Sharing Knowledge on Energy Communities

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Module 3
Heat Production

Part of the SHaKE Educational Package on District Heating and Cooling Systems

Biomass and Waste-to-Energy

Supplementary learning material

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MODULE 3

LECTURE

1.1 Introduction

The transition towards more sustainable and diversified energy systems has increased the importance of renewable and alternative energy sources. Among these, biomass represents a particularly important option because it can be used for heat production, electricity generation and combined heat and power production. Biomass is available in several forms including solid, liquid and gaseous, each requiring different technologies for storage, combustion, energy conversion and emission control. Its local availability and the and the possibility of utilising agricultural forestry and organic residues also make biomass and attractive option for decentralised energy systems or district heating systems. At the same time biomass utilisation is subject to technological and environmental limitations, such as fuel quality variations, ash-related problems. corrosion and the availability of sustainable biomass resources.

1.2 Biomass overview

Biomass is a biologically produced mass of organic matter. If the production and use of organic matter are in balance, it can be considered a renewable energy source. It is a carbon neutral energy source. Although carbon dioxide is produced during the recovery process, it is not considered a greenhouse gas because the carbon dioxide emitted was biogas sequestered from the atmosphere during the biomass formation process several years or decades earlier. Unlike the combustion of fossil fuels, carbon dioxide that has been sequestered for tens of thousands or hundreds of thousands of years is not released into the atmosphere.

Figure 1. Woodchips at a biomass power plant [1]

Biomasses can be divided into three groups according to their state: solid, liquid and gas. Solid biomass can come from woody plants, herbaceous plants or even livestock. Solid biomasses are characterised by easy storage (Figure 1, Figure 2 and Figure 5) and stockpiling. However, the use of solid fuels is the most technology intensive. This is reflected in the energy use of energy conversion systems themselves. The self-consumption rate for solid biomass fired power plants is between 10 and 15%.

The advantages of solid biomass include carbon neutrality, lower nitrogen oxide emissions, but also better combustion efficiency can be achieved more easily with biomass combustion. The typical disadvantages of solid biomasses compared to fossil fuels are the high alkaline earth metal content and the resulting slagging and chlorine corrosion caused by the possible presence of chlorine. Not a particular disadvantage, but solid biomasses have a significant volatile content.

Figure 2. Straw at a biomass power plant [2]

Liquid biomasses are mostly biologically produced liquid fuels characterised by a high energy density, which is characterised by easy (atmospheric pressure tanks) storage. In terms of use, liquid fuels require little further preparation. The high energy density, ease of storage and use make liquid fuels ideal for transport for vehicle propulsion. Typical liquid biomass fuels are bioethanol and biomethanol, the use of which is regulated by several regulations.

Figure 3. Biogas fermenter and gas engine [3]

The use of gaseous biomasses is simple, does not require large energy-intensive shredders, material handling, etc (Figure 3). However, gas cleaning is often necessary. However, the storage of gaseous biomass is a challenging task. Typically, they can be stored at room temperature at higher pressures, but of course there are near atmospheric pressure containers that liquefy the biogas at very low temperatures, but this is not the typical solution for gas storage. There are basically two sources of gaseous biomass. Organically produced biogases, which are combustible gases produced by bacteria during the decomposition of organic matter. The combustible component of the gas is predominantly methane, but there are, also carbon monoxide, carbon dioxide and hydrogen sulphide as pollutants (Table 1). The calorific value of biogas depends on its methane content. Hydrogen sulphide, which causes acidification, can cause corrosion and emission problems when the gas is used.

Table 1.: Typical biogass components (International Energy Agency – Outlook for Biogas and Biomethane, https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane)

Component	**Formula**	**concentration**
Methane	CH_4	**50–70 vol.%**
Carbon dioxide	CO_2	**30–50 vol.%**
Nitrogen	N_2	0–5 vol.%
Oxygen	O_2	0–3 vol.%
Hydrogen	H_2	0–1 vol.%
Hydrogen sulfide	H_2S	0–2000 ppm
Ammonia	NH_3	<100 ppm
Water vapor	H_2O	Variable, often saturated

Overall, biomass utilisation contributes to reducing greenhouse gas emissions but is characterised by low local availability (difficult to set up competitive energy systems with economies of scale) and limited total available biomass supply. Biomass is clearly not a solution to the energy crisis and climate change, but as a local complementary solution, biomass as an energy carrier can be an excellent choice for security of supply reasons. Figure 4. shows a district heating CHP plant which utilise straw as primary fuel.

Figure 4. Straw line at biomass CHP plant [4]

Many district heating systems and other local energy supply systems use biomass boilers. Biomass utilisation by combustion accounts for the vast majority of biomass utilisation in the energy sector.

Figure 5. Woodchips bunker [5]

1.3 Grouping of biomass boilers

1.3.1 Heat transfer medium types

a) warm water

The type of heat transfer medium is essentially determined by the temperature level required by the heat consumer. The most used heat transfer medium is water/vapour because it is cheap, available in large quantities and non-flammable.

A hot-water boiler is said to be a hot-water boiler if the water flow temperature is below 115 °C. The boiler and heating system pressure level is typically 2-3 bar(g). These boilers do not require frequent inspections and are easier to permit and construct. In case of damage to the pressure part, there is no risk of steam escaping. Figure 6. shows the sizes of a 25 MW_{th} biomass heat only plant in Hungary.

Figure 6. Biomass fired heatating plant at Kecskemet [6]

b) hot water

We refer to a hot-water boiler when the forward temperature exceeds 115°C. In this case, the pressure level used is 8-10 bar(g) to keep the water subcooled. The main advantage of hot water as a heat carrier is that a higher temperature difference can be achieved at the consumers, thus eliminating the need for large pipe diameters and reducing the investment cost of the heating system. Special care must be taken when installing and repairing hot water boilers. In case of damage to the pressure part, leakage of steam can be expected. However, high flow temperatures can be achieved. District heating systems are typically equipped with hot water boilers, but high flow temperatures are no longer used to reduce network losses. A typical operating problem with hot water boilers is cavitation, which can lead to damage to the boiler and is caused by a slowed flow in some boiler tubes (e.g. a constricted tube due to a welding defect).

In many cases, old hot water natural gas boilers will be supplemented with warm water biomass boilers, in which case a separator heat exchanger is required to separate the low- and higher-pressure sections.

c) steam

Steam, (saturated steam), as a heat carrier, is of particular importance for heat supply. The former steam-fired district heating systems have largely been phased out for energy efficiency reasons, but steam continues to play a major role in industrial heating. This can be explained by the basic physical properties of steam, such as the very high heat transfer coefficient during condensation and the constant temperature during the condensation of saturated steam. For this reason, steam is still used today for industrial heating processes, be it in car tyre production, the paper industry or the chemical industry.

The temperature of saturated steam condensation is determined by pressure alone, so that the temperature can be controlled by the pressure of the steam to meet a given industrial heat demand. The high condensation heat transfer coefficient means that a relatively small heat transfer surface is sufficient. Due to the high performance that can be achieved with a relatively small heat transfer surface, the heating temperature gradient is also high, allowing a fast-heating rate to be achieved.

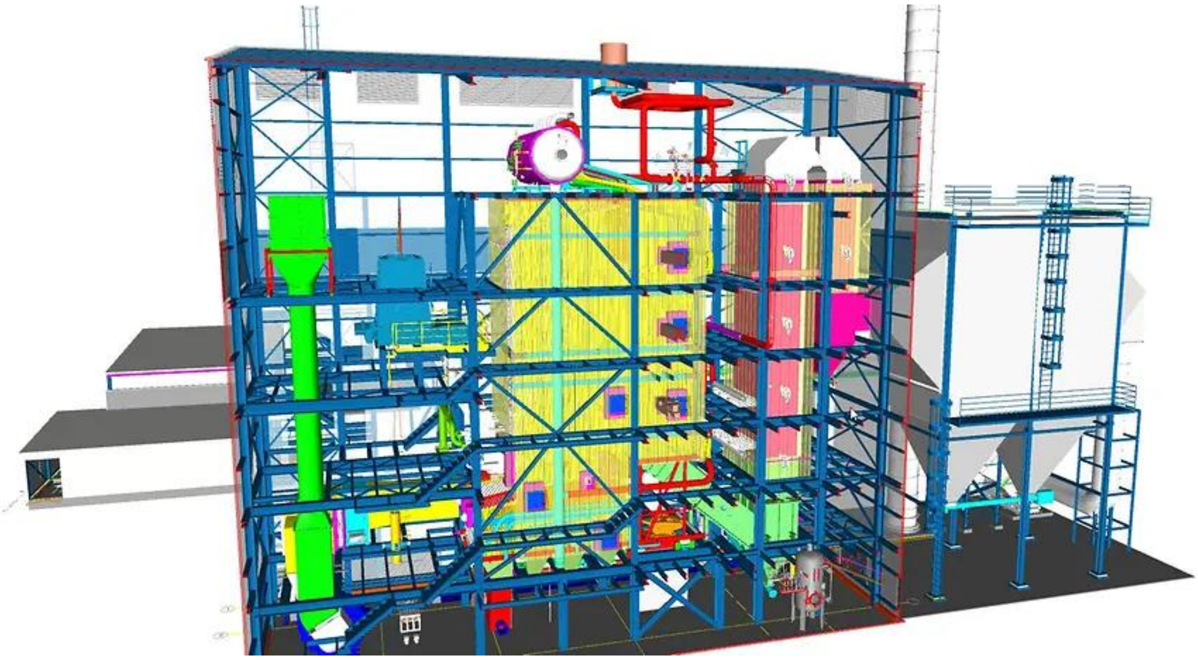

Figure 7. Biomass fired steam boiler [7]

The disadvantages of steam include high heat loss in the network, significant investment costs (higher pipe wall thickness, water softener for boiler, degassing requirements, etc.). Basically, the efficiency of steam boilers is lower than that of hot water boilers, as the continuous operation of the coil on the boiler causes heat losses that do not occur with hot water boilers. However, modern steam boilers (Figure 7), when combined with appropriate water softening systems, can reduce the coil loss and, by using an air preheater, steam boilers can match the efficiency of a hot water boiler.

d) thermal oil

Thermal oil is a special heat transfer medium that theoretically combines the benefits of hot water and warm water (Figure 8). Thermal oil is a carbon-hydrogen compound with a boiling point of more than 100 °C. Thus, very high forward temperatures (180-280 °C) can be achieved at near atmospheric pressure. The type of thermal oil determines the highest available flow temperature. Therefore, thermal oil boilers do not need to be sized for high pressure. There is no need for continuous operation of degassing and other water treatment. A significant advantage is that thermal oil systems can be installed in a blocked system, with less on-site installation than steam boilers or hot water boilers.

A clear disadvantage of thermal oil is the higher investment cost (thermal oil is significantly more expensive than water) and its higher viscosity, which means that the circulation work is more significant. This can also be observed in the way that a thermal oil boiler with the same firing capacity requires a much larger circulating pump. From the point of view of operational safety, it is not negligible that most thermal oils are flammable, so that the risk of fire in the event of a boiler burst is significant.

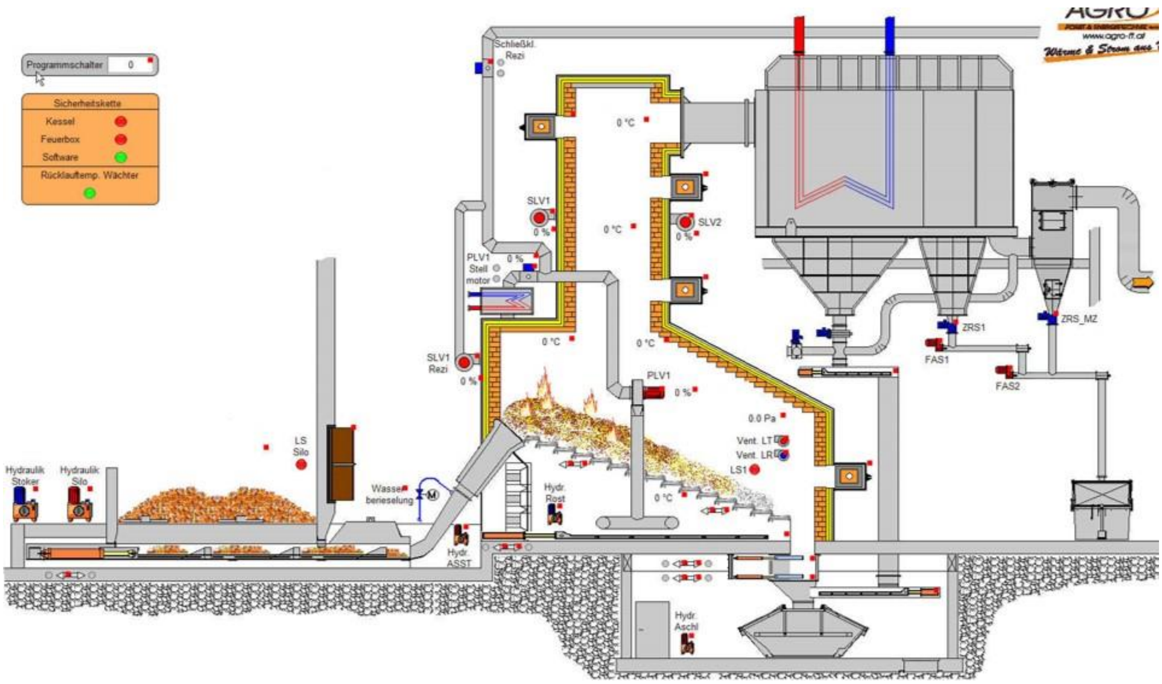

Figure 8. Thermal oil boiler (step grate) [8]

1.3.2 Combustion chamber types

Solid biomass boilers are basically either grate or fluidised bed boilers. Powder firing processes are not specific to biomass and are therefore not discussed in this paper.

The grate is responsible for ensuring the mixing of fuel and air, for the removal of the resulting slag and for the distribution of the primary combustion air introduced. Grille systems are moved to achieve better mixing and automated operation. The grate combustion is simple, robust in design, low maintenance and particularly insensitive to fuel composition, size distribution and foreign matter. Grills can in many cases be provided with cooling to ensure that high combustion chamber temperatures do not damage their structure.

a) step grate

When using the step grate (or reciprocating-grate), the staggered grates move backwards and forwards in a comb-like motion, moving the fuel from one end of the boiler to the other (Figure 9). The step grate is a common design, simple and suitable for the construction of low output installations. In many cases, the combustion chamber is not cooled and there is no heat recovery within the combustion chamber, which is advantageous especially for low unit outputs, as good combustion efficiency and stable combustion chamber temperatures can be achieved even at low power. Feed grids are used for lumpy biomass (e.g. wood chips). Step grates are usually water cooled.

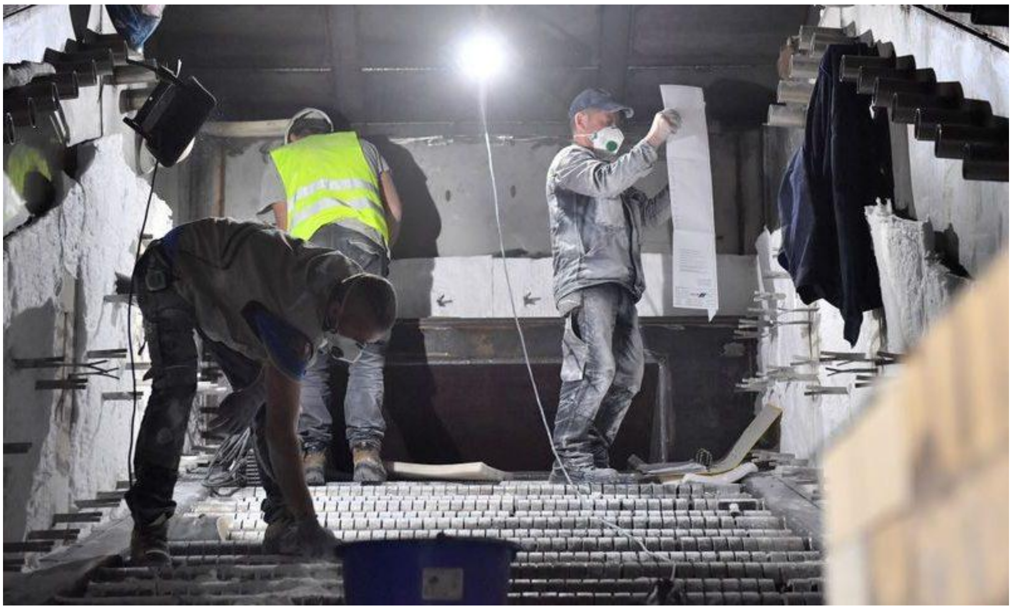

Figure 9. Step grate boiler (7.5 MW) under construction [9]

b) traveling grate

In case of traveling grate combustion, the fuel is fed through the combustor on a horizontal conveyor belt. The grate can only be cooled by the incoming combustion air, so it must be sized for high heat loads. It is generally used for smaller firing capacities (a few MW).

c) vibrating grate

The vibrating grate involves the construction of a sieve-like screen system, which is vibrated by an electric motor, as show on Figure 10. Vibrating grates are used for fibrous biomass (e.g. straw firing). The intensity of the vibration of the grate controls the residence time in the combustion chamber.

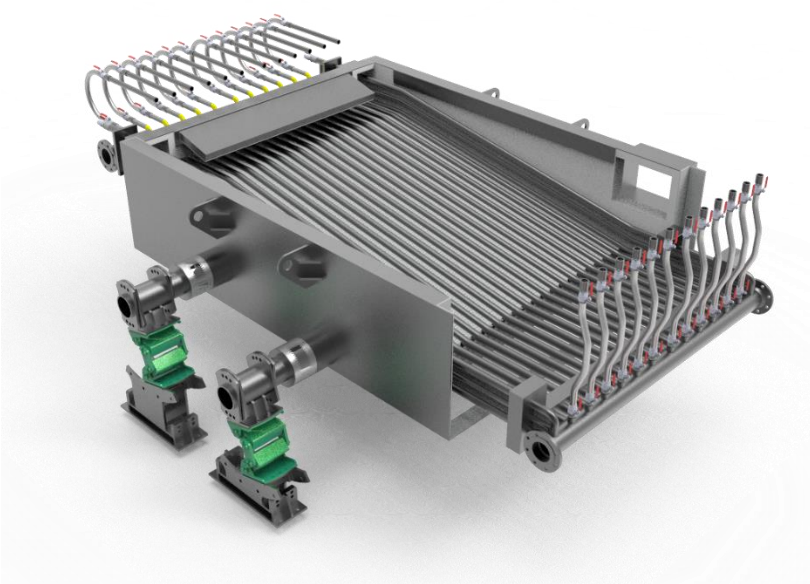

Figure 10. Water cooled vibrating grate (forrás: https://en.akkaya.com.tr/urun/water-cooled-vibrating-grate-system-wcvg/#gallery-0-1)

d) rotating grate

The rotating grate furnace (Figure 11) is composed of large diameter staggered perforated cylinders. Air can flow through the cylinders to the fuel. The cylinders rotate at a slow speed (a few revolutions per minute) to facilitate the movement of the fuel within the boiler.

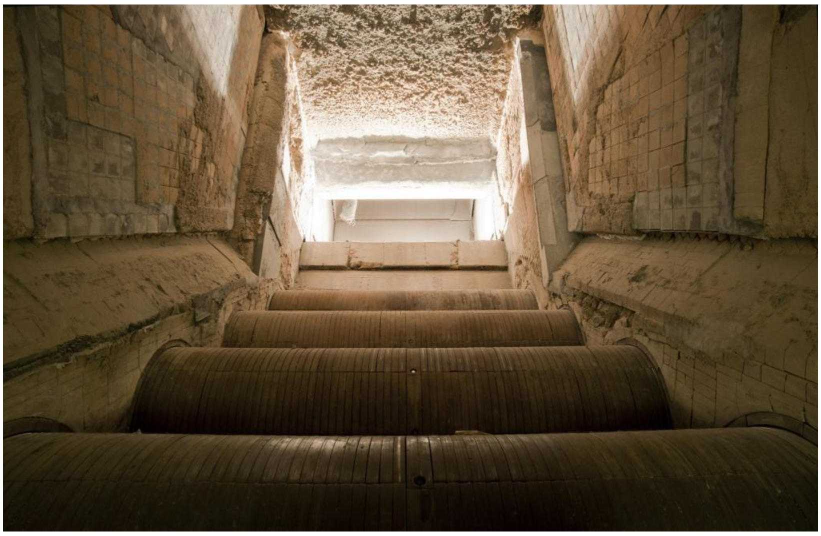

Figure 11. Rotating grate (40 MW) under maintance [10]

e) fluidised bed

Fluidisation firing (Figure 12) is a special process using fluidisable bed material (typically quartz sand). In the fluidized bed, the fuel particles "float" as they burn. This process achieves very good mixing between the fuel and the combustion air, resulting in good combustion efficiency. In addition, local boiling points, which can lead to high nitrogen oxide emissions in grate firing, are eliminated. The release of the combustion heat does not take place on a nearly flat surface but in a larger area, resulting in a lower average combustion chamber temperature, which also has a positive effect on the nitrogen oxide release. The fluidisation combustion process therefore achieves favourable emission parameters with good combustion efficiency. However, it has the disadvantage of higher auxiliary energy requirements for combustion air fans and more complex operation. The typical combustion chamber temperature ranges from 850 to 950 °C. Above this value, the fluidised bed of sand can clump together (form agglomerates), making continuous operation impossible. Biomasses with a low ash bedding temperature (herbaceous biomasses) also increase the risk of agglomerate formation.

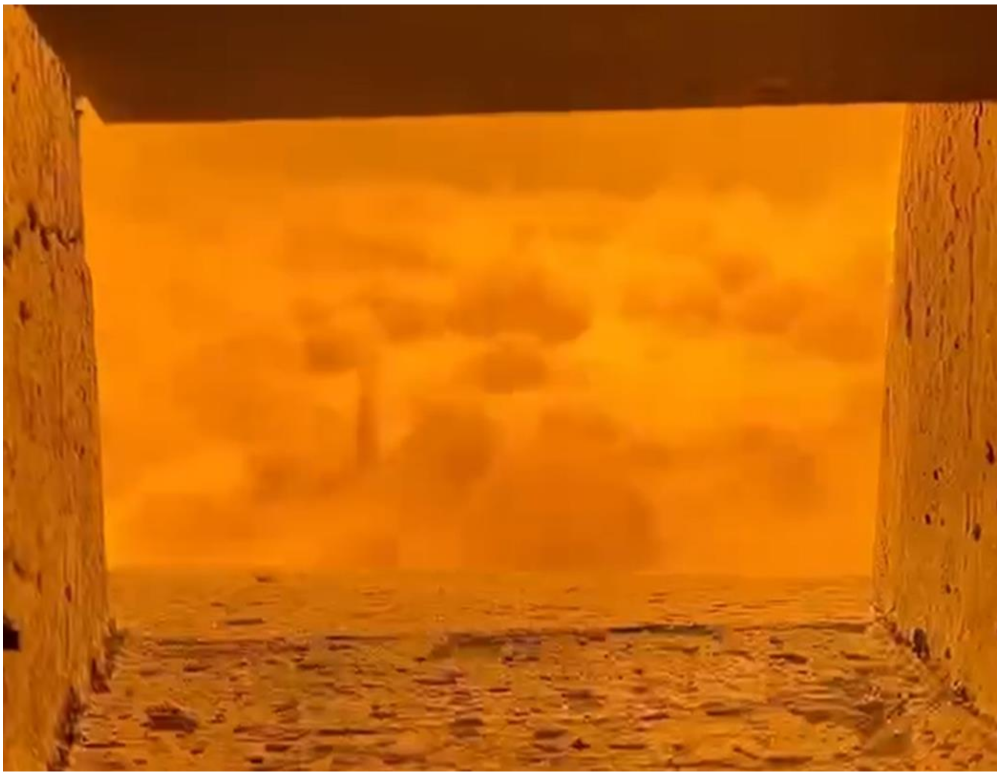

Figure 12. Startup procedure at a bubbling fluidised bed boiler

There are two basic types of fluidisation combustors: bubbling fluidisation, where the fluid bed is located in the so part of the combustion chamber. And the more advanced circulating fluidisation combustor, where the fluid bed circulates in a loop. With this method a higher unit power can be achieved

1.3.3 Applied combustion chamber pressure

The pressure in the combustion chamber is basically controlled by the flue gas fan, if there is no natural ventilation. Traditionally, biomass boilers have a slight vacuum (depression) in the combustion chamber, so that during a mass leakage on the flue gas side of the boiler, no toxic flue gas escapes into the boiler house, but only a slight air intrusion occurs. However, many efforts have also been made to exploit the advantages of increasing the flue gas side pressure in the combustion chamber.

a) depressed combustion chamber

A slight vacuum prevails in the depressed combustion chamber, with a relative value of only a few mbar. However, this slight vacuum is sufficient to prevent the escape of toxic flue gas to the environment through the combustion chamber, but air enters the combustion chamber by uncontrolled means. Of course, minimising air infiltration is still of fundamental interest, as it reduces boiler efficiency (increases flue gas loss). But it is not a safety risk if the boiler is not completely airtight.

The flue gas fan is responsible for maintaining depression if the flue gas discharge is forced flow. In the case of natural draught flue gas venting, the chimney liner maintains the depression in the combustion chamber, but due to the more difficult operation, natural draught is no longer used at higher capacities.

b) pressurised combustion chamber

With a pressurised combustion chamber, the boiler is completely airtight and the combustion air fan ensures the flow through the boiler and the flue gas exhaust system. Thus the combustion chamber is overpressurised by a few mbar. This arrangement allows the flue gas fan to be dispensed with, which is advantageous as it eliminates the need for a high-temperature fan, but raises a number of other problems with fuel supply. For biomass boilers, the use of a pressurised combustion chamber is not common.

c) over pressurised (charged) combustion chamber

In the case of charged boilers, there is a significant (several bar(g)) overpressure in the combustion chamber. Blowers and compressors capable of higher pressures may therefore be responsible for supplying combustion air to the boilers. The higher air pressure increases the heat transfer coefficient between the flue gas and the steel, thus reducing the size of the heat transfer surface required (smaller boilers of similar capacity). However, the supply of fuel to the combustion chamber requires complex systems, since the overpressure must be maintained during the fuel feed. There are several solutions for feeding solid fuels into the pressurised space: various sluice systems, but the most technically reliable is the use of powder firing, whereby the solid fuel is ground into a powder at atmospheric pressure and this powder is injected into the boiler space with a high-pressure auxiliary medium. These systems, in turn, require high quality biomass fuels that are homogeneous and free of foreign matter. These fuels are typically more expensive. For this reason, charged biomass boilers have only been built as part of pilot projects and have never been an economically competitive alternative.

1.4 Energy conversion system for biomass combustion

1.4.1 Steam turbine

Steam turbines are devices with a history dating back more than a century that convert the internal energy of steam into mechanical work (and, via a generator, into electrical energy). The steam turbine is the most commonly used type of thermal power plant in biomass power plants.

In terms of heat output (district heating), we distinguish between three basic types.

a) condensing steam turbine

The condensing steam turbine, where useful heat output is not possible, since the steam expands at a pressure corresponding to the ambient temperature. In this case, electricity generation is maximized, while there is no useful heat output.

b) extraction-condensing steam turbine

The extraction–condensing steam turbine (Figure 13) is one in which a portion of the steam is extracted at a higher pressure (and thus at the saturation temperature), where its temperature is still sufficiently high for district heating (or other heat recovery purposes). This type of turbine is the most commonly used solution for combined heat and power generation, as the condensing turbine section provides a degree of flexibility in production: when there is no heat demand, a larger mass flow can expand toward the condenser; when heat demand increases, less steam expands into the condensing section of the turbine. It is important to note that, in this case, increasing heat output results in a decrease in electrical output. A properly sized extraction-condensing steam turbine can cover a wide range of thermal output. Its advantage is flexible power generation; its disadvantage is that, in the event of significant heat loss, the efficiency of the condensing section decreases, since a much smaller mass flow expands there due to the extraction. The amount of steam extracted can often be controlled by installing overfolw valves into the turbine. By throttling the valve, the amount of steam flowing into the condensation section can be reduced, thereby increasing the amount of steam reaching the heating heat exchangers.

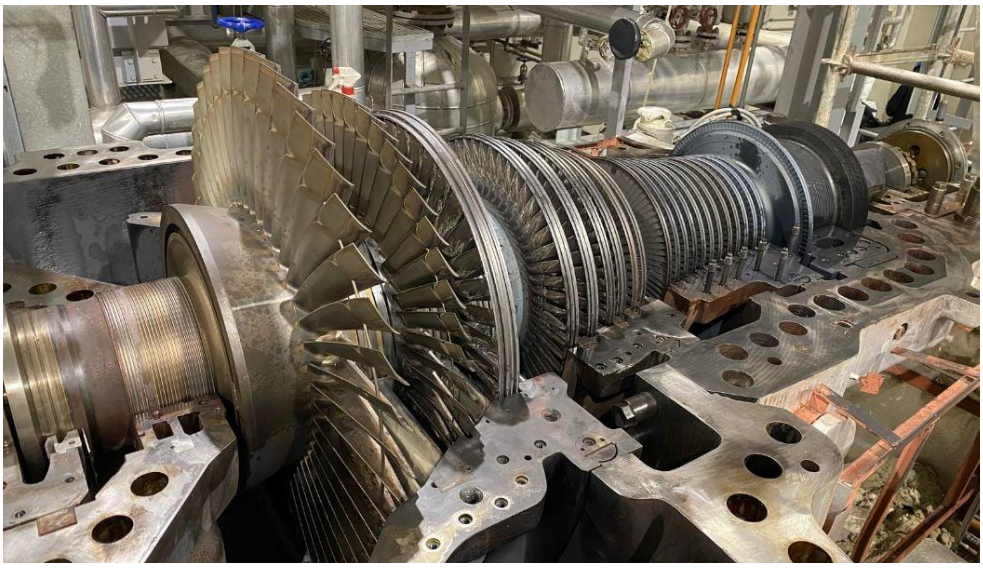

Figure 13. Extracted-condensing steam turbine rotor [11]

c) back pressure steam turbine

The third (and cheapest) type of turbine is the back-pressure steam turbine (Figure 14, Figure 15). In this case, the turbine has no condensing section (which is why this type of turbine is inexpensive, since the largest—and thus most expensive—condensing stages are omitted). In district heating applications, steam exits the turbine at a pressure of 0.8–1.2 bar(g) and is directed to the heating heat exchangers. A distinctive feature of the turbine is that as heat demand decreases, its electrical output also decreases, since there is no heat extraction required for steam condensation (and thus for maintaining the turbine's steam intake). Despite their simplicity, back-pressure turbines are less commonly used in modern variable-flow district heating systems, as it is very difficult to meet heat demands that fluctuate drastically throughout the day. However, they are an ideal, high-efficiency combined heat and power generation method for winter base load. A back-pressure steam turbine is also commonly referred to as a full-heat-exchange turbine, since the entire steam mass flow condenses in the heating heat exchangers. If there is insufficient heat demand, these turbines cannot operate. Tracking time-varying heating demands on the turbine side presents challenges, as the minimum partial load for a typical steam turbine is 40%. At low loads, the forces acting on the turbine blades increase, and the temperature of the exhaust stub also begins to rise due to the deteriorating isentropic efficiency. There is a strict maximum limit for the stub temperature; once this limit is reached, the turbine must be shut down.

Figure 14. Back pressure steam turbine (2 MW_e)

Figure 15. Back pressure steam turbine-generator (27 MW_e) [12]

1.4.2 Organic Rankine Cycle

The Organic Rankine Cycle (ORC) is a highly compact thermal power plant (Figure 16) that can be connected to virtually any heat source. The primary advantage of the ORC is that it can be implemented at low unit capacities, even when housed in a container, which is ideal especially for biomass power plants in the range of a few MW. From a thermodynamic perspective, this is also a Rankine cycle, just like in the case of steam turbines, but here an organic working fluid expands. An additional advantage is that it can operate at lower temperatures (180–300 °C for biomass). A disadvantage is the extremely high specific capital cost.

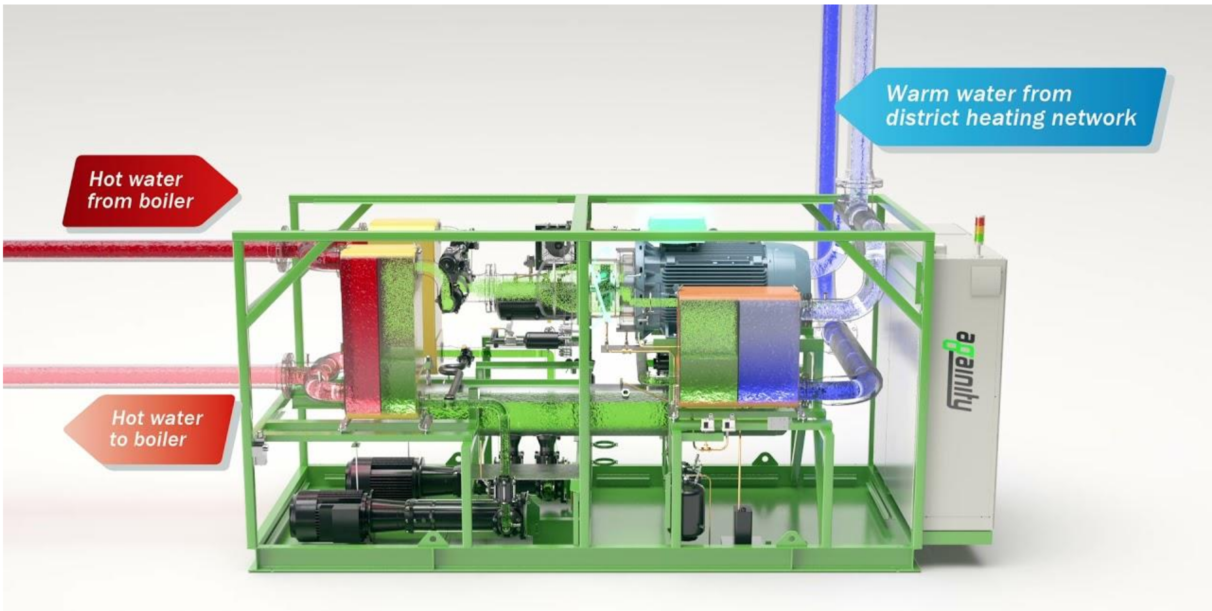

Figure 16. Distric heating ORC [13]

Heat input can be provided by steam generated in a biomass boiler, but thermal oil is generally preferred. Thus, the ORC's organic working fluid does not flow directly into the boiler; instead, there is a thermal oil separation loop. Unfortunately, this increases the system's self-consumption, as a circulation pump must be installed in the thermal oil loop, but it does allow the volume of the ORC's working fluid to be reduced. Cogeneration using an ORC cycle is also feasible; according to international examples, it is often implemented with full heat extraction (i.e., using a back-pressure ORC expander). These systems can essentially supplement the output of a biomass heating plant, and the amount of electricity generated may be sufficient to meet the electricity consumption of the district heating system. The system's electrical efficiency is around 8–10%, compared to water-steam turbine cycles operating at higher pressures and temperatures, which are capable of electrical efficiencies of around 18–24%. Biomass-based ORC cogeneration is therefore a transition between district heating from biomass-fired heating plants and biomass power generation from steam power plants.

1.4.3 Gas engine ang turbine

Gas engine (Figure 17) and gas turbine (Figure 18) power generation can only utilize gaseous biomass. However, they do so with exceptionally high electrical efficiency. Gas engines (Figure 19) operate on the conventional Otto cycle, while gas turbines operate on the Joule-Bryton cycle. Gas engines are more widespread because their electrical efficiency is significantly higher than that of gas turbines, especially at low power levels. The electrical efficiency achievable with gas turbines ranges from 25% to 30%, while biogas engines can operate at efficiencies of 35% to 40%. Another significant advantage is that the torque characteristics of gas engines are more favourable than those of gas turbines, as they can deliver high torque at low RPM. The advantage of gas turbines is that they require less maintenance than gas engines. In many cases, they do not even require lubricating oil (due to the use of air-lubricated bearings).

Figure 17. Biogas engine installation [14]

Gas engines –and, less commonly, gas turbines (Figure 18) –are an integral part of the operation of biogas plants, wastewater treatment plants, and landfills. In many cases, the biogas that is utilized can be considered “waste,” since its production is a byproduct of a waste disposal process.

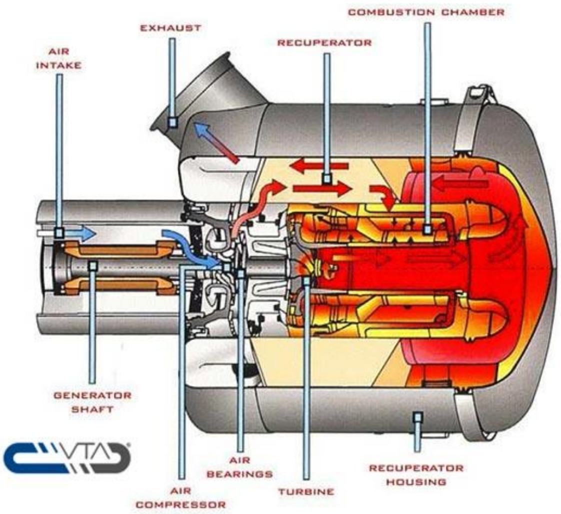

Figure 18. Schem of a micro biogasturbine [15]

The expected service life of biogas engines is shorter than that of natural gas-fired engines, since the fuel contains significant amounts of corrosive gases and may also contain dust, which can lead to wear on the equipment. Since heat recovery is not feasible in most locations (they are too far from district heating systems), a more energy-efficient solution may be to produce biomethane and feed it into the natural gas grid. In this case, the biogas must be purified to natural gas quality; in particular, the corrosive hydrogen sulphide content must be almost completely removed so that it can be fed into the natural gas grid.

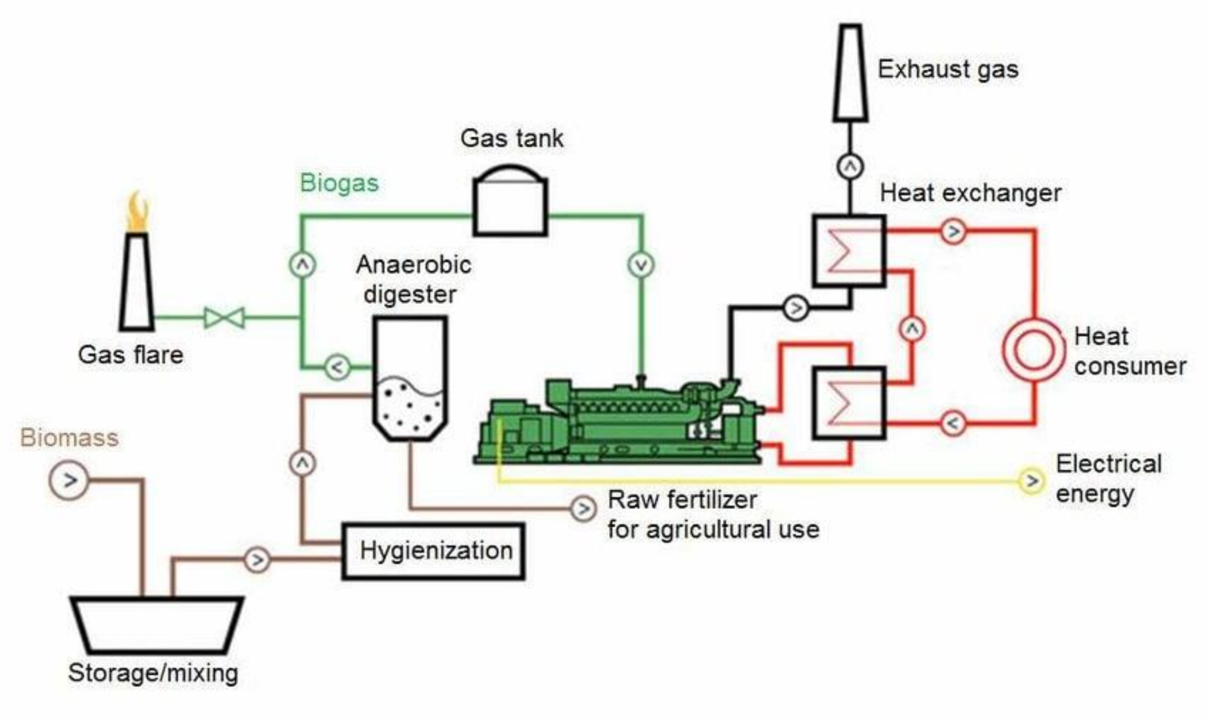

Figure 19. Schem of a biogas plant with gas engine [16]

1.5 Waste to Energy

The energy recovery from waste is a special form of biomass utilization, since this biomass is produced by humans and not by other living organisms. It is strictly distinct from other types of biomasses, first because it has a significant (~50%) fossil content (since the plastics used for energy recovery are made from crude oil). Furthermore, such facilities are subject to entirely different (much stricter) regulations regarding emissions. The energy recovery of waste is the subject of much public debate; however, it can be stated that it is an inseparable part of metropolitan life, since a metropolis generates such a concentrated volume of waste that neither material recycling nor landfilling is a viable solution. Table 2 shows per capita waste generation in various European countries. A higher standard of living is associated with greater consumption and, consequently, higher waste generation.

Table 2.: Waste generation per capita [17]

Country	Municipal waste generated (kg/person/year)	Reference year
AT Austria	**782 kg**	2023
DK Denmark	**755 kg**	2023
BE Belgium	**699 kg**	2023
LU Luxembourg	**~673 kg**	2023

Country	Municipal waste generated (kg/person/year)	Reference year
DE Germany	**~618 kg**	2023
FR France	**~514 kg**	2023
ES Spain	**~467 kg**	2023
IT Italy	**~494 kg**	2023
HU Hungary	**~413 kg**	2023
PL Poland	**387 kg**	2023
EE Estonia	**375 kg**	2023
RO Romania	**305 kg**	2023
EU average	**511 kg**	2023

Waste-to-energy conversion often takes place in conjunction with district heating (CHP), as these waste-to-energy plants are located close to both cities and district heating systems (Figure 20, Figure 21).

Figure 20. Waste to Energy plant in Vienna [18]

a) emisson

The emission limits for waste incineration are the strictest and are significantly stricter than those for biomass (e.g., straw) boilers of the same capacity. Table 3 shows the applicable limits for each pollutant. Compliance with these limits requires advanced flue gas cleaning systems; however, the construction of such systems can minimize the environmental impact of the waste-to-energy plant. In many cases, waste-to-energy plants are located within city limits (e.g., Vienna). This is made possible by modern flue gas cleaning processes. The applicable emission limits (Table 3.) are set forth in the EU's IED Directive 2010/75/EU; stricter limits are specified in BAT-AEL 2019/2010/EU, which applies to newly constructed waste-to-energy plants. Limits stricter than the statutory limits may also be set for a specific facility.

Table 3. Emission limits of Waste Incineration Plants

Pollutant	2010/75/EU IED original ELV	2019/2010/EU BAT-AEL – new plants
Dust	10 mg/Nm³	**<2–5 mg/Nm³**
HCl	10 mg/Nm³	**<2–6 mg/Nm³**
HF	1 mg/Nm³	**<1 mg/Nm³**
SO_2	50 mg/Nm³	**5–30 mg/Nm³**
NO_x (as NO_2)	200 mg/Nm³	**50–120 mg/Nm³**
CO	50 mg/Nm³	**10–50 mg/Nm³**
NH_3	–	**2–10 mg/Nm³**

An important requirement regarding the combustion chamber temperature is that the flue gas must remain at 850 °C for at least 2 seconds after the last air injection point. This is necessary to ensure that dioxin and furan compounds, which are highly harmful to health, are completely burned off. Boilers must be equipped with automatic natural gas backup burners that activate without operator intervention if the temperature drops below 850 °C.

The ignition loss of the furnace ash must remain below 5%; therefore, the ash leaving the boiler must not contain any unburned particles.

Figure 21. Waste to Energy plant in Budapest [19]

b) boilers

With regard to boilers, the most common modern solution is the so-called push-back grate (Figure 22); in this case, the grate elements pull the already burning waste particles under the newly arriving waste, thereby promoting rapid drying and ignition of the fuel. In traditional systems, fluidized-bed combustion and a special rotating grate may also be used. In the case of a rotating grate, the fuel is ignited using an ignition vault (thick heat-radiating masonry). Since the moisture content of the fuel can vary widely depending on weather conditions, the combustion air is typically preheated to 180–240 °C using steam-heated calorifiers. Boilers are highly susceptible to corrosion due to the chlorine content of the fuel. To mitigate corrosion, low steam parameters (40 bar(g), 420 °C) are used.

Figure 22. Grate at a WTE plant [20]

Due to the low steam parameters, the power plant's electrical efficiency lags behind that of biomass power plants of similar capacity; however, ensuring equipment availability (reducing breakdowns) is a more important consideration. Modern boiler design philosophy requires that individual heat exchangers in the boilers be as easily accessible as possible. This is to ensure that anticipated pipe leaks can be repaired with the shortest possible downtime. Efforts are also being made to reduce corrosion-related failures in modern waste-fired boilers through the use of steel superalloys (e.g., Inkaloy 625); however, these alloys significantly increase the capital cost of the boilers, so they are used only on surfaces most exposed to corrosion (e.g., superheaters).

c) steam turbines

Waste-to-energy plants are generally equipped with extraction-condensing steam turbines (Figure 23). Heat exchangers heated by higher-pressure extraction steam are responsible for district heating. If the district heating system does not have a high enough heat demand (e.g., during summer DHW operation), the steam can continue to expand toward the condenser, thereby increasing the power plant's electrical output.

Figure 23. Extracted-condensing steam turbine at waste to Energy plant in Budapest [19]

To increase the efficiency of electricity generation, a two-stage steam extraction process is often used. This means that steam is extracted from the turbine at not one but two pressure levels. This reduces quality losses during heat recovery (high-temperature steam is not wasted on producing low-temperature hot water for heating but is instead used to drive the turbine further).

d) energy efficiency

We can speak of energy recovery from waste when the energy conversion efficiency meets the R1 requirements. The R1 energy efficiency criterion, based on the EU Waste Framework Directive (Directive 2008/98/EC, Annex II), determines whether a facility that incinerates municipal waste qualifies as a recovery (R1 – "Use principally as a fuel or other means to generate energy") rather than a disposal (D10) operation. The calculation is based on an annual energy balance and takes into account the production of electricity and useful heat, as well as the energy content of the waste and auxiliary fuel. Facilities authorized after December 31, 2008, must achieve a value of at least R1 = 0.65, while facilities that were already in operation and authorized prior to 2009 must achieve a value of R1 ≥ 0.60. The R1 value must be calculated using the formula specified by the European Commission, and the applicable climate correction factor (CCF) must also be taken into account in the calculation. [21]

$$R1 = \frac{E_p - \left(E_f + E_i\right)}{0.97 \times \left(E_w + E_f\right)}$$

where:

- Ep = annual energy produced as heat or electricity. Electricity is multiplied by 2.6, while heat produced for commercial use is multiplied by 1.1 (GJ/year).
- Ef = annual energy input to the system from fuels contributing to steam production (GJ/year).
- Ew = annual energy contained in the treated waste, calculated using the net calorific value (NCV) of the waste (GJ/year).
- Ei = annual energy imported into the system, excluding Ew and Ef (GJ/year).
- 0.97 = correction factor accounting for energy losses due to bottom ash and radiation.

For municipal solid waste incineration plants to be classified as an R1 recovery operation, the calculated energy efficiency must be at least 0.60 for installations in operation and permitted before 1 January 2009, or 0.65 for installations permitted after 31 December 2008

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