Advanced Urban Mining: A Summary of the State of the Art of Metal Recovery out of Dry Bottom Ash

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The world's demand for resources will ceaselessly increase in future. This will have a negative impact on availability and price of finite resources. The only way to satisfy the future demand is to minimize the dissipation of the resources during their life-cycle and to close the latter as good as possible. A potential shortage of resources in the future will make the recovery of resources from waste more efficient than their primary production. Another driver towards the minimization of resource dissipation will be the increasingly tighter legislation on environmental protection.

In municipal waste, recyclable resources are very depleted and/or integrated in complex composite materials. The most efficient and reliable way to get rid of any organic material is undoubtedly by incineration, a process which is technically well approved. The basic concept of facilitating and boosting the efficiency of recycling is called thermo recycling and will be presented in this paper.

As a promising option to increase the yields of thermo recycling processing, the concept of metal recovery following dry bottom ash extraction will be visualized by the example of the new plant of ZAV Recycling AG in Hinwil, Switzerland. Metal recovery from dry bottom ash is a big step towards minimizing metal dissipation into landfills while creating high quality secondary raw materials. Moreover, this technology may open new opportunities to avoid landfilling of the mineralic residues in future.

1. Introduction

1.1. Resource consumption trends in Europe

In 2050 world's population is supposed to reach about 9.5 billion individuals. The most drastic growth of population will take place in Africa followed by Asia. Additionally, a lot of now developing countries may triple their current number of people with middle class consumption levels by 2030. Most of those countries exhibit a high population i.e. Brazil and India.

Following those trends, the worldwide demand for resources extraction will dramatically increase. Since natural resources are limited, an increasing demand will have a negative impact on availability and price. Even though Europe won't

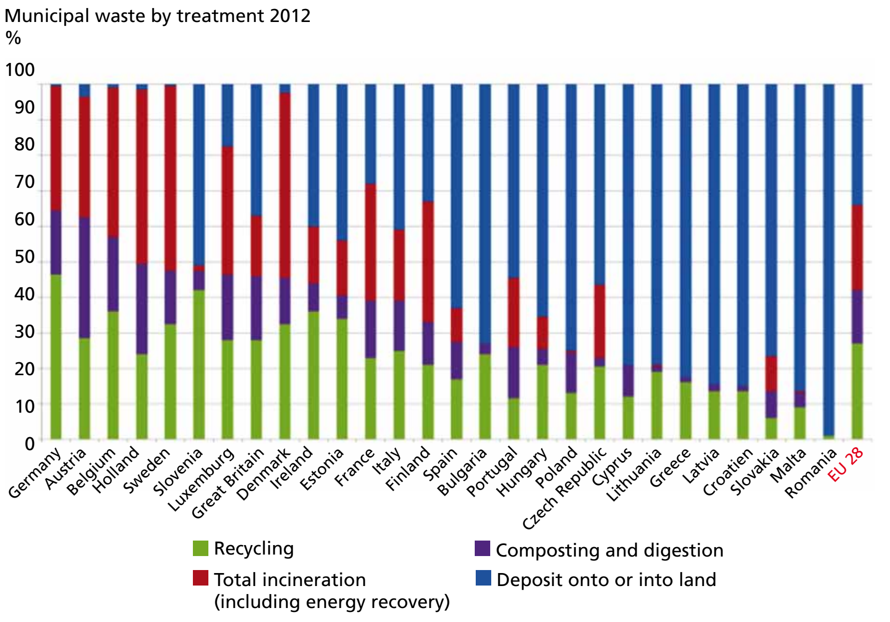

Figure 1: Distribution of EU 28 municipal waste by treatment method

Source: Falkenberg, K.-F.: Reviewing EU Waste Legislation. In: Mineralische Nebenprodukte und Abfälle, Nietwerder: TK Verlag Karl Thomé-Kozmiensky, 2014 experience a serious population growth in near future – predictions even show a slight population decrease – its need for resources will remain at least at current levels.

As a matter of fact, Europe imports 6 times more resources than it exports. The Eurostat Table (Figure 1) picturing the municipal waste management in 2012 shows, that in average, over 30 percent of waste ends up in landfills, and only about 25 percent undergoes material recovery oriented recycling. In terms of yearly material use per person, out of 16 tons, 6 become waste out of which 3 tons end up in landfills [6].

Europe can lower its resource imports by turning its attention to maximizing the resource recovery from waste and therefore practice a truly sustainable use of materials and resources. Of course, the main focus should always be on minimizing waste production and the need for resources. Another important objective should be to limit landfilling to residual waste only, which should in Europe not exceed 5 percent of the generated waste by 2030 [6]. The presented method of dry discharged bottom ash processing could be a huge step in this direction.

1.2. Drivers

Focussing on waste treatment, laws and regulations like emission limit values, economic factors and the public opinion play important roles. Public opinion with increasing consciousness for environmental issues will influence the framework for new regulations, which in turn have significant impact, for instance, on the planning and realization of waste incineration plants.

Today, there's a clear need for regulation in the field of waste management in order to protect people and environment. It basically results from a lack of profitability of waste treatment and disposal. Waste, however, should be regarded as a source of materials and energy. Thermal energy is efficiently used to produce electricity and to supply district heat, whereas technologies are available and economically feasible to provide high quality recycling products from bottom ash as well as from flue gas treatment. With increasing profitability, the need for regulations may automatically decrease.

Thermo recycling offers a very solid opportunity in terms of economic efficiency and low residue levels. The dry bottom ash discharge as a tool for metal recovery, is a promising technology to minimize resource dissipation and to provide high quality recycling products. The aim of this paper is to show that both, thermo recycling and metal recovery following dry bottom ash discharge are indispensable tools to achieve sustainability of the resource cycles.

2. Urban mining

2.1. Urban mining: yesterday's waste, tomorrow's raw material

Urban Mining is the process of reclaiming materials from products, waste and buildings [8]. The expression is referring to the fact, that densely populated areas are considered as *urban mines*, thanks to the concentration of the respective materials which often exceeds by far those of natural mines. To make use of these mines there are multiple processes needed: the identification of anthropogenic deposits, the quantification of the included secondary raw materials, the economic aspects with respect to the available recovery options, the market potential of these materials, the economically feasible recycling, the re-use of identified resources and the integral management of anthropogenic deposits. People are not only considered as consumers anymore, but also as producers of valuable resources [7].

Following the concept of Urban Mining, the economic model of the circular economy can be created. There, recycling is important and the consciousness that products, waste and buildings can be reused as secondary materials after processing. In the circular economy model, life cycles of products shall be closed, as illustrated in Figure 2. There, the materials trapped in products at their end of life are going to be collected, recycled and then be reused after some specific processing [6].

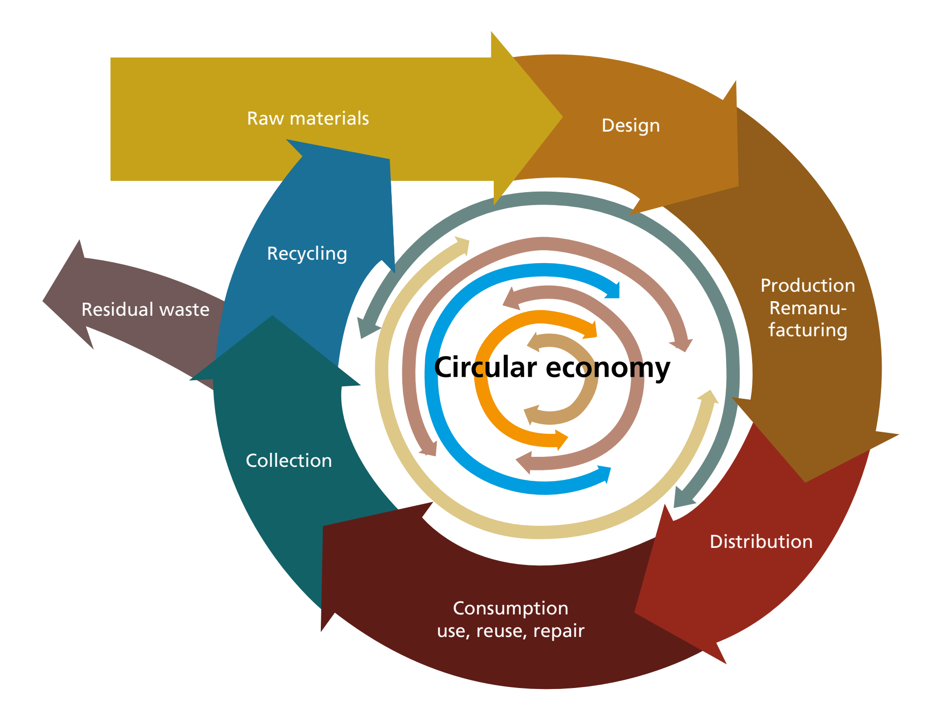

Figure 2: Illustration of the circular economy model

Source: Photo Credit: European Commission DG Environment

2.2. Why is urban mining important?

There are a lot of reasons why we should increasingly focus ourselves on Urban Mining. It is important for a sustainable economic growth and for preserving the environment, too. The resource demand will continue its upwards trend. Prices of basic materials will further increase and therefore, the recovery of metals from the residuals of waste incineration plants will become financially more and more attractive. The concept of the circular economy contributes to preserve valuable materials in our economy instead of loosing them in landfills. With the Urban Mining model we also strengthen our independence in the global competition for access to raw materials and develop our economy in a socially acceptable and economically competitive way [6].

2.3. Methods of urban mining

Some methods of Urban Mining like recycling are implemented in many countries already. As an example, Switzerland has a well-established and widely accepted infrastructure of collection points where recyclable materials are collected. Residuals like domestic waste are collected and fed into waste-to-energy incineration plants where the high energy content of organic material and plastics is efficiently used to produce electricity and heat. After the incineration valuable materials still remain in the ashes and slags. In the past, these materials were deposited and the valuable resources were lost. A recently developed enhanced process allows to recover the metals. In the following chapters this new approach is being discussed: the thermo recycling with metal recovery from dry bottom ash processing which has been developed at the foundation *Zentrum für nachhaltige Abfall- und Ressourcennutzung* (ZAR). [3]

2.3.1. Thermo recycling with metal recovery from dry bottom ash processing

Thermo recycling with metal recovery from dry bottom ash processing is the process of making full use of the energy content of waste while disintegrating it simultaneously into its compounds and elements, followed by physical separation and recovery processes of the metals. It includes the following process steps [1]:

- Waste collection,
- Thermal separation of the waste,
- Utilisation of the renewable energy out of the incineration,
- Flue gas purification,
- Processing the residues of the flue gas cleaning,
- Dry bottom ash discharge,
- Slag conditioning and processing,
- Recovery of materials (e.g. metals) and their reuse as secondary raw materials,
- Reuse of the residual minerals.

The incineration is the key step for the separation. Through this process renewable energy in form of heat and electricity is generated and valuable resources, such as metals, are separated. After some processing these metals can directly be reused. The life cycle of these products can be closed to a high degree [6]. By applying this kind of processing, conventional waste incineration plants are transformed into modern thermo recycling stations.

2.3.2. The importance of thermo recycling

Thermo recycling is the access key to recover those materials, which today are not being recycled and therefore lost. The processing of slags and ashes from the incineration process produces valuable raw materials such as iron, alumina, copper and zinc. The newest generation of plants will comprise installations for the recovery of stainless steel and allows metal separation to particle sizes down to 0.2 mm if the bottom ash has never seen any water before. The light metal aluminium is separated from the fraction of heavier metals. The latter consists mostly of copper and its alloys. Thanks to the small particle size, also many other metals such as the precious metals silver, gold or palladium can be found in significant concentrations and therefore be recovered through subsequent metallurgical processing with positive economic impact to the whole process. Moreover, the variety of recoverable metals is increased, which will also be of strategic importance to countries with limited natural mining resources [10].

2.3.3. The importance of incineration and dry extraction of bottom ash

In addition to the known advantages of the incineration, like the reduction of the waste volume, prevention from pathogenic hazards and therefore the protection of health and environment, it is the incineration that makes the recovery of the resources technically feasible. All plastic components are burned to generate energy, and the reusable metals remain in very good quality. The surface is only slightly oxidized and the metals can mostly be physically separated from each other and from the mineralic residues. Billions of devices for our daily life contain small amounts of these substances which sum up to a considerable mass in the bottom ash. Furthermore, the final products of the incineration process are not reactive any more [10].

Avoiding the reaction of bottom ash with water provides the key to recover metals in their highest quality as well as to very fine particle size.

2.3.4. Advantages and disadvantages of thermo recycling

The main advantage of the incinceration process in thermo recycling is the ease of separating and cleaning metals and inorganic components from all the organics and plastics while using the thermal energy produced. Established physical processes allow the selected and highly efficient recovery of a variety of materials, especially metals, resulting in products that can directly be used as secondary raw materials.

The technique of dry bottom ash discharge has been realized in a few Swiss waste incineration plants, such as KEZO Hinwil, SATOM SA, Monthey, KVA Horgen, and, as from mid 2016, KHKW Hagenholz, Zurich. Like other new technologies, success of further processing the dry bottom ash at industrial scale will be the door opener to adapt current waste incineration techniques to these future demands. Currently, the processing plant of ZAV Recycling AG in Hinwil, Switzerland, is being commissioned and ramping up its production (Figure 3).

Figure 3: Construction site of the new processing plant for dry bottom ash in Hinwil, Switzerland, adjacent to the municipal waste incineration plant KEZO

Source: Roman Weiss, 07.05.2015

3. Advanced resource recovery

3.1. Metals in waste

For a long time waste has been considered primarily to be a threat to the environment (pollutant perspective). Nowadays the perception of waste has changed. Waste is treated as a potential source for secondary resources (resource perspective). Metals are one of the most abundant resource in waste [5].

However, especially in the case of metals, it has been shown that despite of separate collection, an important portion remains in domestic and commercial waste. Small metal components, which were not separated by the consumer out of comfort, constitute only a small fraction of the metals present in the cinder of incineration plants [5].

An important metal carrier are composite goods. Lots of small metal components are bound to plastic materials in goods like packaging materials, pens and other goods of our daily life etc. Those metal components are not accessible to mechanical separation and almost all of them end up in the waste fraction undergoing the incineration process.

Copper in bottom ash mostly stems from electric and electronic trash. Additionally, in Switzerland, almost one third of the batteries still comes with domestic waste and is discharged with the bottom ash in an almost intact state, therefore still containing the heavy metals [5].

The grain size distribution in Figure 4 shows that copper and aluminium are mostly present as small particles while iron can also be found in bigger pieces. A reason for that could be iron coming with wooden waste in form of screws, nails and other components, which are freed during the incineration process [5].

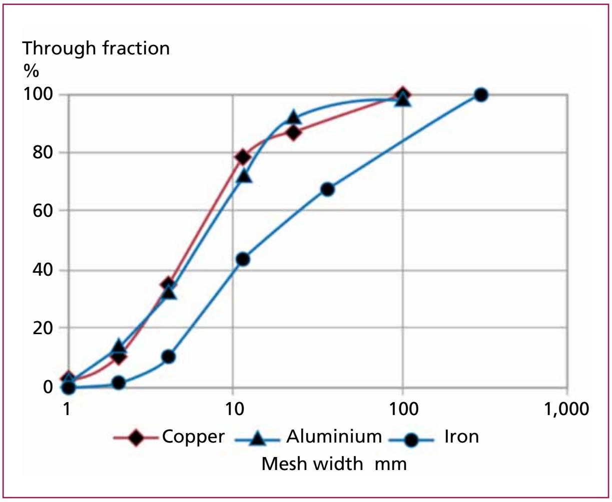

Figure 4:

Grain size distribution of different metals in bottom ash

Source: Bunge, R.: Wieviel Metall steckt im Abfall. In: Mineralische Nebenprodukte und Abfälle, Nietwerder: TK Verlag Karl Thomé-Kozmiensky, 2014

Theoretically, all the metal could be retrieved directly from waste, however, due to the small size of the metal components and their bondage with plastics and textiles, it is far more convenient to retrieve the metals from the bottom ash [5].

The recovery of metals from waste is a process that still needs improvement, especially the processing of bottom ash. In Switzerland, for example, bottom ash accounts for 22 percent of the total waste mass, thus 700,000 tons per year. The iron portion in bottom ash is about 9 percent while the fraction of non-ferrous metals is 3.5 percent. Thus, there are 63,000 tons of iron and 24,500 tons of non-ferrous metals per year that could theoretically be recycled. The actual yield in Switzerland however is 50,000 tons (80 percent) for iron and 9,000 tons (37 percent) for non-ferrous metals [5].

With the thermo recycling using dry bottom ash processing, the aim is to increase primarily the fraction of recycled non-ferrous metals and to improve the quality of the separated metals.

3.2. Dry ash discharge versus wet ash discharge

Dry bottom ash requires direct discharge from the incinerator and should never be exposed to water. This is the most important parameter for an efficient bottom ash processing.

A new process variable that has been added to the incineration process is the tertiary air. The tertiary air supports an optimal incineration process likewise to the primary and secondary air and is therefore integrated in the firing power control. The amount of tertiary air accounts for less than 10 percent of the total combustion air [9]. Before entering the incinerator however, the tertiary air plays a crucial role in the dry bottom ash discharge process. The function of the tertiary air is threefold. As the graphics below shows, it travels in the opposite direction of the conveyor. This allows the bottom ash to be gradually cooled down by the airstream. The further the bottom ash proceeds, the cooler the air becomes so as to ensure a continuous and steady cooling process. The air undergoes the opposite effect and is heating up. The second function of the tertiary air is the afterburning of the bottom ash, which allows to drastically decrease the TOC content, finally enabling a better processing effectiveness of the dry bottom ash. Finally, the tertiary air supports the air sifting and screening, therefore relieving the downstream bottom ash processing system. The bottom ash is discharged continuously via ash drum and the vibration conveyor functions as a first separation of fine ash from coarse ash [2]. The main advantages of the dry bottom ash discharge compared to the wet ash discharge are as follows [9]:

- *The after burning in the vibrator chute allows to reduce the TOC content.*
- *Dry bottom ash shows no significant combustion loss.*
- *The eluate values differ significantly, too. The wet discharged bottom ash shows 5 times higher values for lead, 25 times higher values for cadmium and 250 times higher values for copper.*

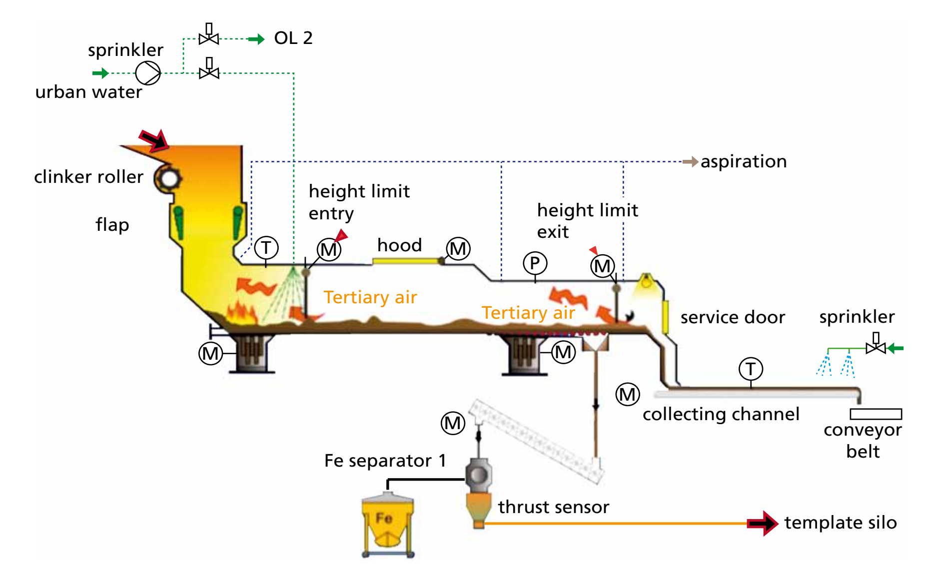

Figure 5: Dry bottom ash discharge scheme

Source: http://zar-ch.ch/zar/kompetenzenprojekte/trockenaustrag, 15.06.2015

- *The water in the wet discharger already starts the cementing and hardening of the bottom ash, whereas the cementing of the dry ash can later be started when and where appropriate.*
- *Granulometry: in the dry bottom ash, substances and particles keep nearly their original surface characteristics. Therefore the possibilities for the separation of the ash according to its size, weight, shape, colour, conductivity etc. are unlimited. Bigger parts can be removed simply and safely.*

The dry ash discharge process is an indispensable tool in order to tackle the objective to treat waste residues in an environmentally responsible way and to maximize meaningful energy exploitation.

The process establishes the basis for an increase of the recovery rate of metals from bottom ash and therefore plays an essential role in the sustainable use of resources.

3.3. ZAV Recycling AG: metal recovery from dry bottom ash

The metal recovery process from dry bottom ash can be divided in a series of process steps. The first step is the separation of magnetic iron and magnetic oxides. After classifying the material, several processes lead to the separation and sorting of non-ferrous metals.

The separation of magnetic iron and magnetic oxide via magnetic separators is essential for the quality of the non-ferrous metals recovery during the subsequent separation processes [4].

Magnetic separators are used at different strength to allow specific separation of ferrous iron and magnetic oxides [4].

Tests at the ZAR foundation have shown, that it is helpful to design the magnetic separators 20 to 50 percent wider than the subsequent eddy-current separators: this allows to reach a similar area loading as in the eddy-current separator as well as to keep the dynamic forces acting on the oxides as low as possible [4].

Special sorting equipment using *electromagnetic cameras* is used to selectively recover stainless steel parts from the bottom ash flow.

After iron and oxides as well as stainless steel have been retrieved, the ash enters the eddy-current separator system, which extracts the non-ferrous metals out of the dry ash and therefore plays an important role in the economics of the whole processing plant.

ZAR developed the concept that allows in the new processing plant to separate non-ferrous metals in the particle range of 0.2 to 600 mm with an efficiency up to 98 percent.

The concept assumes for smaller particle sizes two eddy-current separators in series, the first one separating up to 85 percent of non-ferrous metals and the second one another 13 percent [4]. At first sight the efficiency of the second separator may question its necessity. However, besides having low operating costs, it assures the concentration of heavy metals in the residual mineral fraction being minimal and is therefore ecologically and economically justifiable. The ZAR was able to show the most important characteristics of the magnetic drums when separating non-ferrous metals from dry bottom ash: large drum diameter, strong magnets and low speed. The strong magnet is needed because of the small non-ferrous metal parts which electronic waste increasingly consists of [4].

Today, horizontal transportation belts are usually used in combination with eddy-current separators. ZAR noted, that an inclined belt significantly changes the repulsion parabola of non-ferrous metals. This allows efficient separation of lead and precious metals, although they are normally suffering from a minimal repulsion. As a matter of fact, the slope of the belt permitted to increase the separation efficiency of those metals from 7 percent to 85 percent. The ZAR specified eddy-current separators are designed with a belt slope of 12 percent [4].

When leaving the combustion chamber, the different bottom ash components vary strongly in size. As the efficiency of eddy-current separation depends on the range of particle sizes to be treated simultaneously, different separation units need to be installed. Their operating parameters need to be specifically adjusted to the respective ranges of particle size. Sieving, classifying, and, if necessary, crushing of the dry bottom ash is therefore required to prepare it for optimal metal recovery. Metal recovery in the industrial plant in Hinwil is performed in ranges of 80-30 mm, 30-8 mm, and 8-0.2 mm, respectively. Coarse bottom ash particles that have passed a line (e.g. 80-30 mm) will be crushed and fed into the finer lines subsequently. This guarantees that small inclosed metal parts will be released and sorted out, too. The cycle principle, which the bottom ash undergoes during the processing is based on the fact that mineral ash is breakable, whereas metallic components are not affected in their size by the crusher [4]. Metal parts that are too big will be redirected through the same eddy-current separators again. The target is to separate elemental metals completely from the mineral fraction.

Some metal refinement takes place directly at the bottom ash processing plant, in order to prepare marketable products in a quality that allows their direct reintroduction to the material cycle as secondary raw materials. The metal fractions recovered at the new plant have a very low mineral content and can therefore be recycled at low operating cost, small logistic effort and low energy costs [4].

The separated iron is sent to the smelting plant after being freed from copper and impurities. It does not show ash adhesions and is therefore of remarkably high quality. Moreover, stainless steel is selectively separated and can directly be used in the respective smelters.

The non-ferrous metals are separated in two fractions: aluminium and non-ferrous heavy metal. Aluminium can directly be added to the flowsheet of a smelting plant, while the non-ferrous heavy metals need metallurgical treatment at specialized plants to recover elements like copper, lead, tin, silver, gold, palladium etc.

The plant allows also to separate glass, another product to be kept in the life cycle loop. Finally, the residual material is mineral ash and dust with very low concentrations of metallic impurities. The high quality of the residual minerals creates opportunities to close the cycle also for these materials, opportunities that are being further explored and developed at ZAR in the years to come.

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