METALS RECOVERY FROM INCINERATION BOTTOM ASHES: FUTURE OPPORTUNITIES IN ITALY

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SUMMARY: This paper focuses on materials recovery from bottom ashes produced in Municipal Solid Waste (MSW) incineration. In particular, the amount of aluminium that can be recovered from these residues in 2015 and 2020 in Italy was estimated developing a forecasting model and the environmental benefits associated with metals and inert fraction recovery were evaluated through Life Cycle Assessment (LCA). Using conventional technologies for the separation of non-ferrous metals, an amount of aluminium in the range from 16,500 to 21,000 tonnes is predicted to be recovered in 2015 and from 19,000 to 28,500 tonnes in 2020. LCA shows that the most important benefits of the recovery of bottom ashes are related to metal recycling, while the recovery of the inert fraction plays a minor role.

1. INTRODUCTION

Waste-to-energy treatments of Municipal Solid Waste (MSW) are a fundamental element of the integrated waste management system. They contribute to recover the energy content of non-recyclable fractions and to reduce the environmental impacts caused by the final disposal of waste. However, MSW combustion produces some residues which need to be treated and recovered or disposed.

About 15-25% of the incinerated waste is retrieved as bottom ashes at the output of the furnace. Technical properties of bottom ashes make their reuse appropriate and convenient from an environmental and an economic point of view. Bottom ashes can be used in road construction and in concrete or cement production. However, some treatments are required in order to reduce their content of ferrous and non-ferrous metals as well as to prevent the negative environmental impacts that a direct reuse of the raw bottom ashes can cause due to the high content of heavy metals and polluting agents. Further goal of these treatments is to increase the mechanical properties of the bottom ashes, in view of the recovery of inert materials. These treatments include physical, chemical or thermal treatments such as physical separation of the fine (more contaminated) fraction with screens or drums, extraction of metals through magnetic and eddy current separators, washing with water or chemical solvent to remove soluble heavy metals and salts, ageing process to promote the transformation of bottom ash constituents into more thermodynamically stable forms, addition of Al(III) or Fe(III) salts and cements or other bonding agents to reduce the metals mobility and hence their leaching, vitrification or sintering to immobilize heavy metals into an amorphous glassy phase (Sabbas et al., 2003; Polettini et al., 2007; Astrup et al., 2007).

The recovery of ferrous and non-ferrous metals is an essential step of the bottom ashes treatment process, both for the environmental advantage of metal scraps recycling and for the reduction of the negative effects of metals, especially aluminium, that can result in swelling and expansion in some application including road construction and concrete production (Pecqueur et al., 2001; Muller et al., 2006).

The aim of this paper is to assess the potential of non-ferrous metals recovery, especially aluminium, from MSW incineration bottom ashes in the medium term in Italy. A simplified environmental balance of bottom ashes recovery based on Life Cycle Assessment (LCA) is also included in the project.

2. DEFINITION OF THE MODEL AND OF THE SCENARIOS

The amount of aluminium scraps which can be recovered from bottom ashes has been evaluated through a simple model elaborated by the Authors which is essentially based on the following four quantities: (1) gross MSW production; (2) amount of commercialized aluminium packaging; (3) separate collection rate and (4) capacity of waste-to-energy plants. These and the other variables of the model are summarized in Table 1. For each variable, one or more evolution scenarios were defined to estimate its values in years 2015 and 2020. The number of scenarios is reported in the last column of Table 1, whereas a brief description of the scenarios is reported below.

Table 1 – List of the variables of the model.

ID	Variable description	Number of scenarios
A	Commercialized aluminium packaging	2
B	Gross MSW production	2
C	Separate collection rate	1
D	Aluminium packaging in the separate collection	1
E	Aluminium in RDF	1
F	Non-packaging aluminium in residual waste	1
G1	Residual waste to incineration plants	1
G2	Residual waste to gasification plants	1
H1	RDF to incineration plants	1
H2	RDF to gasification plants	1
I1	Aluminium recovery rate from incinerator bottom ashes	2
I2	Aluminium recovery rate from gasification bottom ashes	2

2.1 Aluminium packaging available on the market

Two scenarios for the evolution of aluminium packaging[1] available on the market have been considered: a high and a moderate growth scenario.

The former results from the projection of data of aluminium packaging commercialised between 2000 and 2007 and is based on a logarithmic curve to fit the data.

[1]Packaging category includes not only “true” packaging but also all the items similar to packaging but that are not submitted to the environmental tax, such as the household foil.

The logarithmic function considers, on one hand, the increase in the request of disposable packaging and, on the other, the reduction of the packaging weight as well as the possibility of the introduction in Italy of an environmental tax on all these disposable material that are currently not subjected to any tax (e.g. aluminium foil).

The second scenario (moderate growth) assumes a yearly growth rate of 1% for the aluminium packaging commercialized and it is therefore representative of an economic situation of low growth and moderate consumption.

2.2 MSW production

The amount of MSW is calculated as the product of the resident population and the MSW production per capita. For this variable, two scenarios have been hypothesised: a moderate growth scenario and a high growth scenario.

For the first one, the MSW per capita production from 2000 to 2007 is interpolated on a 3-parameter-exponential function (equation 1):

$$\Pr oduction_{MSWpercapita}\,(y) = A*(1-\exp^{-k(y-y^0)}) \qquad (1)$$

Where y indicates the time (year), A is the asymptotic value, k is the flexure parameter and y^0 is the translation parameter. Parameter A is set to 560 kg $year^{-1}$ per capita, as some Europeans countries have already stabilized their MSW production at around 500-550 kg $year^{-1}$ per capita. This model considers the future effects of European policies aimed at the reduction of MSW production, or at least at its stabilisation.

The second scenario (high growth) considers a 1% yearly growth rate in MSW per capita production.

2.3 MSW separate collection

The evolution of the rate of separate collection until 2020 has been obtained by interpolating the historical data from 2000 to 2007 on the exponential function of Equation 1, in which the asymptotic value A is set to 100%. In this way, the predicted value of separated collection rate for the year 2020 is very close to the 50% target prescribed by the European Directive 2008/98/EC.

2.4 Aluminium packaging content in the separate collection

The content of aluminium packaging in the separate collection has been estimated with a linear interpolation of the historical data from 2002 to 2007 evaluated as the ratio between recycled aluminium and separate collection of MSW (ISPRA, 2009). Data for years 2000 and 2001 were disregarded, as they do not seem to match the overall trend.

The results show that in the next 20 years, the percentage aluminium content in the separate collection will most likely decrease. This can be explained if one considers that separate collection of packaging is carried out extensively in Italy but not sufficiently to achieve the rate of separate collection established by national and European legislations. To achieve these targets, the separate collection of the organic fractions of MSW, which is presently not so common in Italy, needs improving, hence the percentage of packaging in the separate collection will decrease in the coming years.

2.5 Aluminium content in RDF

The presence of aluminium in the Refuse Derived Fuel (RDF) depends on the technology used in mechanical-biological plants. For simplicity, a constant value of 0.6% has been assumed, based on 34 average data from full-scale plants operating in Italy (CiAl).

2.6 Non-packaging aluminium content in the residual waste

In the residual waste (i.e. the waste after separate collection), not only aluminium packaging but several other aluminium items, such as pots and coffee-pots, may be found. The contribution of such items is difficult to quantify, due to the heterogeneity of MSW.

In this work, a constant ratio of 25% of non-packaging aluminium over total aluminium has been assumed, based on the results of three analyses carried out by the Authors on the residual waste sent to a waste-to-energy plant located in Northern Italy in 2009.

2.7 Waste-to-energy plants capacity

In 2007, 47 waste-to-energy plants were operating in Italy.

The capacity of incineration and gasification plants in 2015 and 2020 has been estimated by adding the capacity of new plants that are likely to be built in Italy, to the capacity installed in 2007. For simplicity, the waste-to-energy plants were classified in two groups: those that burn mostly residual waste as is and those that burn mostly RDF.

According to regional waste management plans, three new incineration plants are likely to be built in Piemonte by 2020, one in Lombardia, two in Emilia Romagna, one in Liguria, two in Toscana, one in Lazio, three in Campania, two in Puglia, one in Calabria, four in Sicilia and two in Sardegna. Moreover, a new line in the incineration plant of Poggibonsi in Toscana and the doubling of the Rufina plant, also in Toscana, are scheduled. Finally, two gasification plants will probably be built by 2015, one in Lombardia and one in Lazio.

2.8 Evolution of the technology in bottom ashes treatment plants

Two technology scenarios were considered: a base scenario and an advanced one.

The base scenario hypothesizes that 30% of the aluminium fed to the furnace and 40% of that fed to the gasification plants can be recovered from bottom ashes. The first value is based on literature data (Association of incinerators NL, 2006; France aluminium recyclage, 2006; Muchova and Rem, 2007) whereas the second value assumes that metal extraction is more efficient from gasification than from incineration bottom ashes, due to a lower metal oxidation (Viganò et al., 2010).

The advanced technology scenario hypothesises that 70% and 80% of the aluminium fed to the furnace can be recovered from bottom ashes, respectively for incineration and gasification plants. The first value has been defined considering the experience of Amsterdam pilot plant (Muchova and Rem, 2007) and other advance technologies described by Manders (2008). The recovery rate from gasification plants has been increased to 80% for the same reason explained before.

3. MODEL RESULTS AND DISCUSSION

The values which have been predicted for the model variables for 2015 and 2020 are summarized in Table 2 and compared with their value in 2007.

Table 2 – Predicted values for the model variables (for variables abbreviations see Table 1).

ID	Scenario	units	2007	2015	2020
A	moderate growth	tonne $year^{-1}$	118,700	128,535	135,092
	high growth	tonne $year^{-1}$	118,700	145,526	162,358
B	moderate growth	10^6 tonne $year^{-1}$	32.55	34.11	34.47
	high growth	10^6 tonne $year^{-1}$	32.55	36.44	38.61
C	-	%	27.5	39.8	46.3
D	-	%	0.43	0.39	0.37
E	-	%	0.6	0.6	0.6
F	-	%*	25	25	25
G1	-	10^3 tonne $year^{-1}$	3,905	9,491	10,405
G2	-	10^3 tonne $year^{-1}$	240	240	240
H1	-	10^3 tonne $year^{-1}$	575	1,209	1,726
H2	-	10^3 tonne $year^{-1}$	92	572	572
I1	base technology	%*	30	30	30
	advanced technology	%*	70	70	70
I2	base technology	%*	40	40	40
	advanced technology	%*	80	80	80

* percentage referred to the total aluminium content in residual waste

The amount of aluminium that can be recovered from bottom ashes in 2015 and 2020 is represented in Figure 2.

If conventional technologies for metals separation are used, between 16,500 and 21,000 tonnes of aluminium can be recovered in 2015 and between 19,000 and 28,500 tonnes in 2020; if advanced technologies are used, the figures increase to 38,000-49,000 tonnes and to 43,500-66,000 tonnes in 2015 and in 2020, respectively. For both scenarios (basic and advanced recovery technologies), the upper bound of the range corresponds to a situation of ‘moderate’ growth in MSW production and of ‘high’ growth in commercialized aluminium packaging; the lower bound corresponds to the opposite situation, i.e. ‘high’ growth of MSW production and ‘moderate’ growth in commercialized aluminium packaging.

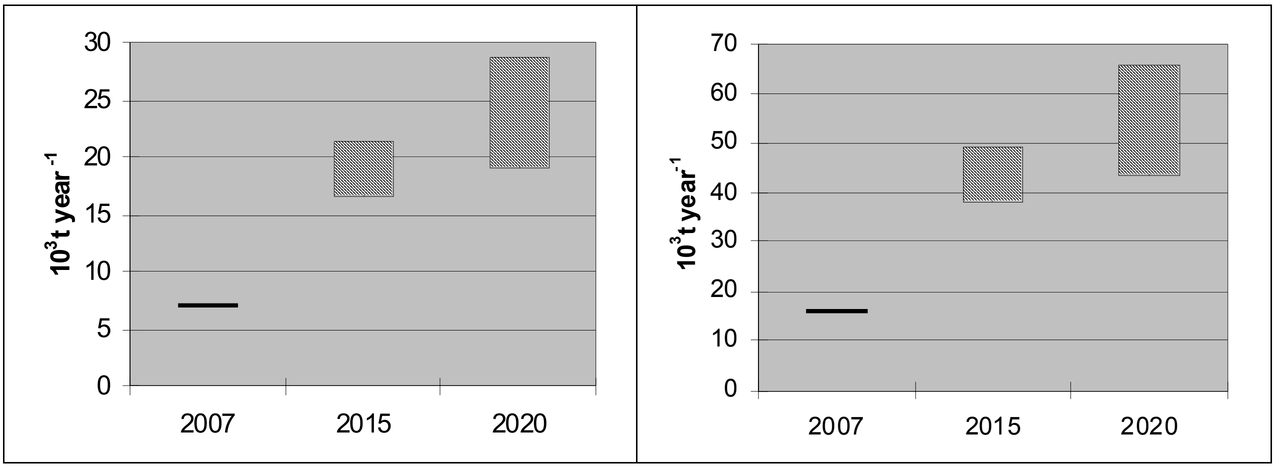

Figure 2. Aluminium recoverable from bottom ashes (left: conventional technologies; right: advanced technologies).

However, some considerations need to be made on the probability associated to the different scenarios depicted in Table 2. For example, an improvement in the recovery technologies is unlikely to happen due to the backward situation of bottom ashes management in Italy and to the fact that a high efficiency in metal separation has so far been possible only on pilot plants or in very specific situations. Consequently, all scenarios of advanced recovery technology are to be considered unlikely to happen.

If one considers the conventional technologies for metals separation, the scenario of high growth of commercialized aluminium packaging and of moderate growth of MSW production seems to be the most likely, since it describes the natural evolution of the historical data. Scenarios with the same growth rate of MSW and commercialized aluminium packaging may be considered quite probable, while the scenario of moderate growth of commercialized aluminium packaging and high growth of MSW production is far less probable, because it describes a situation in which the total consumption of packaging growths with a higher rate than the aluminium packaging one. On the contrary, in recent years, aluminium has conquered a relevant share of packaging market, thanks to its favourable technical properties.

Based on these considerations, the range of the amount of aluminium which is more likely to be recovered from bottom ashes narrows between 18,000 and 21,300 tonnes in 2015, and between 22,200 and 28,500 tonnes in 2020.

If recovery technologies improve, the quantity of recoverable aluminium will evidently increase. However, on the other side, the number of the future incineration plants included in the analysis may be overestimated, due to the rather high uncertainty inherent in this type of forecast (especially data of Sicilia, whose regional plan is currently being reviewed). Therefore the increase of the quantity of aluminium recoverable by using advanced technology may be not much higher than the values suggested above.

Considering that the quantity of aluminium is about 60% of non-ferrous metals, the most likely value of non-ferrous metals recoverable from bottom ashes is 30,000-35,500 tonnes in 2015 and 37,000-47,500 tonnes in 2020.

The quantity of bottom ashes produced by the incineration process can be estimated assuming that they are equal to 20% and 3.5% in mass of, respectively, MSW and RDF sent to waste-to-energy plants. The production of bottom ashes in 2015 and 2020 can thus be estimated in about 2 millions tonnes.

The bottom ashes treatment plants currently installed in Italy have a capacity less than a half of what is needed in the future. Therefore new plants have to be built to allow metals recovery in the amounts estimated in this study.

4. LIFE CYCLE ASSESSMENT

Life cycle assessment (LCA) was carried out to estimate the benefit associated with material recovery from bottom ashes, following the ISO standards 14040 and 14044. The analysed system comprehends the following sub-units: bottom ashes treatment, recycling of the recovered ferrous metals, recycling of the recovered non-ferrous metals, reused of recovered inert materials, and disposal of the residues. The functional unit (FU) is 1 tonne of bottom ashes.

Two impacts were calculated: the total energy demand and the global warming. The Cumulative Energy Demand (Jungbluth and Frischknecht, 2004) and the IPCC 2007 (IPCC, 2007) characterisation methods were adopted, respectively. Instead of using allocation between functions, the substitution by system expansion methodology was applied (Finnveden et al., 2009), identifying which products are replaced on the markets by the arising co-products (i.e. ferrous and non-ferrous metals and inert materials) and thus including their replacement in the model.

4.1 Main assumptions

In the sub-unit of bottom ashes treatment, which implies a process lost of 70 kg as water evaporation/leaching, an electricity consumption of 4 kWh per FU was modelled.

Ecoinvent database (Swiss Centre for Life Cycle Inventories, 2007) was used to model the production of iron and aluminium, both starting from virgin raw materials and from scraps. These last are represented by 78.1 kg of ferrous metal scraps per FU and 13.3 kg of non-ferrous metal scraps per FU. Some changes in the existing process were made, according to the data collected during technical visits (e.g. the efficiencies of the secondary iron melting furnace and of the secondary aluminium melting kiln were set equal to 90.5% and 78% respectively).

Inert materials (751 kg per FU) were supposed to be used in three different ways: in the production of raw meal in cement kilns, in the production of concrete and in road construction. Inert materials used in cement kiln allow the saving of calcareous marl but need an addition of limestone to maintain unchanged the characteristics of the clinker produced from the kiln. Each tonne of inert materials thus substitutes 3.2 kg of calcareous marl but needs 2.2 kg of limestone. When used in the production of cement, inert materials avoided sand (60%) and gravel (40%). Inert materials used in road construction avoided gravel too but they require a pre-treatment which implies the adding of some additives.

Residues (87.6 kg) were assumed to be disposed of in landfill for inert materials.

4.2 Results

The treatment of 1 tonne of bottom ashes aimed at recovering metals and inert materials to be used as secondary materials turned out to be advantageous in terms both of energy saving (2,926 MJeq./FU as average) and CO_2eq. emissions saving (186 kgCO_2eq./FU as average). These benefits are mainly associated with metals recycling, while the recovery of the inert fraction plays a minor role (Figure 3). Among the three different possible ways to use the recovered inert materials, the use in the production of raw meal and of concrete are the most advantageous; the use in road construction is in fact penalised by the adding of additives.

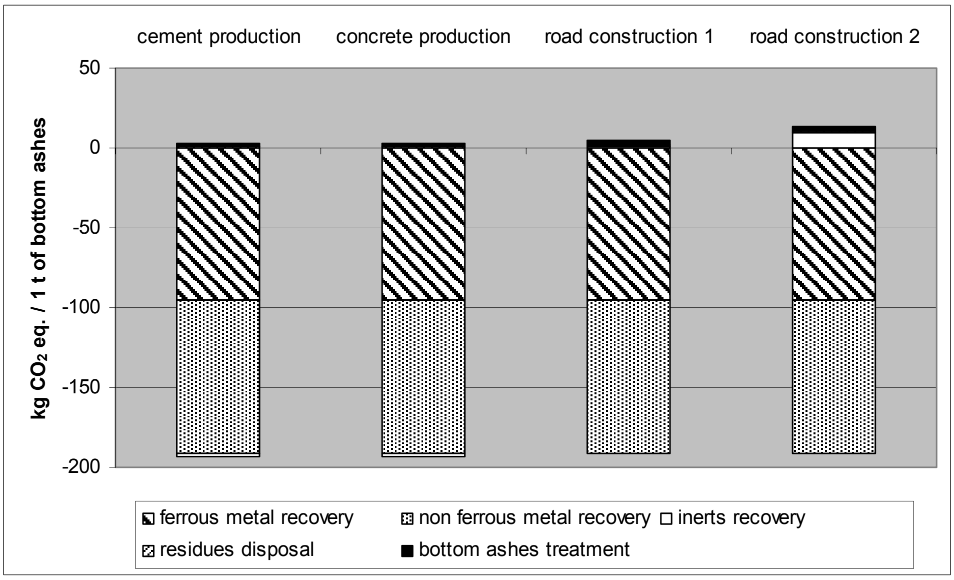

Figure 3: Contribution of each sub-process to the Global Warming Indicator (GWP_{100}) for the treatment of 1 tonne of bottom ashes.

If we consider also the avoided impact associated with the disposal in landfill of the whole tonne of bottom ashes, the savings increase to 3,249 MJeq./FU and 198 kgCO_2eq./FU. This means, considering the estimated production of bottom ashes in 2015 and 2020 (i.e. about 2 million tonnes), a saving of about 6,500 millions of MJeq. and about 400,000 t of CO_2eq.

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