> Substance flows in Swiss e-waste

Metals, non-metals, flame retardants and polychlorinated biphenyls in electrical and electronic devices

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> Summary

Current situation, objectives

The composition of waste arising from small electrical and electronic appliances ("e-waste") in Switzerland was studied for the first time in 2003. In the meantime, however, the composition of many appliances has changed considerably, and new restrictions and bans on certain flame retardants have entered into force in the Ordinance on Chemical Risk Reduction (ORRChem, SR 814.81). This report documents the study that was carried out in 2011 which lists the current concentrations and flows for a variety of substances found in e-waste, and compares these with the levels recorded in 2003. The study focused on the following chemical substances:

Tab. 1 > Substances included in the study

Metals and antimony	Non-metals	Organic compounds
Al, Sb, Pb Cd, Cr, Fe, Cu, Ni, Hg, Zn, Sn	Br, Cl, P	Polychlorinated biphenyls: PCB 28, 52, 101, 118, 123, 126, 138, 153, 156, 157, 167, 180, 189 and total PCB content
		Flame retardants: PBDEs (BDE 28, 47, 99, 100, 153, 154, 183, 197, 206, 207, 208, 209) and resulting pentaBDE, octaBDE and decaBDE; HBCDD, TBBPA, decaBB, TBP, DBE-DBCH, PBT, PBEB, HBB, mirex, EH-TBB, BTBPE, BEH-TEBP, DDC-CO, DBDPE, TTBP-TAZ

Procedure

As was the case in 2003, the study was carried out on the premises of Immark AG in Regensdorf. For the 2011 study, around 220 tonnes of e-waste with representative composition were processed at the above facility. Over a two-day period, samples were collected from all product mass flows (outputs) at the facility in accordance with a defined sampling plan, and were aggregated into composite samples on site. The samples were then analysed by the same laboratory as in the 2003 study. For quality control purposes, and in order to attain lower limits of quantification for various flame retardants, some of the samples were also analysed by EMPA (Swiss Federal Materials Testing and Research Laboratories).

To calculate the substance flows, the concentrations of substances that were detected through the analyses of composite samples from the various outputs were multiplied with the output mass flows. The concentrations of the examined substances in the e-waste (inputs) were calculated on the basis of their concentrations in the output mass flows. In this way it was also possible to calculate the transfer coefficients of the inputs into the individual output flows. To calculate the annual material flows, the findings obtained from the study were projected to the 70 000 tonnes of e-waste that is accumulated each year in Switzerland.

Findings and conclusions

Input material

In order to determine the composition of e-waste it is essential to have a representative mix of the mean annual proportion of appliance categories that are disposed of. With the aid of data supplied by SWICO (Swiss Trade Association for Information, Communications and Organisation Technology), SENS (Swiss Waste Disposal Foundation) and EMPA (Swiss Federal Materials Testing and Research Laboratories), the following appliance mix was ascertained:

> Small household appliances (SENS+SWICO): 25%
> Consumer electronics (SWICO): 36%
> Communications equipment (SWICO): 3%
> Data processing and electronic office equipment (SWICO): 36%

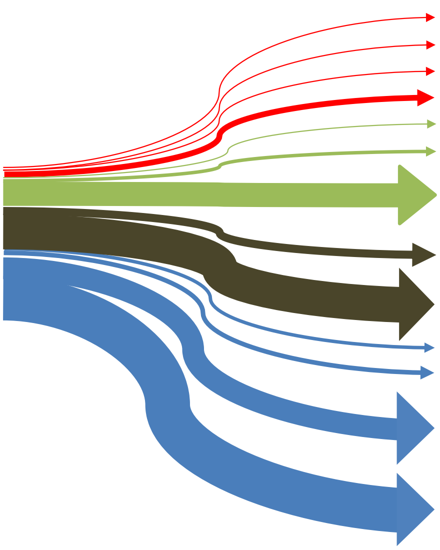
Material and substance flows

The input mix used in the study corresponds very closely to the appliance mix calculated by SENS and SWICO: small household appliances (+3.4 percent), consumer electronics (−18 percent), communications equipment (±0 percent), data processing and electronic office equipment (+4.8 percent).

The distribution of the output mass is roughly as follows: metals, 50 percent; plastics, 30 percent; separated material, 20 percent. Scrap iron accounts for the largest mass flow, followed by fine-grained plastic fractions. 16 percent of e-waste originates from monitor components. The shift on the market towards the use of flat screens means that this figure will constantly decrease. The fractions of scrap non-ferrous metal, fine-grained metal and fine particles that are of particular relevance for the recovery of aluminium (Al), copper (Cu) and other precious metals account for approximately 20 percent of the mass. Figure 1 shows the distribution based on the aggregated output fractions.

Fig. 1 > Distribution of e-waste in the aggregated output fractions

Mass flows 220 t



Output	[-]	[-]
Pollutant carriers	0.00	
Background lighting	0.00	0.05
LCD panels	0.01	
Dust	0.04	
Copper cables	0.01	
Printed circuit boards	0.02	0.19
Monitor components	0.16	
Monitor / laptop casings	0.05	0.28
Fine-grained plastics	0.23	
Fine particles	0.02	
Fine-grained metal	0.03	
Scrap non-ferrous metal	0.14	0.48
Scrap iron	0.29	

Composition of e-waste

Thanks to the carefully compiled input mix and the representative sampling of output flows, it could be anticipated that the results of the analyses would closely correspond to the actual content of the various substances in e-waste in Switzerland.

The three most commonly found metals in e-waste in Switzerland are iron (Fe, 35 percent by weight), aluminium (Al, around 6 percent by weight) and copper (Cu, around 5 percent by weight). The content of all other metals is in the range of up to 1 percent by weight. The content of each of the non-metals covered by the study – phosphorous (P), chlorine (Cl) and bromine (Br) – is in the per mil range of the total input. At above 90 percent, the uncertainty factor for P is very high. This is attributable to the broad range of the measurement results. The most frequently occurring halogenated flame retardants are tetrabromobisphenol A (TBBPA), decabromodiphenyl ether (decaBDE), decabromodiphenyl ethane (DBDPE), 1,2-bis(2,4,6-tribromophenoxy)ethane (BTBPE) and octabromodiphenyl ether (octaBDE). The content of each of these five substances is >100 mg/kg. Their uncertainty factor of around 30 percent reflects the heterogeneous distribution in the fractions. The content of polychlorinated biphenyls (PCBs) in e-waste is around 2 mg/kg (±1 mg/kg). Condensers in electrical appliances are the main source of PCBs in e-waste.

Tab. 2 lists the identified concentrations of the analysed substances in e-waste in Switzerland in 2011.

Tab. 2 > Concentrations of analysed substances in e-waste in Switzerland in 2011

Substance	Mean level and uncertainty [mg/kg]			Substance	Mean level and uncertainty [mg/kg]		
PentaBDE	2.4	±	0.69	Al	62 000	±	9 300
OctaBDE	120	±	33	Sb	1 000	±	100
DecaBDE (BDE 209)	390	±	45	Pb	3 000	±	320
HBCDD	14	±	4.1	Cd	15	±	3.2
TBBPA	630	±	85	Cr	4 500	±	320
DecaBB	4.5	±	2.7	Fe	350 000	±	32 000
TBP*	18	±	1.4	Cu	49 000	±	4 300
DBE-DBCH*	19	±	1.0	Ni	3 600	±	250
PBT*	3.7	±	0.20	Hg	1.5	±	0.15
PBEB*	3.7	±	0.20	Zn	7 900	±	700
HBB	2.9	±	1.7	Sn	2 000	±	220
Mirex*	3.7	±	0.20	Br	4 500	±	510
EH-TBB*	3.7	±	0.20	Cl	6 900	±	1 600
BTBPE	150	±	14	P	530	±	500
BEH-TEBP*	3.7	±	0.20				
DDC-CO	33	±	11				
DBDPE	340	±	200				
TTBP-TAZ	14	±	4.8				
Total PCBs#	2.0	±	1.0				

*Frequently below limit of quantification

In accordance with the Ordinance on Contaminated Sites, the calculation of total PCBs is based on the total of the six PCB congeners 28, 52, 101, 138, 153, 180, multiplied by factor 4.3.

Transfer coefficients indicate which proportions of each substance are transferred during processing to which specific output fractions.

Transfer coefficients

Typical distribution patterns can be identified for each substance (cf. tab. 3):

Tab. 3 > Distribution patterns for the individual substances

Category	Substance	Fraction
Metals and antimony	Al, Zn, Cu	1. Scrap non-ferrous metal, 2. Fine-grained metal
	Cr, Ni	1. Scrap non-ferrous metal, 2. Scrap iron
	Fe	Scrap iron
	Sn	1. Fine-grained metal, 2. Printed circuit boards
	Sb	1. Screen components, 2. Fine-grained plastics
	Pb	Dispersed distribution
	Cd	1. Fine-grained plastics, 2. Pollutant carriers
	Hg	1. Background lighting, 2. Pollutant carriers, 3. Dust
Non-metals	P	1. Monitor and laptop casing, 2. Fine-grained plastic fraction
	Cl	1. Copper cable, 2. Fine-grained plastic fraction, 3. Scrap non-ferrous metal
	Br	1. Fine-grained plastic fraction, 2. Printed circuit boards
Flame retardants	All, except pentaBDE	1. Fine-grained plastic fraction, 2. Monitor and laptop casing
	PentaBDE	1. Dust, 2. Fine-grained plastics
PCBs	All, except PCB 28	1. Dust, 2. Pollutant carriers, 3. Fine-grained plastic fraction
	PCB 28	1. Dust, 2. Fine-grained plastic fraction

In terms of quantity, the three most important elements analysed in e-waste are iron (Fe, 24 000 tonnes p.a.), aluminium (Al, 4300 tonnes p.a.) and copper (Cu, 3300 tonnes p.a.). The quantities of cadmium (Cd) and mercury (Hg) that occur in e-waste are approximately 1 tonne and 100 kg p.a. respectively. With respect to halogenated flame retardants, TBBPA accounts for the largest mass flow (around 40 tonnes p.a.), followed by decaBDE and DBDPE (each around 25 tonnes p.a.). PCBs account for around 140 kg p.a., but because of their highly heterogeneous distribution in appliance components and their low measurement values, a relatively high uncertainty factor (±33 percent) applies to this figure (cf. tab. 4).

Quantities of materials found in e-waste

Tab. 4 > Annual quantities of individual substances for Switzerland, and their uncertainty

Substance	Mean level and uncertainty [tonnes p.a.]			Substance	Mean level and uncertainty [tonnes p.a.]		
PentaBDE	0.16	±	0.057	Al	4 300	±	1 100
OctaBDE	8.4	±	2.8	Sb	69	±	16
DecaBDE (BDE 209)	27	±	6.2	Pb	210	±	47
HBCDD	1.0	±	0.34	Cd	1.0	±	0.30
TBBPA	43	±	10	Cr	310	±	66
DecaBB	0.31	±	0.20	Fe	24 000	±	5 200
TBP*	1.2	±	0.27	Cu	3 400	±	730
DBE-DBCH*	1.3	±	0.27	Ni	250	±	52
PBT*	0.25	±	0.05	Hg	0.10	±	0.023
PBEB*	0.25	±	0.05	Zn	550	±	120
HBB	0.20	±	0.12	Sn	140	±	31
Mirex*	0.25	±	0.05	Br	310	±	71
EH-TBB*	0.25	±	0.05	Cl	480	±	140
BTBPE	10	±	2.3	P	37	±	35
BEH-TEBP*	0.25	±	0.053				
DDC-CO	2.3	±	0.88				
DBDPE	23	±	15				
TTBP-TAZ	1.0	±	0.38				
Total PCBs#	0.14	±	0.046				

*Frequently below limit of quantification

In accordance with the Ordinance on Contaminated Sites, the calculation of total PCBs is based on the total of the six PCB congeners 28, 52, 101, 138, 153, 180, multiplied by factor 4.3.

Proportions in individual output fractions

As can be seen from tab. 5, some elements and compounds are transferred disproportionally to individual output fractions. In the case of some flame retardants as well as PCBs, the proportion of the indicated output fraction is not significantly higher than that of the next most important fraction because of the large uncertainty factor.

Tab. 5 > Proportions in individual output fractions

Category	Substance	Fraction	Proportion	Significant?
Metals	Cd	Fine-grained plastics	55%	Yes
		Pollutant carriers	30%	Yes
	Hg	Background lighting	60%	Yes
		Pollutant carriers	20%	Yes
Flame retardants	DecaBDE	All casings (CRT + LCD)	40%	Yes
	OctaBDE	All casings (CRT + LCD)	40%	No
	TBBPA	All casings (CRT + LCD)	30%	Yesì
	HBCDD	CRT casing	30%	No
	BTBPE	CRT casing	40%	Yes
	DDC-CO	CRT casing	40%	No
	TTBP-TAZ	LCD casing + laptops	45%	No
PCBs	Total PCBs#	Dust	38%	No

In accordance with the Ordinance on Contaminated Sites, the calculation of total PCBs is based on the total of the six PCB congeners 28, 52, 101, 138, 153, 180, multiplied by factor 4.3.

Trend since 2003

The differences in the concentrations of substances in e-waste identified in the studies carried out in 2003 and 2011 permit the conclusion that the applicable restrictions and bans relating to cadmium and persistent organic pollutants (POPs), such as polybrominated diphenyl ethers and PCBs have proved effective. On the other hand, however, it has become apparent that technological developments in the electronics industry and changes in the appliance mix – for example, the introduction of LCD flat screens with cold cathode fluorescent (CCFL) tubes to replace cathode ray tube (CRT) monitors – are likely to change the concentrations of certain substances in e-waste. Thus the concentration of mercury, which is used as a light source in CCFL tubes, in e-waste increased in the period between 2003 and 2011. In the case of some of the analysed substances, changes in concentration were identified that are not significant (cf. tab. 6).

The most notable changes that were identified in e-waste concern pollutant levels. For example, levels of the meanwhile banned substances pentaBDE, octaBDE, and PCBs fell by up to more than 90 percent. These changes are all significant. Among metals, too, pollutants accounted for the most notable changes. While Cd content fell by more than 90 percent, the concentration of Hg increased by more than 120 percent. Because CCFL tubes are removed manually, sorted and disposed of separately, the increase in the concentration of mercury does not go hand in hand with any corresponding emissions. Significant changes were also identified for nickel (Ni), chromium (Cr), antimony (Sb) and tin (Sn), concentrations of which were found to be significantly lower. By contrast, zinc (Zn) and copper (Cu) concentrations were notably higher in 2011. While the levels of Cl and Br were significantly lower, the sharp increase in P due to the high uncertainty factor associated with the measurement levels, was not significant.

Tab. 6 > Changes in concentration since 2003

Substance	Change		Significant?	Substance	Change		Significant?
	[mg/kg]	[%]			[mg/kg]	[%]	
PentaBDE	–32	–93%	Yes	Al	+13 000	+27%	No
OctaBDE	–408	–77%	Yes	Sb	–700	–41%	Yes
DecaBDE (BDE 209)	–120	–24%	Yes	Pb	+100	+3%	No
HBCDD	–3	–18%	No	Cd	–165	–92%	Yes
TBBPA	–770	–55%	Yes	Cr	–5 400	–55%	Yes
Total PCBs#	–11	–85%	Yes	Fe	–10 000	–3%	No
				Cu	+8 000	+20%	Yes
				Ni	–6 700	–65%	Yes
				Hg	+1	+121%	Yes
				Zn	+2 800	+55%	Yes
				Sn	–400	–17%	Yes
				Br	–1 000	–18%	Yes
				Cl	–2 700	–28%	Yes
				P	170	47%	No

In accordance with the Ordinance on Contaminated Sites, the calculation of total PCBs is based on the total of the six PCB congeners 28, 52 , 101, 138, 153, 180, multiplied by factor 4.3.

Recycling potential

In Switzerland, around 24 000 tonnes of iron, 4300 tonnes of aluminium and 3300 tonnes of copper land in electrical and electronic waste each year. This is equivalent to around 2 percent of the total quantity of scrap iron of approximately 1.2 million tonnes per annum. The quantity of scrap aluminium is estimated at around 140 000 tonnes per annum, which means the proportion from e-waste is approximately 3 percent. And in the case of copper, the annual quantity of scrap is around 38 000 tonnes. Here the proportion from e-waste is almost 10 percent.

If these metals are recycled, a great deal of energy can be saved. Through the use of recycled material instead of ores, the potential savings in terms of primary energy are around 95 percent for aluminium, 90 percent for copper and 70 percent in the case of steel.

Pollution situation

The pronounced decline in the average concentration of pollutants in e-waste since 2003 demonstrates that it is possible to bring about a significant change in the situation within just a few years through the introduction of regulatory measures and restrictions, and as a result of technological developments. This applies in particular to pentaBDE, octaBDE and PCBs.

On the input side, the increase in quantity by around 40 percent since 2003 has also had an impact. The flows of substances such as HBCDD or decaBDE, the concentrations of which are lower today, have increased or remained stable versus 2003.

Pending issues and gaps in data

For some fractions, estimates had to be made due to a lack of specific analyses (e.g. high-value and standard printed circuit boards). In other fractions such as batteries and condensers, the significance of the findings is limited because the quantity of the collected samples was low. However, increasing the quantity would have exceeded the specified budget for the project.

In addition, the limits of quantification (LOQ) for measuring the “new” flame retardants and PCBs posed a significant problem. Here, the content in the samples was often below the LOQ. In these cases, the half of the LOQ was considered for carrying out the calculations, and as a consequence, a large number of calculations (e.g. content of PCBs in plastic fractions) may have been overestimated.