

Recycling of Plastics from Waste Electrical and Electronic Equipment (WEEE) – Tentative Results of a Swiss Study

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Abstract

Although principally favorable from a life cycle environmental impact perspective, recycling of plastics from Waste Electrical and Electronic Equipment (WEEE) is not uncontested because of the potential dissipation of hazardous substances into new products. In a study commissioned by the Swiss Foundation for Waste Management (SENS) and the Swiss Association for Information, Communication and Organization Technology (SWICO), the types of plastics occurring in WEEE products and their hazardous substance contents were identified through a literature survey. Considering the results of the survey, actual mass flows of the Swiss WEEE recycling systems and rough estimations of the value added of recycled plastics, large and small electrical household appliances as well as cooling appliances appear to be the WEEE categories with the highest theoretical recycling potential. However, these results are to be considered as tentative due to remaining data gaps and -uncertainties. A more robust and differentiated picture of the recycling potential of plastics from WEEE product categories will be available as soon as the planned sampling campaign will have been performed.

Keywords: Flame retardants, Plastics, Recycling, RoHS, WEEE

1 Introduction

According to a recently performed life cycle assessment (LCA) study (Hischier, 2009), recycling of plastics originating from WEEE products shows clear advantages compared to the incineration in a municipal solid waste incineration (MSWI) plant. Nevertheless, plastic recycling is not uncontested because of the potential dissipation of hazardous substances contained in recycled plastics, such as flame retardants, or hazardous substances generated during the recycling process, such as polybrominated dibenzodioxins (USEPA 1997). This is expected to be particularly true for plastics originating from Waste Electrical and Electronic Equipment (WEEE) (see e.g. Schlummer et al. 2007, Sepúlveda et al. 2009).

In Switzerland, collection and recycling of the bulk categories of WEEE is managed by three producer responsibility organizations (PROs): The 'Swiss Foundation for Waste Management' (SENS), the 'Swiss Lighting Recycling Foundation' (SLRS) and the 'Swiss Association for Information, Communications and Organisational Technology' (SWICO). In

view of increasing the recycling rates and lowering the disposal costs for plastics fractions, SENS and SWICO commissioned the Swiss Laboratories for Materials Testing and Research (Empa) to carry out a study aiming at answering the following questions:

- Which types of plastics do appear in WEEE product categories, and in which quantities?
- To which extent do the identified plastic types contain hazardous substances?
- Which conditions have to be kept in order to consider plastics recycling unproblematic with regard to hazardous substances?

2 Goals, Scope and Methodology

The study, which focuses on Swiss WEEE recycling system product categories, consists of three phases: In the *first phase* of the study, plastic types used in EEE product categories are identified and their amounts as well as their hazardous substance contents are estimated based on available literature and on existing material flow data for the Swiss WEEE recycling system. Amongst others, the following hypotheses serve as starting points for the analyses:

- For selected WEEE product categories and types a few dominant plastics types can be identified, which theoretically could be fed into materials recycling (hypothesis 1);
- The occurrence of hazardous substances is restricted to particular plastics - and WEEE product types (hypothesis 2);
- The concentrations of some hazardous substances regulated by the EU *directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment* (usually referred to as the 'RoHS directive') in relevant plastic types from WEEE are consistently lower than their respective limit values, so that they do not lead to limitations in materials recycling (hypothesis 3).

In the *second phase* of the study, WEEE product categories and plastics types considered to be relevant according to the first phase are further investigated in a sampling campaign followed by chemical analysis. Finally, in the *third phase* of the study, the results of the previous two phases are synthesized and recommendations are formulated for the recyclers and operators of the Swiss WEEE recycling systems.

The results of the study have been documented in an interim report prepared for SENS and SWICO (Wäger et al., 2008). The following contribution presents selected results from this report.

3 Results and Discussion

3.1 Total plastic shares and - amounts in WEEE product categories

For each of the product categories of the Swiss WEEE recycling systems, the total plastic shares and related annual plastic flows were estimated based on a literature survey and on the mass flows of Swiss WEEE product categories for the year 2007. The mass flow data were provided by the operators of the Swiss WEEE recycling systems (SENS, 2008; SWICO, 2008) and Empa, which is responsible for the evaluation of the material flow sheets completed by the Swiss recycling companies at the end of every year (see i.a. Hirschier et al., 2005, Wäger et al., 2009).

Table 1 shows the identified minimum and maximum values for the total plastic shares per product category, as well as the value which was considered to be the most realistic in an 'educated guess' for both the total plastic shares and the related annual total plastic flows. According to Table 1, for WEEE-categories managed by SENS, the highest total plastic shares are found in small electrical appliances (35%), followed by cooling appliances (30%) and large electrical appliances (25%), whereas the annual total plastic flows are highest for large al appliances (5'200 t), followed by small electrical appliances (4'300 t) and cooling appliances (3'600 t). For WEEE product categories related to the SWICO system, the total plastic shares are highest for liquid crystal display (LCD) - monitors (35%), cathode ray tube (CRT) - television sets (30%) and CRT monitors (30%), whereas the annual total plastic flows are highest for other SWICO devices (3'300 t), CRT - monitors (3'200 t) and CRT - television sets (3'000 t). Total plastic share and annual total plastic flows for other SWICO devices are possibly overestimated because of the great uncertainties regarding the composition of this category. In the near future it is expected that the annual total plastic flows from LCD - monitors will increase significantly at the expense of total plastic flows from CRT - television sets and - monitors.

Table 1: Plastic shares in Swiss WEEE product categories and related annual plastic flows

	plastic share			annual plastic flow (in t)
	realistic	maximum	minimum	realistic
SENS				
Large electrical appliances	20%	13%	36%	5200
Small electrical appliances	35%	20%	55%	4300
Cooling appliances	25%	21%	43%	3600
SWICO				
Mixed consumer electronic devices (without televisions)	28%	23%	34%	1300
Cathode ray tube (CRT) - television sets	30%	15%	38%	3000
Cathode ray tube (CRT) - monitors	30%	13%	38%	3200
Liquid Crystal Display (LCD) - monitors	35%	32%	41%	96
Personal computers / servers	8%	6%	13%	310
Laptops	28%	14%	35%	92
Printers	30%	29%	33%	1800
Large copying machines	7%	6%	9%	390
Other SWICO-devices	28%	15%	40%	3300

3.2 Plastic type shares and - amounts in WEEE product categories

Based on the literature survey, the plastics fractions in the different WEEE product categories considered (see 3.1) were analyzed with regard to the share of different plastic types. Figure 1 exemplarily illustrates the results for PC monitors.

The most common plastic types in computers, PC monitors and other office equipment are ABS, ABS/PC-blend and HIPS. In contrast to ABS, the plastic types ABS/PC-blend and HIPS only have been found in older studies and the two mixed fractions containing monitors and television sets, whereas they did not occur in newer CRT- and LCD-monitors or had not been accounted for separately in the respective studies.

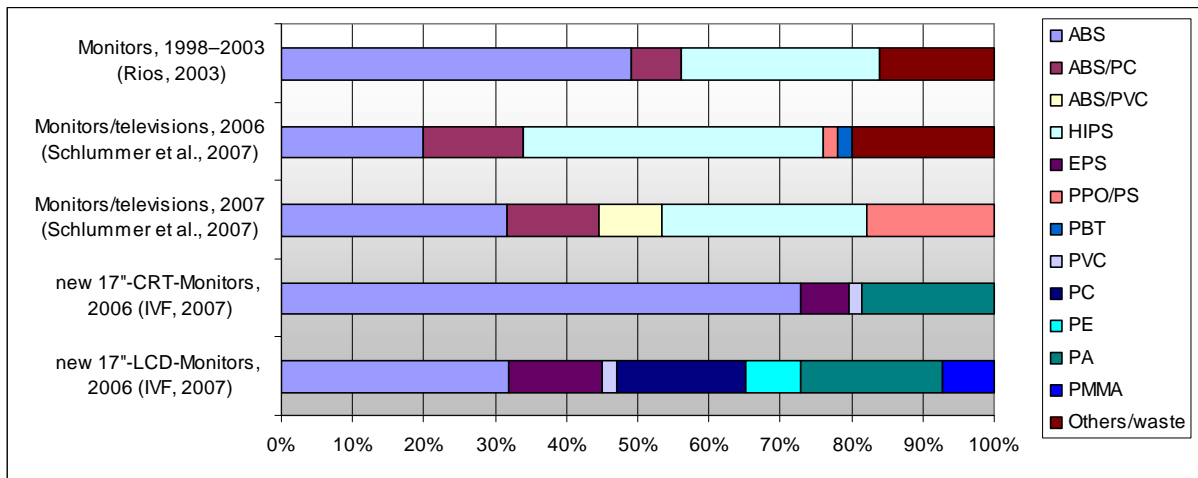


Figure 1: Shares of plastic types in PC-monitors according to different sources (ABS: acrylonitrile butadiene styrene; EPS: extruded polystyrene; HIPS: high impact polystyrene; PA: polyacetate PP; PBT: polybutylene terephthalate; PC: polycarbonate; PE: polyethylene; PMMA: polymethylmethacrylate; PPO: polyphenylene oxide; PS: polystyrene; PUR: polyurethane; PVC: polyvinyl chloride).

When considering the results for the other WEEE product categories, hypothesis 1 reveals to be mostly true. The following plastic types have been identified to be dominant in the different WEEE product categories (in order of decreasing share):

- Consumer electronics including television sets: HIPS and ABS;
- Information technology devices: ABS, HIPS, ABS/PC and PPO/PS;
- Large electrical appliances: PP, PUR, ABS, PS and HIPS;
- Small electrical appliances: PP, HIPS and ABS;
- Cooling appliances: ABS and HIPS, PUR, PP and PVC.

Considering the above-mentioned results and the mass flows of Swiss WEEE product categories in the year 2007, the annual flows of plastic types in all Swiss WEEE product categories were calculated. According to this calculation, in 2007 the most prominent plastic types in Swiss WEEE were ABS and HIPS (6'870 t and 6'570 t, respectively), followed by PP (4'530 t), ABS/PC-blend (2'240 t) and PUR (1'500 t) (see Figure 2).

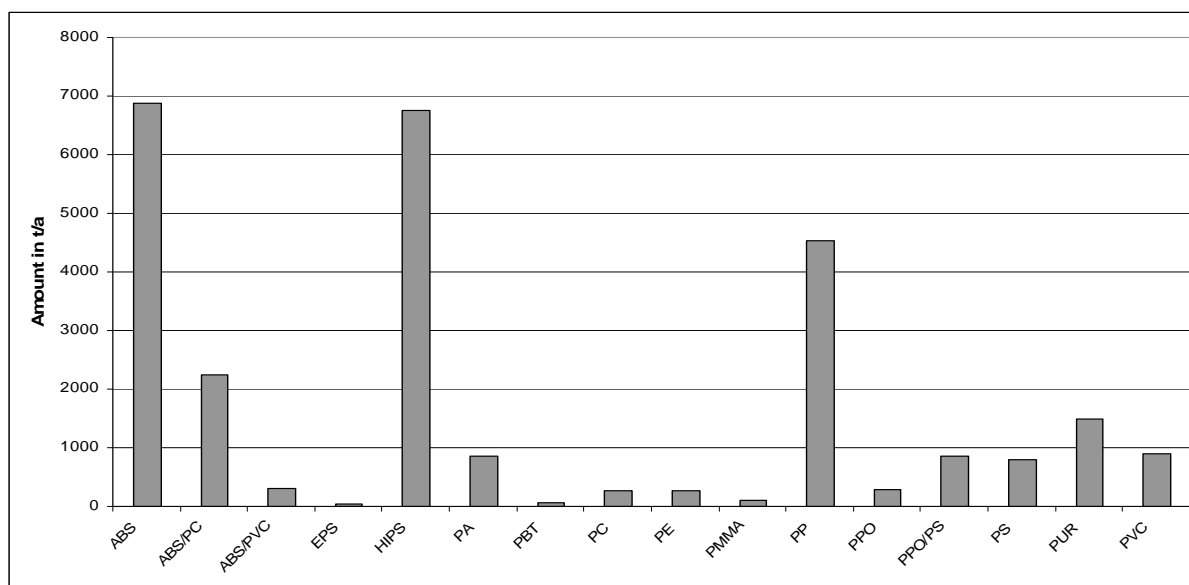


Figure 1: Annual flows of plastic types in Swiss WEEE product categories for the year 2007 (ABS: Acrylonitrile butadiene styrene; EPS: Extruded polystyrene; HIPS: High impact polystyrene; PA: Polyacetate PP: PBT: Polybutylene terephthalate; PC: Polycarbonate; PE: Polyethylene; PMMA: Polymethylmethacrylate; PP; Polypropylene; PPO: Polyphenylene oxide; PS: Polystyrene; PUR: Polyurethane; PVC: Polyvinyl chloride).

3.3 Hazardous substances in plastics from WEEE product categories

For a first appraisal of the hazardous substances content of plastics in WEEE product categories, the concentrations available in literature were compared with the maximum concentration values (MCV) defined in the RoHS directive.

Table 3: Maximum concentration values of hazardous substances regulated in the RoHS directive

	Cd	Cr(VI)	Hg	Pb	PBB	PBDE
Maximum concentration values defined in the RoHS directive, in % by weight	0.01	0.1	0.1	0.1	0.1	0.1

Cd: cadmium; Cr(VI): hexavalent chromium; Hg: mercury; PBB: polybrominated biphenyls; PBDE: polybrominated diphenyl ethers

According to the results of the study by Schlummer et al. (2007), who investigated single television - and PC monitor housings, housing shredder residues and WEEE shredder residues, the concentrations of hexavalent chromium (Cr(VI)) and mercury (Hg) are found to be well below the respective MCV of the RoHS directive. The same is true for lead (Pb), if the slightly elevated value found in WEEE shredder residues is to be attributed to a cross contamination by lead-containing solder and printed circuit boards.

In contrast to these metals, the same study measured cadmium (Cd) in concentrations above and around the MCVs of the RoHS directive. Elevated cadmium concentrations in television - and monitor housings, in particular, have also been found in other studies (Morf et al., 2005 and 2006; Wolf et al., 2001). However, it is expected that as a consequence of the gradual reduction of the application of cadmium based additives in plastics during the last decades, the cadmium content will further decrease (Schlummer et al., 2007).

With regard to flame retardants in WEEE plastics, the following general conclusions can be drawn:

- Decabromodiphenyl ether (Deca-BDE): The MCV is expected to be exceeded in HIPS (in particular: monitor housings, television sets, video devices).
- Octabromodiphenyl ether (Octa-BDE): The MCV is expected to be exceeded in ABS (in particular: monitor housings, television sets, video devices);
- Pentabromodiphenyl ether (Penta-BDE): Except for PUR, the MCV is not expected to be exceeded.
- Polybrominated biphenyls (PBB): The concentrations are expected to be well below the MCV in all plastic types.

The application of Penta-BDE and Octa-BDE is decreasing since the mid 90s. It is expected that this trend will continue, especially due to the implementation of the RoHS directive. For the same reason, a significant decrease in the application is expected for Deca-BDE in the medium- to long-term.

Considering the results of the first phase of the study, hypothesis 2 reveals to be partly true. Especially ABS and HIPS (cadmium, Octa- and Deca-BDE) in electronic devices and PVC (cadmium, hexavalent chromium, lead) could be identified to contain hazardous substances. Electrical appliances typically contain less hazardous substances. Hypothesis 3, finally, reveals to be most probably true for hexavalent chromium, lead, mercury, PBBs and Penta-BDE (with the exception of PVC). More precise assertions are difficult to make due to lack of data and data uncertainties.

4. Conclusions and Outlook

Based on a literature survey, this study has identified plastic types occurring in WEEE product categories, their expected amounts and their hazardous substance contents. The results indicate that approximately 80% w/w of all WEEE are dominated by the plastic types ABS, ABC/PC, HIPS, PP and PUR. Particularly in large and small household appliances and in cooling appliances, but also in other consumer electronics, printers, CRT - monitors and - television sets, these plastic types appear to possess a relevant theoretical recycling potential. On the other hand they are suspected to contain Deca-BDE, Octa-BDE and/or cadmium in concentrations exceeding RoHS limits, while hexavalent chromium, lead, mercury, PBBs and Penta-BDE are more likely to be below the maximum concentration values defined in the RoHS.

Because published data considered in this study are incomplete and reveal uncertainties with regard to the plastic shares in WEEE product categories as well as the hazardous substance contents of plastic types occurring in WEEE products, these interpretations remain, however, tentative. Consequently, to be able to exploit the theoretical recycling potential, the relevant WEEE product categories need to be analyzed more carefully. A sampling campaign aiming at analyzing Deca-BDE, Octa-BDE and cadmium is therefore being set up. The sampling campaign considers mixed categories according to the current recycling practice in Switzerland as well as selected relevant single WEEE categories and - products. The results of the analyses should allow identifying categories and/or products containing critical concentrations of hazardous substances, which in turn would provide the scientific basis for a sustainable recycling of plastics originating from WEEE in Switzerland.

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