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Evaluation of the limits for metals in waste which in the event of being exceeded recovery including metal recovery in backfills or landfills must take place

Summary

For our Environment

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Evaluation of the limits for metals in waste which in the event of being exceeded recovery including metal recovery in backfills or landfills must take place

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„Evaluation of the limits for metals in waste which in the event of being exceeded recovery including metal recovery in backfills or landfills must take place"

Summary of Final Report

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1 Summary

The efficient and careful use of natural resources is a central goal of environmental policy. For this reason, an explicit legal provision was added to the German Waste Management Act (KrWG) in order to prohibit the landfilling of waste containing certain metals under KrWG § 43 para. 1 no. 3. As a result, the metals contained in waste are to be excluded from the substance cycle to a lesser extent than previously. In addition, the need to conserve natural resources is to be taken into account to a greater degree. To establish whether this need is required by law to a currently technically feasible and economically reasonable degree, it is necessary to review the subsidiary regulatory framework.

The German Ordinance on Underground Waste Stowage (VersatzV) contains in, Appendix 1, maximum concentration levels for zinc, lead, copper, tin, chromium, nickel and iron. It is not permitted for waste that exceeds these concentration limits to be used for the production of backfill material or directly as backfill, unless the recovery of the metals contained therein is not technically possible and not economically reasonable. The German Landfill Ordinance (DepV) also includes these concentration limits in the context of waste recycling in landfills (§ 14 para. 2 no. 2).

These maximum concentration levels have already been reviewed and confirmed once in 2007. However, the review focused on their environmental impacts only. In the present study a new review is conducted, taking a practice-oriented approach which focuses on the technical feasibility and the economic effectiveness – particularly in view of disposal and recovery at landfills – at the current time.

1.1 Selection of metals for analysis

In a first step of the analysis, eight metals (antimony, cobalt, manganese, molybdenum, niobium, tantalum, vanadium, tungsten) - in addition to the metals already subject to regulation (lead, chromium, iron, copper, nickel, zinc and tin) - were proposed, for which minimum concentration levels for recycling could be set. This selection was based on the value of the individual metals, dependence on imports, security of supply and their importance as a raw material for industry.

1.2 Selection of wastes for survey

In order to select the waste types for which data is to be gathered from the operators of underground disposal sites and landfills, the waste types and masses that were landfilled, used in landfill construction or the backfilling of mines in 2011 and 2010 were determined and compiled.

To determine the data for the analysis of the currently regulated metals (Pb, Cu, Ni, Fe, Cr, Zn, Sn) from the ABANDA waste analysis database of North Rhine-Westphalia, minimum levels were set. First of all, the maximum concentration levels that are currently in force were used by taking 10% of these values as a basis. These were then revised downwards when ores with lower concentrations are considered mineable or several concentration averages in ABANDA were slightly lower. Finally, the averages were retrieved from the ABANDA database and compiled.

To determine the data for the analysis of the additional metals (Sb, Co, Mn, Mo, Nb, Ta, V, W), the minimum levels were initially set very low (100 mg/kg or 1,000 mg/kg) since these metals are often not found or mined in isolation, but rather in combination with other metals, rendering the determination of a separate mineability impossible. The averages were then retrieved from the ABANDA database and compiled.

For the final selection of waste types, the waste types were determined for which more than 10,000 Mg is backfilled, landfilled and/or used in landfill construction in one year (2010 or 2011) and for which the average of at least one of the regulated metals was larger than the set lower limit. In the second step, waste types were excluded from the analysis when the content of a regulated metal only slightly exceeds the specified lower limit. The waste types found in No. 17 of the German Waste Classification Ordinance ("Construction and Demolition Wastes including excavated material from contaminated sites") were also excluded since it was assumed that the metal contents may occasionally exceed the set levels, but they are found in different binding forms and therefore no statements can be made about the profitability of recycling in these cases. In a third step, the waste types for which 10,000 Mg or less are backfilled, landfilled and/or used in landfill construction in one year (2010 or 2011) were selected according to the following considerations:

- it significantly exceeds the lower limits for the regulated metals,
- it exceeds the lower limits of the additional metals,
- the origin of the waste type (e.g. metal industry) or its form (e.g. used catalytic converters) suggests that it may have a high metal content.

Finally, the waste types not selected due to the above-mentioned criteria and considerations were checked to determine whether there are grounds for including them in the analysis. Reasons for the selection were:

- masses that are used in backfilling, deposited in landfills or used in landfill construction are very high or high and
- there is a concurrent lack of analysis or a low amount of analysis, but a higher metal content is probable due to origin (e.g. metals industry) or type (e.g. metal oxides), or
- it simultaneously exceeds the lower limit of at least one of the other metals.

The results of this selection can be found in Table 4-3 of the long version of this final report.

1.3 Recycling processes

The metals recycling processes currently used in Germany and its neighbouring countries were first of all researched and defined.

In a second step, information on plant input (type, volume and composition of waste) as well as the acceptance requirements for waste that have to be fulfilled for processing (metal content, interfering impurities, chemical bonds) were gathered by means of a survey and/or interviews (by telephone) with the relevant plant operators.

The results for some significant recycling processes are outlined below.

1.3.1 DK process

In the DK process ferrous waste in particular is processed, e.g. filter dusts and sludge from gas cleaning, blast furnace gas dust and sludge, coarse mill scale and mill scale sludge and ferrous residues from the chemical industry and the nonferrous metals industry. Foundry pig iron (used in foundries), blast furnace slag (used as a building material), blast furnace gas (used as fuel), zinc oxide concentrate with more than 60% zinc (used in smelters) and small amounts of crude lead are produced.

For blast furnace gas sludge, there is no other metallurgical process that recovers greater quantities, according to current knowledge.

The iron content should, as far as possible, be about 30% or more. Incidentally, this waste can also contain levels of zinc and lead. Residues with a zinc content below 10% can be recycled. Table 1-1 shows the acceptance criteria.

Table 1-1: Acceptance criteria for DK process

Element	Possible content [% TS]	Optimum content [% TS]
Fe	0 – 100	40 – 100
C	0 – 90	0 – 10
SiO_2	0 – 100	0 – 20 or 70 – 100
CaO	0 – 30	0 – 20
MgO	0 – 35	0 – 5
Al_2O_3	0 – 25	0 – 5
P	0 – 30	0 – 0.1 or 3 – 30*
Cr	0 – 0.5	0 – 0.,1
Cu	0 – 2	0 – 0.5
Ti	0 – 3	0 – 0.3
Mn	0 – 12	0 – 1
As, Sb	0 – 0.10	0 – 0.010
Ni	0 – 4	0 – 0.1
Mo, V	0 – 1.5	0 – 0.1
$Na_2O + K_2O$	0 – 3	0 – 1.5
Zn	0 – 15	0 – 3
Pb	0 – 5	0 – 0.5
Cl	0 – 5	0 – 0.5
F	0 – 4	0 – 0.1
S	0 – 5	0 – 0.5
Hg	< 0,0001	< 0.0001
Cd	0 – 0,10	0 – 0.10
Tl	0 – 0,035	0 – 0.035
Cr (VI)	undetectable	undetectable
Oil/fat	0 – 6	0 – 1

* with P>3%, Cr/Cu should be low

1.3.2 Rolling process in a rotary kiln

This rolling process is a zinc enrichment process for zinc-containing residues, particularly steelwork dusts and a number of other waste types. A rolling oxide is produced that is 58–65 % zinc and 2–6 % lead, which is used as a secondary raw material in zinc smelters (above all in zinc electrolysis).

The process is particularly suited to processing zinc-containing residues with a zinc content of more than 20%, but waste with a zinc content of more than 5 % is also accepted. A disadvantage is that the iron fraction is not recovered. Alongside a high zinc content, the waelz oxide also contains lead from the input material. In zinc production, this is separated during electrolytic cleaning and added as a lead concentrate to lead production.

The survey showed that the amount of zinc content needed for the waste to be accepted differs: ≥ 5% and ≥ 10%. The content of other metals which are allowed to be present in the waste also varies in the different waste types, in some cases significantly (see Table 1-2). Furthermore, restrictions on chlorine, fluorine, sulphur, PCDD/PCDF and organic materials were also stated.

Table 1-2: Restrictions on metal contents in the rolling process

Metal	Restrictions
Lead	None up to ≤ 10 %
Copper	None up to ≤ 2 %
Nickel*	≤ 12 % to ≤ 2 %
Chromium	≤ 12 % to ≤ 2 %
Cobalt	None up to ≤ 1 %
Cadmium	≤ 1 % to ≤ 0,1 %
Arsenic	≤ 0.1 % to < 0.06 %
Mercury	≤ 0.02 % to ≤ 0.01 %

* In the case of inhalable powdery nickel compounds (nickel monoxide, nickel, nickel sulfide, trinickel disulfide, nickelic oxide) there was also a restriction of <0.1%.

1.3.3 Lead recycling processes

Used lead-acid batteries, scrap lead, lead-containing residues, blasting sand and laminated lead foil and display glass are recycled in secondary lead smelters which use KTO processes. This produces lead bullion or tin compounds and slag, and sometimes also lead alloys.

Other secondary lead smelters produce lead from concentrates and residues using the QSL process. In contrast to the conventional method of lead production, the separate process steps of roasting and reduction are combined in a single QSL furnace in a continually running process. It also offers the possibility of processing - in addition to the concentrates - problematic lead residues such as sulphides, sulphates and silicates [IFEU 2007].

In the shaft furnace process, lead bullion is recovered from lead accumulators, the residues of accumulator production and other lead-containing waste. Hard lead alloys (lead-antimony and lead-calcium alloys) and soft lead are produced. In addition, lead oxides (battery oxide and red lead) are produced by the oxidation of fine and soft lead.

1.3.4 Electroreduction process

In the electro-reduction process, steel mill dusts, mill scale and other chromium and nickel-containing waste materials, particularly also dust from stainless steel production, are recycled. The output of this process is the dust fraction with high contents of zinc and lead oxide and a metal fraction with high contents of iron, chromium, nickel and molybdenum, which are reused in stainless steel production [Öko-Institut 2007].

In terms of covering the production costs, the contents of nickel and molybdenum are especially significant. The survey showed that waste with a Ni or Mo content of 1% can be used (technically feasible). However, this content is not enough to cover costs. In times of high prices on the stock exchange, Ni and Mo contents of 2% or more cover costs. A reasonable quantity of iron should also be contained as metal collectors in the waste since a disproportionate amount of slag is otherwise produced, thereby causing the amount of waste generated per tonne of produced alloy to increase.

1.3.5 Plasma process

Although the plasma process uses a different technology to the electro-reduction process, it is similar to that process in terms of inputs and outputs. Dross, scales and other waste from iron and steel production – including waste in the form of ash, residue, slag, scum, dust, sludge and filter cake – are accepted for processing. Certain wastes from industrial pollution control devices are likewise also accepted. More than 80% of the chromium, nickel, molybdenum and iron are recovered for re-use in stainless steel production. The recycled metal is put back on the market either in the form of granules or larger blocks. Zinc and lead are isolated as dust and can also be recycled.

To cover the production costs, the contents of nickel and molybdenum are particularly important (like the electro-reduction process). With regard to cost coverage and iron content in waste, the survey led to the same results as the electro-reduction process.

1.3.6 Nickel smelters

In a nickel smelter, Ni-, Cu-, Co-, Zn-, W-, Mo-, V- and Pb-containing catalysts, dust, sludge, salts, acids and solutions and other waste materials are recycled. The smelter has a number of combined pyro-hydrometallurgical systems, including over roasting furnaces, a smelting furnace and an electrolysis. Final or intermediate products include: precious metal concentrates, non-ferrous metal concentrates (mainly Ni, Co, Mo and V), copper sulphate, nickel sulphate, cobalt sulphate, various alloys and pure metals.

The survey showed that nickel can, in principle, be recovered from residues which have a Ni content of at least 0.5% i.O. From a Ni content of about 5% i.O. and without distorting elements such as zinc or chromium, cost coverage is achieved by the material itself. Otherwise, the waste producer must pay extra. In addition, the waste should be free of cadmium, arsenic, mercury, antimony and PCB. The lead content is dependent on the contents of nickel, cobalt and copper. The cyanide content should be below 1%, while solutions must be free of cyanide. The possible fluorine content is provided upon demand.

1.3.7 Copper smelters

In secondary cooper smelters a large number of wastes such as electronic waste, heavy metal salts, dusts and sludge are accepted for metal extraction or as slag-formers; secondary raw materials with a low copper content are also accepted. Coarse copper with an average copper content of 95% and a tin-lead alloy are produced. Nickel sulphate and precious metals are separated and treated after electrolysis.

1.3.8 Direct reduction process in a rotary hearth furnace

The aim of the so-called Inmetco process is the production of sponge iron[1] and an enriched NE metal fraction by direct reduction of high metal-containing residues from the iron and steel industry. For some time the focus has been on the recycling of nickel-containing batteries.

The main objective in developing these processes was the substitution of the coke required in conventional iron and steel production with a cheaper reducing agent and energy source. As a product of the process, the sponge iron can be used in various ways (in basic oxygen steel making, electric arc furnace). In this way, the Inmetco process allows for uniform disposal and recycling of a number of iron-containing residues from integrated smelters, which due to their properties and/or their high levels of zinc, lead, alkalis or oil can be put back into the steel plant processes only after special conditioning or in some cases not at all.

1.4 Comparison of current limits and acceptance restrictions and reduction of existing and setting of new concentration limits

Information on acceptance restrictions for the metal contents in the various recycling processes were only available for a few metals. The reason for this is that the minimum content is given only for the main element, but not for minor elements recovered at the same time. Moreover, data on the sub-elements generally tends to be maximum possible levels.

For iron, the current minimum concentration is 50% or 500 000 mg/kg. In the DK process waste with a Fe content that is greater than 0% can be accepted. A Fe content of > 40% is said to be optimum.

For zinc, the current minimum concentration is 10% or 100,000 mg/kg. For the rolling process, two different amounts are given as the acceptance levels: 5% in one process and 10% in another.

For nickel the current minimum concentration is currently 2.5% or 25,000 mg/kg. In the electro-reduction process and the plasma process, waste with Ni contents of 1% or more can be processed. However, costs are only covered when – depending on the stock exchange listing – it has a Ni-content of >2%. In the nickel smelter considered, nickel can be recovered from waste with Ni contents of ≥ 0.5% i.O. It only covers costs, however, with Ni contents of about 5% i.O.

There is currently no minimum concentration for molybdenum. In the electro-reduction process and the plasma process, waste with Mo contents of 1% or more can be processed.

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[1] 'Sponge iron' is the solid product of the processes in which high metal-containing (esp. iron), predominantly oxidic input materials are reduced using coal, natural gas or oil [VDEL 1989].

However, it only covers costs – depending on the stock exchange listing – with a Mo content of > 2%.

From the information provided by the recycling companies, particularly with respect to the acceptance criteria, there are indications of recycling opportunities for zinc, iron and nickel in the case of concentrations below the limits specified to date.

The current concentration limits for zinc (≥ 100 g/kg) can thus be halved (to ≥ 50 g/kg). There are no indications of whether zinc can currently be technically recovered from waste with lower levels.

The current minimum concentration for iron of ≥ 500 g/kg can be lowered to at least ≥ 400 g/kg, since there is a company that designates this concentration as optimum. Without considering cost-effectiveness, the minimum concentration could be reduced even further since the same company does not exclude the acceptance of waste with lower levels.

Technically, it is currently possible in two processes to recover nickel from waste with levels of > 1%, with the result that the minimum concentration could, from a purely technical perspective, be lowered from ≥ 25 g/kg to ≥ 10 g/kg. It cannot be stated whether a further reduction is possible, because the content specification of ≥ 0.5% in the third method relates to the original substance. This could be possible with slag, for example from metallurgy, because the water levels are close to zero.

To date, no minimum concentration has been set for molybdenum. In two processes it is currently possible to recover molybdenum from waste with levels of ≥ 1%, so that technically a minimum concentration of ≥ 10 g / kg could be set.

The statements made above only apply to the contents of the primary recovery metals in the corresponding process. However, the metal recovery that is technically possible depends not only on the concentrations of these metals, but also on the concentrations of the metals recovered as by-products, as well as on the contents of other elements and substances contained in the waste. Since both the possible contents of the metals recovered as by-products and the possible contents of the other elements and substances contained in the waste varies from waste to waste, the decision of whether waste is accepted for metal recovery or not will nevertheless be continue to be made on a case-by-case basis.

1.5 Own processing efforts and analyses

Within the scope of the research project, extensive information on different wastes was gathered by means of a comprehensive literature review and surveys. The focus was put on the collection of reliable data, which enable conclusions to be drawn on the respective metal concentrations in individual waste. Moreover, an attempt was made in the first approach to identify - from the origin of the waste and the concentration of metals contained - the compound form in which the metals are found in the waste, if the compound form could not be determined from the waste category name itself.

As a further criterion in selecting the waste to be examined further, the specific hazardousness of the waste was taken into account, e.g. due to mercury and cadmium, high chlorine content and strong dioxin, furan, PCB and PAH, etc. The obvious hazardousness of such substances have then partly led, within the scope of this first selection, to the waste being excluded from further treatments since the latter would likely entail huge problems in the recycling process as well as environmental risks.

The waste types AVV 19 01 11* "Bottom ash and slag containing dangerous substances" and 19 01 12 "Bottom ash and slag other than those mentioned in 19 01 11" - both waste from the incineration of waste - were excluded since they have already been extensively analysed in a parallel UFOPLAN research project. Waste types which originate from the mixing and immobilization of waste serve as an opportunity to ask the operators of the mixing and conditioning systems about the output wastes that have high metal contents. However, it is probably not expedient to use the products from mixing and conditioning in the recovery of recyclable metals.

In order to subsequently identify the waste types that appear suitable for the separation of recyclable metals, the waste types with the highest loads were then ranked for each metal. It was also calculated what proportion of detected metal loads comes from the waste for storage at landfills.

Intensive communication was then carried out with associated partners from the project group who had pledged their support; and a comparison of materials already used for recycling and the waste category numbers was undertaken. An initial indication was found that the selected waste could also be fed into suitable recycling processes.

Taking into account the above-mentioned aspects, the waste types were now selected for which the highest usable loads could be assumed at reasonable cost.

From the selected waste types, the six most suitable waste samples for testing and analysis were selected depending on their availability and following consultation with the German Federal Environment Agency (UBA). The aim here was to select a waste for each metal if possible, so as to prevent one particular metal dominating. Furthermore, due to the expected heterogeneity of waste, two samples of a selected waste type were taken from different waste producers. After extensive consultation with different waste producers, a total of seven representative samples of the following waste, categorized by AVV number, were obtained and analysed:

- No. 10 02 02: Unprocessed slag from the iron and steel industry
- No. 10 04 01: Slags (first and second smelting) from lead thermal metallurgy
- No. 10 05 01: Slags (first and second smelting) from thermal zinc metallurgy
- No. 11 02 02: Sludges from zinc hydrometallurgy
- No. 11 01 09*: Sludges and filter cakes from chemical surface treatment and coating of metals and other materials containing dangerous substances (waste 1: sludge, waste 2: filter cake)
- No. 19 01 13*: Filter dust containing dangerous substances.

After an initial determination of waste characteristics (grain size, residual moisture, general condition of the sample), the metal contents and the crystalline phases of the wastes were determined.

It was found that the measured metal contents are congruent with the levels specified by the waste producers. In a total of four cases the concentration limits were exceeded, but these constituted justifiable exceptions. Despite exceeding the limits, a further treatment of the waste to recover specific metals did not seem worthwhile at present, either because the quantities available for recycling are too low or an additional recycling is not possible for process-related reasons.

A similar result was reached in the comparison of the measured metal concentrations and the lower mineability of ores. Although the metals were found seven times in a concentration within the range of ore mineability, a recovery of the metals is – analogous to the concentration limits –hindered for quantity or process-related reasons.

For the other metals that were measured but have not been regulated to date, no relevant enrichments or compound forms were found that would be advantageous for recovery. Consequently, the recovery of the other metals contained would be too complex for the process, or would have to be developed in the first place because no suitable method for recovery exists. At best, they are in an early stage of development.

For all the wastes analysed, there are integrated disposal or recovery methods available, which can be considered reliable for the future. Nevertheless, from the perspective of the waste producers, recovery or improved recovery of the metals contained would be desirable.

1.6 Development of new processing technologies

There is still a considerable need for development of the technologies for the recovery of special and technology metals. Production residues are already largely being recycled; however, a recovery of metals of strategic economic importance such as antimony, tantalum or the so-called steel stabilizers from consumer waste almost does not take place at all. Even low levels of certain recyclables have considerable potentials, especially in mass flows. The first processes for the recovery of special metals from consumer wastes are in development. The recovery of valuable metals from slag from waste incinerators, smelters and other thermal processes – especially from such waste flows that are not separately collectable or sufficiently sortable – is the counterpart or the complement of a highly efficient recovery of raw materials of strategic economic importance.

In many areas of production and use chains as well as downstream recycling, extensive research and development projects are being carried out in order to improve or enable in the first place the value added, e.g. the funding measures r^{high} innovations (high= 2,3,4, +- impulse) of the German Federal Ministry of Education and Research (BMBF).

As a consequence, the findings, newly developed strategies, methods and processes should be implemented and integrated as quickly as possible so that the removal of raw materials from the economic cycle is curbed and, at best, terminated. After all, only with innovative efficiency technologies is it possible to create competitive advantages for the German economy and to use resources smartly and more efficiently. Three new developments which have the potential to bring about an improvement in the supply situation are provided as examples in the following. In each case, an example of an extraction process, an enrichment procedure and the development of new processes for mechanical treatment is provided since high quality recycling of such recyclables only becomes possible with the interlinkage of technologies.

1.6.1 Electrodynamic fragmentation

Due to the scarcity of raw materials, which has increased in recent years, the recycling of composite materials is becoming increasingly important. With electrodynamic fragmentation [FHG 2015], it is possible selectively to separate and recover a variety of composite materials (e.g. scrap concrete, waste incineration slag, carbon-fibre reinforced plastics). This technology is already used industrially, e.g. for crushing high-purity silicon for the silicon wafer industry and solar cell industry or for the leaching of lithium minerals from the surrounding rock matrix. The advantage of this process lies in the dust- and contamination-free crushing since, compared to mechanical treatment, there is no abrasion.

1.6.2 BIOLEACHING

A branch of biomining based on biotechnology – bioleaching – has developed in the last 20 years from uncontrolled copper leaching from dumped heaps [Dott 2013 Wellmer 1999 Olson 2003]. With a part of up to 25% bioleaching has become a strong economic factor for the copper mining in Chile, Canada and the USA. The technical application of the process is the conversion of insoluble copper, zinc and uranium ores into water-soluble metal sulphates, which are removed from the process again after drainage through compression and precipitation. The development of the commercial bioleaching process has made great strides in recent years. The advantages of bioleaching compared to conventional metal extraction are, for example, leaching at low temperatures and atmospheric pressure, and the elimination of expensive chemicals through the biogenic production of sulphuric acid.

The theoretical basis of bioleaching is the utilisation of inorganic electron donors, mainly reduced sulphur compounds and elemental sulphur, which, based on the sulphur-oxidizing bacteria, are used for energy production [Silverman 1959]. The bacteria is of the Acidithiobacillus species, a group of Gram-negative, aerobic, chemolithotrophic bacteria that are capable of oxidizing not readily soluble metal sulphides reduced in the production of sulphuric acid and thereby turning the metals into a solution. Through biogenic sulphuric acid production the phosphor becomes soluble, resulting in phosphate anions. The leaching potential of Acidithiobacillus is based on two reactions: the thiosulfate mechanism and the polysulfide mechanism [Hollender 2002]. Both reactions lead to a release, i.e. the dissolution, of the heavy metals which remain chemically fixed in the ashes.

1.6.3 Sorting processes

A metal analysed within the scope of the research project [TU Clausthal 2015] is tantalum. Approx. 60% of the global tantalum production is used in the production of high capacity electrolytic capacitors, particularly when large capacities are required in a small size.

Despite its high price of about 400 US$/kg (purity: 99.8%), the recycling rate of tantalum is low overall. Recycling on a significant scale is only currently taking place in the area of production waste. However, it is possible - with a smart interconnection of disassembly steps, intensive pre-sorting and fine-tuned mechanical treatment technology - to recover the tantalum loads contained in the waste. It was possible to develop a process route which produces tantalum concentrates based on new mechanical treatment processes combined with thermal pre-treatment. The process has succeeded in producing, with a yield of approx. 50%, a concentrate with 21% tantalum from 1.5 t laptops, although the individual process steps are not perfectly coordinated with each other, resulting in avoidable tantalum losses in several steps.

1.6.4 Conclusion

The new approaches discussed above make it clear that the recycling of previously untapped waste resources could be made possible with future processes. In addition to further technical development, the flow of information must also be developed between waste producers and potential recyclers to establish a market in which supply and demand are strengthened.

Based on previous considerations, waste from small surface processing plants appears to be particularly suitable for recycling. This waste contains several metals and potentially recyclable materials. The number of processing plants is comparatively large; the yield per processing plant is, however, small.

In order to counteract an additional removal of valuable metals from the economic cycle, to simplify the recycling or to enable it in the first place, the measures described in the implementation proposal are necessary and helpful.

1.7 Proposal for implementation of project results in a regulatory concept

In order to achieve more extensive recycling, the following procedure is recommended:

1. Rules on minimum concentrations:
   a) Adaptation of the concentration levels for zinc, iron and nickel as well as adding molybdenum to the regulated metals,
   b) Expansion of regulation to include waste for disposal at landfills,
   c) Adoption of a positive list of waste, for which the recyclability of metals should be tested.
2. Development of a procedure for exemptions which may exceed the limits:
   a) temporary storage and mono-landfills,
   b) utilization in backfilling or in landfills or storage at landfills.
3. Complementary measures.

1.7.1 Adjustment of set minimum concentrations

It is recommended that the currently applicable rules on the priority of the recovery of metals in the German Backfilling Ordinance (§ 3 in conjunction with Annex 1) - to which the German Landfill Ordinance refers in the context of waste for recovery - are adapted for zinc, iron and nickel and that a value for molybdenum is introduced.

The recommended changes to the minimum concentrations are summarized in the following table.

Table 1-3: Comparison of current and proposed limit concentrations

Metal	Current minimum concentration	Proposed minimum concentration	Difference / New entry
	mg/kg	mg/kg	mg/kg
Fe	≥ 500,000	≥ 400,000	- 100,000
Ni	≥ 25,000	≥ 10,000	- 15,000
Zn	≥ 100,000	≥ 50,000	- 50,000
Mo	-	≥ 10,000	10,000

The minimum concentrations are not intended to be understood as essentially preventing shipments of waste for which some of these levels are exceeded. That would not make sense, since in addition to the actual metal contents a number of other factors determine whether recycling is technically possible or economically feasible.

But concentrations above the minimum levels indicate that there is in principle a resource potential, which should be tested. However, at the final workshop for this project, the opinion prevailed among the participants engaged in the practice, that there is no reason to lower the minimum concentration levels and that the costs for waste disposal would unnecessarily increase for the operators concerned. Regarding the introduction of the positive list and exceptions (see below), the costs for analyses and logistics will not substantially change in the experts' opinion.

1.7.2 Extension of the regulation to include waste disposed of in landfills

The analysis found that overall a high proportion of metal loads in waste for landfilling would potentially be available for recycling.

It was established that more than 50% of the identified metal loads in the analysed waste are without exception found in the waste for landfilling. In the case of chromium, nickel and tin, the portion was 90% to 100% (see Table 1-4). In particular, the waste containing metal contents which exceed the current minimum concentrations is preferentially deposited in landfills. With the non-regulated waste it must be taken into account that the number of samples examined does not allow reliable conclusions. However, it indicates a similarly high proportion of the landfilled metal loads. Therefore, it is recommended that the rules on minimum concentrations are expanded to include waste for landfilling.

At the final workshop, the country representatives were forewarned about the expansion of the regulation since the completion of the processes for landfilling could be greatly delayed and, as a result, in individual cases waste could not be transported for disposal in due time. The representatives of the backfilling mines pointed out that the non-regulation of waste for disposal distorts competition, with the result that disposal is promoted over recovery.

In principle, an extension of the regulation to other waste treatment plants such as CPB, stabilization and mechanical treatment would be useful as long as recycling is not already an objective. It was not the task of this study to examine this. However, a targeted examination of this issue is recommended.

Table 1-4: Metal loads from waste for landfilling and their percentage from the total loads determined (potential of the selected waste)

Metal	%	Mg/a
Lead	73	4,300
Chromium	100	36,000
Iron	73	343,500
Copper	58	28,300
Nickel	92	7,000
Zinc	61	139,000
Tin	98	900
Antimony	19	180
Cobalt	90	4,500
Manganese	78	34,900
Molybdenum	93	230
Vanadium	93	2,300
Tungsten	100	1,300

1.7.3 Creation of a positive list

To limit the scope of the analysis, the testing requirement should be limited to waste that have potentially high metal contents. Positive lists could, for example, be drawn up and revised at regular intervals. In the analysis the waste should be considered which is already being recycled today and which therefore is currently not included in the statistics on recovery in backfilling and landfills or in the statistics on disposal in landfills.

The creation of a positive list would also have the advantage that certain waste could be specifically excluded despite high potentials or an exception rule could be introduced. Such waste includes, for example, waste which has already passed through a targeted recycling process for recovering metals or possibly waste which is to be retrievably deposited on mono-landfills, since it is to be expected in the foreseeable future that the technical and/or economic conditions will change in such cases.

1.7.4 Rule on exceptions

Since the metal content alone is not sufficient to determine whether recycling is technically possible and economically reasonable, it is foreseeable that waste shall also be recovered or disposed of in backfill or landfills if the stated minimum concentration levels for metals are exceeded. Therefore, the waste producer must be given the opportunity to give reasons for why the waste is not suitable for metal recycling even though the metal contents concerned are above the limits.

It therefore seems expedient to include questions regarding the exception rules in a separate regulation as an aid for the waste producers when submitting reasons for exceptions and for administrative authorities for the inspection. The exemption clauses should detail the specific waste types in the form of a catalogue and should take into account additional conditions, including those relating to:

- mass waste flow, content of potential recycles and pollutants,
- significance of the resource potential, determined by content (mass) in the waste flows for raw material production (global / regional if necessary, if basic material companies are available) and concentration (compared to levels in primary raw materials or waste flows of a similar kind that have already gone through a recycling process)
- types of binding of the recyclables/pollutants in waste and the elution potential,
- ratio of recyclables and accompanying elements that hamper cost-effective recovery
- physical form of the waste (dry, pasty, compact, powdery etc.) and resulting requirements/costs for the treatment, including water content (particularly in the case of sludges and filter cake)
- current value of the target metals on the stock exchange, long-term price developments, exchange rates (on a global basis) and strategic scarcity criteria (classification as raw materials of strategic economic importance),
- consideration of the upstream process depth and the maturity of the corresponding processes (simple method or BAT etc.).

Given the complexity of the matter and changing framework conditions, a regulation in the form of a technical guide or a LAGA leaflet, which can be regularly revised without necessitating a new legislative process, may make more sense than a comprehensive extension of the German Landfill Ordinance or the Backfilling Ordinance. The assessment would have to be made on a case-by-case basis by the respective authorities, but could be based on a standardised assessment matrix. This should make possible a systematic comparison of the diverse framework conditions. It seems important to distinguish between the following in this context:

- waste that is normally subjected to further processing,
- waste that is to be retrievably stored, also for an interim period, on a mono-landfill and which can be recovered at a later date but for which recovery is currently not technically possible or economically reasonable[2] and
- waste that is to be irretrievably removed from the economic cycle (function of the pollutant sink)

For corresponding rules, the developments of the planned EU zero-waste directive should be considered and, if appropriate, influenced via appropriate contributions.

1.8 Complementary measures for increasing recycling

A helpful approach may be to differentiate the wastes concerned according to their origin.

[2] At the final project workshop, it was stated that there are legal problems involved in a requirement for mono-landfill or temporary storage, in the case that the alternative would be usage in, for example, the backfilling of mines. As a result, necessary conditions from legal point of view would be necessary - in addition to a precise definition of the waste concerned - to implement this proposed approach.

Residues that arise in efficient production and recycling processes are usually treated according to the state-of-the-art technology; the companies thereby have a strong motivation to recover the recyclables contained therein and to continually improve the recovery processes. In addition, materials are often put into the processes used which have already passed through many upstream treatment processes with the aim of metal recovery. If these processes are classified as BAT or near-BAT in terms of recovery or diminishing the concentration of the target metals, short-term additional requirements are not necessary.

The situation can be different with production residues and sub-flows of waste treatment in which the target metals were not the focus of the treatment processes. For producers of such waste, the safe disposal of the waste arising in production is particularly relevant and the recovery of the metals from the produced waste is usually not part of their actual area of business. In addition, the quantities of waste generated are often low and there is therefore only a limited possibility of subsequently integrating such "small quantities" in suitable recycling processes. In contrast to the residues from efficient production and recycling processes for which recovery tends to be limited by barriers presented by the processing technology, there is more often an organizational, information and communication gap between the waste producers and the appropriate recyclers in this case.

To improve the organization, information and communication situation, it would be helpful if a central database with the acceptance criteria of recyclers (minimum quantities and content, binding types, physical waste characteristics, etc.) is created so that when minimum concentration levels are exceeded, an initial comparison can be made of the recyclable material content in waste and the acceptance criteria of the waste producers, thereby reducing the number of exemption rules. This would have to go beyond the currently existing information from waste exchanges and databases, if possible. It should be checked whether a protected data space can be created for this purpose and the fundamental question of who should have access to it also needs to be addressed. This needs to be discussed within the competent authorities.

In order to reduce barriers relating to the process technology where technical solutions are still lacking, incentives should be created to further improve the recycling processes and to integrate some existing pre-developed methods for improving metal recovery, which have not yet been implemented due to economic constraints. Supporting information can be used on relevant issues pertaining to the participating organizations and companies which are supported by governmental funding, research projects and innovative pilot projects.

When the minimum concentration levels are exceeded before the improved processes have been developed and integrated, the raw material potential should be kept available for the future; landfilling should be divided into separate and a retrievable storage, making possible the use of today’s waste as tomorrow’s raw materials. A mono landfill, as used today in many cases, is a useful and well-tested option in this regard.

Further potentials for increasing recycling quantities from the above-mentioned waste can be achieved by testing the processes themselves and by the targeted and sustained segregation of waste. In this respect, it would be useful to revisit and intensify waste prevention and recycling efforts from the 1990s within the scope of implementation of § 5.1.3 German Federal Immission Control Act (BImSchG) and to connect to ongoing resource conservation programs.

Much of the waste considered comes from waste treatment plants in which various wastes have been decontaminated and/or prepared for further safe disposal, e.g. backfilling or landfilling. In the process, different wastes with varying levels of metal contents are mixed and still have, in some cases, significant metal contents after this mixing. This includes:

- 19 02: Wastes from specific physico/chemical treatments of industrial waste, more than 700,000 Mg/a, of which more than 60,000 Mg are metals in total,
- 19 03: Stabilised and solidified wastes, 1.3 million Mg/a, of which more than 18,000 Mg are metals in total,
- 19 12: Wastes from the mechanical treatment of waste, approx. 600,000 Mg/a, of which more than 14,000 Mg are metals in total.

Therefore, it is recommended that the rules on the ranking of the metals to be recovered are expanded, particularly to include the input in CPB and similar waste treatment plants.

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