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Metal Recycling at Waste Incineration Plants and Mechanical Waste Treatment Plants

Alexander Gosten

For the German waste management sector and in politics in total, the subject of metal recycling has gained considerable significance, which can be traced back to the following developments:

1. Scrap metal and ore prices have increased over recent years. The economical significance of metal recycling in the disposal of urban waste such as household waste or bulky waste has increased and sorting technology has improved.

2. In climate protection, substantial CO_2 reductions can be achieved from metal recycling. The mathematical aspects of metal recycling lead to a clear improvement of the climate balance of the disposal process and all related processes.
3. The buzzword *shortage of resources* has caused a noticeable increase in political attention to metal recycling. Since the assumption is that metal resources are becoming more scarce, awareness of the necessity to recycle metal has increased.

1. The discussion about the diverse possibilities for recycling metal is currently not just based upon economic aspects, because climate and resource protection are in the meantime being primarily advocated as key criteria. Since the proceeds from scrap metal have noticeably increased, the interest in who makes profits at which stage along the disposal chain has become an important motive for those participating in the discussion.

2. In order to document proof that there is progress in climate protection, the attention of various value-adding chains and regional considerations is being drawn to the fact that one ton of collected scrap metal can lead to a direct saving of CO_2 equivalents of a new primary production of iron ore and steel. Based upon climate protection calculations to fulfil climate protection objectives, political statements are made about the favourability of various treatment processes. From this viewpoint, costs are neglected and it is claimed that the optimum level is identical to the maximum recycling level. Therefore it is necessary to take a closer look at the various metal recycling processes, together with their effects upon the economics of the process and climate protection. Fundamentally, the maximisation of metal yield is something positive, although the energy resources and costs increase with the last gramme of metal recycling.

Depending upon the selection of the process, it can result in a shift in which market participants profit from metal recycling from household waste.

3. Concern about the future availability of metals in Germany drives the discussion and requires that in future, processes are deployed that provide a maximum in recycling. Given this consideration, insufficient attention is paid to costs and climate protection.

1. Initial Situation and current Questions

Metals are the only raw materials that can be recycled as often as required. Collecting scrap metal and remelting metal has taken place for a very long time. The fundamental aspects of ore preparation and metallurgy have been used just as long and are still being developed further, while the collection and disposal of scrap metal has become highly developed in industry and commercial enterprises. In Germany, it can be said that hardly any metal *goes to waste* in the production process.

However, this article deals with metals within so-called household waste. Until 2005, it was legally permitted to dump urban waste, which includes all household waste, in landfill sites with the consequence that metals were also deposited in these landfill sites. Based upon varying consumer habits and living standards in the regions, metal content at household waste landfill sites varies substantially. Indeed it can be said that certain household waste landfill sites contain virtually no metal. At an old BSR landfill site for example, the average metal content amounts to some 1.5 % Fe (see ref. [1]). There are probably also landfill sites that have a provably higher metal content. Should scarcity and prices increase considerably, these man-made storage sites could fundamentally be exploited as mines. In mining, it is in the meantime thoroughly economical and standard practice to recycle old tips and slurry pits.

With an average content of 2 to 4 % metal in household or residual waste, the potential in Germany with some 14 million tons of household or residual waste amounts to an annual 280,000 to 560,000 tons (see ref. [2, 3]). This only takes into account household or residual waste that is collected by the municipal authorities or a representative body. The 42 million tons of urban waste include respective amounts of dry recyclables such as paper, glass, bulky waste, packaging, household-type and commercial waste, as well as green and organic waste.

It must, however, be taken into account that the metal in household waste is not present in the quality (purity) to make it directly processable in metallurgy from both economical and technological points of view. In industrial processing however, single variety scrap metal can be recycled that contains no contaminants of note. Fundamentally, it is not clear how the average metal content in household waste has been calculated in individual cases.

By comparison, over 20 million tons of scrap metal are collected, processed and partially exported annually in Germany.

The proportion of highly-concentrated metal that can be metallurgically processed and recycled from household or residual waste consequently amounts to 1 to 2 % of the national amount of scrap metal. The origin of this scrap metal, be it household waste, trade or industry cannot be proved in individual cases.

The current questions in Germany are:

- How can it be assured that potential is exploited to as high a degree as possible?
- At which stage in the disposal process is metal recycling most viable?

This is assuming that the recycling potential is not yet fully exploited and can still be clearly increased.

The question does not, however, mean for whom metal recycling is most viable nor who should participate in it.

Since 2005, landfill dumping of untreated urban waste has been prohibited in Germany. Since this time, two various approaches in household waste disposal in Germany are being advocated and implemented:

1. Household waste incineration, with subsequent metal separation.
2. Mechanical, physical or biological pre-treatment with subsequent incineration at an industrial plant or substitute fuel power station. The metals are recycled in the mechanical pre-treatment prior to the incineration process.

Add to this the fact that in Germany, the conventional household waste bin and *yellow bin* for packaging are being supplemented by a so-called *recyclables bin* or *recyclables collection*. The introduction of the recyclables collection is politically motivated by concern that metal as a resource will be used up within the near future and that metal recycling is still being neglected in household waste disposal. In the ecological evaluation of an additional recyclables collection within the context of climatic balance, metal recycling is a decisive driver, particularly when the assumption is made that metal resources in household waste have so far only been recycled to a very small extent.

In Germany, the dialogue between representatives of mechanical pre-treatment plants and those of direct incineration has unfortunately not always been objective and in some cases, the dialogue simply seems to have been more a question of faith.

At the moment, a high extent of household waste incineration is more cost-efficient, which is because of the development of profits and recovery of energy and metals.

Sorting recyclables could in future be performed in connection with packaging in lightweight packaging sorting plants. With some municipal authorities, the collection of packaging and recyclables will in future be carried out together. There were also individual attempts to directly sort recyclables from household waste in modified trade waste sorting plants. It is the objective of recyclables collection to recover recyclables that previously had to be proactively brought to recycling collection points by residents. Here the assumption is that more waste components such as e.g. certain plastics, paper or for that matter metal can be recycled.

It is assumed that metals would be lost within the waste incineration process.

With both aforementioned approaches to waste treatment it is a concrete question at which stage of urban waste disposal metal should be extracted from household or trade waste, inasmuch as they are not processed separately.

Since it is no longer allowed in Germany to dump household waste in landfill sites, an incineration process is always involved in the disposal of urban waste. Depending upon market requirements, the largest proportion from the sorted contents of the yellow packaging bin or a joint recyclables bin will also be incinerated in future as sorted residuals, mixed plastics or substitute fuel.

This is followed by slag or metal refining. Metal recycling can therefore take place before or after the incineration process.

In essence it is primarily a question of which is ultimately more beneficial from economical and ecological points of view, although what is actually decisive for those concerned is the question of who gets the revenue from the metal.

In practice, the first opportunity is taken to reclaim the metal so that it is always removed from waste prior to it reaching the substitute fuel power stations or industrial power stations.

2. Initial situation for Berlin City Cleaning Services (BSR)

Berlin City Cleaning Services is an institution established under public law in the German capital by the *Berliner Betriebe-Gesetz* (Berlin Works Act) and its mandate includes the provision of safe and secure disposal for the residents of Berlin at all times.

To this end, BSR daily collects waste from 3.4 million inhabitants, numerous trade establishments and many millions of tourists. BSR is attempting to recycle a maximum amount of energy and genuine recyclables from deposited waste and at the moment, BSR is operating twenty different economic disposal plants and has experience both in metal recycling at thermal plants as well as various mechanical plants. In the meantime, almost all waste is recycled in accordance with the European Waste Framework Directive. Metal recycling has increased in significance in many ways here.

According to an extensive analysis carried out in 2008, the metal content in Berlin household waste amounted to an average of 2.1 %. At recycling depots, BSR collects metal separately, which is not taken into consideration in these statistics. A federal household waste analysis by the companies IFEU and Prognos (see ref. [2]) assumes an average proportion of 3.8 % metal in household waste. As an example for household waste, this proportion was calculated on the basis of the so-called *grey bin* or *residual waste bin* for the year 2010.

The fact that it is the natural endeavour of BSR to reclaim as much metal as possible from waste has the following reasons:

1. The proceeds are needed in order to realise further favourable waste disposal charges for Berlin residents.
2. The accountable emission credits contribute to the climatic balance of the State of Berlin.
3. The conservation of metal resources in countries such as Germany has been long since viable in order to reduce dependence upon imports and contribute towards the conservation of natural resources for future generations.

Since BSR operates both a waste incineration station as well as mechanical plants, statements can be made about both various approaches.

BSR uses both approaches and with the *Orange Box* bin has also intensively looked at the subject of the separated capture of recyclables.

BSR sees the achievement of three objectives:

1. Maximising revenue from waste
2. Maximising climate protection
3. Maximising resource protection by means of material recycling

3. A Maximum of Metal Concentration leads absolutely to Metal Losses

Since the resources required for metal recycling are increasing with growing collection efficiency, it is not possible for all objectives to be fulfilled at the same time.

As is already known from ore preparation in mining, the greater the purity or the metal concentration in recycling products, the greater the volumes of metal that are lost in the sorting remains. In mining, this residue is known as *mine dumps* or *tailings*. Apart from the technical side effects of the respective sorting processes, this is because of the fact that the metals are not present in pure form, but rather mixed together with other minerals or incorporated within another material, or because they are *concealed* by other materials during sorting. The metal can be encrusted by slag or the metals are within another article such as a nail inside a piece of wood or the motor inside a plastic toy.

It is only by means of further reduction in size or incineration, which requires more energy, that these metals can be separated and reclaimed. This additional expense leads to there being an economic limit for every treatment process, beyond which any further yield from recycling is no longer profitable.

Consequently, at the moment there are still provable metal contents in sorting residue or slag. It is only when revenue exceeds certain threshold values or technological innovation offers new economic methods that the extent of metal recycling will also noticeably increase in terms of resource conservation.

4. Metal Recycling at Waste Incineration Plants

For some fifty years, waste has been treated at the waste incineration plant in Berlin Ruhleben.

The entire waste is burned for longer than 2 seconds at over 850 degrees centigrade and in the short term the incineration temperatures of the flue gases even exceed 1,000 degrees centigrade, which leads to complete incineration of all organic components and toxins.

It is of significance for the metals that the grate temperatures are clearly below the respective melting temperatures of the metals. Since metals do not *burn* at these temperatures, they neither penetrate the slag nor the flue gas cleaning residues and it is only very light flakes of metal that are pulled in by the flue gases. These reach the zones with high temperature, where they oxidise or evaporate and can then be found on the walls of the fireproof brick lining or the catalysts.

4.1. Metal Recycling from Filter Cake

The metal contents of filter cake have been examined in Berlin. Gold and silver could not be found so far, although other metals including rare earths could be traced in laboratories, but their concentration is so low that any reclamation is not economically viable. Filter cake is used as backfill in underground salt or potash mining. Should metal prices eventually increase considerably because of extreme scarcity, these man-made storage sites could fundamentally be exploited again as mines. But as far as the filter cake at the Ruhleben waste incineration plant is concerned, the timing for this method is far in the future, in the opinion of the author.

What is important, however, is the fundamental capability of storing raw materials from incineration processes in concentrated form at certain known locations from where they can be recovered. The author knows for a fact that certain waste deposited underground has been recovered to reclaim materials contained therein.

4.2. Metal Recycling from Slag

The treatment of ashes is made by a combination of magnetic separators and classifying machines. For the group of ferrous and non-ferrous metals there are various magnetic separators on the market and depending upon the grain size, humidity and throughput, suitable models can be selected and set up.

Finer penetration can be attained using additional crushing machines for post-treatment such as impact mills or cross-flow shredders. Cross-flow shredders have not made their mark in operating with slag so far, because of the high wear and energy costs.

The separation of non-magnetic coarse scrap metal and copper-bearing scrap metal is performed by means of visual recognition and here, automatic sorting is still ripe for development.

At further stages in treatment, float/sink and flotation separation are used. These plants are so far not situated directly at the incineration plants, but are rather specialist slag treatment plants in Germany. These plants are within a sector which is highly competitive and consequently about which little is reported.

At the Ruhleben waste incineration plant, five types of scrap metal are generated. Apart from this, there is the type of scrap known as *scrap metal from workshops* generated by maintenance work. This was previously simply *disposed of* together with all other ferrous scrap. (Figure 1). Awareness of the value of scrap metal has noticeably increased.

The most common type of scrap metal is fine ferrous scrap metal. The composition can be seen in Figure 2. As already explained, this fraction contains non-ferrous metals and slag, stones and glass. In this fraction there is coalescence with metal or fine weakly-magnetic elements. Parts of the iron are completely enclosed in slag, so that these partially have to be reclaimed as slag.

Figure 1: Products of Waste Incineration Plant

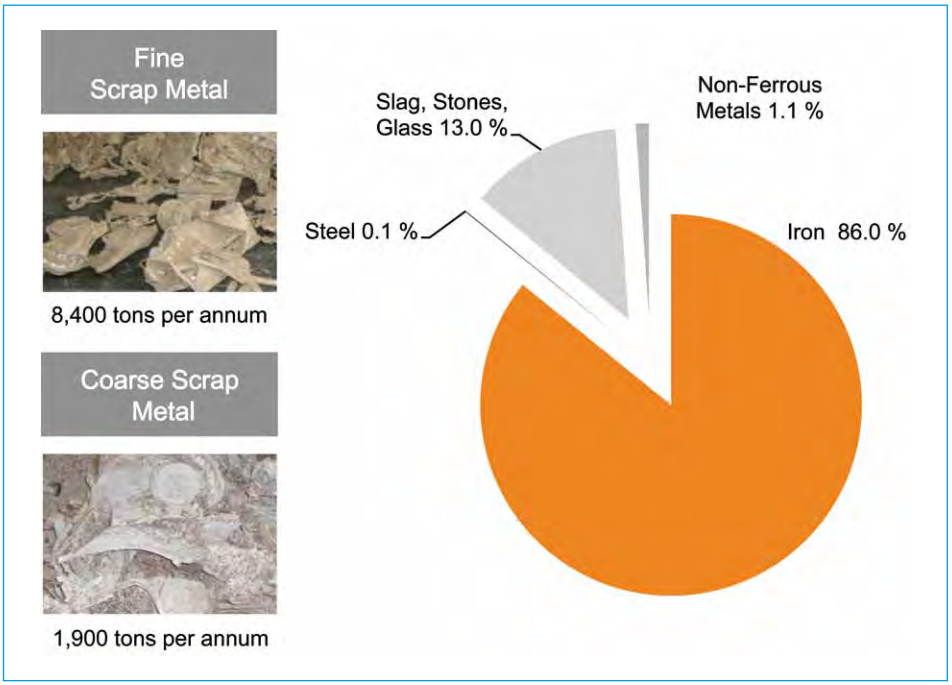

Figure 2: Scrap Qualities at Waste Incineration Plant Ruhleben – Composition of Iron Scrap (fine/coarse)

Should the iron content be increased to almost 100 % by further technical resources, the absolute iron recycling volume is reduced because all coalescence or weakly magnetic elements are reintroduced to the slag.

This fine scrap metal fraction can be directly handled by the current array of certain blast furnaces, so that it is a product that can be again converted into steel. The most recent status of the European definition of the end of waste suitability, however, assigns this fraction to waste legislation.

What is of substantial economic significance is the fraction of non-ferrous metals and as can be seen in Figure 3, it consists by over 50 % of aluminium and 20 % of other metals, which disproves the theory that aluminium can be completely burned in waste incineration plants. The mixture of various metals is purchased by metal processors operating across Europe. This fraction is not directly used in blast furnaces or smelting plants, but is rather treated so that metallic concentrates emerge which are suitable for metallurgical processes.

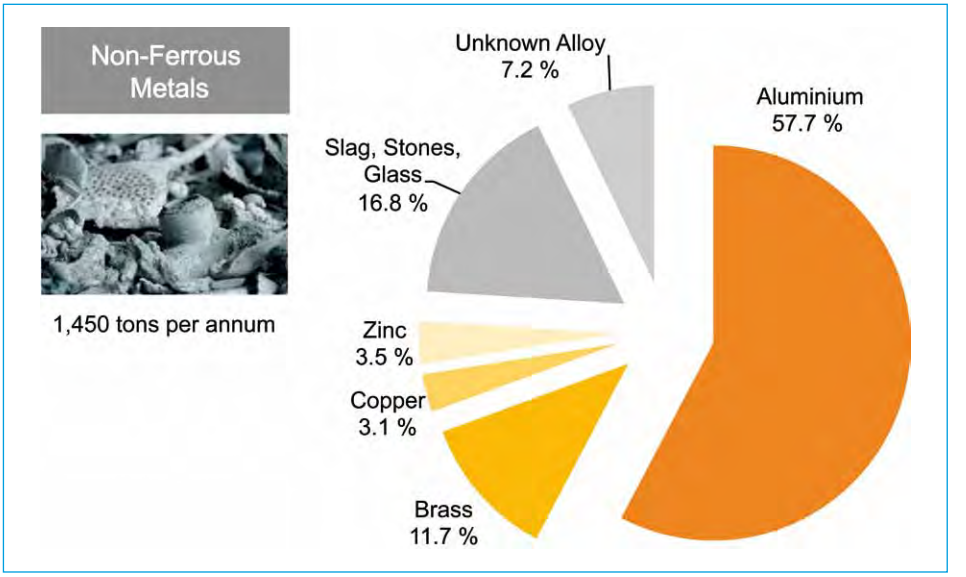

Figure 3: Scrap Qualities at Waste Incineration Plant Ruhleben – Composition of Non-Ferrous Metals

The copper-bearing fraction largely comprises copper coils as found in electrical motors.

The aforementioned metal content of 2.1 % in Berlin waste can be proved in slag and filter cake. In Berlin, a scrap metal volume of 22 to 24 kg scrap metal per ton of household waste is recycled and sold, which in terms of waste amounts to a recycling factor in excess of 100 %. If the metal concentration of the various qualities is taken into account, the recycling quota currently amounts to some 90 %.

At the BSR Ruhleben waste incineration plant, only a small proportion of metals within the household waste is lost as slag, filter cake or by means of evaporation.

The author assumes that these metal losses can continue to be reduced by means of further technical measure in slag treatment. The efforts of BSR are particularly being directed at non-ferrous metals, the value of which is to some extent 10 times higher than the ferrous fractions.

The development of metal recycling from the ashes of waste incineration plants has by no means reached conclusion and various approaches are becoming apparent. The author is confident that recycling quotes for non-ferrous metals can still be increased.

4.3. Systemic Analysis of Metal Recycling from Waste Incineration Plants

When systemically analysing the opportunities of metal recovery from waste incineration plants in Germany, the recycling quotas of the specialised slag recyclers – who operate in harsh competition against each other and constantly work on improvements – have to be implicitly taken into consideration. As in classic mining, the learning process has been driven by trial and error for decades.

Numerous incineration plants do not separate metal on their sites or do so only very rudimentarily, transferring the slag to specialised slag treatment facilities under long-term contracts, which then separate the metals as completely as possible. Naturally, these operators are not interested in reporting about their successful work.

In the statistical analysis of the German waste removal industry however, this approach leads to the assumption that only very small amounts of metal are recycled at German waste incineration plants. The consequence is that the process of waste incineration is undervalued in the climate and resource analysis. Unfortunately, the interested lobbyists for the mechanical means of the first waste treatment step propagate this intensively, which ultimately leads to wrong political decisions when evaluating and developing the German waste removal industry.

The industry states that the metal content in household waste slag is about 7 to 10 %. At a ratio of slag resulting from the entered amount of household waste at 20 to 30 %, this corresponds to the above mentioned metal content of the household waste. The scrap metal volumes produced by waste incineration plants and slag treatment facilities in Germany are closer to the potential identified above. However, it is impossible to determine what is sourced from household waste, trade waste or from industrial production, which is why the data cannot be transferred unverified.

The treatment of metals from the slag and ash of waste incineration plants can easily produce marketable qualities and although the technological process has not been completed yet, further advancements are to be expected.

It is an interesting question to what extent aluminium actually vaporises or metal scatters via the filter cake or slags, but the author has not found any recent studies to answer this.

5. Metal Extraction from Mechanical Treatment Plants

Since 2005, BSR has been operating two mechanical physical plants (MPP) together with a private partner in the Berlin districts of Pankow and Reinickendorf. Furthermore, metal is recycled in a scrap wood and bulky waste treatment plant as well as a tarboard treatment plant.

5.1. Scrap Wood and Bulky Waste Treatment

BSR also operates a treatment plant for scrap wood and bulky waste (AAS). It contains the three treatment steps of grinding, metal separation and optical sorting. The waste from the AAS does not come from the classic household waste containers, but from the recycling depot, from special bulky waste collections from homes and from bulky waste that people bring directly to the plant. Eight fractions are sorted from this mix of waste.

Figure 4 shows the composition of the iron fractions. The iron content of almost 78 % is lower than that from the incineration plant. As can be seen on the photo, the metal is coalesced with other materials, for example plastics. The material is completely impure and has to be treated once more, where the usable iron content is further reduced from 78 %. The external treaters do not give any exact information about this. BSR regularly checks, whether this material should be fed once more into the Ruhleben waste incineration plant.

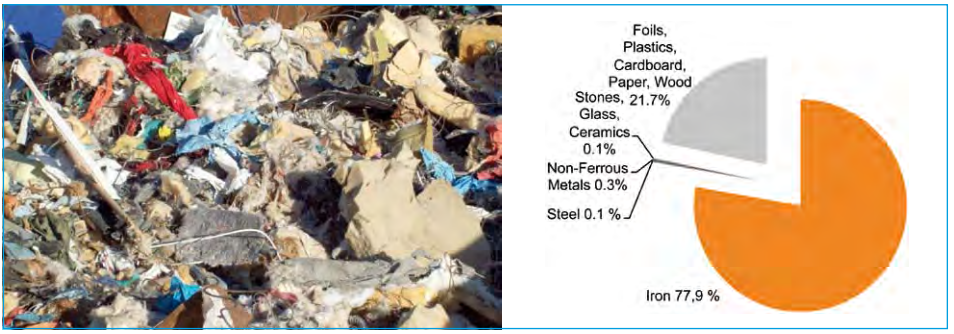

Figure 4: Composition of Iron Scrap – Bulky Waste Treatment Plant

The obviously significantly lower metal content of inferior quality leads to a considerably lower metal yield. The ratio to the volume of fine scrap metal from the incineration plant is 2.5 to 1.

Even more extreme is the ratio to the average revenue from all fractions of incineration, which also takes the gains from all other metal fractions into consideration. This ratio is 4.5 to 1.

The market appreciates that the scrap volumes from incineration only consist of metal and mineral components.

5.2. Metal Extraction from a Mechanical Physical Sorting Plant

The procedural difference as compared to waste incineration is shown in Figure 5. The physical element is the drying process.

Five fractions are produced in addition to water-rich, hot air and they are shown in Figure 6. As can be seen, the scrap fraction can not be immediately recognised as such from a distance.

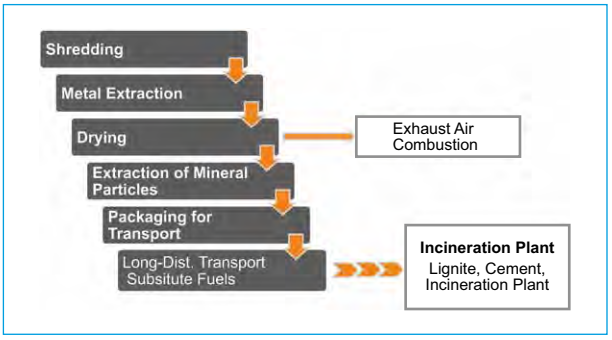

Figure 5:

Process Steps at Mechanical Physical Stabilisation Plant

Figure 6:

Products of Mechanical Physical Stabilisation Plant Pankow

Although the waste contains just 2.1 % of metal, the official waste report states recycling of 4.7 %, which is obviously only possible if the metal content of the metal fraction is considerably lower.

The causes for this are the following technological effects:

- The magnetic extractors identify the metal in the waste which passes them on a band conveyor, up to a depth of 10 to 20 cm. The result is that everything that lies between the metal and the magnet will also be picked up.
- In such mechanical processes the metal is almost never present in its pure form. In the case of a frying pan for example, the entire pan is sorted into the scrap fraction, including its wooden or plastic handle, its coating and all other impurities. In the scrap of a waste incineration plant, in contrast, only the metal remains, because everything else has been burnt. This is just one example and the same effect applies, for instance, to a metal handle on a paint bucket or a toaster.

This quality is acknowledged by the scrap trade in corresponding prices, so that it is possible that payments have to be made for the scrap fraction from mechanical treatment. Depending on the market situation, the price per ton of scrap from an incineration plant is 3 to 5 times higher than for that from an MPP.

The differences between the metal gains from the incineration plant as compared to those from an MPP are considerable per ton of waste, in that the recyclables or the metal gains from the waste in the incineration plant are higher than that from the mechanical pretreatment. The ratio will in future depend on the processing costs for contaminants, which require the next step of scrap treatment.

5.3. Systemic Analysis of Metal Recycling in a Mechanical Treatment Plant

When the waste is fed into a mechanical plant like a mechanical biological plant, a mechanical physical plant or a regular sorting plant for trade waste and light packaging waste, the different fractions are then incinerated to remove the so-called substitute fuels or sorting

residues. All synthetic materials that cannot be profitably marketed, like the fraction of so-called *mixed plastics*, are also burnt. Incineration takes place in specially constructed substitute fuel plants, which are in effect quite similar to the classic waste incineration plants, in cement plants or as co-incineration in coal or industrial power stations.

The so-called dissociation does not happen in either of the mechanical waste treatment processes, whether mechanical, physical or biological. Metals remain within their coalescence and with all their impurities, so that these will be added to the scrap fraction or will not be separated out and instead leave the treatment process as sorting residue or substitute fuel. The reason for this can be the speed of the band conveyor, the magnetic separator or the diligence of the personnel at the manual sorting bands. A further explanation could be that the metal parts are too heavy to be pulled from the material flow with the magnetic separator or that they are covered by other contaminants and thus cannot be identified.

If the flakes of metal are too light, they can be entrained by the material flow and also cannot be separated.

Therefore the scrap from mechanical plants, which also includes packaging treatment plants, is generally of a quality that has to be treated in specialised treatment plants in Germany in order to be concentrated to a marketable scrap quality. The proponents of mechanical treatment however keep quiet about this fact. Indeed one often boasts a metal output that is higher than the metal content of the household waste treated.

As the substitute fuels or sorting residues have been freed of most metals, a further metal extraction is hardly worthwhile and these are then redistributed into the biosphere, together with the slag and ashes. Classic industrial power stations may partly utilise substitute fuels, but forego further slag treatment because the regular fuel coal does not contain any metal. Any metals contained therein are then irretrievably lost as a resource or climatic factor.

The so-called scrap fractions from mechanical plants are sometimes also exported to Asia or Africa, which does not add to the protection of resources in Germany and is also extremely alarming from an environmental point of view.

6. Climate Protection and Metal Recycling

Certain values have become established for climate protection on the basis of metal recycling. The recycling of one ton of metal reduces the emission of CO_2 in terms of figures, when otherwise natural ores would have to be utilised for the production of metal:

The following CO_2 equivalents are credited for fuels:

1 kg of hard coal	411 g
1 kWh of electricity in Berlin	741 g

The following CO_2 equivalents are credited for metals:

1 kg of iron	945 g
1 kg of aluminium	9,307 g
1 kg of copper	5,714 g
1 kg gold	18,727,000 g
1 kg of mineral substances	4 g

Due to the very high values of CO_2 equivalents for metal recycling, a process that generates large recycling volumes can be beneficial in terms of climate protection criteria. Mechanical plants often produce higher quotas than incineration plants, and sometimes – as already mentioned – even larger amounts as contained within the raw waste.

When looking at mechanical plants, the significantly lower metal contents should always be taken into consideration. Additionally there is the impact of the transport to the treatment facilities, where the necessary further treatment procedures are carried out; it is here that energy expenditure also has to be considered for the climate balance.

A further consideration for evaluation is the disposal of the so-called sorting residues. In certain circumstances however, it is still possible to dispose of sorting residues in clay or gravel quarries or on landfills respectively. While this may, on the one hand, be the cheapest solution, it is at the same time the most harmful to the climate and this fact has so far generally not been mentioned in climate balances.

As a result, environmentally and politically wrong conclusions would be drawn from this, but these qualities are probably evaluated most accurately by the market. The analytical studies for the definition of the real metal contents as well as their assessment from the climate perspective seem to have only just been started.

7. Summary

Whether the treatment and sorting facility for metal recycling is right next to a waste incineration plant, or whether this is done at the treatment facility of a dedicated company, is a business decision that has to be taken by each incineration plant individually. Systemically this is of lower priority, although the additional costs for transport will have to be taken into consideration in the climate balance.

The mechanical plants are generating larger volumes, which are, however, of a considerably lower quality.

The systemic comparisons do not currently take all aspects sufficiently into consideration, so that many assertions do not stand up to a critical examination. The evaluation process, however, will be developed further over the next few years.

Even in mechanical treatment plants a separation of metals and rare earths is only possible to a basic extent. A truly single variety separation can only be achieved through metallurgical processes for which there is only a limited number of kilns in Europe.

For economical reasons, only a narrow treatment depth is sensible. Only when certain metals become considerably more scarce and their prices increase, will the scope of mechanical and metallurgical treatment rise.

It is crucial that the metals are not diffusely scattered during the disposal process.

A conclusive statement cannot currently be made, because the issue should probably be analysed in a more complex and differentiated way as is being done in some of the current publications.

Through further innovations, technological developments and rising profits, the recycling of metal will be increased in all disposal processes, which will be of benefit for all involved and for all targets that are associated with metal recycling.

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