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A citizen's guide to waste incineration

Abstract: Waste incineration is a controversial topic, even in technologically advanced and highly industrialized countries. Due to the complexity of this issue, it is necessary to approach the analysis from a broader perspective that encompasses all relevant aspects of the incineration process. This paper examines not only the technological dimensions but also the institutional conditions that support the implementation of the waste management hierarchy, as well as the principles of proximity and self-sufficiency. Special attention is given to the energy recovery of waste through various incineration and co-incineration technologies, with a focus on mechanisms that enable the control and reduction of harmful emissions.

Keywords: waste incineration, incineration, landfills, pollution, waste-to-energy

1. Introduction

In the Republic of Serbia, there is a constant increase in the amount of waste generated, which is a direct consequence of accelerated urbanization, industrialization, and rising purchasing power of the population. This phenomenon, which can rightly be called a "disease of modern times," is increasingly taking on global dimensions, with developing countries being particularly exposed to its negative impacts. One of the key challenges in the field of waste management is inadequate waste separation at the source, a problem also faced by all European Union member states. The lack of systematic sorting leads to the production of waste of insufficient quality for reuse, recycling, or other forms of recovery.

Energy recovery from waste is becoming an increasingly common solution, especially in urban areas worldwide. In the European Union, the leading countries in the construction and operation of municipal waste incineration plants are France (127 plants), Germany (89), and Italy (44). A similar situation exists in the treatment of hazardous waste, with France leading with 48 plants and Germany following with 31. According to available data, waste

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represents one of the largest sources of methane emissions caused by human activity, accounting for 15–20%, with a rising trend.

However, despite the importance of waste management, it is often marginalized even within panels and debates dedicated to climate change. Such practices result in an insufficient understanding of the link between inadequate waste management and greenhouse gas emissions.

According to Eurostat data, citizens of the Republic of Serbia generate over 3.1 million tonnes of municipal waste annually. Of this amount, more than 2.5 million tonnes are disposed of in landfills, a significant portion of which ends up in unsanitary locations. This practice contradicts the waste management hierarchy established by the Waste Management Law, according to which landfilling represents the last and least desirable option. In addition to its lack of environmental sustainability, landfills in Serbia frequently experience fires, further exacerbating ecological risks. Accordingly, landfilling cannot be considered a long-term sustainable solution.

Unlike other complex challenges related to climate change and sustainable development that require a high degree of innovation, solutions in the field of waste management already exist and are applicable in practice. Energy recovery from waste offers not only environmental but also socioeconomic benefits, enabling a circular approach to energy production and consumption based on the principles of reuse, recycling, and resource regeneration. This model has the potential to contribute to sustainable development, as well as to create new jobs and business opportunities at the local level.

In accordance with the provisions of Directive 2010/75/EU on industrial emissions (Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010), two types of thermal waste treatment are recognized), incineration plants and co-incineration plants.

An incineration plant is defined as any stationary or mobile technical unit intended for the thermal treatment of waste—with or without energy recovery—where the waste is treated through oxidation, pyrolysis, gasification, or plasma processes, provided that the resulting substances are subsequently burned.

On the other hand, a co-incineration plant is a technical unit whose primary purpose is the production of energy or material products (e.g., cement), with waste used as a primary or supplementary fuel. In this case as well, treatment involves processes such as pyrolysis, gasification, and plasma technology, with the final products of these processes also subsequently burned.

The key difference between these two types of plants lies in their primary purpose: while incineration may or may not involve energy recovery, co-incineration is directly linked to the production of energy or materials. Both definitions are implemented in the Waste Management Law, which provides the fundamental regulatory framework for thermal waste treatment in the Republic of Serbia.

2. Thermal treatment – waste incineration

Every waste thermal treatment facility must have basic elements on site, including a reception area,

Photo: Freepik

waste storage, in some cases a waste preparation unit, an incineration plant, and optionally a facility for the physico-chemical treatment of ash from the plant and a container for disposal of such waste.

Procedures for receiving waste, its treatment, and disposal of residues are strict and regulated by the Waste Management Law ("Official Gazette of the RS," Nos. 36/09, 88/10, 14/16, 95/18 – other law, and 35/23) and by the specific Regulation on the technical and technological requirements for the design, construction, equipping, and operation of plants and types of waste for thermal treatment, emission limit values, and their monitoring ("Official Gazette of the RS," No. 103/23), which further regulates the conditions for thermal waste treatment.

The combustion process itself takes place in high-temperature chambers, at temperatures above

850°C, or 1,100°C in the case of waste containing halogenated organic substances. At these temperatures, waste decomposes and transitions into a gaseous state, allowing further treatment of the gases in accordance with environmental standards.

Types of waste thermal treatment plants

Waste thermal treatment plants are classified based on the type of chamber in which the incineration process takes place. With the development of technology and the emergence of innovative solutions in waste management, various systems have become available that allow treatment to be adapted according to the type and characteristics of the waste. However, to ensure compliance with standards related to human health and environmental protection, it is necessary to rely on the Best Available Techniques (BAT)as described in the European Union's reference document on waste incineration (*BAT Reference Document for Waste Incineration)*). This document identifies three main types of chambers for thermal waste treatment:

i. grate chambers,
ii. rotary kilns,
iii. fluidized bed chambers.

i. Grate chambers

Grate chambers represent the most widespread type of technology in plants for the thermal treatment of mixed municipal waste. It is estimated that around 90% of incineration plants in the European Union use this technology. In addition to mixed municipal waste, these chambers also treat other types of non-hazardous waste—commercial and industrial in origin—as well as sewage sludge.

This type of facility usually includes a reception bunker where waste is directly unloaded from transport vehicles, a mechanized grate for combustion (most commonly the so-called Martin grate), a bottom ash collection tank, an air supply system necessary for combustion, the combustion chamber itself, and auxiliary burners to support the process.

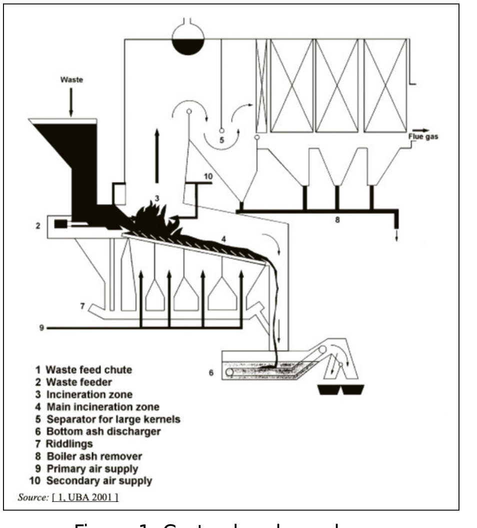


Figure 1. Grate chamber scheme
*BAT Reference Document for Waste Incineration

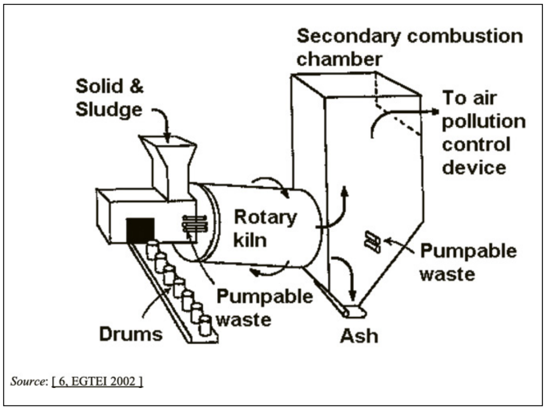
Grate incinerators are designed to enable efficient and complete combustion of waste, with particular attention paid to temperature parameters, gas residence time, and oxygen concentration. To ensure optimal conditions for the thermal decomposition of organic compounds, the gases generated during the combustion process must be maintained at a minimum temperature for at least two seconds, with an oxygen concentration of no less than 6%.

Combustion temperatures in grate chambers range from 850°C to 1,100°C, with higher temperature regimes applied in cases where hazardous waste is treated. Controlling these parameters is crucial to ensure process safety and to prevent the emission of toxic compounds into the environment.

One of the main indicators of combustion process quality is the concentration of carbon monoxide in the flue gases. A high content of this gas indicates incomplete combustion, which can lead to inefficient thermal treatment and increased emissions of pollutants.

Rotary kilns

Rotary kilns are highly durable, allowing almost any type of waste, regardless of its type or composition, to be efficiently thermally treated in this facility. Rotary kilns are widely used for the incineration of hazardous waste. Operating temperatures of rotary kilns range from 850°C to 1,200°C.



Source: [6, EGTEI 2002]

Figure 2. Rotary kiln scheme*

*BAT Reference Document for Waste Incineration

A rotary kiln is a type of thermal chamber consisting of a cylindrical vessel slightly inclined relative to the horizontal axis. It operates on the principle of rotation or oscillation around its axis, which allows waste to gradually move through the chamber by gravity. This type of facility is particularly suited for the treatment of various forms of waste, including liquid, gaseous, and pasty (pumped) waste, which is injected directly into the chamber. This method of dosing significantly reduces the risk of incidents during handling and minimizes worker exposure to hazardous substances.

The residence time of solid material in a rotary kiln is determined by the cylinder's angle of inclination and rotation speed. The typical residence time of waste in the chamber ranges from 30 to 90 minutes, which is sufficient to achieve complete combustion and process stability. Due to their flexibility and ability to process waste of different physical states and compositions, rotary kilns are often used in plants for the incineration of industrial and hazardous waste.

iii. Fluidized bed chambers

Fluidized bed plants are primarily used for the thermal treatment of finely prepared and homogenized waste, such as prepared alternative fuel (RDF – *Refuse-Derived Fuel*) and sewage sludge. This technology, which has been used for decades to burn homogeneous fuels such as coal, raw lignite, biomass, and sludge, is based on the principle of fluidizing solid particles in a layer of heated sand or ash into which the waste is introduced for thermal treatment.

Combustion temperatures in the fluidized bed range from 850°C to 950°C. Although these conditions are suitable for the treatment of non-hazardous waste, the indicated temperature range makes this technology less suitable for the incineration of hazardous waste, as well as waste containing high concentrations of halogenated organic compounds (especially chlorine).

The plant itself consists of a vertically oriented cylindrical chamber with a refractory lining. Waste is continuously fed into the reaction zone—the fluidized bed—via dosing systems such as pumps and mechanical feeders. Within the bed, processes of drying, evaporation, ignition, and final combustion take place, ensuring high thermal efficiency and process stability, provided the input material is homogeneous.

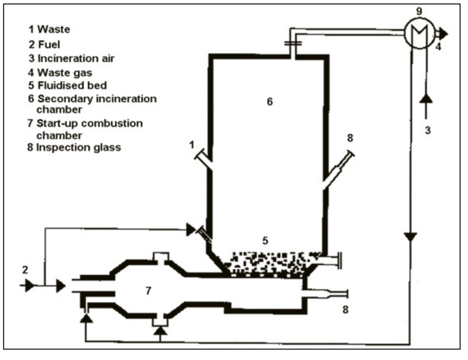


Figure 3. Fluidized bed furnace scheme*
*BAT Reference Document for Waste Incineration

3. Energy recovery from waste

Incineration plants are designed to include heat exchange devices that convert the hot gases from the furnace into useful energy. Waste combustion in an incinerator is an exothermic process that releases heat. Most of the energy produced during this process is transferred to the flue gases, and cooling of the flue gases enables two key processes:

- energy recovery from the hot flue gases;
- purifying of the flue gases before they are released into the atmosphere.

In plants that do not perform heat recovery, gases are usually cooled by injecting water, air, or both. However, most modern plants use boilers that serve two primary functions:

- cooling the flue gases;
- transferring heat from the flue gases to another fluid, usually water, which is converted into steam within the boiler.

The characteristics of flue gases depend on the composition of the waste being treated. For example, hazardous waste often shows large variations in composition and may contain significant concentrations of corrosive substances, such as chlorides, which further affect the composition and quality of combustion.

The energy transferred can be used on-site (replacing imported energy for plant needs) and/or off-site. It can be applied to various processes, such as:

- district heating systems;
- industrial processes requiring heat and steam;
- occasionally, as driving power for cooling and air-conditioning systems.

Additionally, the generated electricity is often supplied to national distribution grids or used within the plant itself.

The efficiency of energy recovery depends on the chemical and physical characteristics of the waste being incinerated. Various local factors can influence the characteristics of waste, including: the addition of industrial waste to municipal waste, on-site or off-site waste treatment, and different waste collection and separation regimes. Market factors can also redirect certain waste streams to other forms of treatment or away from them.

In some cases, operators may have very limited influence on the characteristics of the delivered waste, while in other cases their influence can be significant.

Ranges and typical net calorific values for some types of input waste for incineration (Rios, L., & Picazo-Tadeo, A. J., 2023) are presented in Table 1.

Table 1. Ranges and typical net calorific values for some types of input waste for incineration*

Input waste	Comment and example	Lower calorific value in the original material (including moisture)	
		Range (Gj/t)	Average (GJ/t)
Mixed municipal waste	Mixed household waste from homes	6.3-10.5	9
Bulky waste	Furniture, for example from households	10,5–16,8	13
Waste similar to mixed municipal waste	Waste with similar properties to mixed household waste originating from shops or offices	7,6–12,6	11
Residue from mixed municipal waste after separation	Waste from which fractions for recycling and composting have previously been separated	6,3–11,5	10
Commercial waste	Separately collected waste from shops or offices	10–15	12.5
Packaging waste	Separately collected packaging waste	17–25	20
RDF	Pellet or pelletized material obtained from the treatment of municipal and similar non-hazardous waste	11–26	18
Products from specific industrial waste	Residues of paper or plastic	18–23	20
Hazardous waste	Chemical and other hazardous wastes	0.5–20	9.75
Sewage sludge	Generated after wastewater treatment	See below	See below
	Raw (dried to 25% dry matter)	1.7–2.5	2.1
	Digested (dried to 25% dry matter)	0.5–1.2	0.8

*Rios, L., & Picazo-Tadeo, A. J., 2023 J. 2023

Besides the quality of the waste and technical aspects, the efficiency of the waste incineration process largely depends on the options for utilizing the energy produced. The highest efficiency of waste energy use is usually achieved when the heat from the incineration process is recovered, allowing continuous energy supply for district heating, process steam, and similar applications, or in combination with electricity generation. However, the implementation of such energy supply systems heavily depends on the plant's location, particularly the availability of reliable energy users.

Electricity generation alone, without simultaneous heat supply, is more commonly applied and generally represents a stable way to recover energy from waste. This approach is less dependent on local circumstances, as the electricity is fed directly into the national power grid.

In cases where there is no demand for thermal energy, the produced heat is often used on-site to support the incineration process, significantly reducing the need for imported energy. For plants incinerating municipal waste, this type of internal energy use can reach up to 10% of the total energy produced from waste incineration.

In general, factors to consider when selecting the design of an incineration plant can vary, as shown in Table 2.

Table 2. Factors considered in incineration plant design*

Factors for consideration	Detailed aspects for consideration
Input waste	Quantity and quality Availability, traceability, quality variations depending on the season Possible changes in the nature and quantity of waste Effects of primary separation and recycling
Energy sale potential	Thermal energy Sale to local communities Sale to private industry Use of heat in processes Geographical aspects and infrastructure for heat transfer pipelines Duration of energy demand and contracts Obligations for supply availability Seasonal requirements Substitutes and alternative ways of obtaining energy in the region Security of contracted energy supply Electricity National power grid, on-site energy use Electricity price Loans or incentives that may affect investment Technical requirements regarding capacity and energy production capabilities

Factors for consideration	Detailed aspects for consideration
Local conditions	Meteorological conditions Acceptability of 'plume' from water vapour (cooling tower) Access to cold water (river or sea)
Combination of heat and energy	Distribution by season Future distribution
Other	Choice between increasing output energy, reducing investment costs, and complexity of treatment operations Permissible noise level Site availability Architectural challenges

*BAT Reference Document for Waste Incineration

4. Flue gas cleaning system

The flue gas cleaning system is one of the most important elements of any waste thermal treatment facility, as it plays a key role in reducing pollution and preventing the emission of hazardous substances into the environment. This system is designed to ensure that harmful gases generated during waste incineration are adequately treated before being released into the atmosphere.

Depending on the type and quantity of waste, the temperature developed in the primary furnace, and the types of pollutants expected, appropriate techniques are designed for the reduction and elimination of pollution. Typical flue gas cleaning systems include combinations of various techniques, such as gas scrubbing in scrubbers combined with bag filters, to achieve maximum efficiency in removing harmful substances.

One of the greatest public concerns regarding waste incineration relates to emissions of dioxins and furans (PCDDs – polychlorinated dibenzo-p-dioxins and PCDFs – polychlorinated dibenzofurans). These substances are by-products of various industrial processes but can also be formed during forest fires. Dioxins and furans belong to a group of persistent organic pollutants that pose a significant risk to human health and the environment.

Prevention of dioxin and furan formation in modern waste incineration plants is achieved by using technologies that increase the temperature in secondary flue gas combustion chambers, with a residence time of at least two seconds. In facilities that incinerate waste at temperatures above 1,100°C, dioxin and furan emissions are well below the levels prescribed in reference documents, ensuring compliance with strict environmental standards.

5. Conclusion

Sustainable waste management is a key component in responding to global environmental challenges and is particularly important for developing countries. According to data from 2020, only 8.6% of the total waste generated is utilized in accordance with circular economy principles. This percentage is lower compared to 9.1% in 2018, a consequence of increased exploitation of natural resources, growth in material stockpiles, and low levels of recycling and end-of-life quality in production cycles (De Wit, Hoogzaad, Von Daniels, 2020).

Diverting waste from landfills to incineration or co-incineration facilities has significant environmental and climate benefits. This process prevents methane emissions, one of the most potent greenhouse gases. Methane released during the decomposition of organic waste in landfills has a global warming potential up to 86 times greater than carbon dioxide (CO_2) over a 20-year period, according to the European Environment Agency. Transitioning to energy recovery from waste through thermal treatment also helps reduce these harmful emissions and contributes to mitigating the negative effects of climate change.

Given that the average calorific value of solid municipal waste is around 9 GJ/t, its use in energy production represents a promising approach that can significantly contribute to addressing two important issues: waste management and the growing demand for energy. This process not only allows for the effective utilization of waste but can also play a key role in transitioning to a more sustainable model of production and consumption, in which energy is derived from renewable sources and negative environmental impacts are reduced.

New and existing municipal waste incineration plants must achieve electricity production efficiency of 20–35% and heat production efficiency of 72–91% in accordance with reference documents.

New and existing hazardous waste incineration plants must achieve boiler efficiency of 60–80%, while sewage sludge incineration plants must reach 60–70%.

New generation plants are more efficient at processing larger amounts of waste, which increases the demand for high-quality waste for incineration. This trend in waste treatment has significant implications for waste management. Specifically, there is a growing need to shift away from landfilling, which is particularly important as the pace of waste prevention plans has slowed, while disposal and cross-border movement of waste have increased significantly.

In this context, countries or regions that still rely on landfilling should carefully analyse the costs of disposal compared to the costs of constructing thermal treatment (incineration) plants. This analysis must include factors such as the number of people who will use the produced energy and the quantity and quality of waste that will be used as fuel.

Using waste as an alternative fuel represents a long-term and sustainable investment, especially given the decreasing availability of fossil fuels. Furthermore, considering the lower emissions of harmful gases compared to traditional fuels, this approach can be considered a more efficient and environmentally acceptable solution.

We have shown that there are numerous aspects often overlooked when choosing technology and designing waste incineration plants, which can

Photo: Freepik

have a significant impact on the final results in waste-to-energy production.

The main challenges, however, relate to quality and quantity of waste intended for incineration. These factors not only justify the energy efficiency of the plant but also support investments in this type of infrastructure, as well as their impact on environmental quality.

Creating an adequate institutional framework is essential to achieve satisfactory levels of energy recovery. This requires stricter control over waste sent to landfills, because otherwise the plant may exceed actual and projected needs.

Properly planned and implemented waste-to-energy initiatives can result in large amounts of energy, which can be used for producing heat and electricity. Through this process, waste gains a new life, transforming into a useful resource essential for modern society.

The construction of such plants in the Republic of Serbia, which produce energy from waste, is more cost-effective in the long term than maintaining landfills. Moreover, these plants offer significant environmental benefits, as they emit fewer pollutants and pose lower risks in the event of accidents. Green solutions for alternative energy sources are key in the modern era and should be prioritised to reduce the amount of disposed waste and carbon dioxide emissions.

In conclusion, waste incineration plants represent a sustainable option in the context of global efforts to reduce pollution and improve energy efficiency. This technology, when properly managed and combined with the application of best available techniques, can significantly contribute to achieving circular economy goals and reducing negative environmental impacts.

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