TEXTE
50/2010

Improvement of Environmentally Relevant Qualities of Slags from Waste-to-Energy Plants

Summary

Umwelt Bundesamt

| TEXTE | 50/2010

Project No. (FKZ) 363 01 256
Report No. (UBA-FB) 001409

Improvement of Environmentally Relevant Qualities of Slags from Waste-to-Energy Plants

Summary

by

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UMWELTBUNDESAMT

This publication is only available online. It can be downloaded from
http://www.uba.de/uba-info-medien-e/4025.html
along with the complete version (in German).

Publisher:	Federal Environment Agency (Umweltbundesamt) P.O.B. 14 06 06813 Dessau-Roßlau Germany Phone: +49-340-2103-0 Fax: +49-340-2103 2285 Email: info@umweltbundesamt.de Internet: http://www.umweltbundesamt.de http://fuer-mensch-und-umwelt.de/
Edited by:	Section III 2.4 Waste Technology, Waste Technology Transfer Markus Gleis, Benjamin Wiechmann

Dessau-Roßlau, October 2010

Summary

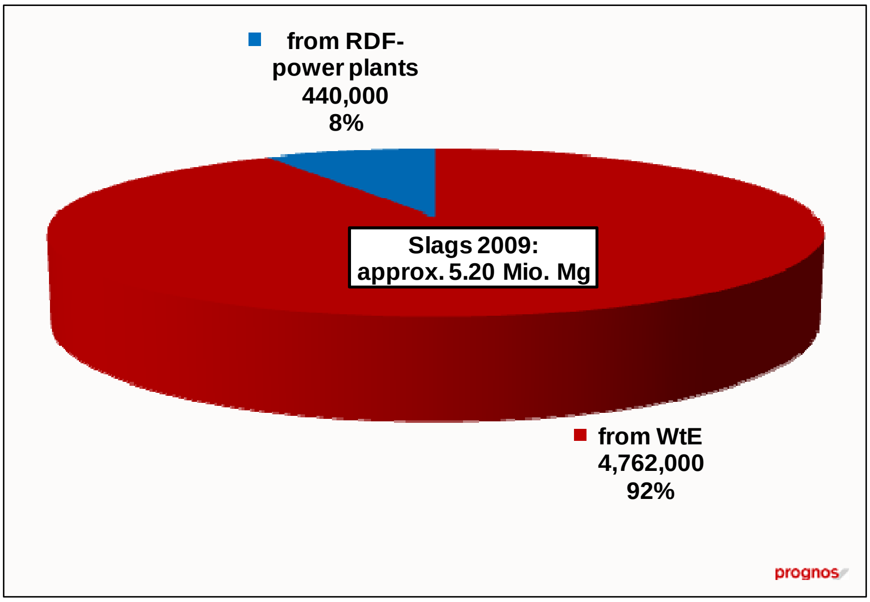
This expert opinion describes options for improving slag quality (further measures for processing slag, as well as improvements of grate firing in terms of firing-technology), to ensure a slag recovery that is as sustainable as possible. In the context of this project, the term “slag” serves as a synonym for solid incineration residues that are generated during the incineration of wastes or of refuse derived fuels and that are separated there (e.g. from the deslagger). The term “slags” is also used as a synonym for grate ashes.

The main focus of this expertise is on resource and climate protection issues with respect to slag processing. Resource protection refers to the saving of resources and natural raw materials, such as, for example, water and metal ores. Climate protection in this context means CO_2 mitigation through a high specific net energy generation in waste incineration plants, as well as a reduced energy use due to avoided new production of metals, which can be recycled from slag processing.

The main measure for improving climate and resource protection in slag processing consists therefore of separating as much metal as possible from slags. By recycling those separated slags, the energy that is needed for the extraction from ores and the raw material ore itself can be saved. This advantage in terms of energy, however, can be partially compensated by the energy use potentially needed for the improvement of slag processing.

Further important aspects include the protection of water and soils, as well as the suitability of processed slag for an adequate recovery. These last criteria, however, are not central for this expertise. Currently, 69 municipal solid waste incinerators, hereinafter referred to as Waste-to-Energy (WTE) plants, and 23 refuse derived fuel (RDF) power plants with grate firing are in operation in Germany. Their total capacity amounts to more than 21 million Mg per year. Another 13 RDF power plants with grate firing are under planning or partially under construction and will start operating already 2010.

Figure Z.1: Assumed amount of slags from WTE and RDF plants with grate firing in Germany 2009

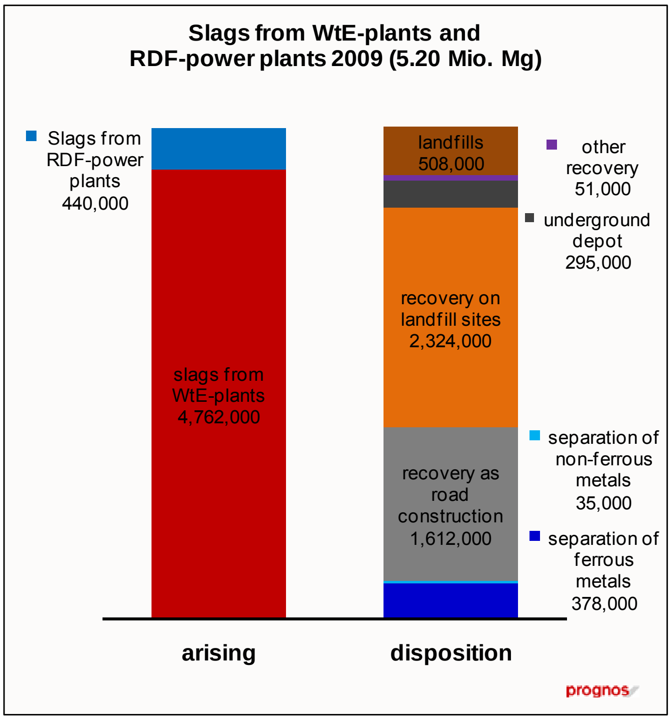


Source: [ITAD2009] und research Prognos AG 2009

The total amount of slags from WTE plants and RDF power plants equaled about 5.2 million Mg in 2009. About 4.8 million Mg, that is, 92% of those slags were produced during the thermal treatment of residual waste in WTE plants.

About 75% (3.95 Mio. Mg) of the assumed amount of slags from WTE and RDF plants with grate systems in 2009 was recycled in landfill and road construction. About 10 % (0.5 Mio. Mg) was disposed on landfills. Further 8 % (0.4 Mio. Mg) of ferrous or non-ferrous metals was recycled by internal or external slag treatment. Figure Z.2 shows the whole amount and the recycling paths of the assumed 5.2 Mio. Mg slags in 2009.

Figure Z.2: Assumed quantity and recycling paths of slags from WTE and RDF plants with grate firing in Germany 2009



Source: [ITAD2009] und research Prognos AG 2009

The following figures show the existing requirements to slag qualities for recycling, for example in road contruction, in Germany.

Figure Z.3: Requirements to slag qualities for recycling in Germany (eluates and solids)

parameter	unit	German "LAGA Merkblatt" M19 (1994)
pH value		7 - 13
conductivity	µS/cm	6,000
lead	mg/kg	0.5
cadmium	mg/kg	0.05
chloride	mg/kg	2,500
chromium	mg/kg	2
copper	mg/kg	3
nickel	mg/kg	0.4
mercury	mg/kg	0.01
sulfate	mg/kg	6,000
zinc	mg/kg	3

parameter	unit	German "LAGA Merkblatt" M19 (1994)
C org.	mg/kg TS	
arsenic	mg/kg TS	
lead	mg/kg TS	6,000
cadmium	mg/kg TS	20
chromium	mg/kg TS	2,000
copper	mg/kg TS	7,000
nickel	mg/kg TS	500
mercury	mg/kg TS	
zinc	mg/kg TS	10,000

The following figure Z.4 shows the range of solid material parameters of WTE-slag which results from a survey among ITAD members in 2006/2007. The values refer to both raw slag as well as aged slag.

Figure Z.4: Range of solid material parameters of WTE-slag (raw slag and aged slag) according to ITAD for 2006/2007

parameter	unit	range
TOC	% by weight	0.3 - 5
EOX	mg/kg	0.05 - 3
arsenic	mg/kg	3 - 15
lead	mg/kg	1,000 - 3,500
cadmium	mg/kg	2 - 20
chromium	mg/kg	200 - 1000
copper	mg/kg	1,000 - 10,000
nickel	mg/kg	100 - 500
mercury	mg/kg	< 10
zinc	mg/kg	2,000 - 7,000

Source: [ITAD2009]

External slag treatment

To meet the requirements the following minimum standards for slag treatment must be fulfilled [LUE2004], [BREF2006], [PRE1998]:

- Separation of unburnt material,
- Separation of ferrous and non-ferrous metals,
- Screening of the wished grain size distribution,
- Volume stabilization (structural-physical properties) and
- Reduction of leachibility of salts and heavy metals.

The conventional (dry) slag treatment consists of a combination of mechanical treatment steps and can be named as state of the art. The single steps and their functions are shown in figue Z.5.

Figure Z.5: Process steps of the conventional slag treatment

No.	Process step	Function
1	sifting	classification of slag
2	air separation	separation of unburnt (lightweight) material
3	magneic separation	separation of ferrous material
4	eddy current separation	separation of non-ferrous material
5	crushing	crushing for better separation
6	ageing (storage for a few week)	Volume stabilization, reduction of reactivity, Immobilization of salts ans heavy metals

The number of steps and way of treatment depend on the slag recycler and his possibilities to merchandise the products.

Figure Z.6 shows the process steps of the improved slag treatment, consisting of proven process steps as well. But in contrast to the conventional treatment also wet process steps will be used.

Figure Z.6: Process steps of the improved slag treatment

No.	Process step	Function
1	sifting	classification of slag
2	wet separation	separation of unburnt (lightweight) material, leach out of salts
3	magneic separation	separation of ferrous material
4	eddy current separation	separation of non-ferrous material
5	sand separation	recycling of different sand types

Figure Z.7 shows the range of slag eluate parameters of all WTE plants in Germany (ITAD2009), the average value 2001 to 2004 of the WTE plant MVR (Müllverwertungsanlage Rugenberger Damm, Hamburg, Germany) and of an improved slag treatment (plant „Scherer und Kohl“, Germany) compared to the existing LAGA-values.

Figure Z.7: Slag qualities of the conventional and improved slag treatment (eluate values)

Parameter	Unit	Germany "LAGA-values" (1994)	conventional treatment, average range [ITAD2009]	MVR (average value 2001 - 2004, conventional treatment) [ZWA2006]	improved treatment "Scherer + Kohl" [LUE2004]
pH value		7 - 13	11 - 13	11 - 13	k.A.
Conductivity	µS/cm	6,000	1,000 - 4,000	1,168	k.A.
Pb	mg/kg	0.5	k.A.	u.N.	u.N.
Cd	mg/kg	0.05	k.A.	u.N.	u.N.
Cl	mg/kg	2,500	1,000 - 4,000	810	290
Cr	mg/kg	2	0.1 - 1	0.22	u.N.
Cu	mg/kg	3	1 - 5	0.85	u.N.
Ni	mg/kg	0.4	k.A.	u.N.	u.N.
Hg	mg/kg	0.01	k.A.		u.N.
Sulfate	mg/kg	6,000	2,000 - 6,000	1,510	430
Zn	mg/kg	3	1 - 3	0.35	u.N.
u.N. - values below detection limit; k.A. - not applicable					

Source: [ITAD2009, ZWA 2006, LUE2004]

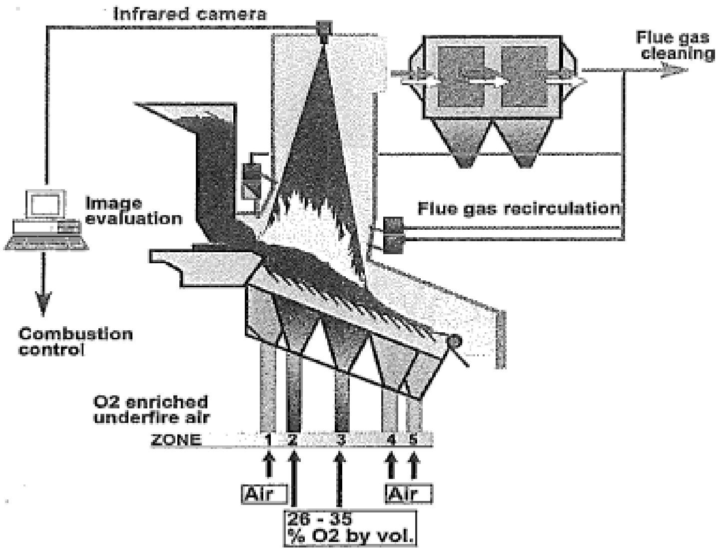
Integrated systems to improve slag quality

The SYNCOM process of "MARTIN GmbH für Umwelt- und Energietechnik, Munich, Germany" is an additional system in WTE plants with a reverse-acting grate. This process is in operation in two plants, one in Austria and one in Japan. In the BREF paper about best available techniques (BAT) it is named „Emerging Technology" [BREF2006].

The SYNCOM process (see figure Z.8) adds three components to the regular grate firing process:

- Enrichment of the primary air by oxigen,
- Infrared camera with fuzzy logic combustion control and
- Flue gas recirculation.

Figure Z.8: SYNCOM process

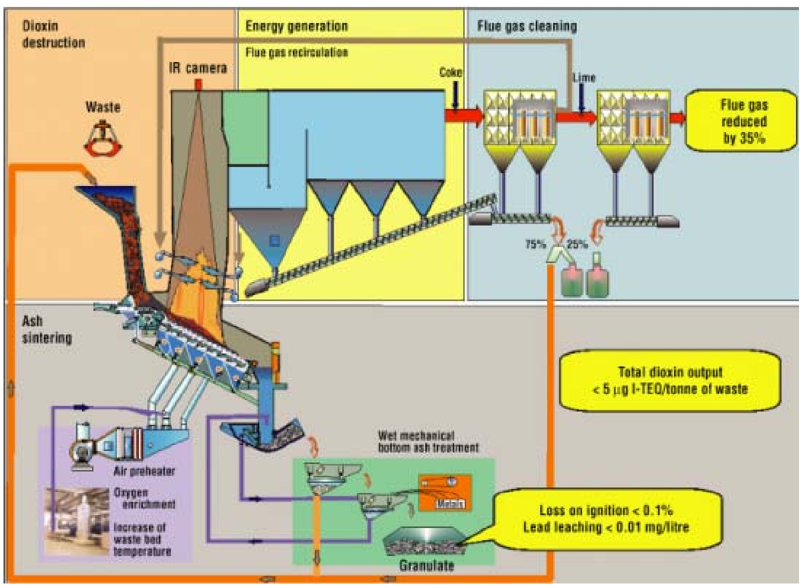


Source: [MAR2001]

The SYNCOM-Plus process (figure Z.9) adds the following components the SYNCOM process:

- Wet-mechanical slag treatment
- Refeeding of the fine coarse of the slag and a part of fly and boiler ash into the furnace.

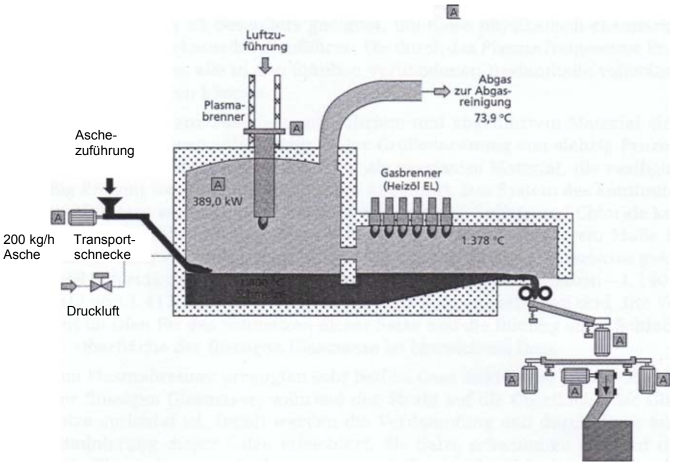
Figure Z.9: SYNCOM-Plus process



Source: [MAR2005]

The technology of plasma melting (figure Z.10) is a high temperature process to melt the slag to receive a glasslike material after cooling.

Figure Z.10: Simplified process scheme of the plasma melting furnace



Source: [ROS2004]

Figure Z.11 shows a comparison between a regular WTE plant and the three above described processes regarding flue gas volumes, emissions, consumption of auxiliaries, energy and costs.

Figure Z.11: Comparison between the processes regarding flue gas volumes, emissions, consumption of auxiliaries, energy and costs

	WTE-plant + separation of metals	**SYNCOM + separation of metals**	**SYNCOM-Plus + separation of metals**	**WTE-plant + separation of metals + plasma-melting**
flue gas flow	ca. 5,700 Nm³/Mgwaste	ca. 3,700 Nm³/Mgwaste	ca. 3,700 Nm³/Mgwaste	ca. 5,750 Nm³/Mgwaste
emission rates at stack; ca.	HCl: 0.54 kg/h SO_2: 2.68 kg/h	HCl: 0.32 kg/h SO_2: 1.60 kg/h	HCl: 0.32 kg/h SO_2: 1.60 kg/h	HCl: 0.54 kg/h SO_2: 2.69 kg/h
consumption: hydrated lime	ca. 141 kg/h	ca. 150 kg/h	ca. 157 kg/h	ca. 205 kg/h
auxiliary power	ca. 128 kWh/Mgwaste	ca. 211 kWh/Mgwaste	ca. 218 kWh/Mgwaste	ca. 556 kWh/Mgwaste
net power supply	ca. 536 kWh/Mgwaste	ca. 466 kWh/Mgwaste	ca. 455 kWh/Mgwaste	ca. 112 kWh/Mgwaste
specific treatment costs	ca. 74.50 €/Mgwaste	ca. 80 €/Mgwaste	ca. 82 €/Mgwaste	ca. 102.50 €/Mgwaste

The above comparison shows the advantages as well as disadvantages of each process for the compared items.

To evaluate the processes regarding to the question of improving slag quality eluate values of the processes will be compared to each other and to the quality of the described external slag treatment (figure Z.12).

Figure Z.12: Slag qualitities of the described processes compared to each other and to the quality of the described external slag treatment (eluate values)

Parameter	Unit	Germany "LAGA-values" (1994)	conventional treatment, average range [ITAD2009]	MVR (average value 2001 - 2004, conventional treatment) [ZWA2006]	improved treatment "Scherer + Kohl" [LUE2004]	SYNCOM-slag, 12 weeks aged, [FES2005]	SYNCOM-Plus-slag, not aged, (average values) [MAR2004]	molten slag, not aged, pilot plant [ROS2004]
As	mg/kg	k.A.	k.A.	k.A.	k.A.	< 0.1	0.1	0.01
Ba	mg/kg	k.A.	k.A.	k.A.	k.A.	1	2	0.06
Pb	mg/kg	0.5	k.A.	u.N.	u.N.	< 0.08	0.1	0.01
Cd	mg/kg	0.05	k.A.	u.N.	u.N.	< 0.01	0.01	0.001
Cl	mg/kg	2,500	1,000 - 4,000	810	290	740	216	10
Cr	mg/kg	3	1 - 5	0.85	u.N.	0.22	0.3	0.01
Cu	mg/kg	0.4	k.A.	u.N.	u.N.	< 0.01	0.2	0.01
Ni	mg/kg	0.01	k.A.	k.A.	u.N.	< 0.01	0.002	0.0005
Hg	mg/kg	k.A.	k.A.	k.A.	k.A.	0,1	0,1	0.01
Sulfate	mg/kg	6,000	2,000 - 6,000	1,510	430	655	k.A.	15
Zn	mg/kg	3	1 - 3	0,35	u.N.	0.15	k.A.	k.A.

u.N. - values below detection limit; k.A. - not applicable

Sorce: [ITAD2009; ZWA2006; LUE2004; FES2005; MAR2004, ROS2004]

All processes meet the German requirements for slag quality. The results of the comparison can be summarized by the following order of the eluate values for copper and chloride.

The order of the eluate values for copper looks as follows:

Plasma melting process “Scherer + Kohl”	SYNCOM SYNCOM-Plus	Conventional slag treatment „MVR“	WTE plant with dry slag treatment
better			worse

The order of the eluate values for chloride looks as follows:

Plasma melting process	SYNCOM-Plus “Scherer + Kohl”	SYNCOM „Conventional slag treatment „MVR“	WTE plant with dry slag treatment
better			worse

Figure Z.13 summarizes the processes considered in this study in a qualitative comparison. The criteria that are most important for resource and climate protection are marked in orange.

Figure Z.13: Qualitative comparison of processes considered in this study (see chapter 7 for details)

process	metal separation	leachability of heavy metals	auxiliary power	amount of boiler ash	water consump-tion	treatment costs	reference situation	established process
WTE-plant with wet deasher	+	o	+	o	o	+	state of the art	++
WTE-plant with dry deasher	+	o coarse fraction: + fine fraction: -	+	-	+	+	1 real size pilot plant 1 plant in erection	o-
SYNCOM	+	+	o	+	o	o	1 real size pilot plant 1 plant in Europe 1 plant in Japan	+
SYNCOM-Plus	+	+ to ++	o	++	o	o	1 real size pilot plant 1 plant in Europe retrofitted	o
WTE-plant + metal separation + plasma-melting-furnace	+	++	--	++	o	-	no plant known	--
WTE-plant + plasma-melting-furnace	-	++	--	++	o	--	no plants in Europe plants in Japan	o-

Legend: ++ very good + good o average o- not average - poor -- very poor

The current technology of **WTE plants** in connection with current slag processing technology (be it internal or external) is still to be considered state-of-the-art with respect to resource and climate protection, given its good energy efficiency, high recovery quotas of iron and non-ferrous (NF) metals. An even better recovery of NF metals can basically be reached by further classification and separation through eddy current or induction separators.

Under the assumption that all other NF metals can be neglected in terms of their amount, relative to copper and aluminum, an improved processing in German WTE plants would yield an additional total amount of NF metals of 17,000 Mg/a, compared to the current recovery quota for NF metals. This amount would correspond to a cumulative energy demand of about 50,000 MWh/a, which represents the energy necessary for the production process based on primary energy sources.

Crushing the coarse fraction prior to a further classification could facilitate an even better separation of NF metals. When proceeding in such a way, however, one needs to avoid the production of non-negligible amounts of mineral fine grain, which could negatively affect the processed slag's properties related to building physics. Moreover, one could produce additional material flows that could not be recovered. Regarding energy and resource protection, such advanced recovery especially of NF metals is, in any case, reasonable. It should be weighed against the disadvantages described above.

The range of eluate for slags that are produced with this technology is in particular due to differences in waste composition. Normally, such a range allows for material recycling consistent with existing recycling requirements. This view is supported by the fact that slugs from WTE plants are currently being used in earthworks, road building and landfill construction on a large scale. The authors of this expertise are not aware of any proven environmental damages that have been caused by using slags from WTE plants as building materials.

Relative to wet deashing, dry deashing has the disadvantage that it produces larger amounts of boiler ashes which need to be disposed of. Moreover, the screened, polluted fine fraction of the slag usually also needs to be disposed with the consequence of potentially higher amounts for disposal when compared with dry deashing. Harmful substances in the fine fraction could be removed through acidic washing, but this produces further waste and effluent streams, and increases the demand for fresh water. For existing fly ash washers – which are widespread in Switzerland, but do not exist in Germany – dry deashing is interesting, though. Here, however, extensive research is necessary regarding additional raw materials and output quality.

Compared to conventional processes, the **alternative processes** for **sintering** or **melting of combustion residues** analyzed here perform partially moderate and partially markedly worse regarding resource and climate protection. The separation of iron and NF metals through downstream processing is feasible with both the SYNCOM and the SYNCOM-Plus processes. The plasma-melting process allows for separating both iron and NF metals from the wet slag prior to feeding the slag into the plasma-melting furnace. This process, however, has the worst energy balance of all processes considered in this expertise. But the SYNCOM and SYNCOM-Plus processes as well have a moderately higher energy demand compared to a conventional WTE plant with wet deashing and dry slag processing.

When comparing the processes “conventional grate firing with metal separation”, “SYNCOM with metal separation”, “SYNCOM-Plus with metal separation” and “conventional grate firing with metal separation and plasma-melting” with respect to climate protection, it becomes clear that plasma-melting ranks worst mainly due to its high auxiliary power demand (figure Z.14).

The respective energy advantage (from net electricity production and contribution through metal recovery) of the three processes relative to conventional grate firing with metal separation is shown in figure Z.14.

Figure Z.14: Comparison of processes regarding climate protection

	WTE-plant + separation of metals	**SYNCOM + separation of metals**	**SYNCOM-Plus + separation of metals**	**WTE-plant + separation of metals + plasma-melting**
energy advantage	about 420 kWh/Mg_{waste}	about 350 kWh/Mg_{waste}	about 340 kWh/Mg_{waste}	0 kWh/Mg_{waste}

Figure Z.13 above, however, also shows the significant advantages of alternative processes. These have been designed to obtain residues with a low environmental impact via a low leachability of pollutants.

The **plasma-melting process** yields the best results for all eluate values; SYNCOM and SYNCOM-Plus are above average. Conventional WTE plants are relatively worse, but they usually meet the German requirements for leachability of slags for recovery.

The relevant aspects of resource conservation (metal separation and water use) are similar for all processes, with the exception being plasma-melting without metal separation.

Slag processing with all processes described above result in a good separation of metals (iron and NF metals).

The relevant differences include, first, aspects of climate protection (energy use and energy production), and second, slag quality (leachability).

Strong climate protection (i.e. a high net electricity output) reduces slag quality (higher leachability values) – and vice versa.