# Resource Recovery from Incineration Bottom Ash: Basics, Concepts, Principles

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Waste-to-energy (WtE) is one of the leading technologies for municipal solid waste (MSW) treatment in Europe. According to Eurostat data, in 2015, 27 % of MSW was utilized in WtE plants, which represents more than 80 million tons per year. Therefore, the European annual production of incineration bottom ash (IBA) is about 20 million tons, as it is about 25 wt% of input MSW [5]. In the European List of Waste, IBA is listed as *mirror entry* (i.e. waste materials which should be classified as either non-hazardous or hazardous, depending on its hazardous properties and/or content of hazardous substances) under codes 19 01 11 and 19 01 12.

Recent trends indicate that WtE allows, apart from utilization of the energy content of waste, also the recovery of various valuable components. Hence, WtE can be included in the key technologies that can put the circular economy concept into practice. Secondary raw materials in the case of WtE are solid residues, especially IBA, as it is a secondary source, particularly of ferrous metals (Fe) and non-ferrous metals (NF) and glass. Moreover, the residual mineral fraction can be used for various applications in the construction industry, i.e. as aggregates substitute for bound or unbound applications, in cement manufacturing or, as indicated by recent research, also in more sophisticated applications, e.g. for ceramics production. Recovery of these metals can also cause huge greenhouse gas savings. Alone in Europe, metal recovery from IBA reduces greenhouse gas emissions by approximately 3.2 million tonnes of $CO_2$ equivalent [2].

A significant development in technologies for metals or glass recovery during the last decade can be noted. These technologies have become common part of WtE plants all over the Europe.

## 1. Incineration bottom ash recovery potential

Incineration bottom ash production in Europe is about 20 million tons per year. IBA is a very heterogeneous material. Its composition is determined mainly by the composition of incinerated waste that could be very variable depending on national consumer's habits and the performance of separate collection system. The overall IBA material composition is shown in Table 1.

| | Range wt% | Particle size distribution |
|---|---|---|
| iron scrap (Fe) | 6 – 13 | approx. 80 % in particles > 10 mm |
| non-ferrous metals (NF) | 1.3 – 4.0 | spread in all size fractions |
| glass shards | 9 – 26 | majority in fraction 4-16 mm |
| unburnt organic matter | 1 – 5 | |
| mineral fraction | 50 – 70 | |

Table 1:

IBA material composition

Sources:

del Valle-Zermeño, R.; Gómez-Manrique, J.; Giro-Paloma, J.; Formosa, J.; Chimenos, J. M.: Material characterization of the MSWI bottom ash as a function of particle size. Effects of glass recycling over time. Sci. Total Environ, 2017, pp. 581–582, 897–905

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The recovery efficiency of various techniques is determined strongly by the particle size of recovered material, hence, the particle size distribution of metal particles together with their total content in IBA and liberation are essential knowledge for recovery potential evaluation.

## 2. Recovery of metals

Technologies for NF recovery from IBA started to emerge in 1990s. Nowadays, they are common practice in many developed countries and rapid development towards higher efficiency has been recorded within last few years.

Metal recovery technologies for wet as well as for dry IBA are based mostly on dry-mechanical processes. However, some treatment plants work on wet principle as well. They have recently spread particularly in the Netherlands because of their IBA *Green Deal* and within the strict end-of-waste criteria for IBA utilization in construction industry.

Metal recovery can take place directly at the WtE plant. Conventional treatment plants are usually employed on site with the exception of large centralized WtE plants with capacity of at least 400 kt of waste per year (i.e. generating about 100 kt of IBA), when it can be economically feasible to build an advanced plant with high efficiency. A centralized IBA treatment plant receiving the material from several different plants is another option.

High efficiency of NF recovery justifies the higher investment required for advanced IBA treatment plants caused primarily by crushing, the presence of multiple eddy current separators (ECS; usually two for each size stream in several streams), or sensor-based separators for stainless steel. For small WtE plants, which cannot afford such an investment, centralized IBA treatment plant or mobile treatment plants are good options.

Two main types of IBA discharge systems exist: wet and dry-based. The most widespread is the wet extraction system, which allows to quench the hot IBA by means of the contact with water, combined with subsequent handling with a ram discharger or a chain transport system [5]. Dry discharge system is relatively rare in up-to-date WtE plants, but it has several advantages for metal recovery efficiency.

Two main approaches of metal recovery are possible (Table 2)

- maximum efficiency of metal recovery with no intention to use mineral fraction in construction industry, or
- metal recovery with limited efficiency and application of mineral fraction in construction industry.

The whole IBA treatment is determined by the above-mentioned aims, starting from discharge system and ending with e.g. IBA crushing or ageing.

Large amount of different treatment plants has been built across the Europe. Each treatment train is unique. However, principles of pre-treatment and separation are similar. Latest data show that, for raw IBA, the average recovered amounts are 63 kg of iron scrap and 17 kg of NF per ton of IBA. However, the recovery rate of NF is essentially determined by the treatment train setup and can lead to recovery from 5 kg per ton of IBA for conventional setups up to 22 kg for advanced ones. The recovery rate increases with the number of apparatus in the treatment train, e.g. 12 ECS are employed in treatment train that can recover 20 kg of NF per ton of IBA. However, the amount of recovered metals is naturally affected by the IBA composition mentioned in Table 1. The average electricity consumption is 3 kWh per ton of treated IBA, but for some plants up to 15 kWh were found [4].

Table 2: IBA treatment principles

| Parameter | IBA residual fraction applied in construction industry | No intention to use IBA in construction industry |
|---|---|---|
| dry discharge | not applicable because of insufficient weathering/ageing | optional as no sticky fine fraction is formed |
| wet discharge | necessary for initiation of ageing reactions | possible, but may cause problems in recovery of metals from fine particles |
| ageing | necessary for IBA stabilization | optional for IBA humidity decrease prior to treatment |
| crushing | optional for large IBA fractions over 40 mm | optional for all size fractions for liberating of agglomerated metals and recovery efficiency increase |
| wind sifter | necessary for removal of unburnt organic material | optional for removal of unburnt organic matter |

## 2.1. Discharge system

### 2.1.1. Wet discharge

Efficient metal recovery from IBA from WtE plants equipped with wet discharge is a challenge because of sticky IBA character and hardening process that occurs. The water content of the IBA after quenching is 12-25 %, depending on the discharge system. Quenching process leads to IBA mineralogical and structure changes due to CaO reaction with water to $Ca(OH)_2$ – portlandite. Portlandite reacts during storage or ageing process with atmospheric $CO_2$ and forms $CaCO_3$ (calcite). Hence, the main objective of several pretreatment steps such as ageing and crushing is to minimize the detrimental effect of the quench products formation on metal recovery process. However, for IBA utilization in construction industry, wet discharge system is necessary, as humidity is required for several stabilization reactions such as CaO conversion to portlandite and its carbonation, hydrocalumite or Friedel's salt formation or ettringite formation.

### 2.1.2. Dry discharge

Dry IBA discharge is up to now rare, however, it is a good solution for countries with no intention to use IBA in construction industry, as dry discharge allows metal recovery with higher efficiency. Dry IBA is easier to screen into defined particle size fractions. Furthermore, metals are not agglomerated into clusters by sticky wet fine ash particles and are more easily accessible by technologies such as eddy-current separation or sensor-based separation. Other advantages are savings in water consumption and treatment and thus reduced transport costs and the reduction in organic carbon content.

Additionally, the leaching properties of the resulting IBA is altered [8]. Drawbacks are the necessity to store and process IBA in covered or closed containers and apparatus and to landfill mineral IBA fraction.

## 2.2. Pretreatment steps

### 2.2.1. Ageing

Ageing is often used for treating of the bulk of IBA before metal recovery process and it is a necessary step for IBA stabilization before it is processed into construction material. Wet discharge system has to be employed prior to ageing, as water content is necessary for ageing reactions to take place. Leaching properties are improved and IBA water content decreased during ageing. Ageing usually lasts 4-12 weeks [11]. Lower content of water enables easier handling of IBA in subsequent treatment and results in higher recovery rates. The optimal IBA humidity for metal recovery is 10-12 %. Lower humidity can cause problems with dust emissions during treatment, higher humidity can decrease recovery efficiency due to sticky IBA character.

Ageing also affects metals character and liberation in IBA. Several studies claimed that, under ageing conditions, metal corrosion occurs and, for example, within three-month period approx. 30 % of Al undergoes oxidation reaction to $Al_2O_3$ [9], Cu and brass does not undergo oxidation reaction, hence, their content in elemental form is not decreased during the IBA ageing.

### 2.2.2. Sizing

IBA fractioning is important pretreatment step in the metal recovery process. Sieving allows obtaining of narrow and homogenous particle size fraction flow and therefore optimization of downstream apparatus such as ECS.

Sieving into two or three streams is common practice in conventional plants, however, in advanced and highly efficient plants, sieving up to 6-9 fractions can occur.

For large size fractions finger sieves are often employed, drum sieves are equipped for intermediate size fractions and flip flop sieves for fine fraction.

### 2.2.3. Crushing

Crushing is a fundamental step for the improvement of metal recovery as it liberates metals incorporated in mineral agglomerates. It is often employed for particles over 40 mm. Crushing of smaller fractions can have detrimental consequences to IBA utilization in construction industry, particularly for road subbase layer, where natural IBA granulometry is suitable. For other applications, e.g. for cement or concrete production, crushing down to 2-4 mm is a required pretreatment step. Therefore, the decision about crushing inclusion in treatment train should be made with respect to final utilization of IBA.

## 2.3. Treatment steps

### 2.3.1. Magnetic separation

Iron scrap basic magnetic separation is applied at the majority of WtE plants. This is usually done directly after IBA discharge by overband magnets. Such separation is limited to large pieces of scrap. In treatment trains for NF recovery multi-step magnetic separation is usually employed for each stream. Overband magnets are used for iron scrap, in second stage, drum magnets are often used for magnetic fraction removal (iron oxides and agglomerates with their content) as the magnetic fraction deteriorates NF efficiency separation on ECS. This magnetic fraction is often later returned to IBA mineral residue from treatment train.

### 2.3.2. Eddy current separation

Eddy current separators (ECS) are used for non-ferrous metals separation as they are able to separate non-magnetic electrically conductive particles from non-conductive ones. Different separability can be noted for various NF as their separability depends on the ratio of metal density and conductivity. Therefore, aluminium can be easily separated, on the contrary, brass or bronze are more difficult to separate. The core of ECS is a magnetic drum, therefore, magnetic particles worsen NF separation and deep removal of iron scrap and magnetic fraction is a necessary prerequisite step prior to ECS. Effective separation is also possible only for fully liberated particles as NF incorporated in IBA bulk often go with non-conductive stream. The size of metal particles is another parameter that strongly affects separation, hence, ECS requires a proper calibration for each size fraction. It is a good practice to adopt different rotation speed of magnetic drums for each size fraction. For coarse particles above 5 mm, the rotation speed of 2,000-3,000 rpm (typical for standard ECS) is often used. To achieve high recovery efficiency for fine fraction (< 5 mm), it is necessary to adopt advanced ECS with a rotation speed of over 4,000 rpm (up to 6,000 rpm). In advanced treatment trains, two subsequent ECS are often used for increasing of metal recovery.

### 2.3.3. Sensor based separation

Recent trends in IBA processing include sensor-based separators for metal and glass particles [1]. Most common is the magnetic induction separation by electromagnetic sensors that can identify all kinds of metals, including stainless steel, with particle size down to 4 mm. Both the separation efficiency and purity can exceed 90 %. The sensor is placed under the conveyor belt with a thin layer of IBA, detected metals are ejected from flow with a set of compressed air nozzles. Other types of sensors can be used as well, e.g. X-ray fluorescence analysis (XRF) for the detection of different metals, optical sensors for transparent materials, or cameras for distinguishing the materials according to the color or shape. Due to the complexity and costs of these, sensor-based separators are currently suitable for materials with higher economical value, such as stainless steel, and are employed rarely and only in advanced treatment plants. For example, an induction sorting system is in operation at the Afatek IBA sorting plant in Copenhagen, Denmark, where stainless steel particles of size down to 8 mm are separated.

## 2.4. Treatment trains

### 2.4.1. Conventional

Conventional approach is sometimes used in treatment trains directly installed in WtE plants. In this process, the bottom ash is often screened only into two fractions, e.g. 0-4 mm and 4-45 mm. Each fraction undergoes magnetic and eddy-current separation to recover iron scrap and NF. The residue of the larger fraction is crushed and fed back into the process.

The separation efficiency of these conventional technologies is around 80 % for magnetic metals and 20–30 % for non-ferrous metals of their total content in bottom ash. Further increase in separation efficiency can be achieved e.g. by bottom ash pre-drying and sizing into several narrow fractions [11].

### 2.4.2. Advanced

There are large variabilities in setups of advanced treatment trains, however, the principles are the same for all plants. These plants are often built centrally and treat IBA from several WtE plants or are next to a large centralized WtE plants with capacity over 400 kt of MSW per year. Particles over 40-60 mm are often crushed and fed back into the input. IBA is then screened into several size fractions, usually 5-9, and each fraction is treated separately. The treatment consists of iron scrap recovery with overband magnets,

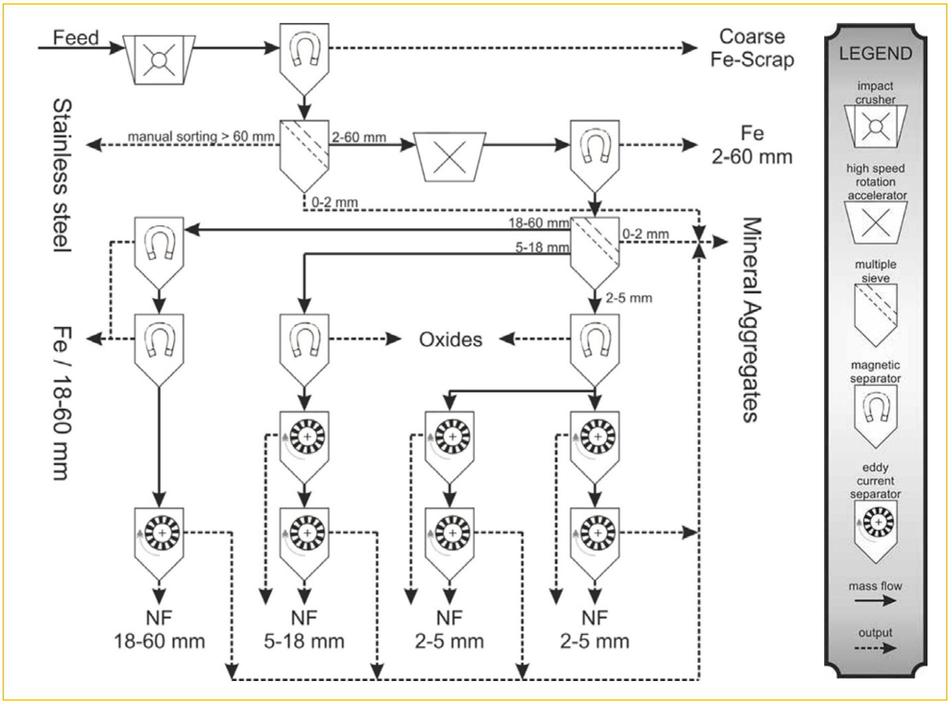


Figure 1: Example of advanced treatment train for particles over 2 mm

Source: Holm, O.; Simon, F.-G.: Innovative treatment trains of bottom ash (BA) from municipal solid waste incineration (MSWI) in Germany, In: Waste Management, Volume 59, 2017, pp. 229-236. https://doi.org/10.1016/j.wasman.2016.09.004.

magnetic fractions or iron oxides separation with drum magnets and two eddy current separators in series. For particles over 4 mm, an induction sorting system for stainless steel recovery can be employed as well. Recent trends show that metal recovery is possible even from particles below 2 mm, so in modern treatment plants such as Afatek (Copenhagen, Denmark), another two treatment trains for fraction 0.5-1.0 and 1.0-2.0 mm have been built.

These complex treatment trains can recover over 20 kg of NF and over 80 kg of iron scrap per ton of IBA, that means efficiency of over 80 %. However, these values are of course dependent on the content of metals in IBA.

### 2.4.3. Wet treatment

Two main directions of wet treatment can be stressed. The first one is with the aim to remove soluble compounds and heavy metal species from IBA fine fractions. This approach is currently spreading in The Netherlands due to their Green Deal. Moreover, two plants based on the wet technology are currently operating in Germany and Italy. The plant in Germany is focused on the extensive recycling of the mineral fraction. The wet processing is used to transfer soluble salts such as alkaline and alkaline earth chlorides and sulfates to a fine fraction (approx. < 0.25 mm), which is separated as a filter cake. Almost 60 % of total sulfate can be concentrated in the filter cake, which accounted for approx. 10 % of IBA mass. To avoid the formation of the mineral coatings on the metals and, thereby, to increase the recovery rates and the quality of the metal fractions, the treatment method does not include the ageing of IBA.

Another option is to use wet separation techniques for metal recovery. This type of plant had been built for treatment IBA from Amsterdam WtE plant [7]. However, due to economic reasons, it was replaced by Advanced Dry Recovery (ADR) process. Nowadays, this approach is relatively rare due to water consumption. For example, jigging can be used for effective recovery of heavy non-ferrous metals and removal of IBA fine fractions, that can increase overall recovery rate of light NF on ECS downstream.

## 3. Glass recovery

Sensor based separation of glass was demonstrated at a pilot plant built at WtE plant in Bratislava, Slovakia. IBA is pre-treated in a process called *cullet sublimation* in order to remove agglomerates and paper labels from glass shards, as they decrease the efficiency of sensor-based separation. The first step of pre-treatment is screening out the oversized particles and fines under 7 mm. The resulting middle fraction can contain up to 50 % of glass shards. In the next step, the material is dried in a fluid-bed dryer and then cleaned in a dry-washing process by attrition, followed by cooling and de-dusting. After this stage, iron scrap and NF are separated and finally glass is sorted out by an optical sensor-based separator. The glass is detected by transillumination by light of a specific color temperature which is able to distinguish different glass colors and heat-resistant glass. Detected glass pieces are ejected from stream of particles by compressed air nozzle. The efficiency of glass recovery can reach 75 % [6]. Nowadays, the plant is not operated due to economic reasons.

## 4. Conclusions

Incineration bottom ash (IBA) is a source of valuable components, such as non-ferrous metals or iron scrap, as it contains up to 4 % of non-ferrous metals and 13 % of iron scrap. Technologies for their recovery started to emerge in 1990s and, nowadays, they are common practice in many developed countries. Metal recovery technologies for wet as well as for dry IBA are based mostly on dry-mechanical processes. However, some treatment plants work on wet principle as well. Metal recovery can take place directly at the WtE plant or at centralized IBA treatment plant receiving the material from several different plants. Two main approaches of metal recovery can be outlined, i.e. with metal recovery efficiency maximalization and no intention to use mineral fraction in construction industry, or with metal recovery with limited efficiency and application of mineral fraction in construction industry. The whole IBA treatment is determined by the above-mentioned aims, starting from discharge system and ending with e.g. IBA crushing or ageing. Dry IBA discharge is a good solution for metal recovery maximization, as it prevents several problems with wet IBA treatment. However, wet discharge is much more commonly installed in WtE plants. Wet IBA character and sticky fine particles cause several problems in IBA treatment. Therefore, several pre-treatment steps such as crushing, and ageing must be employed. Ageing is also a prerequisite step prior to IBA utilization in construction industry. Metal separation itself is commonly done by magnetic separators for iron scrap, eddy current separators for NF and sensor-based separators for stainless steel. There is a big variability in setups of treatment trains and nearly each one is unique. Advanced treatment trains usually contain IBA sieving into more than 5 size fractions and multi-step magnetic and eddy current separation. These modern and advanced treatment trains can recover more than 20 kg of non-ferrous metals and 80 kg of iron scrap per ton of IBA.

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