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LCA of metal recovery from waste incineration bottom ash

E. ALLEGRINI^{1,*}, A. BOLDRIN¹, J. KALLESØE² and T.F. ASTRUP¹

¹ Department of Environmental Engineering, Technical University of Denmark, Building 113, DK-2800 Lyngby, Denmark.

² Afatek Ltd, Selinevej 18, DK-2300 Copenhagen, Denmark.

*Corresponding author: elia@env.dtu.dk, +45 45251572

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Abstract

The important role gained by waste incineration in European waste management systems is recently clashing with increasing concerns about loss of resources in waste, i.e. metals. Even though the recovery of valuable resources in residues from waste incineration is becoming a widespread practice, a significant portions of valuables resources remains in the ash and ends up in disposal sites. The goal of this study was to investigate the environmental benefits of metal recovery from waste incineration bottom ash through life cycle assessment (LCA).

The Danish system was used as case study and direct data from a metal recovery facility were used, while literature data and information on advanced metal sorting systems were used to build hypothetical scenarios achieving high recovery efficiencies. Impacts were characterized with respect to the impact categories global warming potential (GWP) and mineral abiotic resource depletion (AD_{mineral}).

Results showed benefits due to metal recovery for GWP and AD_{mineral}: benefits were higher for scenarios where higher recovery efficiencies were achieved despite of the increased energy demand of the sorting system. Critical aspects concerning substitution between recycled metal and avoided products were pointed out. These will be part of a following work where also toxic categories and burdens related to the disposal/use of the BA will be addressed.

1- INTRODUCTION

Incineration is a widespread waste treatment technology. Advantages such as pathogens destruction, waste volume reduction and energy recovery made this technology attractive, so that incineration is currently one of the main treatments applied for household waste management in Europe. However, increasing discussions about possible losses of resources through the incineration process followed by new waste policies are discrediting waste incineration with respect to source segregation and recycling. Nevertheless, recovery of resources especially metals in the scrap form can be performed after the incineration process by treating the output streams of the process.

Recovery of metal scrap from waste incineration bottom ash (BA) is becoming a common practice. Ferrous (Fe) and Non-Ferrous (NFe) metals are recovered to a different extent depending on the level of complexity of the sorting system adopted. Sorting systems include physical separation technologies such as sieves, magnets and eddy current separators but also modification of these simple systems are being developed and implemented to achieve higher recovery efficiency. But how much can be invested – in terms of energy and resources - for increasing metal recovery before overcoming the environmental benefits obtained through recycling?

Several studies have investigated the environmental performances of recovering metals from waste incineration BA focusing on specific systems. But the more generic problem of assessing the limits (environmentally speaking) of recovering metals has not been discussed thoroughly. In this study the above research question is addressed using a life cycle assessment (LCA) methodology, and a preliminary approach and results are reported in this conference proceeding.

2- MATERIALS AND METHODS

LCA methodology was applied in this study using the consequential approach, thus marginal data were used. The goal of the study was the identification of a trend in the environmental performance of recovering metals from waste incineration bottom ash while increasing sorting efforts and efficiencies and including the quality of the recovered material as well.

The functional unit was “treatment of 1 Mg of waste incineration bottom ash”. The geographical scope was Denmark and the temporal scope was 10 years. The zero burden assumption was applied to disregard of all impacts related to waste and BA generation. The study was performed using the LCA model SimaPro v.8.0.2

Five scenarios were compared in this study, each of them representing a different level of complexity of the sorting system. Table 1 reports the composition of the BA in term of scrap metals content and recovery efficiencies achieved in each scenario. Metals considered in this study were: Al scrap; heavy non-ferrous scrap (HNFe) such as Cu; stainless steel (SS); and ferrous metals (Fe). Scenario 3 represents the state-of-the-art in Denmark and recovery efficiency and sorting system are based on a previous characterization study [1]. In scenario 1 NFe scrap is not recovered from the BA; scenario 2 represents the Danish state of the art until 2009; scenario 4 includes metal recovery from the fine fraction of the BA down to 1 mm and increased complexity of the sorting system in terms of number of sorting machines and system configuration; scenario 5 hypothesizes recovery of metals down to 0.5 mm and maximum achievable efficiency for the various scrap metals. Metal recovery efficiency by treating the fine fraction of the BA (i.e. below 2 mm) was assumed based on data reported in the scientific literature. Data about energy demand of the sorting system were based on direct measurement performed at the sorting facility.

Metal scrap	Fe	Al	HNFe	SS
BA composition	7.2% ww	1.4% ww	0.49% ww	0.29% ww
Recovery efficiency				
Scenario 1	85%	-	-	-
Scenario 2	85%	17%	18%	2.6%
Scenario 3	85%	62%	43%	85%
Scenario 4	85%	70%	54%	95%
Scenario 5	95%	97%	86%	95%

Table 1: scrap metal content and recovery efficiency. [ww: wet weight]

In scenario 1, BA is disposed in landfill while in the other scenarios BA is utilised as aggregate surrogate in road sub-bases, thus substituting natural gravel. The assessment of the disposal/utilisation of the BA was done following the approach and the assumption reported in [2]. The avoided production of natural gravel in road construction was included by system expansion, thus subtracting the avoided impacts due to the marginal technology for natural gravel production. Figure 1 provides an overview of the processes included in the system boundaries.

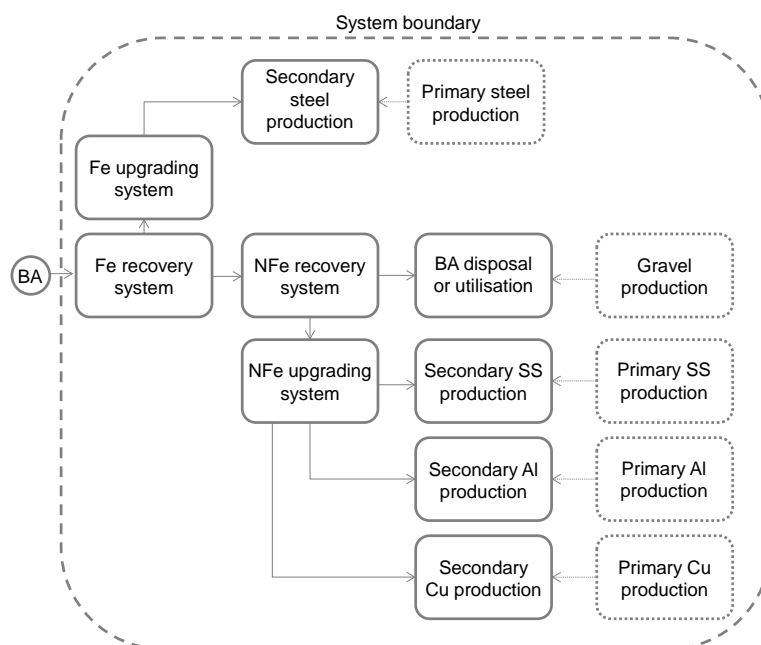


Figure 1: overview of the processes included in the system boundaries.

The recycling of the scrap metals was assumed to occur within Europe, thus average EU technology was used to model secondary production of metals and the European marginal technology for electricity production was used in the secondary production. Following the approach by [3], the European marginal technology for electricity production was assumed being “electricity from hard coal”. System expansion was used to include the benefits due to the avoided production of primary metals. The marginal technology for each primary metal production was selected following the approach described in [4]. Based on the existing trends for metal productions as reported for example in [5-10], which showed an increasing metal market and the increasing importance of Chinese industry, marginal technologies were defined to be located in China and thus the Chinese marginal technology for electricity

production was used (i.e. hard coal). Inventory data for metal production as well as for transportation and energy provision were retrieved from Ecoinvent v.2.

Metal scrap considered for recycling were Al, Cu, SS and Steel. In Al secondary production losses of metallic aluminium because of oxidation and contamination were taken into consideration based on information obtained through personal communication with the secondary aluminium industry and from previous literature studies (e.g. [11]). Different aluminium yields were considered for individual grain size fractions, since the oxidation levels increase with decreasing Al scrap size. For the sorted HNF_e metals only Cu was considered for secondary production since information about amount of other HNF_e metals recovered after the electrolytic refinery were not available. Data about content of Cu in the HNF_e fraction were retrieved from [1].

Emissions to the natural environment were characterized with respect to impact categories GWP (IPCC 2007) and AD_{mineral} (CML 2013)). The impact assessment was based on a time horizon of 100 years.

3- RESULTS AND DISCUSSION

Figure 1 reports the preliminary results for GWP and AD_{mineral}. The recovery of scrap metals from waste incineration BA resulted in net benefits in the two impact categories. With savings ranging between -100 and -400 kg CO₂ Eq and -5E-04 and -2E-04 kg Sb Eq per Mg of BA treated. Burdens relative to the sorting system were found negligible with respect to the savings obtained by avoiding the production of primary aluminium and steel. Also transportation and BA disposal/utilization had little importance with respect to metal recycling. Thus sorting and recovery of an increasing amount of scrap metals resulted in increased net benefits for GWP even though the quality of the additionally recovered metals is lower due to high oxidation levels of the fine fraction.

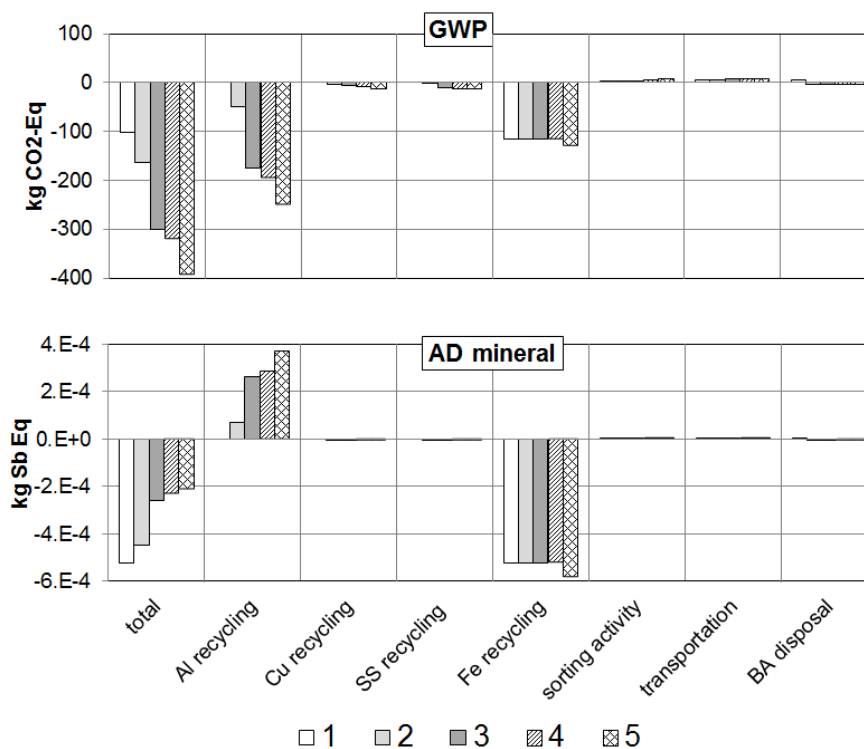


Figure 2: LCA results.

An opposite trend was found for ADmineral where increasing aluminium recovery led to lower benefits. This was due to the use of Zn as alloying element in secondary Al production. However, the amount of Zn added for cast aluminium production was based on the value given in the Ecoinvent database, while the amount of Zn and other alloys employed can vary depending on the final alloy product and on the input scrap to the refining process. As common practice the incineration scrap are input to secondary refiners mixed with Al scrap from various origins and quality, and the output can also vary within a wide range of alloys. Thus, such a result should be considered carefully, especially because of the high characterization factor for Zn in the ADmineral impact category (i.e. five orders of magnitude higher than Al). Excluding the contribution of Zn, the ADmineral score for aluminium recycling was negative.

The abovementioned considerations suggest that environmental assessment of metal recycling is associated with significant uncertainty. Another important source of uncertainty is the choice of the marginal process responding to the marginal change in metal demand due to the increased scrap recycling, and to which extent the new secondary product substitutes the marginal one. At the state of the art, most of incineration metal scrap is used by refiners to produce mainly cast alloy EN AB-46000 –according to the standard EN 1676:1997 - which is largely employed in the car industry. In this preliminary study, primary aluminium produced in China was defined as marginal and the substitution between secondary and primary was set to 100%. However this approach disregards the change of inherent properties between primary and secondary production leading to unavoidable downcycling of aluminium and attributes to the secondary product all the benefits of avoiding primary production. While using an attributional approach the downcycling can be expressed by the ratio between market prices of the scrap - e.g. [12-13] -, in consequential LCA the identification of the marginal material requires a more detailed overview of the metal industry and market mechanisms. For example, a marginal increase of secondary aluminium alloy available for the car industry in a growing world car industry is covered by new competitive materials which will be used to tackle the increasing demand. In this case primary aluminium could be selected as marginal since the car industry is continuously shifting from steel/cast iron components to aluminium ones. But only addressing the European car industry which has seen a decline in production in the last decade, the marginal could actually be the steel/cast iron that is being gradually pushing out of the car industry in favour of aluminium.

4- CONCLUSIONS

In this paper, the preliminary results of an LCA study addressing benefits from metal recovery from waste incineration BA are reported. The LCA was performed using a consequential approach and five scenarios with increasing sorting complexity and efficiency were analysed with respect to GWP and ADmineral. The results showed increasing benefits by increasing metal recovery because of the negligible contribution to GWP of the sorting system itself, and because of the significant benefits related to the avoided production of primary aluminium. Net benefits were also found looking at the depletion of mineral resources, even though the increased recycling of Al resulted in decreasing benefits due to the assumed addition of the alloying element Zn in the secondary production.

These preliminary results supported the importance of enhancing resource recovery from waste incineration BA in order to increase the sustainability of waste-to-energy systems and waste management systems in general. However, critical aspects are pointed out, underlining the uncertainty related to the selection of the marginal technology/material and the level of substitution between secondary products and substituted marginal.

In a future study these aspects will be addressed in more detailed and other impact categories – i.e. toxic categories- will be considered in order to include also impacts related to the use of the treated BA in various disposal/utilization scenarios.

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