.6.2. Nitrogen oxides removal

In cases for which reduction of nitrogen oxides (NOx) emissions from agrobiomass boilers is required, the application of Selective Non Catalytic Reduction (SNCR) techniques can be very effective. For the denitrification of exhaust gases in agrobiomass boilers the selective non-catalytic reduction (SNCR) method is very effective and can achieve NOx reductions in the range of 20 to 70 %[22].

Selective Catalytic Reduction (SCR) technologies can achieve even higher NOx reduction (up to 90 %), however such systems are only applied in larger scale, industrial applications.

1.6.2.1. Selective non-catalytic reduction (SNCR)

SNCR involves injecting either ammonia or urea into the firebox of a boiler at a location where the flue gas is between 900 and 1,100 °C to react with the nitrogen oxides formed in the combust process. The resulting product of the chemical redox reaction is molecular nitrogen (N_2), carbon dioxide (CO_2) and water (H_2O). Since a certain furnace volume is needed to disperse and evaporate the additive, SNCR is not meaningful for small—scale boilers.

[20] Becker, K. H., Zhu, W., & Lopez, J. L. (2016). Microplasmas: Environmental and Biological Applications. Encyclopedia of Plasma Technology, 791–805. https://doi.org/10.1081/e-eplt-120051237
[21] https://oekosolve.ch/
[22] www.valmet.com/energyproduction/air-emission-control/nox-reduction

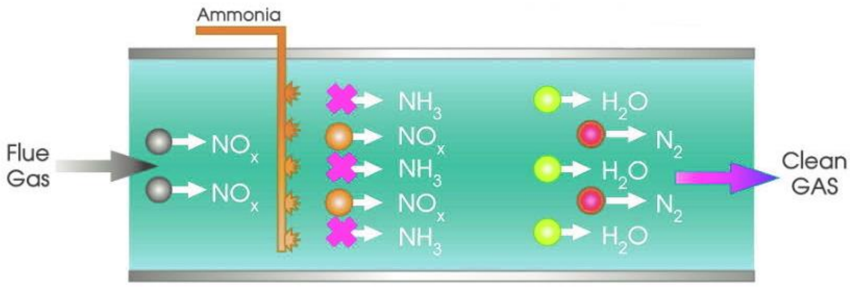

Figure 23: Selective non-catalytic reduction [Image source: IFS[23]]

1.6.3. Acidic flue gas constituents control

For HCl and SO_2 removal, dry sorption systems may be used in agrobiomass heating applications.

1.6.3.1. Dry sorption systems

The separation of acidic flue gas constituents via dry sorption is a simultaneous and absorptive gas/solid reaction which takes place in the sorbent employed in the process. In this process, the gaseous pollutants are bound to the surface of the introduced solid. The additives can then be separated from the flue gas together with the dust particles (typically in a subsequent fabric filter). These systems are characterised based on the additive applied and can be either sodium based (application of $NaHCO_3$) or lime based (application of $Ca(OH)_2$) systems.

1.7. Emission limits for agrobiomass boilers

1.7.1. The Ecodesign Regulation

The Ecodesign Directive[24] 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.

Specific regulations on different products complement the Ecodesign Directive. In particular, the so-called LOTs 15 (solid fuel boilers) and 20 (space heaters) cover heating appliances with biomass fuels.

The Regulation does not apply in the following cases:

(a) boilers generating heat exclusively for providing hot drinking or sanitary water;

(b) boilers for heating and distributing gaseous heat transfer media such as vapour or air;

(c) solid fuel cogeneration boilers with a maximum electrical capacity of 50 kW or more;

(d) non-woody biomass boilers.

[23] https://ifsolutions.com/power-plant-nox-reduction-scr-vs-sncr/
[24] 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

The Regulation provides the following definitions for "woody" and "non-woody" biomass:

- "woody biomass" means biomass originating from trees, bushes and shrubs, including log wood, chipped wood, compressed wood in the form of pellets, compressed wood in the form of briquettes, and sawdust.
- "non-woody biomass" means biomass other than woody biomass, including straw, miscanthus, reeds, kernels, grains, olive stones, olive cakes and nut shells.

As such, Ecodesign excludes from its scope many agrobiomass types; it does however include agricultural prunings and plantation removal biomass, since it can be classified as "woody".

The Regulation for solid fuel boilers has come into force since 1 January 2020. Solid fuel boilers within the scope of the Regulation have to comply with specific requirements regarding their seasonal space heating efficiency and emissions, as well as production information, which are described in Annex II of the Regulation. The following table summarizes the seasonal[25] efficiency and emission limits for solid biomass boilers.

Table 1: Ecodesign Regulation seasonal efficiency and emission limits for solid biomass boilers.

<table>
<tr><th rowspan="2">Feeding Method</th><th rowspan="2">Nominal heat output</th><th rowspan="2">Seasonal space heating energy efficiency</th><th colspan="4">Seasonal space heating emission limits (mg/m³ at 10 % oxygen concentration)</th></tr>
<tr><th>Carbon Monoxide, CO</th><th>Organic Gaseous Compounds, OGC</th><th>Particle Matter, PM</th><th>Nitrogen Oxides, NOx</th></tr>
<tr><td rowspan="2">Manual</td><td>≤ 20 kW</td><td>≥ 75 %</td><td rowspan="2">700</td><td rowspan="2">30</td><td rowspan="2">60</td><td rowspan="4">200</td></tr>
<tr><td>> 20 kW</td><td>≥ 77 %</td></tr>
<tr><td rowspan="2">Automated</td><td>≤ 20 kW</td><td>≥ 75 %</td><td rowspan="2">500</td><td rowspan="2">20</td><td rowspan="2">40</td></tr>
<tr><td>> 20 kW</td><td>≥ 77 %</td></tr>
<tr><td colspan="2">Benchmarks for Best Available Techniques (BATs)</td><td>90 % condensing
84 % non-condensing</td><td>6</td><td>1</td><td>2</td><td>97</td></tr>
<tr><td colspan="7">Note: At the time of entry into force of the Regulation, no single solid fuel boiler was identified meeting all the benchmark values. Several solid fuel boilers met one or more of these values.</td></tr>
</table>

A review of the Regulation for solid fuels boilers is foreseen under Article 7 by 1 January 2022 at the latest with the aim to:

(a) to include solid fuel boilers with a rated heat output of up to 1,000 kW;

(b) to include non-woody biomass boilers, with ecodesign requirements for their specific types of pollutant emissions;

(c) to set stricter ecodesign requirements beyond 2020 for energy efficiency and for emissions of particulate matter, organic gaseous compounds and carbon monoxide; and

[25] The seasonal space efficiency and emission limits are defined as a kind of weighted average between the values at the rated thermal output and a reduced (30 or 50 %) thermal output. The exact definitions for measurements and calculations are provided in Annex III of the Regulation.

(d) to vary the verification tolerances.

1.7.2. The Medium Combustion Plant Directive

The Medium Combustion Plant (MCP) Directive[26] regulates emissions from combustion plants with a thermal input between 1 and 50 MW.

Combustion plants under the MCP are grouped into two main categories:

- "Existing", meaning a combustion plant put into operation before 20 December 2018 or for which a permit was granted before 19 December 2017 pursuant to national legislation provided that the plant is put into operation no later than 20 December 2018.
  "New", meaning a combustion plant other than an existing combustion plant.

The MCP Directive includes agrobiomass in its scope and in fact introduces some specific emission limits for straw. Some facilities are excluded from its scope, such as "on-farm combustion plants with a total rated thermal input less than or equal to 5 MW, that exclusively use unprocessed poultry manure, as referred to in Article 9(a) of Regulation (EC) No 1069/2009[27] of the European Parliament and of the Council, as a fuel". The main emission limits for combustion plants using solid biomass are provided in Annex II of the Directive; it should be noted that some exceptions for specific installations may apply.

Table 2: Solid biomass emission limits under the MCP Directive.

Medium combustion plant type (other than engines and gas turbines)	Rated thermal input (MW)	Emission limits (mg/m^3 at a 6 % oxygen concentration) for solid biomass		
		Sulphur Dioxide, SO_2	Nitrogen Oxides, NOx	Dust
Existing	1 - 5	200 * / 300 (straw)	650	50
Existing	> 5	200 * / 300 (straw)	650	30
New	1 – 5	200 *	500	50
New	5 – 20	200 *	300	30
New	20 – 50	200 *	300	20
* Not applicable for plants firing exclusively woody biomass				

A review of the MCP Directive is foreseen in Article 12. In particular:

- By 1 January 2020, the Commission shall review progress in relation to the energy efficiency of medium combustion plants and assess the benefits of setting minimum energy efficiency standards in line with best available techniques.
- By 1 January 2023, the Commission shall assess the need to review the provisions concerning plants which are part of SIS or MIS, as well as Part 2 of Annex II, on the basis of state-of-the-art technologies.

[26] Directive (EU) 2015/2193 of the European Parliament and of the Council of 25 November 2015 on the limitation of emissions of certain pollutants into the air from medium combustion plants
[27] Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October 2009 laying down health rules as regards animal by-products and derived products not intended for human consumption

- As part of this review, the Commission shall also assess whether for certain or all types of medium combustion plants there is a need to regulate CO emissions.
- Thereafter, a review shall take place every ten years and shall include an assessment of whether it is appropriate to set stricter emission limit values, in particular for new medium combustion plants.

The European Commission shall submit a report on the results of the aforementioned reviews to the European Parliament and to the Council accompanied by a legislative proposal where appropriate.

2. Agrobiomass fuels

Within the scope of the AgroBioHeat project, the following working definition is used for agrobiomass:

"biomass sources either from solid, vegetal, by-products or residues (e.g. straw, prunings, olive stones, rise husk, etc.), or from dedicated perennial energy crops, both of the grassy, lignocellulosic variety (e.g miscanthus, switchgrass) and the woody variety (e.g. short rotation coppices – SRC - such as willow and poplar)".

This definition covers a wide range of materials, with varying properties. A common feature is that they are produced from the activities of the agricultural or agro-industrial sectors and not from forestry, fishery or urban activities (e.g. municipal waste, etc.).

If commercialised, agrobiomass can be found in various tradeable forms depending on its origin, harvesting system and final end-use: as whole bales (e.g. for straw), as shredded/ hog fuel/ chips, as densified products (e.g. pellets, briquettes) or as granular material (e.g. olive stones).

In the framework of this report and for the purposes of most project activities, agrobiomass can be sorted in three large groups: **agricultural residues**, **agro-industrial residues** and **dedicated energy crops**. The following sections provide details on the main agrobiomass types of each group, presenting information on their usual marketable forms, typical yield, current uses and European potential are presented. In addition, indicative fuel properties are provided. However, it should be stated that the composition of individual assortments of can vary significantly depending on numerous factors (harvesting time and method, crop variety, age of the crop, agronomic practices, soil conditions, etc.) and any given values are only indicative.

2.1. Agricultural residues

Agricultural residues are solid vegetal residues left in the field after harvest or pruning. Agriculture produces hundreds of millions of tonnes of residues globally every year and although they are a promising feedstock for bioenergy use, they are currently underutilized.

2.1.1. Straw

Straw is one of the most abundant agricultural residues available. Straw is an agricultural by-product consisting of dry stalks of cereal plants after the grain and chaff have been removed. It makes up about half of the total biomass yield of cereal crops such as barley, oats, rice, rye, oilseed rape and wheat.

Denmark is leading in utilizing straw for energy purposes, using about 1.5 million tonnes of straw every year, a development that was achieved through the implementation of the of the Danish Biomass Action Plan[28].

- **Form:** Straw is usually harvested and stored in bales. If not used directly in bale form, it can be chopped and, if desired, upgraded to pellets or briquettes.

[28] Torben Skøtt. (2011). Straw to energy. www.inbiom.dk/download/viden_biomasse/halmpjeceuk_2011.pdf

- **Yield:** Typical yield for straw is between 2.5 – 4 t (dry matter) per hectare. Straw is available from July to August for winter crops and from late August to late September for spring sown crops[29].
- **Use:** For energetic purposes, straw is mostly used for electricity and/or heat generation in direct combustion in dedicated facilities, since it is considered a "difficult" fuel due to its low ash melting temperatures. Apart from that, straw is used as animal feed, for mushroom compost, as animal bedding or it can be mulched into the soil in order to increase soil organic matter content[30].
- **Potential:** The Biomass Futures project estimated that the cereal straw potential in the EU-27 (excluding Croatia) for 2020 would be in the range of 127 million tons dry matter, considering also competing, non-energy uses[31]. The BIOCORE project estimated that the annual quantity of harvestable straw for the EU, Ukraine and Balkan countries is 215 million tonnes dry matter, of which 75 % is from wheat and barley and the remaining 25 % from corn. France, Germany, Ukraine, the United Kingdom, Poland, Spain, Italy, Romania and Hungary produce 90 % of the harvestable straw[32].

Figure 24: Field with large round straw bales

[29] www.teagasc.ie/publications/2010/868/868_StrawForEnergy.pdf
[30] Copeland, J., & Turley, D. (2008). *National and regional supply/demand balance for agricultural straw in Great Britain*. www.nnfcc.co.uk/publications/report-supply-demand-agricultural-straw
[31] B. Elbersen et al. (2012) Biomass Futures Deliverable 3.3: Spatially Detailed and Quantified Overview of EU Biomass Potential Taking into Account the Main Criteria Determining Biomass Availability from Different Sources. https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/biomass_futures_atlas_of_technical_and_economic_biomass_potential_en.pdf
[32] Helin T. et al. (2012) BIOCORE Deliverable D1.1: Availability of lignocellulosic biomass types of interest in the study regions. http://www.biocore-europe.org/file/D1_1%20Availability%20of%20lignocellulosic%20biomass%20types%20of%20interest%20in%20the%20study%20regions.pdf

In Table 3, typical values for wheat straw are presented, while more information about the typical variation of these properties can be found in Annex B of EN ISO 17225-1.

Table 3: Indicative fuel composition – wheat straw

Property	Unit	Wheat straw
Moisture, M	w-% a.r.	15
Ash, A	w-% d.b.	5.0
Net Calorific Value, NCV	MJ/kg a.r.	14.6
Bulk Density, BD	kg/m^3 a.r.	100 (bales) / 60 (chopped)
Energy Density	MWh/m^3 a.r.	0.41 (bales) / 0.24 (chopped)
Nitrogen, N	w-% d.b.	0.5
Sulphur, S	w-% d.b.	0.1
Chlorine, Cl	w-% d.b.	0.4
Calcium, Ca	mg/kg d.b.	4,000
Potassium, K	mg/kg d.b.	10,000
Sodium, Na	mg/kg d.b.	500
Silica, Si	mg/kg d.b.	10,000

a.r.: as received, d.b.: dry base

2.1.2. Prunings and plantation removal

Pruning is the established horticultural practice of cutting and removing selected parts of a tree in order to control growth, remove dead/diseased wod and stimulate the formation of flowers and fruit buds; the term also refers to the residual biomass generated by the practice.

For productive trees in a plantation / orchard, different types of prunings and with varying frequencies may be performed in various steps of the plantation’s life: maintenance, structuring, removal of old branches, grafting, topping, blooming and others.

Trees may also be found in agricultural settings in the form of hedges / hedgerows; in that case, their main aim is to form barriers and/or mark boundaries of a field. Hedgerows may also play other roles, such as regulating the micro-climate and water movements, preserving soil, enhancing biodiversity and others. Hedgerows also need to be pruned periodically for their maintenance.

Figure 25: Management of hedgerows [Image source: AILE]

Thick parts of pruning wood are traditionally collected separately and used as firewood in most cases; however, most of the pruning biomass is left on the field and is either burned in open fires or – less frequently - mulched in the soil.

Plantation removal is the clearing out of trees at the end of the lifetime of a plantation. The termination of a plantation can be driven by changes in the food market, by agricultural policies or by other particular reasons, like disease. Some parts of the tree may be used as firewood, but others, such as the stump, roots and thin branches are often unutilized and disposed in open fires[33].

The main permanent crops in Europe are olives, grapes and nuts, followed by pome, stone and citrus fruits. The countries in Europe that have currently the largest areas of permanent crops are Spain, Italy, Greece and France.

- <u>**Form**</u>: The portion of prunings that cannot be used as firewood may be harvested and stored in bales or they may be chipped either manually or by mechanized systems. For plantation removal, equipment similar to the ones used in forestry may be used for harvesting and firewood and wood chips are usually produced. The chips or hog fuel produced form prunings or plantation removal can, if desired, be further upgraded to pellets.
- <u>**Yield**</u>: Typical annual yield for pruning is between from 1-4 t (DM) per kilometre of hedge or 1-3 t per hectare (dry matter) of permanent crops, depending on the crop, pruning practice and other factors. The biomass yield for plantation removals of mature trees may be in the range of 50 t per hectare (dry matter); again, the exact values vary depending on the size / age of tree and varieties, local conditions, etc.
- <u>**Use**</u>: Prunings and wood from plantation removal are mostly underutilized in Europe. A small portion is used as firewood but the most common practice is to burn prunings and plantation removal in open fires or in some cases to be mulched in the soil. Their energetic utilization in modern combustion systems usually corresponds to less than 5% of the management practices[34].

[33] uP_running project Monograph (2018) Biomass from agricultural pruning and plantation removals a feasible practice promoted by the uP-running project. www.up-running.eu/wp-content/uploads/2018/09/1st-Monograph_vDEF-2.pdf
[34] uP_running project, ibid.

- **Potential**: For 2018, Eurostat estimated that there are approximately 11.5 million ha of permanent crops in the EU-28. It is estimated that the technical potential for agricultural pruning biomass in Europe is more than 12.5 million dry tonnes per year[35].
- **Fuel certification**: Olive tree and vineyard pruning chips and pellets can be certified with the BIOmasud® quality scheme.

Figure 26: Olive tree pruning hog fuel [Image source: CERTH]

Figure 27: Olive tree pruning pellets fuel [Image source: CERTH / AGROinLOG project]

Figure 28: Pile of vineyard pruning hog fuel [Image source: CIRCE]

Figure 29: Vineyard pruning pellets [Image source: Pelets de la Mancha[36]]

In Table 4, typical average values for olive tree pruning hog fuel and vineyard pruning pellets are presented. More information about the chemical composition and variations in fuel properties of these fuels can be found in Annex B of EN ISO 17225-1 and deliverable D3.2 of the Biomasud Plus project (Biomasud Plus project, 2018).

[35] Dyjakon, A., & García-Galindo, D. (2019). Implementing agricultural pruning to energy in Europe: Technical, economic and implementation potentials. Energies, 12(8). https://doi.org/10.3390/en12081513
[36] http://www.peletsdelamancha.com

Table 4: Indicative fuel composition – olive tree and vineyard prunings

Property	Units	Olive tree pruning hog fuel	Vineyard pruning pellets
Moisture, M	w-% a.r.	27	10
Ash, A	w-% d.b.	4.2	4.5
Net Calorific Value, NCV	MJ/kg a.r.	12.9	15.7
Bulk Density, BD	kg/m^3 a.r.	230	710
Energy Density	MWh/m^3 a.r.	0.83	3.10
Nitrogen, N	w-% d.b.	0.93	0.81
Sulphur, S	w-% d.b.	0.08	0.07
Chlorine, Cl	w-% d.b.	0.04	0.02
Calcium, Ca	mg/kg d.b.	9,000	10,000
Potassium, K	mg/kg d.b.	5,600	5,400
Sodium, Na	mg/kg d.b.	460	170
Silica, Si	mg/kg d.b.	2,100	2,800

a.r.: as received, d.b.: dry base

2.2. Agro-industrial residues

2.2.1. Olive stones

The main by-product of olive oil extraction is the olive cake. Olive cake is processed in pomace mills for the extraction of pomace oil. The residue of this process is the exhausted olive cake, a solid biofuel that consists of the stone, flesh and skin of the olive fruit. A portion of the exhausted olive cake is consumed by the pomace mills to provide heat for drying.

Exhausted olive cake can be used as an industrial fuel, but has its limitations mainly due to the high ash and nitrogen contents and the strong smell of the fuel.

Olive stones are a product of the separation of olive cake, where the woody stone is separated from the olive flesh and skin and are produced from olive or pomace mills. Olive stones are odourless, have a low ash and moisture content and are a very attractive fuel for domestic heating.

- **Form:** Olive stones and exhausted olive cake are in most cases available in the form of crushed granular fuel.
- **Yield:** The weight of the olive stone ranges from 10 to 20 % of the whole fruit.
- **Use:** Olive stones are used as fuel for heating purposes either in the domestic or industrial facilities. Apart from combustion, olive stones are used to produce activated carbon for odour, taste or contaminant removal and as raw material for furfural production. In addition, olive stones may find applications as abrasives and in cosmetics as an exfoliation component[37].
- **Potential:** For 2015, Biomasud Plus project estimated that the annual potential for olive stones in Spain, Greece, Italy, Portugal, Croatia and Slovenia was approximately 770.000 dry tonnes. (Biomasud Plus project, 2017)

[37] Rodríguez, G., Lama, A., Rodríguez, R., Jiménez, A., Guillén, R., & Fernández-Bolaños, J. (2008). Olive stone an attractive source of bioactive and valuable compounds. In *Bioresource Technology* (Vol. 99, Issue 13, pp. 5261–5269). Elsevier. https://doi.org/10.1016/j.biortech.2007.11.027

- **Certification schemes:** Olive stones can be certified with the BIOmasud® quality scheme. They can be classified either as fuels for small installations <400kW (classes A1 and A2) or big installations >400 kW (class B).


Figure 30: Exhausted olive cake (left) and olive stones (right) [Image source: CERTH]

In Table 5, typical values for olive stones are presented, as well as the respective limits of the BIOmasud® quality scheme (BIOmasud® Handbook v15.0). More information about the chemical composition and variations in fuel properties of these fuels can be found in Annex B of EN ISO 17225-1 and D3.2 of the Biomasud Plus project[38]. Please note that the given limits are only indicative of the quality requirements of the BIOmasud® scheme.

Table 5: Indicative fuel composition and BIOmasud® limits – olive stones

Property	Unit	Olive stones	BIOmasud® class limits (v15.0)		
			A1	A2	B
Moisture, M	w-% a.r.	15	≤ 12	≤ 12	≤ 16
Ash, A	w-% d.b.	1.2	≤ 0.7	≤ 1.0	≤ 1.5
Net Calorific Value, NCV	MJ/kg a.r.	15.8	≥ 15.7	≥ 15.7	≥ 14.9
Bulk Density, BD	kg/m^3 a.r.	730	≥ 700	≥650	≥600
Energy Density	MWh/m^3 a.r.	3.20	≥ 3.05*	≥ 2.83*	≥ 2.48*
Nitrogen, N	w-% d.b.	0.3	≤ 0.3	≤ 0.4	≤ 0.6
Sulphur, S	w-% d.b.	0.02	≤ 0.03	≤ 0.04	≤ 0.05
Chlorine, Cl	w-% d.b.	0.1	≤ 0.03	≤ 0.04	≤ 0.05
Calcium, Ca	mg/kg d.b.	1,300	-	-	-
Potassium, K	mg/kg d.b.	2,300	-	-	-
Sodium, Na	mg/kg d.b.	600	-	-	-
Silica, Si	mg/kg d.b.	900	-	-	-

a.r.: as received, d.b.: dry base; * calculated value

2.2.2. Nut shells

Nut shells are a by-product of the nut hulling industry. Cracked nut shells are separated from the nut meat using aspirators. Nut shells are a lignocellulosic residue with energy content comparable to other

[38] Biomasud Plus project. (2018). D3.2 Selected biofuels characterization results and quality assessment report. http://biomasudplus.eu/wp-content/uploads/2018/05/Biomasud_Plus_Deliverable-3_2def-2.pdf

biomass fuels and low moisture and ash contents. These properties make nut shells a very attractive fuel for domestic heating.

- **Form:** These types of agrindustrial residues are in most cases available in the form of crushed granular fuel.
- **Yield:** In most cases, the nut shell represents approximately 50% of the total weight of the nut.
- **Use:** Nut shells are used for heating purposes either in domestic or industrial applications. They have been considered as a raw material for the production of activated carbon and furfural[39] or simple as soil cover for gardening applications.
- **Potential:** For 2015, Biomasud Plus project estimated that the annual potential for nut shells in Spain, Greece, Italy, Portugal, Croatia and Slovenia was approximately 270,000 dry tonnes[40].
- **Certification schemes:** Almond shells, pine nut shells, walnut shells, pistachio shells, walnut shells, pistachio shells and hazelnut shells can be certified with the BIOmasud® quality scheme. These fuels can be classified either as fuels for small installations < 400kW (classes A1 and A2) or big installations > 400 kW (class B).

Figure 31: Crushed almond shells [Image source: Pellets del Sur[41]]

Figure 32: Hazelnut shells [Image source: EcoCombustibili® / Biom s.r.l.[42]]

In Table 6, typical values for almond shells are presented, as well as the respective limits of the BIOmasud® quality scheme (BIOmasud® Handbook v15.0) for almond shells. More information about the chemical composition and variations in fuel properties of these fuels can be found in Annex B of EN ISO 17225-1 and D3.2 of the Biomasud Plus project[43]. Please note that the given limits are only indicative of the quality requirements of the BIOmasud® scheme.

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[39] DENİRBAŞ, A., AKDENİZ, F., ERDOGAN, Y., & PAMUK, V. (1996). Kinetics for fast pyrolysis of hazel nut shell. Fuel Science and Technology International, 14(3), 405–415. https://doi.org/10.1080/08843759608947587
[40] Biomasud Plus project. (2017). D 2.1 Residential heating biofuels market state of the art. http://biomasudplus.eu/wp-content/uploads/2017/09/D2.1-Market_report_Consolitated-6.pdf
[41] www.pelletsdelsur.com
[42] www.eco-combustibili.it
[43] Biomasud Plus (2018), ibid.

Table 6: Indicative fuel composition and BIOmasud® limits – almond shells

Property	Units	Almond shells	BIOmasud® class limits (v15.0)		
			A1	A2	B
Moisture, M	w-% a.r.	11	≤ 12	≤ 12	≤ 16
Ash, A	w-% d.b.	1.6	≤ 0.7	≤ 1.5	≤ 2.0
Net Calorific Value, NCV	MJ/kg a.r.	16.1	≥ 15.0	≥ 15.0	≥ 14.2
Bulk Density, BD	kg/m^3 a.r.	410	≥ 500	≥ 300	≥ 270
Energy Density	MWh/m^3 a.r.	1.83	≥ 2.08*	≥ 1.25*	≥ 1.07*
Nitrogen, N	w-% d.b.	0.4	≤ 0.4	≤ 0.6	≤ 0.8
Sulphur, S	w-% d.b.	0.01	≤ 0.03	≤ 0.03	≤ 0.04
Chlorine, Cl	w-% d.b.	0.02	≤ 0.02	≤ 0.02	≤ 0.03
Calcium, Ca	mg/kg d.b.	1,300	-	-	-
Potassium, K	mg/kg d.b.	4,600	-	-	-
Sodium, Na	mg/kg d.b.	2,500	-	-	-
Silica, Si	mg/kg d.b.	630	-	-	-

a.r.: as received, d.b.: dry base; * calculated value

2.2.3. Sunflower husks

The sunflower is a herbaceous oilseed crop that is cultivated in various countries for cooking oil, biodiesel, animal feed and confectionary. Among its advantages are its relatively short growth cycle, high resistance to drought and adaptation to different soil conditions. The top producer countries of sunflowers are the Russian Federation, Ukraine, the European Union (mostly Romania and Bulgaria) and Argentina, which produce roughly half of the world's sunflower seed production and over 60 % of sunflower oil production.

Sunflower husks are a by-product of the sunflower oil extraction process and can be found in big quantities in sunflower oil factories.

The high energy content, low price and high energy density of sunflower husk pellets make them a very popular and widely marketed solid biofuel.

- **Form:** After separation from the seeds, the husks can be used as is (granular form) or be further upgraded to pellets or briquettes.
- **Yield:** Sunflower husks comprise approximately 20-30 % of the total processed seed weight[44].
- **Use:** Sunflower husks are a popular industrial fuel for heating and/or electricity production.
- **Potential:** On the European continent, 18.07 million hectares (70 % of the world surface) are cultivated with sunflowers, of which 16.31 million are in eastern countries like Russia, Ukraine, Moldova, Romania and Bulgaria[45].

[44] Seiler, G. J., & Gulya, T. J. (2016). Sunflower: Overview. Reference Module in Food Science. https://doi.org/10.1515/agriceng-2017-0008

[45] Perea-Moreno, M. A., Manzano-Agugliaro, F., & Perea-Moreno, A. J. (2018). Sustainable energy based on sunflower seed husk boiler for residential buildings. Sustainability (Switzerland), 10(10). https://doi.org/10.3390/su10103407

Figure 33: Sunflower husk pellets [Image source: CERTH]

Table 7 presents typical fuel properties sunflower husk pellets; Annex B of EN ISO 17225-1 provides more information on typical variations in these properties.

Table 7: Indicative fuel composition – sunflower husk pellets

Property	Unit	Sunflower husk pellets
Moisture, M	w-% a.r.	10
Ash, A	w-% d.b.	4.0
Net Calorific Value, NCV	MJ/kg a.r.	15.7
Bulk Density, BD	kg/m^3 a.r.	550
Energy Density	MWh/m^3 a.r.	2.40
Nitrogen, N	w-% d.b.	0.8
Sulphur, S	w-% d.b.	0.1
Chlorine, Cl	w-% d.b.	0.06
Calcium, Ca	mg/kg d.b.	5,000
Potassium, K	mg/kg d.b.	11,000
Sodium, Na	mg/kg d.b.	50
Silica, Si	mg/kg d.b.	600

a.r.: as received, d.b.: dry base

2.3. Dedicated energy crops

Dedicated energy crops are plants grown specifically for their energetic value.

AgroBioHeat is looking into lignocellulosic energy crops which are utilized in thermochemical conversion processes – other types of energy crops, e.g. oilseed and starch crops are used for production of liquid biofuels (e.g. biodiesel, bioethanol) and are not included in the scope of the project.

Lignocellulosic energy crops can be either herbaceous (e.g. miscanthus) or woody (eg. willow, poplar). Adaptable to a wide range of climate and soil conditions, they can be successfully grown on lands not ecologically suited for conventional farming practices, while delivering several ecosystem services.

2.3.1. Miscanthus

The genus Miscanthus comprises around 17 species of non-wood rhizomatous tall grasses native to subtropical and tropical regions. The main characteristics of Miscanthus are its exceptional adaptability to different climates, the feasibility for cultivation on poor quality soils, the high dry matter yields and the extraordinary disease and pest resistance, low fertilization requirements[46].

- **Form**: Miscanthus can either be mowed and baled, or it can be chipped during harvesting using forage harvesters (as used for maize). If desired, miscanthus biomass can also be further upgraded to pellets or briquettes. However, for heating applications, the most common format of using miscanthus is either in whole bales or as chopped material.
- **Yield**: Yields reported across Europe vary according to location and harvest date, but typical yields are approximately 10 t dry matter per hectare per annum. To obtain the best biomass quality for use as a combustion fuel, miscanthus is normally harvested in spring (March or early April) after it has had time to dry in the field[47].
- **Use**: Miscanthus may be used as a fuel for combustion to produce heat, electricity, or combined heat and electricity. It is used for direct firing of thermal power stations, in farm-scale boilers and and in small-scale biomass burners. A market is also being developed for miscanthus pellet-fired heating boilers. Alternative uses due to its high water absorption capacity include use as animal bedding and production of building and packaging materials[48].
- **Potential**: Miscanthus is cultivated in at least 24,620 ha in Europe. Countries having at least 1,000 ha of miscanthus are the United Kingdom, Germany, France, Austria, Italy; Poland, Ireland, Romania, Croatia, Slovenia, Slovakia, the Netherlands, Czech and Belgium follow[49].

[46] Bilandzija, N., Jurisic, V., Voca, N., Leto, J., Matin, A., Sito, S., & Kricka, T. (2017). Combustion properties of Miscanthus x giganteus biomass – Optimization of harvest time. *Journal of the Energy Institute*, *90*(4), 528–533. https://doi.org/10.1016/j.joei.2016.05.009

[47] Panoutsou, C., & Alexopoulou, E. (2020). Costs and profitability of crops for bioeconomy in the EU. Energies, 13(5). https://doi.org/10.3390/en13051222

[48] Alexopoulou, E. (Ed.) (2018). Perennial Grasses for Bioenergy and Bioproducts. Academic Press.

[49] Bioenergy Europe (2019) Statistical Report: Biomass Supply. https://bioenergyeurope.org/statistical-report.html

Figure 34: Miscanthus harvester / chipper [Image source: J.E.Doll, Michigan State University[50]]

Figure 35: Harvesting of miscanthus bales [Image source: Terravesta[51]]

In Table 8, typical properties for Miscanthus are presented, while more information about their typical variation can be found in Annex B of EN ISO 17225-1.

Table 8: Indicative fuel composition - miscanthus

Property	Unit	Miscanthus
Moisture, M	w-% a.r.	15
Ash, A	w-% d.b.	4.0
Net Calorific Value, NCV	MJ/kg a.r.	14.7
Bulk Density, BD	kg/m^3 a.r.	130 (chopped)
Energy Density	MWh/m^3 a.r.	0.53 (chopped)
Nitrogen, N	w-% d.b.	0.7
Sulphur, S	w-% d.b.	0.2
Chlorine, Cl	w-% d.b.	0.2
Calcium, Ca	mg/kg d.b.	2,000
Potassium, K	mg/kg d.b.	7,000
Sodium, Na	mg/kg d.b.	70
Silica, Si	mg/kg d.b.	8,000

a.r.: as received, d.b.: dry base

2.3.2. Short Rotation Coppice

Short rotation coppice are woody fast growing tree species that are cultivated with the aim to produce high biomass yields in a short period that can be used for energy purposes. Coppice is characterized by the ability of selected tree species to re-grow with new sprouts after the plant is cut down. The perennial woody species in Europe that are grown specifically for their energetic value are willow, poplar and to a lesser extend alder, eucalyptus and black locust. SRC are planted at a high density (12,000 – 15,000 trees per hectare) and are repeatedly harvested, usually in a three-year cycle over a period of 20 to 25 years. Willow and poplar can tolerate a range of climatic conditions. For the establishment of an SRC plantation, it is advisable to use plant material that has been tested under the local conditions in practice[52,53].

[50] https://lter.kbs.msu.edu/ngg_tag/farming/
[51] www.terravesta.com/news/covid-19-workplace-policy/
[52] www6.inrae.fr/creff_eng/content/download/3268/33199/version/1/file/CREFF+SRC+technical+guideline.pdf
[53] Dimitriou, I., & Rutz, D. (2015). Sustainable Short Rotation Coppice. A Handbook. http://www.srcplus.eu/images/Handbook_SRCplus.pdf

- **Form:** SRC are usually harvested with mechanized means cut and chip in one operation to provide wood chips. If desired, the produced wood chips can be further upgraded to pellets.
- **Yield:** Harvesting should be carried out in the winter, after leaf fall and before bud burst. Feasible annual yields in Europe are in the range of 5-18 t (dry matter) per hectare. The total amount of dry biomass per harvest is calculated by the annual yield and the years of cultivation.
- **Use:** The final product of SRC is wood chips, which are mainly used for combustion processes. They may be also used in the pulp and paper industry, for wood-based composites like plywood or for other bio-products. Special aspects of willow utilization include weaved consumer products like baskets or furniture[54] and willow extract that has cosmetic and pharmaceutical uses[55].
- **Potential:** The latest statistical report of Bioenergy Europe indicated that 20,691 ha of poplar and 19,378 ha of willow were cultivated in the EU-28. Poplar plantations can be found in Poland, Hungary, Czech, Romania, Sweden, Austria and Latvia. Willow can primarily be found in Sweden, Poland, Romania, Ireland Latviaand Hungary, with some smaller plots in Austria and Belgium[56].
- **Certification schemes:** SRC pellets can be certified with the ENplus® quality scheme, while SRC wood chips can be certified with the GoodChips® quality scheme.

Figure 36: Willow harvesting / chipping [Image source: GEA]

[54] Isebrands, J. G., & Richardson, J. (2017). Poplars and Willows: Trees for Society and the Environment. The Food and Agriculture Organization of the United Nations and CABI. http://www.fao.org/3/a-i2670e.pdf
[55] https://salixin.com/
[56] Bioenergy Europe (2019), ibid.

Figure 37: Willow chips [Image source: GEA]

In Table 9, average typical values for willow and poplar are presented, while more information about the typical variation of these properties can be found in Annex B of EN ISO 17225-1.

Table 9: Indicative fuel composition – willow & poplar

Property	Unit	Willow & Poplar
Moisture, M	w-% a.r.	50 (fresh)
Ash, A	w-% d.b.	2.0
Net Calorific Value, NCV	MJ/kg a.r.	8.0
Bulk Density, BD	kg/m^3 a.r.	250 (chips)
Energy Density	MWh/m^3 a.r.	0.56 (chips)
Nitrogen, N	w-% d.b.	0.5
Sulphur, S	w-% d.b.	0.04
Chlorine, Cl	w-% d.b.	0.02
Calcium, Ca	mg/kg d.b.	5,000
Potassium, K	mg/kg d.b.	2,500
Sodium, Na	mg/kg d.b.	25
Silica, Si	mg/kg d.b.	500

a.r.: as received, d.b.: dry base

References

1. van Loo, S., Koppejan, J. (Ed.) (2008) The Handbook of Biomass Combustion and Co-firing. Earthscan. ISBN: 978-1-84407-249-1
2. Quaak, P. Knoef H., Stassen H.E. (1999) Energy from Biomass - A Review of Combustion and Gasification Technologies. World Bank Publications. ISBN: 0-8213-4335-1
3. EN ISO 17225-1:2014 Solid biofuels — Fuel specifications and classes — Part 1: General requirements