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COMPARING THE UTILIZATION OF WASTE PLASTICS IN HOT METAL AND CEMENT PRODUCTION

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SUMMARY: According to the waste management hierarchy it is most favorable to prevent the generation of waste, followed by its re-use. If both measures are not applicable, the generated waste should undergo recycling processes. As many waste plastics are still difficult to recycle, plastics utilization in the hot metal production and in the cement industry represent a suitable way for the management of plastic waste according to the waste management hierarchy. The waste plastics utilized have to meet certain standards, and different limits according to process emissions have to be fulfilled. In the present paper the utilization of waste plastics in both processes is compared. Thereby, special focus is given to the flows of Cadmium and Mercury induced by the waste plastics.

1. INTRODUCTION

In 2013 European plastics production exceeded 57 Mt. In comparison, 25 years ago production figures amounted to not even half of it (27.4 Mt in 1989). At a global scale plastics production increased even much faster, it tripled within the same time period. The amount of waste plastics annually generated also increased substantially during the last decades and reached around 25 Mt in 2012 for the EU27, Norway and Switzerland. From this amount around 26 % have been recycled, 36 % have been used for energy recovery and the remaining 38 % have still been landfilled (PlasticsEurope, 2015).

However, according to the waste management hierarchy (see Figure **1**), the most favorable option would be to prevent the generation of waste, followed by its re-use. If both measures are not applicable, the generated waste and thus also waste plastics should undergo recycling processes (material recovery). The least favorable options are energy recovery followed by waste disposal.

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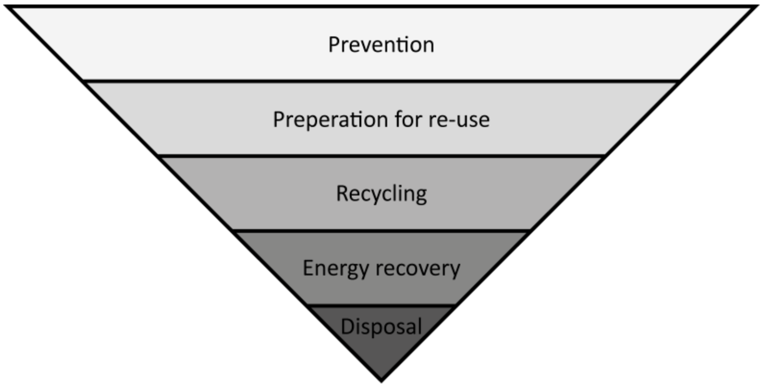

Figure 1: Waste management hierarchy according to (European Parliament and Council of the European Union, 2008)

In Austria plastics waste management is somehow different than in most other European countries. This difference is mainly based on the Austrian landfill directive, which prohibits the landfilling of waste with a significant share of organic matter (total organic carbon (TOC) content of the waste landfilled must be less than 5 %). Thus, in 2010 waste plastics generated or imported to Austria, were used to 21 % for material recycling, 67 % were thermally utilized in different plants and only 2 % were still landfilled (based on Feketitsch and Laner (2015)).

Figure **2** gives an overview of the flows of waste plastics in Austria in 2010. Thereby, it becomes obvious that the main flows of waste plastics are related with the generation of waste in other applications (250 kt) and packaging waste (280 kt). The building industry contributes 45 kt and the transport sector around 58 kt to the total waste quantity. From the total waste emergence 170 kt ends up in the cement rotary kiln. Only 74 kt of waste plastics are utilized in the steel industry. The remaining plastics wastes are mainly utilized in waste-to-energy plants (345 kt), partly mechanical recycled (157 kt), a rather small amount is reused (4 kt) and about 15 kt are landfilled.

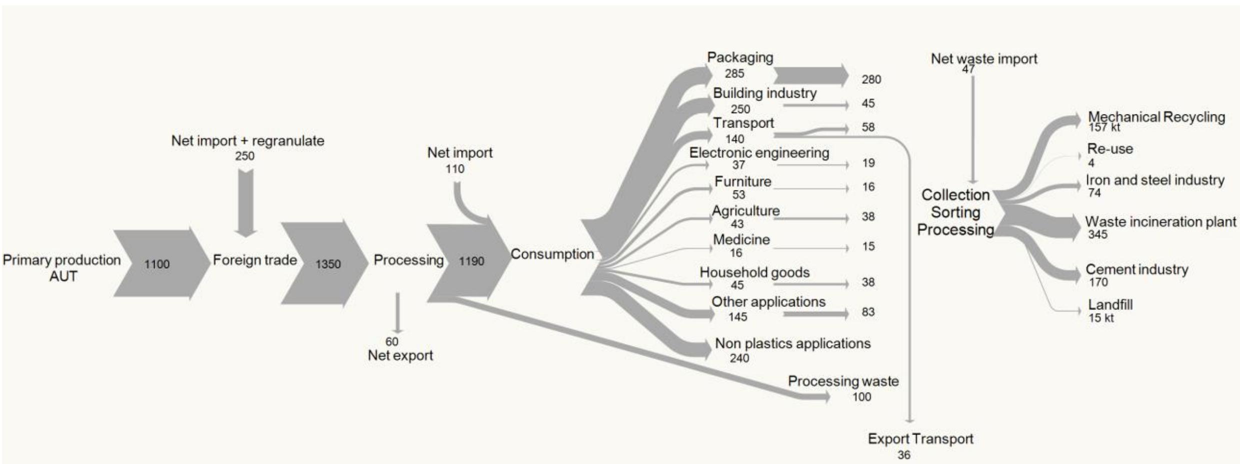

Figure 2: Flows of Waste Plastics in [kt] in Austria for 2010 (based on Feketitsch and Laner (2015))

Thus, from Figure **2** it becomes obvious that reuse of waste plastics is hardly possible and material recycling is limited to sorted or separated plastics waste containing “pure” fractions of certain polymers.

According to the waste management hierarchy the utilization of waste plastics in cement kiln or in the iron and steel industry is more favorable than their combustion in Waste-to-Energy plants.

However, for the utilization in the cement or the hot metal (HM) production waste plastics have to meet certain requirements. Besides physical characteristics (e.g. grain size, heating value, water content) these requirements include also limit values for certain elements (e.g., Chlorine or heavy metals). The latter should ensure high quality products, process stability and the compliance with environmental regulations.

As of all above mentioned options for waste plastics management, utilization in cement kilns or blast furnaces are most comparable (e.g., with respect to their classification according to the waste hierarchy, physical and chemical requirements of the waste plastics) and thus also compatible, the present paper aims at a comprehensive analysis and comparison of both utilization methods.

2. Material and Methods

In a first step, legal and technical requirements for the utilization of waste plastics in the cement production and the hot metal production process are compared, focusing mainly on limit values of trace elements present in plastics waste. In a second step detailed material flow analyses for Cadmium (Cd) and Mercury (Hg) for both processes are elaborated and subsequently compared.

Thereby, special focus is given to the outputs of the processes.

2.1 Hot metal production

One import process route for the HM production is still the blast furnace process. The amount of HM generated in blast furnaces in Europe (EU28) ranges between 72,652 kt (in 2009) and 94,257 kt (in 2011) per year (Worldsteel association, 2014).

For the HM production different input materials are necessary. The main input materials are iron bearing materials and coke, which is used as a reducing agent. The iron bearing materials can include, e.g., lump iron ores, pellets and sinter. Beside these two main inputs, alternative reducing agents, such as crude tar and heavy oil, e.g., can be used. Also waste plastics represent an alternative reducing agent and help to reduce the amount of coke needed in the process. Additional, the hot blast is needed to form the reduction gas for the chemical reactions. Due to the gas cleaning processes also process water and recycled circulation water is needed. The process outputs include not only the product, the HM, and the slag (by-product), but also the cast house off-gas and the top gas, which have to be cleaned. For the top gas cleaning a dust catcher and a wet scrubber are used.

Figure **3** illustrates a schematic model of a blast furnace process. The system includes the blast furnace itself and the gas cleaning devices. The latter are used for cleaning the top gas and the off-gas, which occurs at the tapping stand. The blast furnace, presented in this model, has a hearth diameter of 12 m and a daily production rate of 8,500 t HM. In this plant waste plastics are utilized up to an amount of 35 kg/t HM.

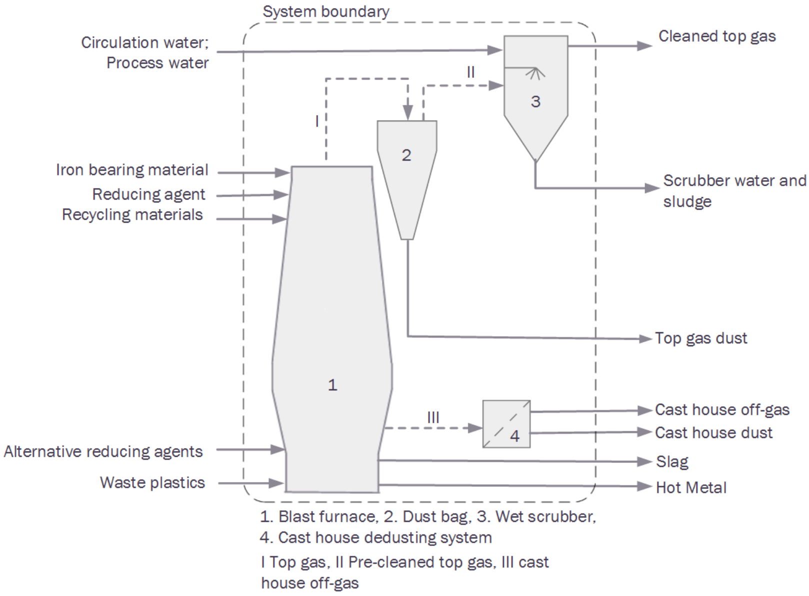

Figure 3: Blast furnace process model based on Trinkel et al. (2015)

For this plant annual mean values characterizing the amount and composition of the different input and output materials (based on measurement data which are recorded due to environmental and process control reasons) were available for the time period 2009 to 2012. The data included annual mean values for the mass- and volume flow measurements, and for the respective contents of the heavy metals Cd and Hg.

2.2 Cement production

The annual amount of cement produced in Europe (EU28) was around 200 Mt/a between 2009 and 2012 (Cembureau).

The two principal processes for the cement production are the clinker production and the cement mill. Figure **4** illustrate these two processes, whereby for the clinker production the sub-processes are indicated (e.g. rotary kiln, calciner). The rotary kiln is mainly used in the clinker production process. The main input material for the clinker production is the raw mix. This raw mix consists, e.g., of limestone, clay and lime marl (VDI 2094, 2003). As secondary raw materials different foundry sands and slags are used, for example. Moreover, different energy sources are needed.

These include different fossil fuels (e.g. coals, natural gas) and RDF (e.g. sewage sludge, residual materials from paper industry) including waste plastics. The clinker is further processed in the cement mill together with different additives (e.g. blast furnace slag, fly ash). The only two outputs of the cement production process are the cement and the off-gas.

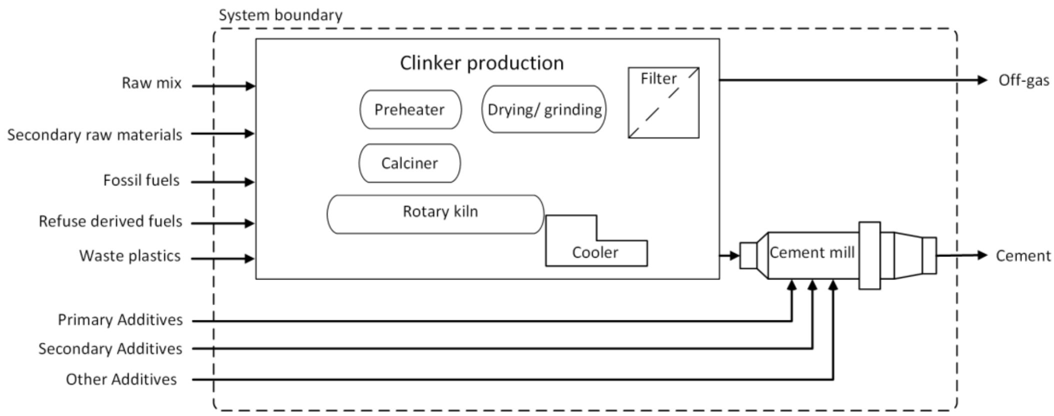

Figure 4: Modell of Cement industry based on Joint research centre (2013) and Lederer et al. (2015)

For balancing Cd and Hg flows through the cement production process, mass and concentration data were used according to Lederer et al. (2015). In their work they evaluated heavy metal flows through the cement production.

4. RESULTS

4.1 Requirements for the utilization of refuse derived fuels

Refuse derived fuels (RDF), in the present case namely waste plastics, which are utilized in the cement production or in the HM production process are subject to certain standards. According to the Austrian Waste Incineration Ordinance (AVV, 2002, as amended) RDF have to meet the limits (given in [mg/MJ]) which are listed on the left side in Table **1**. These limit values are valid for the clinker production process. The values given have been converted from [mg/MJ] to [mg/kg] assuming an average lower heating value of RDF of 25 MJ/kg. This was done in order to make them comparable with the limit values specified for the utilization of waste plastics in the blast furnace.

Table 1: Limits for the utilization of RDF in the cement production according to (AVV, 2002, as amended)

Limit values for	*Median*	*80 % percentile*	*Median*	*80 % percentile*
Parameter	[mg/MJ]		[mg/kg]*	
Sb	7	10	175	250
As	2	3	50	75
Pb	20	36	375	900
Cd	0.23	0.46	5.8	11.5
Cr	25	37	625	925
Co	1.5	2.7	37.5	67.5
Ni	10	18	250	450
Hg	0.075	0.15	1.875	3.75

** assuming an average lower heating value of 25 MJ/kg*

Moreover, the cement has to meet quality standards of DIN EN 197-1 (2011). According to this standard the Cl content in the cement is limited to 0.01 %. This limit is necessary for the product quality, but also because of process control reasons. Thus, it also affects the quality of input materials utilized in the cement production process. Cl contents of RDF should thus be below 10,000 mg/kg (recommended by Lorber et al. (2010)).

Waste plastics utilized in the blast furnace process have to meet two limits. The first limit is for taking delivery of the material and has to be understood as 80 % percentile limit, which means that maximum 20% of the delivered batches (each amounting to 400 tons) may show higher contents.

The second limit restricts the composition of the mixture of waste plastics finally utilized in the blast furnace. Both limits are given on the left side in Table **2** [mg/kg DM (dry matter)].

On the right hand side of Table **2** the 80 % percentile limits for the takeover are converted into [mg/MJ] assuming a typical heating value for the utilized waste plastics of about 31 MJ/kg.

Table 2: Limits for waste plastics in the HM production process for the considered blast furnace (Environmental impact assessment, 2007)

Limits values for	*For taking delivery*	*For utilization*	*For taking delivery*
Parameter	80 % percentile		80 % percentile
	[mg/kg DM]		[mg/MJ]*
Cl	20,000	20,000	645
S	5,000	5,000	16
As	5	5	0.16
Pb	250	250	8.1
Cd	9	9	0.29
Cr	500	500	16
Cu	1,000	1,000	32
Ni	500	500	16
Hg	0.5	0.5	0.016
Zn	1,000	1,000	32

** assuming an average lower heating value of 31 MJ/kg*

From Table **1** and Table **2** it becomes obvious that the number of parameters which have to meet certain limits are different for both processes. For the utilization of waste plastics in blast furnaces one has to consider ten parameters which are restricted. In comparison in cement industry 8 parameters are given. If one compares the 80 % percentile limit for the cement production process and the 80 % percentile limit for the taking delivery of the HM production process it becomes obvious that the limits for Nickel (Ni) (16 mg/MJ for the HM production process; 18 mg/MJ for the cement production process) are quite similar. The values for Chromium (Cr), for example, are quite different with 16 mg/MJ for the HM production process and 37 mg/MJ for the cement production process. However, it must be noted that for the comparison of the limits of both processes, either the limits for the cement production process or the limits for the HM production process have to be converted into another unit. This conversion, however, bears some uncertainties, as typical heating values for the utilized waste plastics have to be assumed.

4.2 Process inputs

4.2.1 Input materials for hot metal production

Table **3** summarizes the necessary amount of input materials for the hot metal production. The main input materials are the iron bearing materials (> 75 %) including different lump ores, pellets and sinter and the coke as a reducing agent (20 % of the total input). The waste plastics represent just 1.4 % (28 kg/t HM) of the total input.

Table 3: Amount of input materials for HM production

Input	[kg/t HM]
Iron bearing materials	1,520
Coke	382
Recycling materials (Fe rich)	2.1
Alternative reducing agents	37
Waste plastics	28

These input materials contribute to a different extent to the total input of Cd and Hg into the process. The contribution from one particular input material to the overall heavy metal input is depending on the utilized amount of the particular material und its respective heavy metal concentration.

Figure **5** shows the share of different input materials to the total input of Cd (left) and Hg (right).

The total Cd input in the blast furnace process is less than 400 mg/t HM, whereby the iron bearing materials represent the main input for Cd. It must be noted that the Cd input via the iron bearing materials and the reducing agent has been estimated based on the fact that the total Cd output observed has been significantly higher than the total Cd input measured. This difference in Cd flows is attributed to the fact that Cd concentrations of most iron bearing materials and in the reducing agent are below the limit of quantification (LOQ = 0.5 mg/kg) and thus the entire input cannot be quantified by measurements. However, it is most likely that the iron bearing materials and the reducing agent, respectively, contain Cd to a very low concentration (less than half of the LOQ), which already would explain the observed differences between entire input and output of Cd.

The waste plastics are the second largest input for Cd with a share of approximately 34 %. Other alternative reducing agents utilized contribute to about 9 % to the total Cd input.

The total Hg input is less than 40 mg/t HM (right-hand side of Figure **5**). Thereby, a high share of Hg refers to the iron bearing materials and the reducing agents, respectively. Alike to Cd, it must be noted for Hg, that the contribution for these materials is estimated based on the balance error (total output > total input) observed for Hg. This difference for Hg may also result from the fact that most of the input measurements are below the LOQ (LOQ = 0.1 mg/kg). Other inputs for Hg are the alternative reducing agents, which contribute to about 39 % to the total Hg input. The waste plastics have a share of less than 20 %.

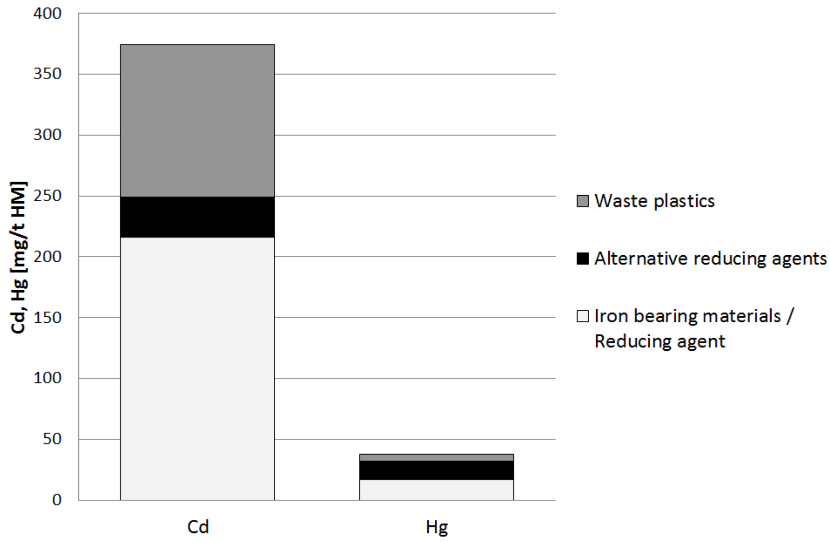

Figure 5: Cd (left) and Hg (right) input into HM production via different materials (given in [mg/t HM])

4.2.2 Input materials for cement production

Table **4** summarizes the amounts of the different input materials utilized in the cement production according to Lederer et al. (2015). The raw mix as the main input for the cement production process contributes to more than 65 % of overall material input. Waste plastics thermally utilized contribute to 3.3 % to the total material input.

Table 4: Specific amount of input materials for cement production (given in [kg/t cement]) - according to Lederer et al. (2015)

Input	[kg/t cement]
Primary raw material	1,023
Secondary raw material	109
Fossil fuels	36
Refuse derived fuels	40
Waste plastics	51
Primary additives	74
Secondary additives	200

All input materials contribute to a different share to the total Cd and the Hg input, respectively. This is due to the utilized amount and their concentration of the respective heavy metals.

Figure **6** shows the contribution of each input material to the overall Cd and Hg input. The total Cd input (left side of Figure **6**) is slightly higher than 600 mg/t cement. All in all about 30 % of the total Cd introduced into the process originates from the utilization of waste plastics. The other RDFs have a share of less than 20 % to the total Cd input. The primary raw materials contribute to more than 20 %.

The total Hg input (shown on the right side of Figure **6**) is less than 250 mg/t cement. The utilized waste plastics contribute with more than 50 % at most to the overall Hg input. The second largest input for Hg is the raw mix with 25 %. All other inputs have a share of less than 7 %.

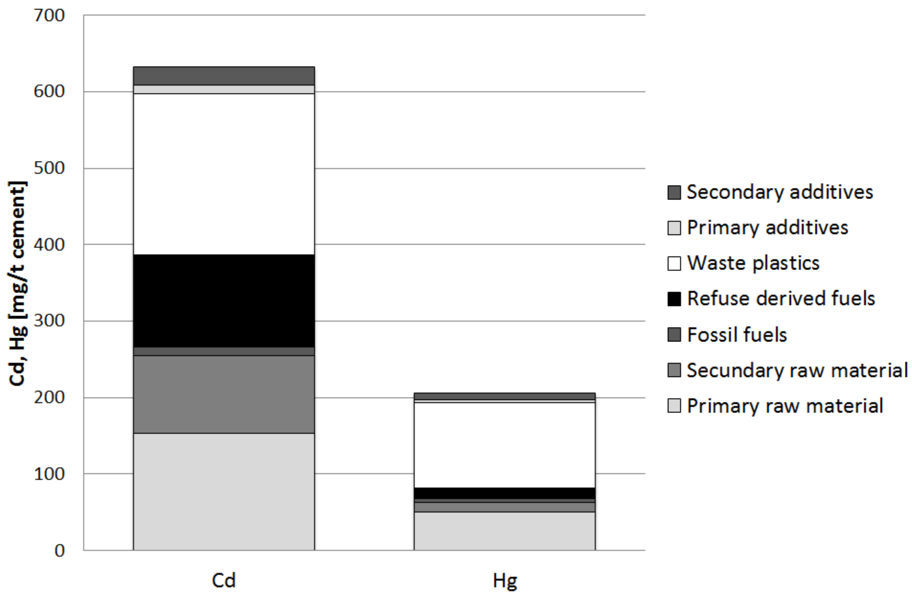

Figure 6: Cd (left) and Hg (right) input into the cement production process via different input materials (given in [mg/t cement]) - based on (Lederer et al., 2015)

It must be noted that the amount of Hg and Cd input via the secondary additives (including blast furnace slag) has been corrected. This was done because the Cd and Hg concentration for the blast furnace slag assumed by Lederer et al. (2015) seemed to be implausible. Therefore, they have been corrected according to the measurements carried by Proctor et al. (2000).

4.3 Output materials

4.3.1 Requirements regarding process emissions

Both processes face different limits for their output flows. A direct comparison of these limits is challenging, as the amount and also the constitution of the different output flows are different.

Nevertheless, in Table **5** ranges for the composition of the top gas (after two-stage cleaning) and the off-gas from the clinker production according to the BAT (best available techniques) documents for these processes are given.

It must be noted that the top gas (after two stage cleaning) in an integrated steel plant is not directly released to the atmosphere but further used for energy recovery.

From Table **5** it becomes obvious that the data given in the BAT are hardly comparable because of the different parameters given in the BAT documents.

Table 5. Comparison of emissions from European cement kilns given in the BAT (Joint research centre, 2013) and the blast furnace top gas composition (after two stage treatment) (Remus et al., 2013)

Cement production Emission ranges from European cement kilns		*HM production Blast furnace top gas composition (after two stage treatment)*	
	g/t clinker		g/t HM
Dust	0.62 – 522.1	Dust	1 - 20
NO_x	330 – 4,670		
SO_2	up to 11,120	H_2S	17 - 26
CO	460 – 4,600	CO	300,000 – 700,000
CO_2	Approx. 672g/t Cement	CO_2	400,000 – 900,000
TOC/ VOC	2.3 – 1,380	H_2	1,000 – 7,500
HF	0.021 – 2.3		
HCl	0.046 - 46		
Hg	0 – 0.069	Mn	0.22 – 0.37
∑(Cd, Tl)	0 – 1.564	Pb	0.02 – 0.07
∑(As, Sb, Pb, Cr, Co, Cu, Mn, Ni, V)	0 – 9.2	Zn	0.07 – 0.22

4.3.2 Distrubtion of Cd and Hg in the different outputs of hot metal production process

Figure **7** shows the main Cd output flows for the HM production process. The left bar of Figure **7** indicates the total Cd output (< 400 mg/t HM) of the blast furnace process. Cd is mainly transferred into in the outputs scrubber water, scrubber sludge, top gas dust und cast house dust. The biggest output flow represents the scrubber sludge (> 80 %). This output is fed into a hydrocyclone that separates the sludge into two fractions (not shown in Figure **3**).

The fraction of low heavy metal concentrations and high contents of iron is internally recycled in the sinter plant. The other part (high contents of heavy metals, such as Zinc) has to be landfilled.

Another significant output for Cd is the top gas dust (> 10 %). Also this material is usually utilized in the sinter plant. Beside these two output flows, also the scrubber water may contain some amount of Cd (< 3 %). This output flow is not leaving HM production process, since there is a closed process water loop for the top gas cleaning device. Furthermore, a very low amount of Cd accumulates in the cast house dust (less than 0.25 % of the total Cd Output). Only about 0.05% of the total Cd output leaves the process via the cleaned top gas (not shown in Figure **7**).

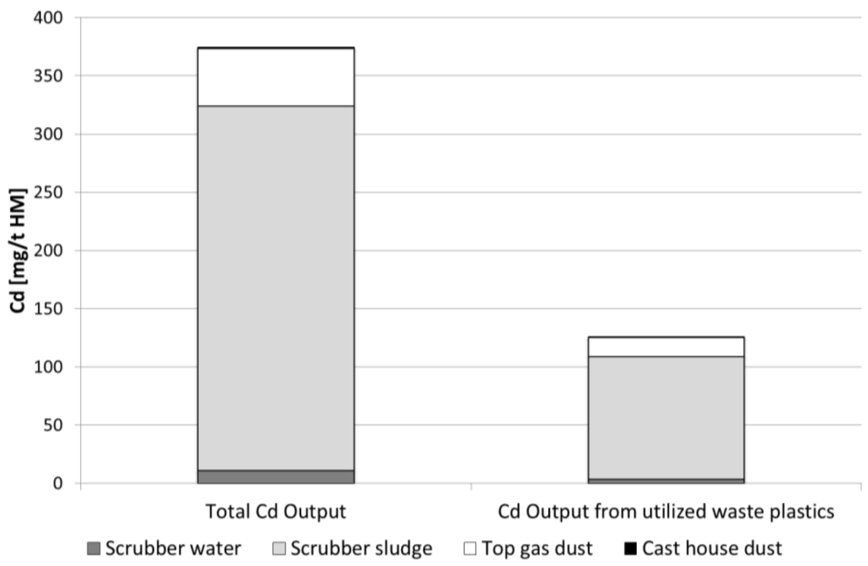

Figure 7: Specific Cd output from HM production process (left bar - total Cd output; right bar Cd output due to waste plastics utilization) given in [mg/t HM]

The right bar in Figure **7** indicates the Cd output that traces back to the waste plastics utilized. It amounts to about 120 mg Cd/t HM. This amount was further used to calculate the theoretical Cd output originating from the waste plastics utilized in [mg/MJ]. For this calculation a mean heating value of 31 MJ was assumed. According to this calculation the total Cd output stemming from the utilization of waste plastics is slightly more than 0.14 mg/MJ energy input via plastics (see Figure **8**).

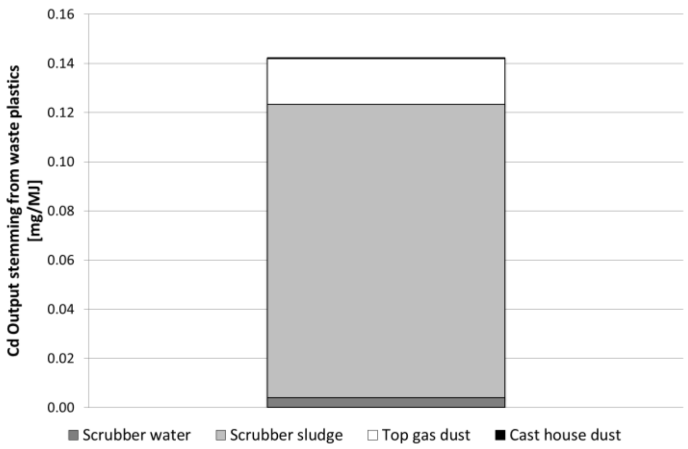

Figure 8: Specific Cd output for the HM production due to waste plastics utilization (given in [mg/MJ])

Figure **9** shows the specific Hg output (in [mg/t HM]) for the HM production process. The total Hg output (left hand side of Figure **9**) for this process is less than 40 mg/t HM. The biggest output flow is the scrubber sludge with a share of more than 80 % of the total output. The cleaned top gas and the top gas dust contain each less than 10 % of the total Hg output. Also the cast house dust contributes to a very small amount to the total Hg output with less than 0.05 %.

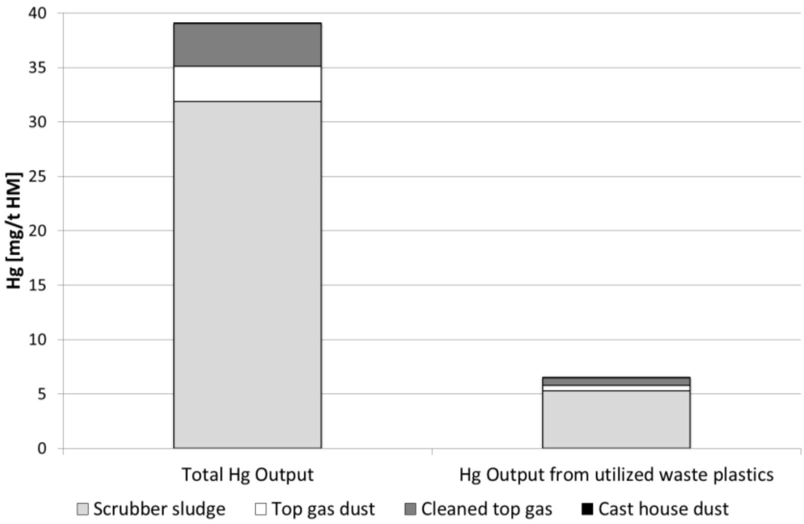

Figure 9: Specific Hg output from HM production process (left bar - total Hg output; right bar Hg output due to waste plastics utilization) given in [mg/t HM]

The Hg output, which originates from the utilized waste plastics is given on the right side of Figure **9** and is around 6 mg/t HM.

This amount was further used to calculate the specific Hg output stemming from waste plastics utilization in [mg/MJ] (see Figure **10**). For this calculation again, a mean heating value of 31 MJ was assumed.

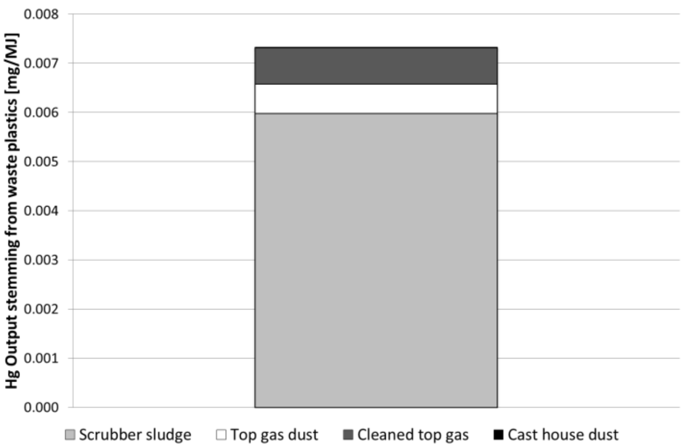

Figure 10: Specific Hg output for the HM production due to waste plastics utilization (given in [mg/MJ])

4.3.3 Distrubtion of Cd and Hg in the different outputs of cement production process

At the cement production process only two output flows occur, namely the cement as the final product and the off-gas. In Figure **11** the total specific Cd output for the cement production process is indicated by the left bar of the figure. Cd accumulates almost exclusively in the cement (> 99 %), only to a very small extent Cd exits the process via the off gas.

The Cd output directly related to the utilization of waste plastics is about one third of the total Cd output (right bar of Figure **11**).

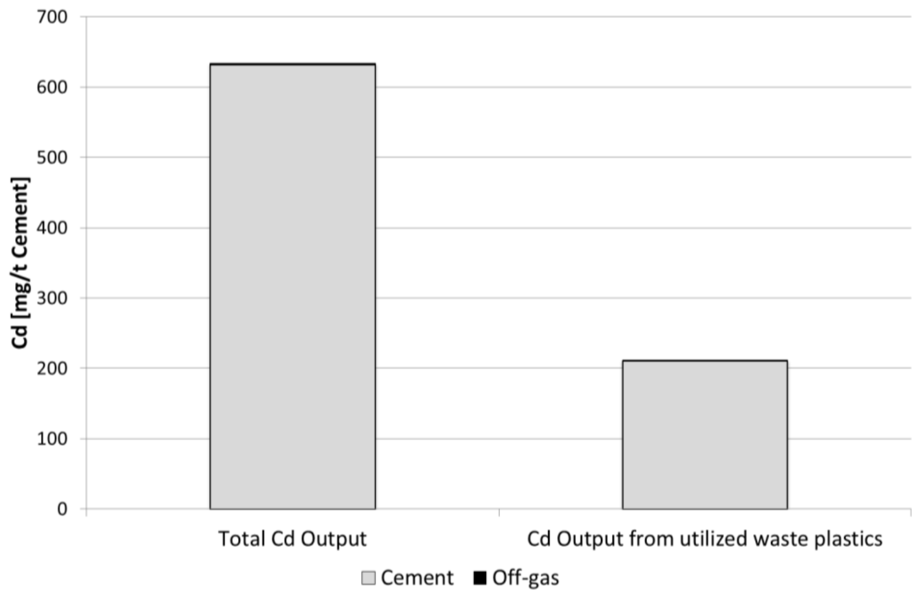

Figure 11: Cd output from the cement production process (left bar - total Cd output; right bar - Cd output due to waste plastics utilization) according to Lederer et al. (2015) given in [mg/t cement]

The share of Cd output due to waste plastics with respect to the energy content of the waste plastics utilized is given in Figure **12**. For this calculation an average lower heating value of 21.5 MJ was used. This value was calculated according to the data given in Mauschitz (2012).

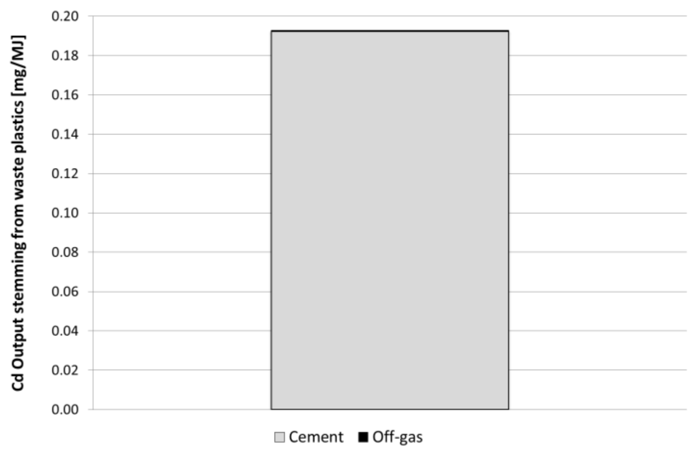

Figure 12: Specific Cd output from the cement producion due to waste plastics utilization (given in [mg/MJ]) - according to Lederer et al. (2015)

Alike to Cd, also for Hg the main output is the cement, which collects about 75 % of the total Hg output (see Figure **13**). The off-gas however also contributes to more than 20 % to the overall Hg output. The specific Hg output from cement production due to waste plastics utilization amounts to slightly more than 100 mg/t cement.

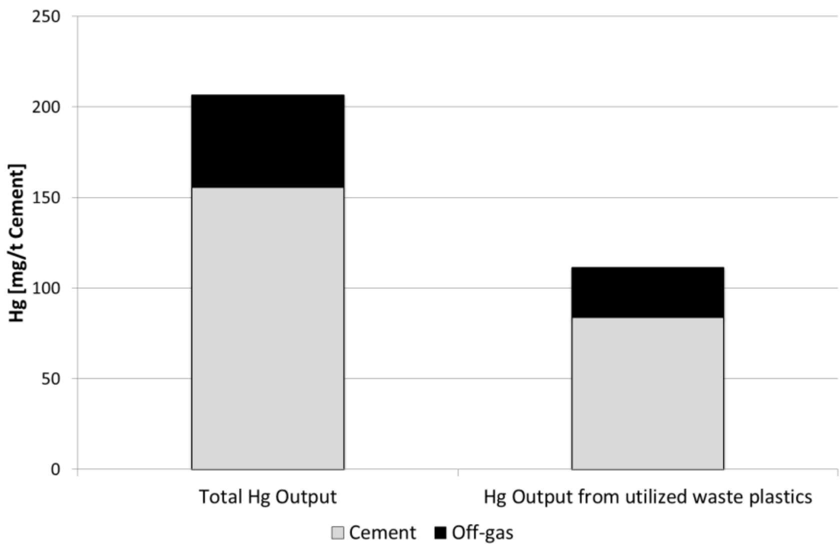

Figure 13: Hg output from the cement production process (left bar - total Hg output; right bar - Hg output due to waste plastics utilization) according to Lederer et al. (2015) given in [mg/t cement]

Figure **14** shows the Hg output stemming from waste plastics in [mg/MJ]. Alike to the calculation for the Cd output, an average heating value of 21.5 MJ was used for the calculation.

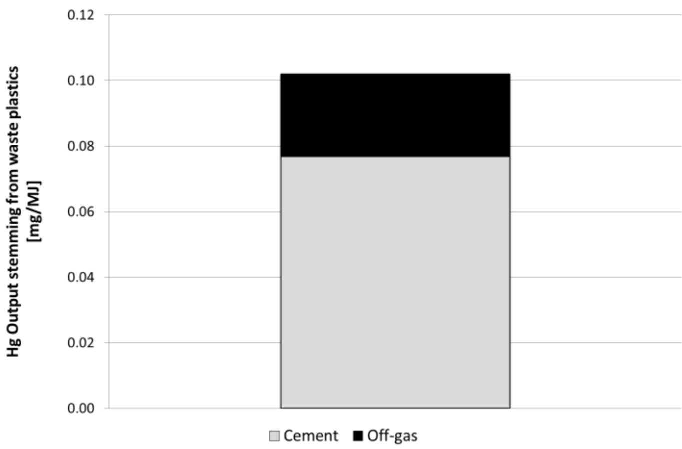

Figure 14: Specific Hg output from the cement production due to waste plastics utilization (given in [mg/MJ]) - according to Lederer et al. (2015)

5. CONCLUSIONS

Many waste plastics represent a difficult to recycle material. According to the European waste management hierarchy their utilization in the hot metal production and in the cement production represents a more favorable way than their combustion in Waste-to-Energy plants. Due to process or environmental reasons, the waste plastics utilized have to meet certain standards and limits with respect to their chemical and physical composition.

RDF (including waste plastics utilized in industrial plants) faces different limits for the utilization in the cement and in the hot metal production. Waste plastics utilized in the considered blast furnace process have to meet limits at the delivery and at the final utilization (see Table **2**).

The waste plastics, which are utilized in the cement production process, however, are regulated by limits for the final utilization only (see Table **1**). As the limit values for waste plastics utilization at both industries refer to different units, a conversion assuming an average calorific value for the plastic waste was necessary in order to compare them. The results of the comparison indicate that some limits, e.g., for Ni are quite similar, whereas for other substances (e.g., Cr) large differences can be observed.

The amounts of waste plastics utilized in the process are different. The specific amount of waste plastics utilized in the hot metal production process, is around 28 kg plastics/t HM (average value of the considered blast furnace for a 3 year period). In comparison, the specific amount of waste plastics utilized in the cement production is nearly twice as high (51 kg plastics/t cement).

The comparison of the Cd input for both processes indicates that the total Cd input per t of product is for the cement production process slightly higher (> 600 mg/t cement) than for HM production process (< 400 mg/t HM). The share to which the utilized waste plastics contribute to the total Cd input is for both processes alike and amounts to around 30 %. Thus, the main input for Cd is stemming from ordinary (geogenic) input materials.

In the case of Hg, the overall input for the HM production process is less than 40 mg/t HM. The waste plastics contribute to around 17 % to the overall input. The main inputs are the other alternative reducing agents with less than 40 % and the iron bearing materials and the reducing agent with around 45 %. In comparison, in the cement production process the total Hg input reaches 200 mg/t cement. The contribution of the utilized waste plastics to the overall Hg input is in the cement production process around 50 %. In this case it must be noted that Lederer et al. (2015) assumed a quite high mean value for the Hg content of waste plastics (2.2 mg/kg). According to Denner and Köppel (2014) it is more likely that the Hg concentration is around 0.3 mg/kg. They determined this concentration during a ring trial for RDF and recycling wood. The RDF material was in their case a mixture of waste plastics and cardboard. Thus, it is most likely that the input stemming from waste plastics given by Lederer et al. (2015) is overestimated (211 mg/t cement).

By assuming a mean Hg concentration of 0.3 mg/kg the Hg input due to the waste plastics utilization would be around 16 mg/t cement. Thus, alike to Cd also for Hg a significant input refers to geogenic input materials.

Comparing air emissions of both processes (using the BAT documents) was not possible due to the different reported parameters. If the same parameters are given in the BAT documents, their ranges were nevertheless hardly possible because of the wide range of values given.

If one compares the output flows for both processes, it becomes obvious that the cement production process has only two output flows. These are the cement, which represents the product of this process, and the off-gas. Regarding to Cd, more than 99 % of the total output accumulates in the cement. In the hot metal production process the main output flows for Cd are the scrubber sludge and water, the top gas dust and the gas house dust. The amount of Cd which leaves the process with the cleaned top gas is very low (less than 0.05 % of the total Cd output), which is comparable with the amount of Cd in the off-gas of the cement production process. The specific Cd output due to the utilization of waste plastics, amounts for both processes around one third of the total Cd output (see Figure **7** and Figure **11**).

If one compares the Cd output stemming from the waste plastics utilized based on their typical heating value, it becomes obvious that the Cd output (issuing from waste plastics) in [mg/MJ] is for the cement production process less than 0.2 mg/MJ (Figure **12**). The Cd output coming from waste plastics from the HM production is quite similar with around 0.14 mg/MJ (see Figure **8**). The comparison for the specific Hg output in mg/MJ provides a different result. The specific Hg output stemming from the utilized waste plastics in the HM production is less than 0.008 mg/MJ. In the cement production the specific Hg output reaches 0.1 mg/MJ. This relatively high amount of Hg results from the above described overestimated input amount. Thus, it is more likely that the specific Hg output is around 0.01 mg/MJ and consequently comparable with the hot metal production.

It must be noted that the calculation of Cd and Hg input and out from the HM production process is based on process measurement data. The calculation of the Cd and Hg output from the cement production process is based on literature data according to Lederer et al. (2015).

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