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Innovative and BREF proven material recycling of MSWI bottom ashes

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Abstract

With the publication of the renewed European Waste Framework Directive 2008/98 the EU re-emphasised that their thematic strategy on waste prevention and recycling will become more important. Member States are asked to take measures in terms of legislation and waste management plans to increase recovery of energy from the incineration of municipal solid waste (MSW) and to increase the different recycling rates of several materials. The EU's long term ambition is to become world's leader as "recycling society". In this strategy, the grate furnace technology used by state-of-the-art Waste-to-Energy plants plays a very important role. The technology is widely used for the thermal treatment of municipal solid waste and comparable industrial waste and has been dramatically improved in order to make it more sustainable. Latest developments have been focused on the optimisation of energy recovery and the recovery of materials such as bottom ashes, ferrous and non-ferrous metals. In this paper, a state-of-the-art integrated installation is described with focus on the bottom ash recycling. Referring to VITO's (Flemish Institute for Research) research in 2008, the ash recycling unit of Indaver NV based on a wet approach has been appointed as Best Available Technique (BAT). Although from a technical point of view the Indaver NV facility can be considered as a state-of-the-art installation, still many problems remain with respect to the economical feasibility taking into account the lack of support by actual legislation and the poor perception of the recovered material in comparison to other construction materials.

Introduction

Belgium consists of three regions: Flanders (Northern part with approx. 6 million inhabitants), Wallonia (Southern part) and Brussels (capital). In Flanders 3.3 million tonnes of municipal solid waste was collected in 2005. This MSW is collected separately in several fractions: small hazardous waste (paint cans, batteries, fluorescent tubes), glass, metals, PMD (packaging waste: plastic bottles, metal, drinking bricks), paper and cardboard, building and demolition waste, WEEE (waste electronic and electrical equipment), VFG (vegetables, fruit, garden), green waste, *etc*. The degree of separate collection and recycling in Flanders is 71% per capita, which is one of the highest figures in the EU.

The remaining fraction, *i.e.* the fraction that cannot be reused or recycled is to be incinerated in so called Waste-to-Energy (WtE) plants based on the grate furnace technology. About 1.2 million tonne of non-recyclable, non-hazardous waste is incinerated yearly in 10 WtE plants in Flanders. 72 wt% of this burned waste originates from municipal solid waste. 25 wt% consists of comparable non-hazardous industrial waste. The remaining 3 wt% contains non-infectious medical waste and non-hazardous wastewater sludges and/or filtercakes. Indaver NV is operating on their site at Doel near Antwerp the largest of these incinerators in Flanders, with a total capacity of approx. 400000 tonne/year. Figure 1 provides a simplified overview of the mass flows for MSW treatment.

The incineration in Flanders results in a yearly production of 230000 tonne (raw) bottom ash (water included) resulting in ratios of 12.9 up to 22.7 wt% of the incoming waste. In Flanders there are two treatment facilities for the treatment of these bottom ashes: one is operated by Indaver NV with a capacity of 165000

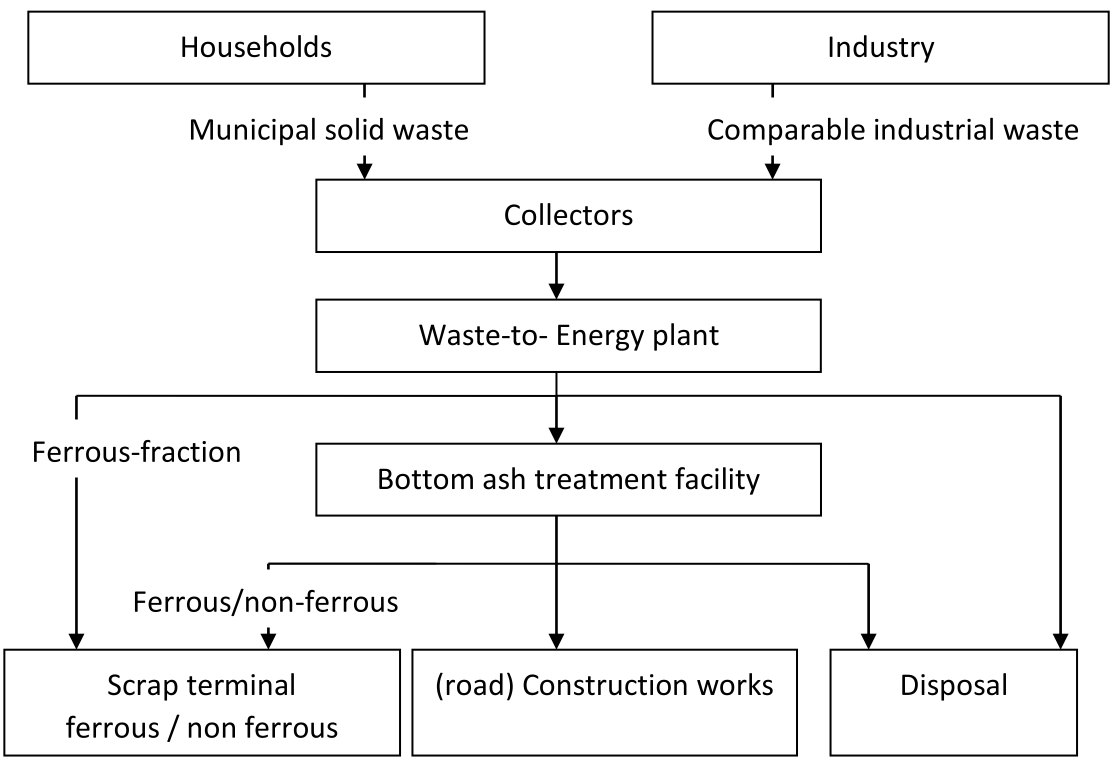

Figure 1: Flow chart, explaining the mass flow from origin to final destination[1]

tonne/year using a wet process, the other is operated by SITA (Valomac) and treats bottom ashes coming from Flanders, Wallonia and Brussels using a dry process. The latter installation has a capacity of 250000 tonne/year.[1]

In the European BREF on Waste Incineration,[2] some general Best Available Techniques (BAT) are described for the treatment of bottom ashes:

- The separation of remaining ferrous and non-ferrous metals from bottom ash, as far as practicably and economically viable, for their recovery
- The treatment of bottom ash (either on- or off-site), by a suitable combination of:
    - Dry bottom ash treatment with or without ageing, or
    - Wet bottom ash treatment with or without ageing, or,
    - Thermal treatment, or,
    - Screening and crushing to the extent that is required to meet the specifications set for its use at the receiving, treatment or disposal site *e.g.*, to achieve a leaching level for metals and salts that is in compliance with the local environmental conditions at the place of use.

In addition it is stated that the operation of the incinerator will have an impact on the quality of the raw bottom ashes: "in general BAT for waste incineration is considered to be the use of a suitable combination of the techniques and principles for improving waste burnout to the extent that is required so as to achieve a TOC (total organic carbon) value in the ash residues of below 3 wt% and typically between 1 and 2 wt%, including in particular the use of a combination of furnace design, furnace operation and waste throughput rate that provides sufficient agitation and residence time of the waste in the furnace at sufficiently high temperatures, including any ash burn-out areas".

So it is considered BAT to recover the ferrous and non-ferrous fractions from the bottom ash. To improve the environmental as well as building technical characteristics of the bottom ash it is BAT to fractionate the bottom ashes in a wet or dry process followed by natural or accelerated carbonation of the aggregates. For the fine granulate fractions, which result from the wet or dry ash treatment facility, there are several possible recycling and disposal routes: *e.g.*, mixing of the fine fraction (or part thereof) with the coarser granulate fraction(s), sintering or immobilisation of the fine fraction, or landfilling. The selection of one of these recycling or disposal routes largely depends on the local market conditions and local environmental regulations and policy.

The dry bottom ash treatment is the most widely used, and generally results in a bottom ash granulate that in many neighbouring countries can be used in the road construction industry. In Flanders, however, this type of treatment offers no guarantee that the obtained granulates will comply with environmental standards of VLAREA[3] criteria for reuse. Therefore, the success of the dry bottom ash treatment seems to depend largely on the quality of the original raw bottom ash as stated earlier in the BAT considerations of the EU BREF on Waste Incineration. This paper will focus on the wet process for the treatment of raw bottom ashes, as it is operated by Indaver NV.

Waste-to-Energy Plant

The grate furnace complex of Indaver NV is situated in an industrial zone close to Antwerp (Antwerpen Linkeroever, *i.e.* left bank of the river Schelde), in the vicinity of one of the most important petrochemical and chemical industrial complexes in the world. The closest villages are Kallo (2.5 km to the south) and Doel (3 km northwest). The municipality of Beveren is situated 6 km to the south.

The incineration plant is comprised of three grate furnace lines,[4,5] *i.e.* a furnace with a boiler, gas washing and a chimney. Two lines each have a nominal treatment capacity of 13.3 tonne/h, the third one of 21.5 tonne/h, in total 48.1 tonne/h. Figure 2 schematically shows the components of a grate furnace line.

The waste is delivered via a bunker. Using a crane it is brought from the bunker onto the moving grate where it is incinerated at a minimum temperature of 850°C (up to

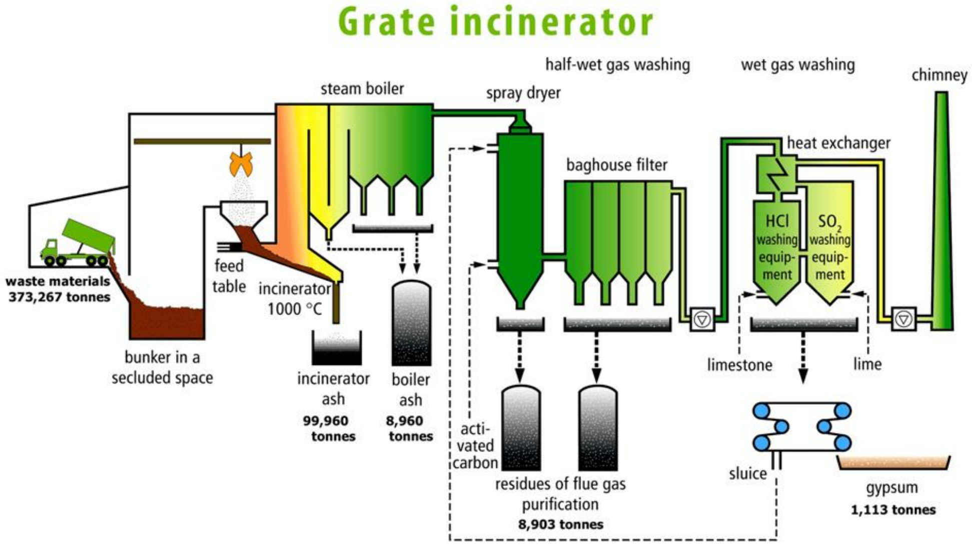

Figure 2: Schematic representation of the MSWI Waste-to-Energy plant in Doel

1000°C). This gives bottom ash (incinerator ash) and flue gas. The flue gas is passed through a boiler. Each line is equipped with a boiler with a thermal power of 40.0 (two lines) or 67.5 MW (one line) depending on the capacity (total thermal power 147.5 MW). These boilers are equipped with an economiser in order to heat the feed-water and with a super heater to heat the saturated steam (45 bar, 257°C) further to 40 bar and 400°C. During cooling of the flue gas in the boiler, boiler ash is deposited and is collected. In Figure 1 also the amount of residues is represented, based on the companies' mass balance of 2004.[1] Approximately 99960 tonne of raw bottom ashes are produced yearly. Referring to a total input of 373276 tonne of incoming waste, this amount of raw bottom ashes represents approx. 26.7 %.

Wet treatment of bottom ashes

Figure 3 schematically shows the installation for the wet treatment of bottom ash consisting of various mechanical parts with different functions: washing, sieving and separating.[4,5]

In a first step a robust bar sieve removes large parts of metal and stone (not shown in Figure 3). Water is then added and the material > 50 mm is removed by a first sieve-wash unit (rotary sieve). Ferrous metals are removed magnetically from this fraction and the rest of the material > 50 mm is partly sent back to the grate incinerator. The finer material (< 50 mm) passes through a washer barrel to separate the light organic material from the granulates, which is also sent back to the grate incinerator. Another screening and washing unit separates the particles in three different fractions with different sizes in ranges of 6–50 mm, 2–6 mm and < 2 mm. Ferrous separators retrieve the iron from the two larger fractions. Non-ferrous separators, based on Eddy current, are foreseen for the two larger fractions to

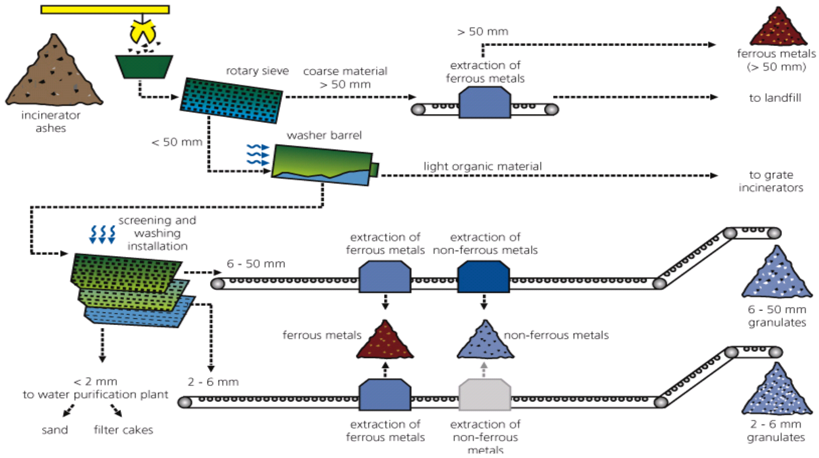

Figure 3: Schematic presentation of the wet separation process.

separate mainly aluminum and copper. In practice they are always in use for the 6–50 mm fraction, and are optional (only used to improve the quality of the end-product, when the end-product is applied in building materials) for the 2–6 mm fraction, where the yield of non-ferrous metal is low. Finally, the fraction <2 mm is separated in a sludge fraction (< 0,1 mm) and a sand fraction (0,1–2 mm). The sludge is landfilled without stabilisation. The ash treatment facility has a capacity of 165000 tonne/year. Although the wet treatment installation uses large quantities of water (L/S = 0,5–1), not much water is actually ''consumed'' and no wastewater is discharged. The water used in the ash treatment facility is collected from potential contaminated rainwater and clean rainwater from the open air storage facility, and is continuously re-circulated. Only 5% of the water is purged and used for several other process applications on the site. In order to improve (decrease) metal leaching (see further), the obtained granulates (6–50 mm and 2–6 mm) are aged for 3 months in 5–10 m high heaps, located at the site of the incineration plant in open air on a paved floor with collection of the percolating rain water, exposing them to wind and rain. The reactions taking place during this time tend to decrease heavy metal leaching.

Material recovery

As mentioned before, Figure 2 gives representative data relative to the mass balance of the incineration installation, resulting from a test carried out in 2004. Table 1 gives the different end-products from the wet treatment of the bottom ashes.

The wet process for sieving the bottom ash has distinct advantages over dry-sieving in view of quality-assurance: the light organic fraction floats in the washer barrel and can easily be removed, soluble salts are readily washed out, visually clean end-products (granulates) are obtained, and sieving efficiency is high. The ferrous and non-ferrous metal fractions can be further recycled as high quality raw material. These fractions are 100% sold to scrap companies

For the 2–6 mm and 6–50 mm granulate fractions, Table 2 gives concentration data for some toxic organic components and metal leaching data after 3 months of aging and compares them to the limit values for reuse as secondary raw materials in building applications given in the VLAREA (Decision of the Flemish Government on waste prevention and management).[3]

Table 1: End products from wet treatment of bottom ashes

Fraction	Application	wt% of bottom ash
Ferrous – metal Non ferrous- metal Granulate 2 – 6 mm Granulate 6 – 50 mm	Recycling, highest quality Recycling, highest quality Granular or monolithic applications in constructions	8.5 1.0 14 27
Total of "free use" application (no further monitoring required)		50.5
Sand 0,1 – 2mm	Controlled application in construction on landfill (covering)	32
Total of application with further monitoring		32
Sludge < 0,1 mm Organic Others	Landfill Returned to grate furnace landfill	8 1 8.5
Total to be disposed of		17.5

Table 2: Dioxins/PAH and concentration of leachable metal compounds according to NEN 7343 or EN12457-3 (two step leaching test)[3]

	Fraction granulate		**VLAREA CMA 2//II/A.9.1. (leaching test) Limit value**
	2 – 6 mm	**6 – 50 mm**	
Dioxins (PCDD / PCDF)	< 5 pg TEQ/g	< 5 pg TEQ/g	
PAH (individual values)	< 0.03 mg/kg DM	< 0.03 mg/kg DM	
Leaching metals (mg/kg)			
Arsenic (As)	< 0.025	< 0.05	0.8
Cadmium (Cd)	< 0.01	< 0.01	0.03
Chromium (Cr) (total)	< 0.03	< 0.05	0.5
Copper (Cu)	0.17 – 0.50	0.04 – 0.49	0.5
Lead (Pb)	< 0.03	< 0.10	1.3
Nickel (Ni)	< 0.025	< 0.05	0.75
Zinc (Zn)	< 0.03	< 0.10	2.8

The results for PCDD/PCDF and PAH are very low. For all elements, except Cu, the leaching results were below the detection limit, which is for all elements well below the VLAREA standard. All results thus complied with the VLAREA standards, the only critical parameter being Cu leaching. The necessary certificates for use as secondary raw material were obtained from OVAM, the Flemish Waste Agency, allowing the use of these materials as granular material in construction applications and as additive in monolithic construction materials. These certificates have to be renewed each 5 years. In total *ca.* 50 wt% of the bottom ash (13.0% of the mass of the original waste) can thus be transformed into commercially applicable raw materials, under VLAREA, one of the most stringent regulations in Europe.

The sand fraction (0,1–2 mm) does not comply with the VLAREA[3] requirements for secondary raw materials, even after 3 months of aging, but complies with the criteria for acceptance on non-hazardous waste landfills. It can, *e.g.*, be applied in the production of covering layers on landfills. *Ca.* 32 wt% of the bottom ash (8.2% of the mass of the original waste) is thus usefully applied with further monitoring.

The sludge from the washing plant and the large parts of stone removed by sieving before the wet bottom ash treatment plant, along with part of the fraction of material > 50 mm removed by screening and washing, are landfilled without stabilisation.

Legal restrictions

According to the European waste definition (art. 2 of the Waste Framework Directive 2008/98) the raw bottom ashes still have to be considered as a waste. Referring to European Waste Catalogue (EU decision 2000/532) raw bottom ashes have to be classified as non-hazardous waste with code 19 01 12. Although the new WFD has foreseen the introduction of "end-of-waste" status, technical criteria ase missing on a EU level to go ahead with the granulates of the ash treatment facility. As long as formal EU criteria are missing, the Member States can develop their own legal framework to encourage the reuse of materials.

In Flanders, the "free use" of granulates as "secondary raw material" (which is similar to "end-of-waste status") is regulated by the VLAREA,[3] the Decision of the Flemish Government on waste prevention and management. The granulates can be used in construction applications as far as following requirements are respected. For a set of organic parameters (*e.g.* PAH, MAH, PCB, EOX, mineral oil) the limit values in terms of total concentration in Table 3 are very stringent but in general they are respected without any problem.

Table 3: VLAREA[3] limit values: total concentrations of organic components for free use of granulates in construction applications (expressed as mg/kg DM)

MONOCYCLIC AROMATIC HYDROCARBONS	
Benzene	0.5
Ethyl benzene	5
Styrene	1.5
Toluene	15
Xylene	15
POLYCYCLIC AROMATIC HYDROCARBONS	
Benzo(a)antracene	35
Benzo(a)pyrene	8.5
Benzo(ghi)perylene	35
Benzo(b)fluorantene	55
Benzo(k)fluorantene	55
Chrysene	400
Fenantrene	30
Fluorantene	40
Indeno(1,2,3cd)pyrene	35
Naftalene	20
OTHER ORGANIC SUBSTANCES	
Extractable organic halogen compounds (EOX)	10
Hexane	1
Heptane	25
Mineral oil	1000
Octane	90
Polychlorinated biphenyls (PCB)	0.5

Referring to the limit values of total content of inorganic components in Table 4 (*e.g.*, heavy metals) the numbers only have to be considered as target values. Although the total concentrations of Zn and Cu are higher than the mentioned target values in Table 4, these parameters do not create structural problems but result in a restriction for the use in construction works.

On the other hand, the limit values for the leaching of heavy metals, as already presented in Table 2, are critical for Cu. It was found earlier that the leaching of Cu is significantly enhanced by the complexation with dissolved organic carbon. It's very likely that fulvic acids are responsible for the high Cu concentrations in granulate leachates.[6,7] During natural ageing Cu leaching also slowly decreases. It is believed

Table 4: VLAREA[3] target values: total concentrations of inorganic components for free use of granulates in construction applications (expressed as mg/kg DM)

METALS	
Arsenic (As)	250
Cadmium (Cd)	10
Chromium (Cr)	1250
Copper (Cu)	375
Mercury (Hg)	5
Lead (Pb)	1250
Nickel (Ni)	250
Zinc (Zn)	1250

that carbonation plays an important role in the ageing process but research on these topics is still ongoing to optimise and/or influence the ageing process. Today, ageing stands for related chemical processes such as carbonation, hydratation, oxidation, and stabilisation of organic substances. It is believed that the first reaction is the most relevant in the alkaline granulates:

$$CaO + H_2O \rightarrow Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

When all three sets of criteria are respected, OVAM, the Flemish Public Waste Agency, will deliver a so-called "secondary raw material" certificate, which allows the producer of the granulates to put the materials on the market as a product (and no longer as waste). The certificate also defines the allowed technical application. In the case of the Indaver NV granulates the recovered materials can be used in construction works up to a height of 70 cm. In general, the certificate is valid for 5 years.

Although ageing of the granulates during min. 3 months is necessary to obtain products that comply with the VLAREA criteria, the most limiting legal factor is the fact that a) the obtained granulates will not necessarily be considered as an "end-of-waste" material in other regions, b) the legal framework in other regions may be total different or based on other leaching conditions although similar applications are considered: *e.g.* the limit value for leaching of Cu is almost double for free use in the Netherlands.[8,9]

Market restrictions

The market perception on the use of granulates is still negative, because the products have been produced by WtE plants As long as incineration plants still have their negative image it will remain difficult to develop a regular business for the marketing of these granulates. In addition, often huge amounts are required for construction works in which ash treatment plants can only play a minor role. Today, approximately 8 million tonne of granulates/year are produced by the recycling facilities for construction and demolition waste in Flanders. It is obvious that with a share of 50 up to 100 ktonne/year the impact of the ash treatment plants on the market is very limited.

As a result of that, last year all granulates were used in the end capping of landfills for non-hazardous waste in Flanders; an application which is useful for the landfill operator but with no profit for the producer of the granulates. For the ferrous and non-ferrous fraction nice (market driven) prices were given in 2010: approximately 160 €/tonne for ferrous, 1300 €/tonne for non-ferrous.

Socio-economical restrictions

The advantages of material recycling are that less landfill space is needed and that the obtained products may replace other raw materials which should be otherwise mined. To facilitate the recycling of bottom ashes, the authorities can take several initiatives: *e.g.* participating in the investment of an ash treatment facility, introducing landfill bans and/or taxes, or facilitating the re-use of the granulates. Until now, raw bottom ashes can be disposed of on landfills for hazardous, non-hazardous and inert waste. For the landfilling of raw bottom ashes no taxes are applicable because based on the "*non bis in idem* principle" in Flanders, the producer of this waste does not have to pay twice if taxes have been paid already for incineration of the original waste. On the other hand, the use of raw bottom ashes can be also useful in the construction of the landfill and the end capping. A suggestion could be that limited or zero taxes are only allowed if raw bottom ashes are used for construction purposes of the landfill itself, but as long as market limitations are existing this would not be an option.

In addition, especially for bottom ashes from High Temperature Incinerators (mainly dealing with industrial waste), based on rotary kiln technology, the political will is low to encourage the reuse of materials. For granulates produced from WtE bottom ashes a local legal framework is available but the Flemish authorities themselves do not yet allow the use of these granulates for construction works that are ordered by themselves. The Flemish Minister of Environment agreed to support and facilitate the use of these granulates in construction works ordered by themselves, but it still takes a lot of time to come up with a finalised action plan.

Conclusions

With the publication of the new European Waste Framework Directive 2008/98 the European Union expressed its long term ambition to become a world leader as a modern “recycling society”. The recycling of bottom ashes from state-of-the-art Waste-to-Energy plants can play an important role to increase the re-use of granulates and to avoid the mining of new raw materials.

Indaver’s wet treatment of bottom ashes results in high quality ferrous and non-ferrous fractiosn for which the market demand is still present. On the other hand the VLAREA legal environmental conditions for the free use of the granulates 2–6 mm and 6–50 mm are limiting the use of it to the Flemish region. The main reason of that is the very stringent leaching condition with respect to Cu. The leaching of Cu from the granulates is believed to be influenced by elevated amounts of fulvic acids in the raw bottom ashes. After ageing of 3 months the granulates fulfil the legal conditions but the local market is not yet very active in taking these “secondary raw material” (according to Flemish legislation) products for construction works. The discussed wet treatment of bottom ashes is considered as BAT by the Flemish authorities and the EU (referring to EU BREF on Waste Incineration).

To improve the business in bottom ash granulates, local authorities should take the lead in applying these granulates in construction works ordered by themselves, while the EU should harmonise the EU technical criteria to allow it to become an “end-of-waste” material, whereas the construction industry should be encouraged to use these recycled materials.

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