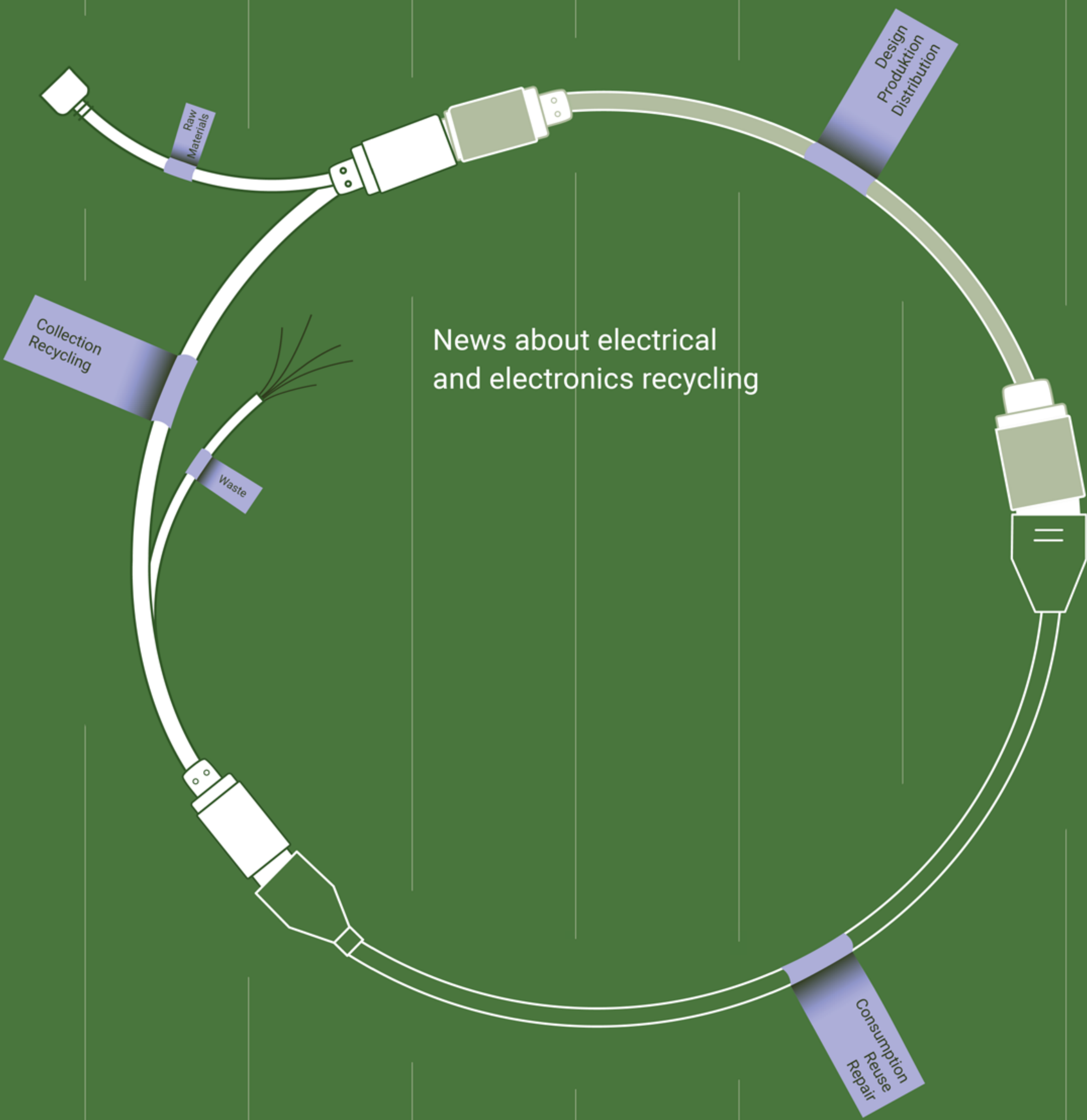
Swico and SENS

TECHNICAL REPORT 2023



News about electrical and electronics recycling

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Swico Recycling is a special fund within the Swico Trade Association and deals exclusively with cost-covering recycling of waste electrical and electronic equipment. Swico aims to extract raw materials and dispose of pollutants in an environmentally friendly way. The focus of Swico is on equipment in the fields of computing, consumer electronics, office equipment, telecommunications, the printing industry as well as measuring and medical instruments, such as copiers, printers, televisions, MP3 players, mobile phones, cameras, etc.

Close cooperation with the Swiss Federal Laboratories for Materials Science and Technology (Empa), a research and service institute for material sciences and technology development within the ETH, plays a crucial role in ensuring that Swico can enforce high and uniform quality standards throughout Switzerland with all waste management services.

SENS eRecycling is an independent, neutral, non-profit foundation that operates under the SENS eRecycling brand. As an expert in the sustainable recycling of waste electrical and electronic equipment in and around the house, lamps and lighting equipment, photovoltaic systems as well as vehicle and industrial batteries, the SENS Foundation makes a significant contribution to setting pioneering benchmarks in eRecycling.

To this end, it works in close cooperation with specialist networks in which the parties involved in the recycling of electrical and electronic equipment are represented. In cooperation with its partners, SENS eRecycling is geared towards ensuring that the recycling of this equipment is compliant with economic and ecological principles.

Recycling as a focal point

Climate change takes the top spot in the Swiss population's worry barometer, which means that public awareness of the ecological footprint of products and services is also growing. It is particularly high when it comes to the manufacture of electrical and electronic equipment (EEE), which is why closing the material cycles is of special importance.

To our delight, the recycling of WEEE is quite rightly becoming a focal point of society and politics. The industry organisations SENS and Swico have an impressive track record that may have received insufficient attention in the past. With increased public interest, we now have the opportunity to publicise our transparency efforts, which include this Technical Report as well as our constant improvements and innovations in the recycling process.

With this in mind, we are looking to the upcoming political developments with confidence. This year, parliament is tackling the revision of the Environmental Protection Act (EPA) with the intention of expanding it to include the principles of the circular economy. SENS and Swico have supported this matter since day one and are examining sensible and targeted measures to round out the closure of the cycles. Due to rising international requirements for the environmentally friendly manufacture of electrical and electronic equipment, the reuse of recycled material will once again become increasingly important.

With the annual Technical Report, we as a private-sector organisation voluntarily fulfil high due diligence and transparency obligations. We hope that all interested readers from society, politics and particularly the administration enjoy this report and find these insights exciting!

Judith Bellaiche
Swico

Pasqual Zopp
SENS

Swico and SENS competent and sustainable

For over 25 years, the two take-back systems Swico and SENS eRecycling have ensured the resource-efficient take-back and recycling as well as the professional disposal of electrical and electronic equipment.

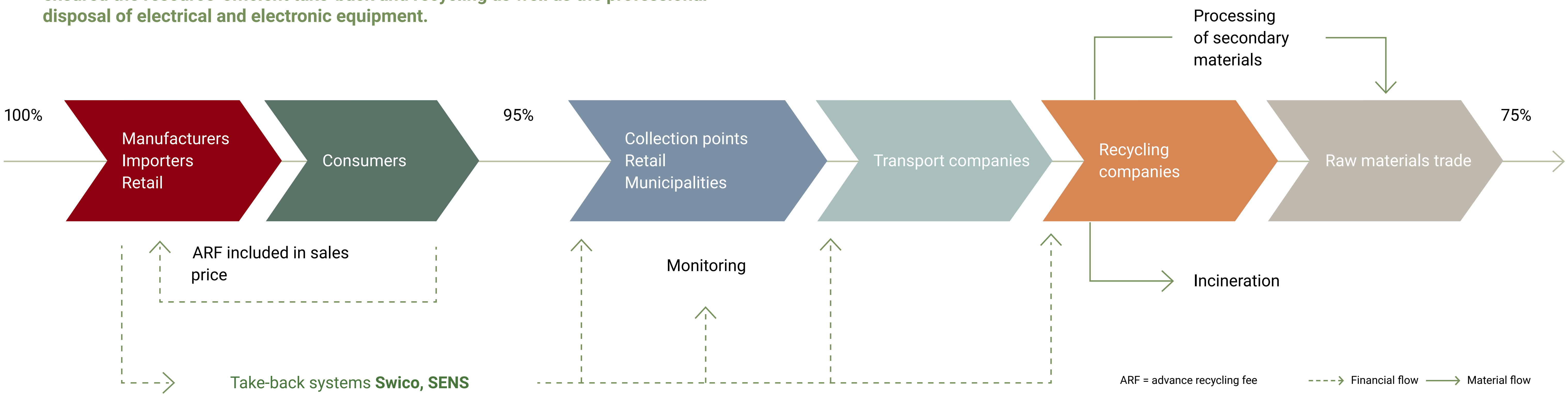


Figure 1: Overview of the take-back systems

There are historical reasons for the existence of two systems: in the early years of institutionalised recycling, industry-specific systems were established. The aim of these was to guarantee proximity to the relevant industry in order to respond to its specific requirements. It also allowed initial reservations about participation in a take-back system, which remains voluntary to this day, to be broken down. Depending on the type of electrical or electronic equipment in question, Swico or SENS is now responsible for take-back systems.

In 2022, the two systems disposed of around 121,000 tonnes of waste electrical and electronic equipment. This means that Swico and SENS have also made a significant contribution to reintroducing valuable resources into the production cycle. With the international networking of the two organisations at a European level – for example as a member of the Forum for Waste Electrical and Electronic Equipment (WEEE Forum) – they also help to set cross-border standards for the recycling of electrical and electronic equipment.

The Ordinance on the Return, Taking Back and Disposal of Electrical and Electronic Equipment (ORDEE) obliges retailers, manufacturers and importers to take back equipment they stock in their product range free of charge. In order to be able to finance sustainable and environmentally responsible recycling of electrical and electronic equipment competitively, an advance recycling fee (ARF) is included in the sales price for this equipment. The ARF is an efficient financing instrument which guarantees that Swico and SENS can ensure proper processing of the equipment in their respective area and continue to face challenges in the future.

Instruction leaflets and recommendations on ballasts and lithium batteries

Heinz Böni and Roman Eppenberger

Last year, recommendations were developed for handling lithium batteries during disassembly in dismantling facilities. These serve to improve occupational health and safety and to protect the environment from harmful effects. In addition, the topic of polychlorinated biphenyls (PCBs) in electrical and electronic equipment was again – or still is – an essential topic at the heart of this work. A separate instruction leaflet was written by the SENS TC for this purpose.

PCBs in ballasts
PCBs are poorly biodegradable pollutants that are dangerous for humans and animals, even in very small quantities. Although the use of PCBs has been banned since 1986, capacitors containing PCBs are still found in waste electrical and electronic equipment (WEEE). They are now mainly found in the ballasts of lighting equipment. Removing these capacitors before recycling WEEE is therefore incredibly important.

PCB-containing capacitors that have been improperly removed from ballasts are one of the most likely reasons behind the continued detection of increased PCB content in the fine fractions from the mechanical processing of WEEE. However, they are difficult to identify. As a result, SENS eRecycling has created an instruction leaflet that outlines how to deal with capacitors containing PCBs[1]. It is an aid for identifying and removing capacitive ballasts with capacitors suspected of containing PCBs. These differ from the electronic ballasts that have no capacitors.

Handling lithium batteries during disassembly
The Swico/SENS TC recently developed and published recommendations in response to recurring questions and uncertainty regarding the handling of lithium batteries (LiBs) during disassembly[2]: WEEE containing LiBs must be disassembled carefully. Short circuits caused by impact, pressure, deformation, perforation, etc., must be avoided. Special dismantling sites must be set up for the removal of LiBs from WEEE. These must be equipped with suitable tools. For LiBs that are potentially hazardous due to damage or a high energy density, the protruding poles must be masked or packed in plastic bags. If a lithium battery is inflated, place it in a container of sand or vermiculite to isolate and insulate it. If pouch cells are discharged in water or a salt solution, precautions must be taken to handle any gases that may be produced and the water must be disposed of as hazardous waste (LVA Code 16 10 01 (S)). If this cannot be verified via analysis, the requirements for discharge into the sewer system must be complied with.

The instructions also provide detailed recommendations for storing the removed batteries.

[1] ↗ 'Umgang mit PCB-haltigen Vorschaltgeräten' (2022) (pdf)
[2] ↗ 'Empfehlungen im Umgang mit Lithiumbatterien bei der Demontage' (2022) (pdf)

Successor solution for the material flow recording tool
As the issuance of the new ORDEE has provided clarity regarding the future of systems and responsibility for auditing, the 'Toocy Succession' project has been resumed.

A catalogue of requirements for the successor solution was developed last year. The objective is to be able to record the material flow data as quickly as possible using the successor solution. There have been no changes among the auditors over the past year.

The audit team currently consists of nine auditors: Andreas Bill, Anahide Bondolfi, Heinz Böni, Manuele Capelli, Stefanie Conrad, Flora Conte, Niklaus Renner, Daniel Savi and Thekla Scherer.

Correct handling of lithium batteries during disassembly. (Photo: Solenthaler Recycling)

Processed volumes slightly decrease

Fabian Elsener and Flora Conte

The volume of waste electrical and electronic equipment (WEEE) processed has been declining since 2020. A key reason for the decline is the miniaturisation of WEEE. In addition, fewer refrigerators, freezers and air conditioners were processed. Volumes of large electrical equipment increased slightly, which was offset by a decline in small electrical equipment.

In 2022, the Swico and SENS recycling companies processed around 121,000 tonnes of WEEE. Compared to the previous year, this represents a 5% decline (see Table 1 and Figure 1). This volume is slightly lower than the long-term average of around 125,000 tonnes. The volume of electronic equipment (-15%) continues to decrease in line with the long-term trend. This is partly due to the decline in heavy cathode ray tubes (CRTs) from computer monitors and televisions. The number of refrigerators, freezers and air conditioners also fell by around 6% compared to the previous year. A slight increase of 2% can be observed for large electrical equipment. The volumes of small electrical equipment decreased in the same ratio.

The volume of photovoltaic equipment processed was exceeded again this year. Alongside the expansion of renewable energies, this is due to the fact that many of the PV modules damaged by hail in 2021 were only recycled in 2022.
The volume of non-ORDEE equipment that is not included in the lists provided in the Swiss Ordinance on the Return, Taking Back and Disposal of Electrical and Electronic Equipment (ORDEE) has decreased by 5% compared to the previous year.

Recovering recyclables
Recyclables are recovered from the processed WEEE and pollutants are separated by means of manual and mechanical processing (Figure 2). Metals make up the quantitatively most significant group of recyclable materials (59%). They're followed by plastic-metal mixtures (21%) and plastics[1] (8%). Cable and glass each account for around 2% of the total quantity of recycled materials. The particularly valuable printed circuit boards account for around 1.1% of the total quantity.

Year	Large electrical appliances	Refrigerators, freezers & air conditioners	Small electrical appliances	Electronic equipment	Lighting equipment	Photovoltaics	Non-ORDEE equipment	Total tonnes/year
2009	30,400	15,300	14,900	47,300	1,100		1,200	110,200
2010	30,700	15,900	15,400	50,700	1,130		3,500	117,400
2011	27,800	16,800	16,300	51,300	1,110		5,200	118,500
2012	30,300	17,500	18,800	55,500	960		6,000	129,100
2013	30,600	16,700	22,300	53,200	1,100		4,000	127,900
2014	29,400	17,200	23,900	52,000	1,100		3,000	126,600
2015	32,900	18,100	25,000	51,900	1,100	100	3,000	132,100
2016	32,500	19,200	27,900	49,000	1,100	100	1,900	131,800
2017	28,100	19,400	26,700	46,000	970	300	1,300	122,800
2018	34,200	19,900	27,600	41,900	1,100	300	1,000	125,900
2019	35,800	19,900	28,700	41,000	1,000	300	1,000	127,600
2020	37,100	20,100	29,800	40,600	1,000	200	1,000	129,800
2021	35,300	20,200	31,300	36,900	1,000	500	1,900	127,100
2022	36,100	18,900	30,700	31,500	1,000	1,000	1,800	121,000
Change compared to the previous year	**2%**	**-6%**	**-2%**	**-15%**	**0%**	**100%**	**-5%**	**-5%**

Table 1: Total volume of processed electrical and electronic equipment in Switzerland in tonnes from the material flow recording system

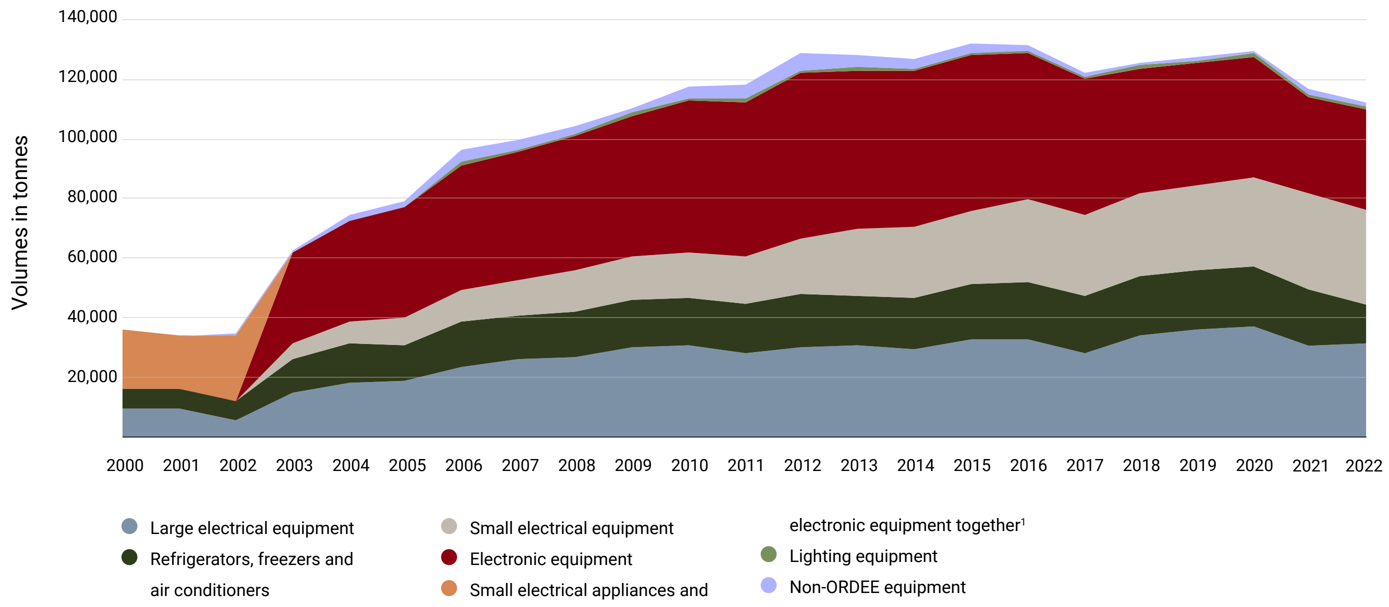


Figure 1: Development of the equipment quantities processed in Switzerland in tonnes

The fractions from the recycling companies are sent for further processing, where they are recycled or utilised thermally. The recycling companies have to provide evidence of material flows to document the further processing of these fractions. Individual downstream recipients are audited by the SENS Swico TC auditors at irregular intervals.

Ferrous metals are processed in Switzerland or the EU. Plastic/metal mixtures are separated further. Individual mixed fractions are still directly used for thermal recycling, although this proportion is constantly decreasing thanks to new processing options. Glass fractions as well as cables, printed circuit boards and batteries are also sent to special recycling operations (often in the EU).

Pollutant removal
The share of pollutants produced accounts for around 1% of the total quantity (Figure 2). In addition to returning recyclables to the material cycle, pollutant removal is one of the main tasks undertaken by recycling companies. The pollutants are either removed manually in dismantling facilities or mechanically separated using specialised processes. For example, capacitors suspected of containing PCBs in large household appliances or ballasts as well as batteries from small WEEE are manually removed.

Pollutant removal and handling must be constantly adapted to changing technologies and the latest findings. Companies must also remain capable of properly removing and disposing of pollutants from older generations of equipment. This places high demands on the work of the recycling companies and necessitates reliable quality assurance systems.

Trends in dismantling
In order to visualise a trend in manual dismantling, Figure 3 shows the quantity of the fractions batteries, capacitors and printed circuit boards relative to the total quantity over the years. It is clear that the proportion of – often manually – separated printed circuit boards is consistently decreasing. This indicates that printed circuit boards are becoming less and less valuable and also that devices are being dismantled less comprehensively before they are mechanically processed.

[1] Plastics include both recycled and non-recycled plastics such as shredder light groups.

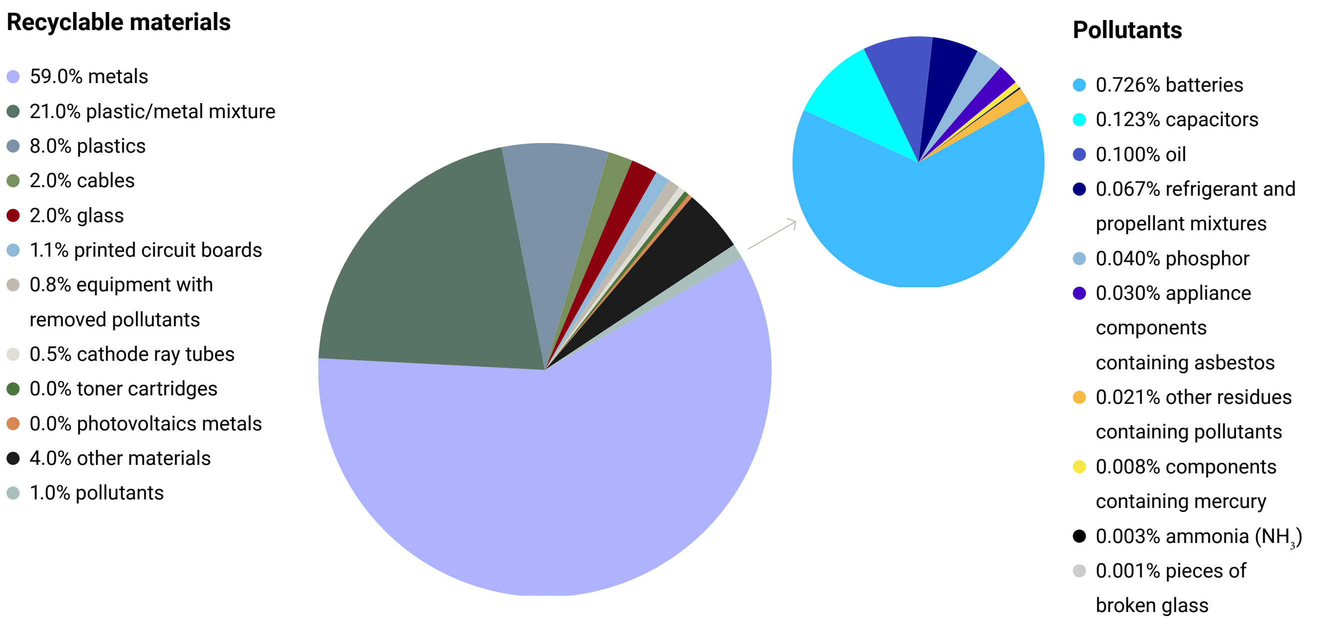


Figure 2: Composition of the fractions produced in % of weight in 2022. Hazardous substances, which make up around 1% of the total composition, are shown in the pie chart on the right.

It is also apparent that the proportion of batteries is rising. Battery-powered devices can be expected to increase. There has been a slight decrease in the proportion of removed capacitors over the last three years.

Development among electronic equipment
Swico regularly inspects the quantities and the type of returned electronic equipment. To this end, it conducts market basket analyses and performs product group processing tests (Table 2). In 2022, Swico took back 40,085 tonnes of electronic equipment, which is 7% less than in the previous year.

The weights and quantities of CRT monitors and televisions taken back are still in decline, thus continuing the long-term trend. The weight of FPD monitors and televisions taken back fell by around 10% compared to the previous year, although the number of units only fell by 3%. The number of mobile phones and consumer electronics continues to rise. However, as the average weights of mobile phones and consumer electronics have fallen, the result has been a drop in weight of almost 10% and 6% respectively. For the remaining groups such as PCs, laptops, printers, photocopiers and other IT equipment, the collected weight decreased, which can be attributed to a decrease in the unit quantity. The composition of the individual equipment categories is determined by processing tests carried out by Swico Recycling companies. During these, a predetermined volume of equipment is collected and the fractions resulting from the processing activities are documented. The detailed take-back quantities of electronic equipment and its composition are listed in Table 2.

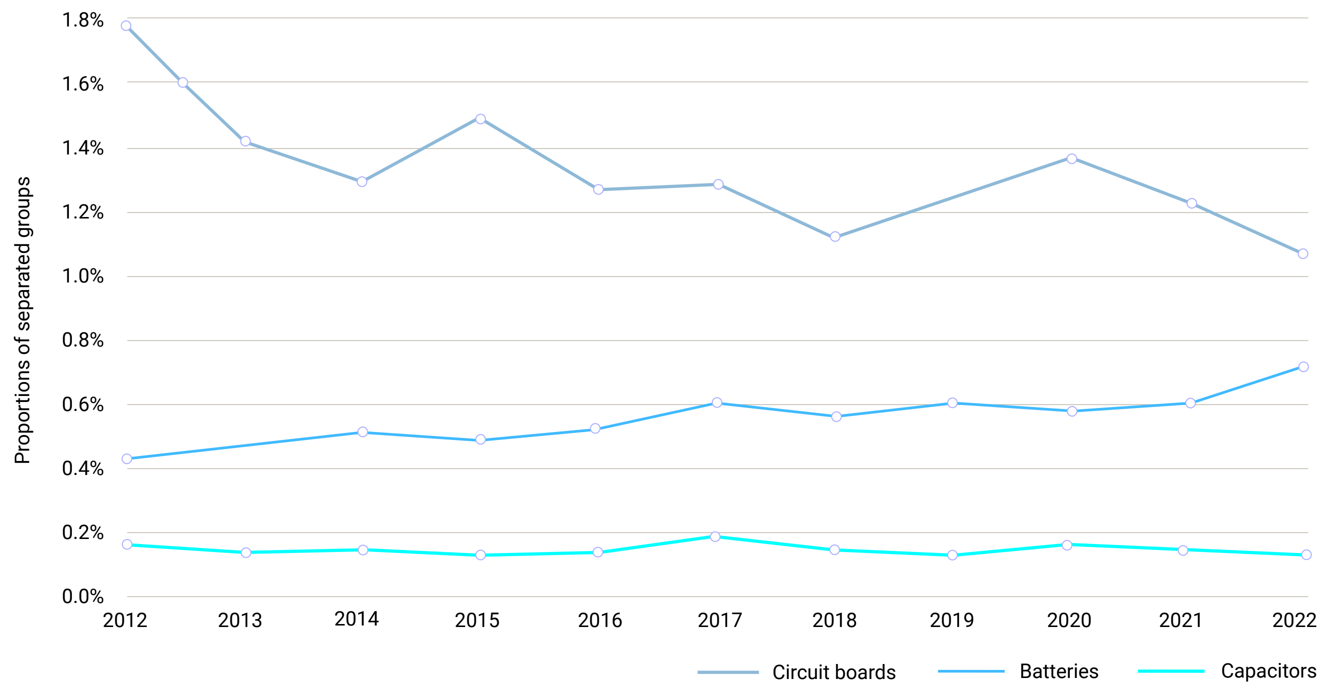


Figure 3: Development of the separated batteries, capacitors and circuit printed boards relative to the total quantity

Equipment type	Quantity[4]	Average weight	Metals	Plastics	Metal/ plastic mixtures	Cables	Glass and/or LCD modules	Printed circuit boards	Pollut- ants	Others[5]	Total	Increase/ decrease compared to 2021
	in thousands	in kg	in tonnes	in tonnes	in tonnes	in tonnes	in tonnes	in tonnes	in tonnes	in tonnes	in tonnes	
PC monitors, CRT	9	17.0	22	30	14	4	65	13	0	1	150	-9%
PC monitors, FPD[1]	521	6.5	1,206	1,207	73	42	501	239	35	84	3,387	-12%
PCs/servers	325	11.0	2,940	207	10	109		298	11		3,575	-5%
Laptops	443	2.2	286	285	100	5	86	142	67	4	975	-12%
Printers	422	10.8	1,615	2,452	281	25	31	79	1	74	4,558	-9%
Large-scale copiers and equipment	32	137.3	2,390	164	1,570	79	3	36	38	112	4,392	-8%
IT, mixed[2]	867	2.4	1,112	77	767	37	2	16	18	52	2,081	-3%
CRT TVs	38	25.9	97	201	33	3	635	12	1	1	982	-9%
FPD TVs	350	22.9	3,873	1,442	845	110	703	673	89	279	8,015	-6%
Consumer electronics, mixed[3]	3,760	2.6	5,271	359	3,552	179	5	77	85	249	9,776	-6%
Mobile phones	1,015	0.1	22	47			7	29	27		132	-11%
Remaining phones	1,100	1.7	1,017	67	673	34	1	15	16	47	1,870	-7%
Photo/video	218	0.7	73	5	53	3	0	1	1	4	142	-11%
Dental											52	-20%
Total in tonnes			**19,926**	**6,543**	**7,969**	**630**	**2,039**	**1,630**	**389**	**907**	**40,085[6]**	**-7%**
Total in per cent			**50%**	**16%**	**20%**	**2%**	**5%**	**4%**	**1%**	**2%**	**100%**	

[1] FPD: flat panel displays, different technologies (LCD, plasma, OLED, etc.)
[2] IT equipment, mixed, not including monitors, PCs/servers, laptops, printers, large-scale copiers and equipment
[3] Consumer electronics, mixed, not including televisions
[4] Projection
[5] Packaging and other waste, toner cartridges
[6] This figure is greater than the 31,500 tonnes of electronic equipment in Table 1 as it also includes equipment disposed of by A-signatories under direct contracts. In addition, the quantity processed can be seen in Table 1 and the quantity collected here.

Table 2: Swico volumes collected and composition by type of equipment (2022)
Source: Fabian Elsener, Carbotech, based on Swico processing and market basket analyses (2022)

The recycling of electronic equipment contributes significantly to climate protection

Heinz Böni

The constantly accelerating progress of social and technological development goes hand in hand with a high consumption of raw materials. As a result, our infrastructure and consumer goods become reservoirs of raw materials that are extracted from the earth during the manufacture of products using energy-intensive and environmentally harmful methods. In this light, the importance of recovering raw materials and reintroducing them into the production cycle becomes a crucial task. 'Urban mining' is absolutely necessary to reduce the consumption of raw materials. Swico, the trade association of the ICT and online industry in Switzerland, makes a significant contribution to closing material cycles and reducing the consequences of climate change by recycling waste electronic devices.

This coming year, the recycling of waste electronic devices in the Swico Recycling system will celebrate its 30th anniversary. With the systems from Swico and SENS, Switzerland is a pioneer in Europe. It began making the manufacturers of electrical and electronic equipment take accountability early on and before there was a legal obligation to do so. The aim was to have them assume greater producer responsibility by taking back and recycling the equipment.

What started at Swico in 1994 with just a few companies is now a take-back system with 620 Convention signatories, 600 official collection points, 6,000 dealer return points and currently around 43,000 tonnes of collected equipment per year. Swico works with eight recycling partners across Switzerland to process the electronic equipment. They are affiliated with around 80 dismantling facilities that remove potentially hazardous components as well as valuable components such as printed circuit boards from the equipment. In total, around 2,000 jobs[1] have been set up throughout the take-back system, including management, logistics and auditing roles. This results in a sophisticated network of partners that manages the urban electronic equipment mine. The two main objectives are the recovery of valuable raw materials from the equipment and the environmentally friendly disposal of the components that contain pollutants. These objectives also make a significant contribution to reducing CO_2 emissions by returning various metals and plastics to the production cycle.

Large amounts of recovered metals and plastics

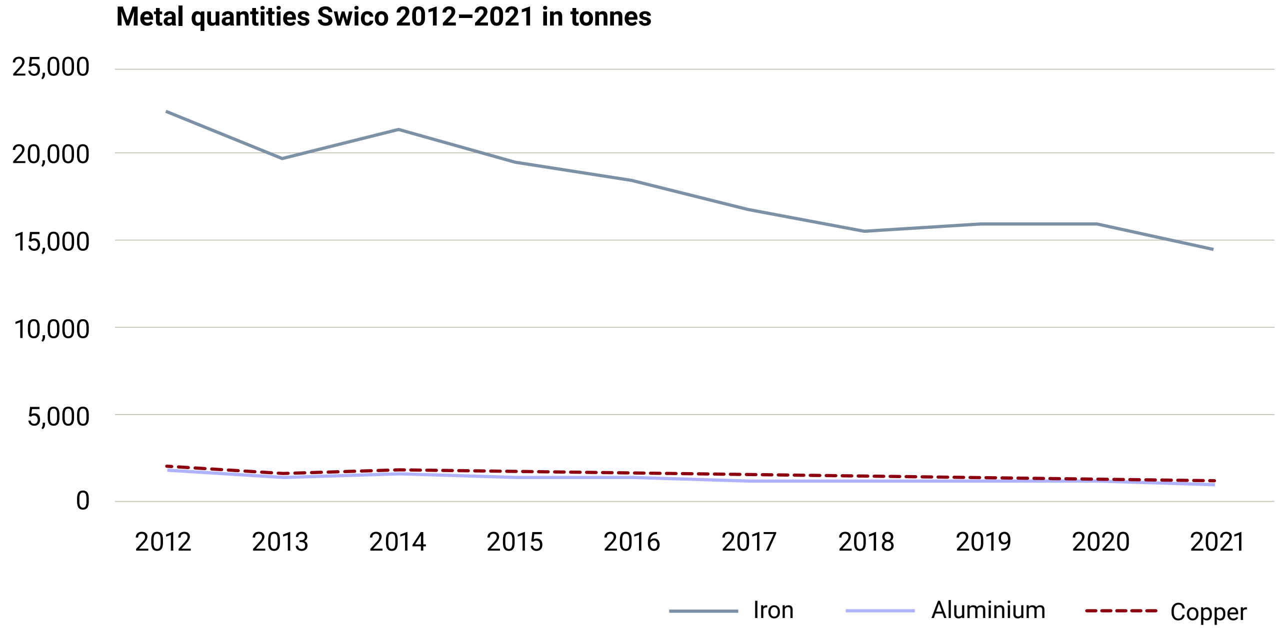
Vital raw materials were recovered from the 46,000 tonnes of electronic equipment collected in 2021 (see Table 1)[2].

- Over 16,000 t industrial metals such as iron, aluminium and copper
- Approx. 4,700 t reusable plastics
- Approx. 1 t precious metals such as gold, silver and palladium

When you look at a period of ten years (2012–2021), you can see enormous amounts of recovered metals and plastics.

- 196,000 t iron (equates to ten Eiffel Towers)
- 15,500 t aluminium
- 16,600 t copper (equates to 106 KKL roofs)
- 55,000 t recyclable plastics
- 1,600 kg gold (equates to 410,000 wedding rings)
- 8,300 kg silver

Figure 1 shows the course of the recovered industrial metals iron, aluminium and copper as well as the most important precious metals gold, silver and palladium over a period of ten years.



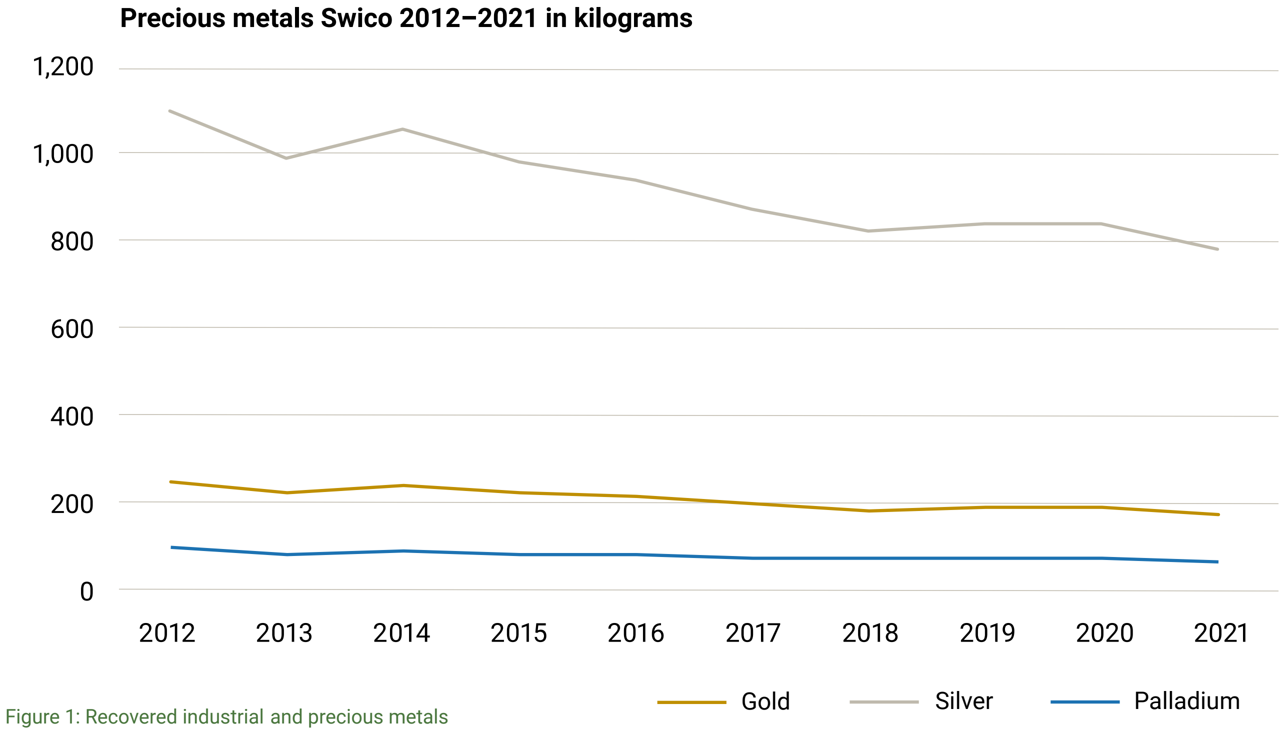


Figure 1: Recovered industrial and precious metals in the Swico system 2012–2021

[1] Rough estimate
[2] Data from batch tests and annual statistics (cf. Swico Technical and Annual Reports)

Eliminating pollutants from the cycle
Components containing pollutants are also removed from the equipment. In 2021, these included (see Figure 2)[3]:

- Approx. 263 t batteries
- Approx. 63 t capacitors with potentially environmentally hazardous substances
- Approx. 8 t components containing mercury from backlights
- Approx. 91 t lead glass from old CRT displays

Over a period of ten years, this equated to a total of around 2,800 t of batteries, 750 t of capacitors, 6,600 t of lead glass and 44 t of components containing mercury.

Recycling as a key contribution to reducing CO_2 emissions
The contribution of recycling to reducing CO_2 emissions is huge. Through the recovery of the metals iron, aluminium, copper, gold, silver and palladium, which replace primary raw materials, around 3 million tonnes of CO_2 emissions were theoretically[4] saved in 2021 (see Table 1). This corresponds to approximately one fifth of the CO_2 emissions from transport fuel emissions in the same year[5]. This estimate does not include other metals or plastics. The positive environmental impact of the removal and environmentally friendly disposal of the components that contain pollutants must also be taken into account.

Components containing pollutants disposed of via Swico 2012–2021 in tonnes

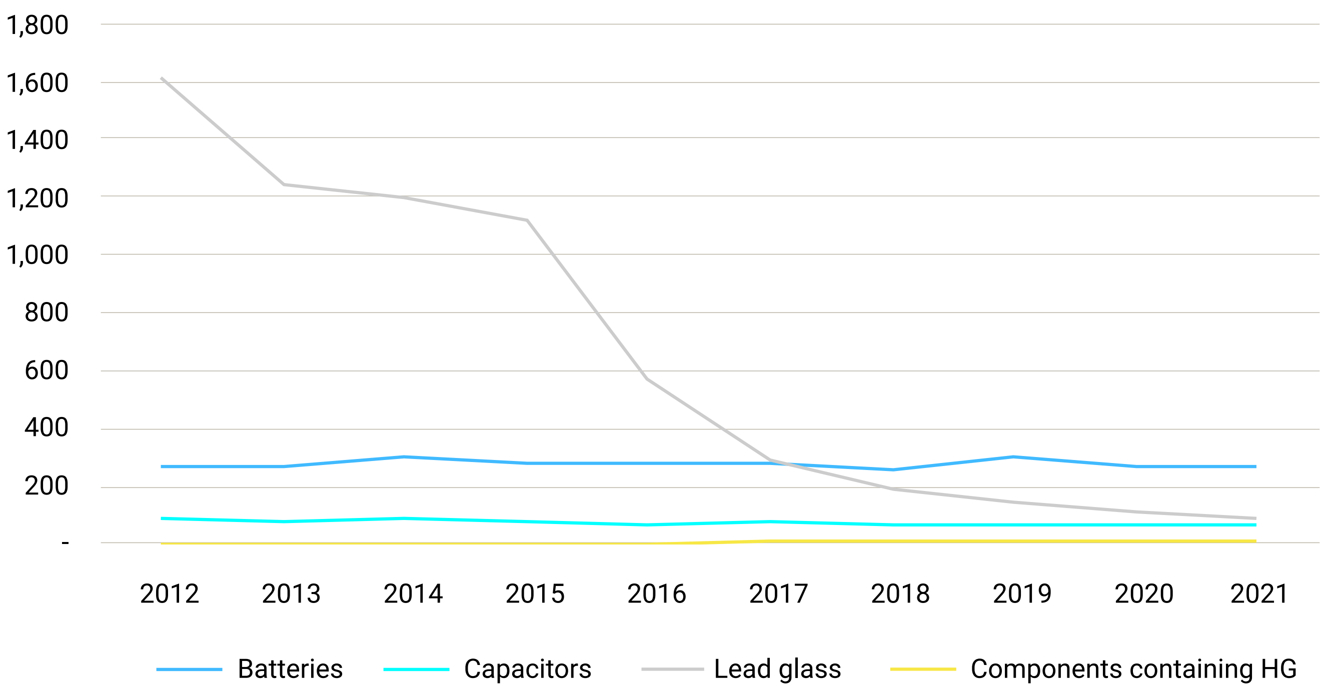


Figure 2: Components containing pollutants disposed of in the Swico system 2012–2021

[3] The calculated proportion of components containing pollutants corresponds to the national average in Switzerland (including SENS equipment).
[4] The CO_2 emissions from recycling were not taken into account as these are smaller than those from the primary mining of the metals by several orders of magnitude.
[5] Source: Federal Office for the Environment, 14.81 million t CO_2 were emitted by traffic in 2021.

CO_2 savings from metal recovery in 2012–2021 in (t CO_2-eq) excluding gold

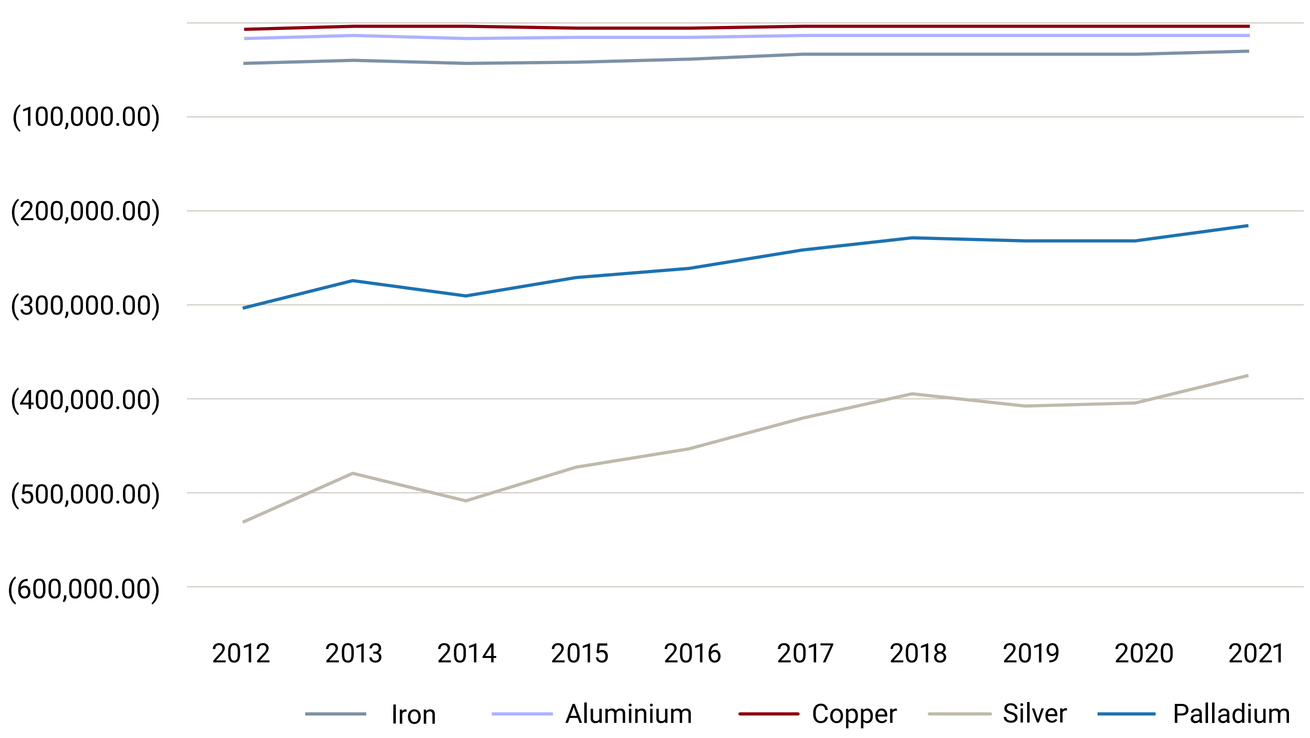


Figure 3: CO_2 savings due to the recovery of the most important secondary raw materials in the Swico system 2012–2021 (excluding gold; gold alone constitutes around 80% of the CO_2 savings)

		2021	
Iron	[t CO_2-eq]	-30,822.78	1.02%
Aluminium	[t CO_2-eq]	-9,320.94	0.31%
Copper	[t CO_2-eq]	-1,882.18	0.06%
Gold	[t CO_2-eq]	-2,405,249.52	79.26%
Silver	[t CO_2-eq]	-373,005.64	12.29%
Palladium	[t CO_2-eq]	-214,337.51	7.06%
CO_2 savings		**3,034,619.00**	

Table 1: CO_2 savings due to the recovery of the most important secondary raw materials in the Swico system 2012–2021 (including gold)

Figure 3 shows the course of the CO_2 savings in the Swico system over the last ten years.

Around two-thirds of raw materials go back into the production cycle
In Swico's take-back system, around 66% of the included materials are returned to the production cycle as secondary materials. This particularly includes copper, aluminium and iron, as well as precious metals such as gold and other dispersed metals. Of the remaining 34% (mainly plastics), 80% is used to generate energy. About 7% of the total amount has to be disposed of for good.

Material recovery and recycling rates for flat panel displays

Manuele Capelli and Heinz Böni

In Switzerland, VDUs have been professionally collected and recycled for almost 30 years. This allows for the recovery of valuable raw materials and the disposal of pollutant-containing components. To determine the quality of the processing of electronic equipment, batch tests are carried out at recycling companies as part of the Swico industry solution. These tests provide information about the recycling potential of such equipment.

Ever since CRT displays were superseded by flat panel displays (FPDs), there has been a continuous evolution in flat panel display technology. First-generation FPDs contain CCFL tubes as backlights. CCFL stands for cold-cathode fluorescent lamp. They are thin, oblong glass tubes that emit a white light and are built into the back of the screen. These devices have been superseded by LED-backlit FPDs that use LEDs – light-emitting diodes – for illumination. OLED devices, which are equipped with organic LEDs, are the latest technology.

Removal of pollutants

Something that doesn't really matter to the user of a PC monitor or television is actually extremely important when it comes to processing. The glass tubes of CCFL FPDs contain the extremely toxic pollutant mercury. As detailed in the 2020 Technical Report, the amount of mercury in such televisions is estimated to lie between 64 mg and 200 mg. To ensure that the mercury is not released and does not come into contact with the other components, the glass tubes must be either manually removed or processed at a partially or fully mechanical plant. The mercury can thereby be separated from the other materials in a controlled manner via a closed process. In Switzerland, manual removal takes place in specially set up dismantling facilities for WEEE. There is no mercury in LED or OLED flat panel displays. The removal of pollutants and the resulting environmentally friendly processing make up a significant proportion of the recycling costs. Collection of the advance recycling fee ensures the financing of correct processing.

Mechanical processing

The FPD screens with the mercury removed, as well as mercury-free LED and OLED screens, can be mechanically processed at a specialised recycling plant operated under negative pressure: they are shredded and mechanically/visually separated into various groups of recyclables. These are transported to recovery plants. For example, a fraction containing virtually pure iron is shipped to a steel mill to recover secondary iron.

Material flows and components

As shown in Figure 2, screens are made up of a number of components such as iron, aluminium, copper, printed circuit boards containing gold and silver, and various high-quality plastics such as a plexiglass sheet. All these materials are recovered in the Swico system. Plastics contaminated with pollutants and liquid crystal displays are technically not recyclable and are incinerated in a waste incineration plant. Components such as capacitors and CCFL tubes that contain pollutants are destroyed in an environmentally friendly manner. Overall, 60% to 80% of the screen material is returned to the material cycle. The recovery rate for the metals iron, aluminium and copper is over 90%. Around 40% to 60% of plastic volumes can be recycled due to the use of flame-retardant additives.

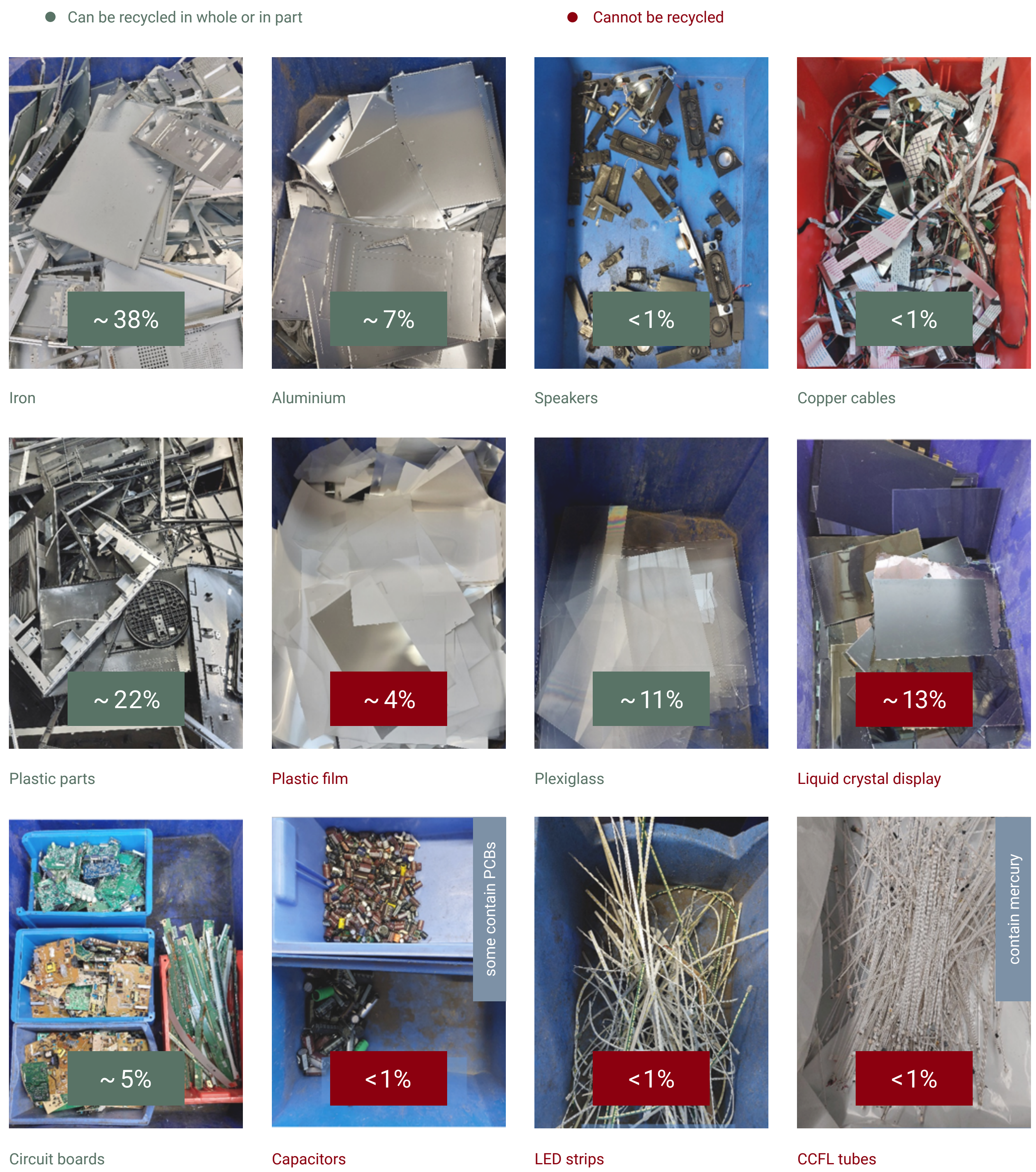


Figure 2: Composition in weight percentage of flat panel displays, mean values from 73 LED devices and 177 FPDs with CCFL devices, source: 2022 Altola AG batch test

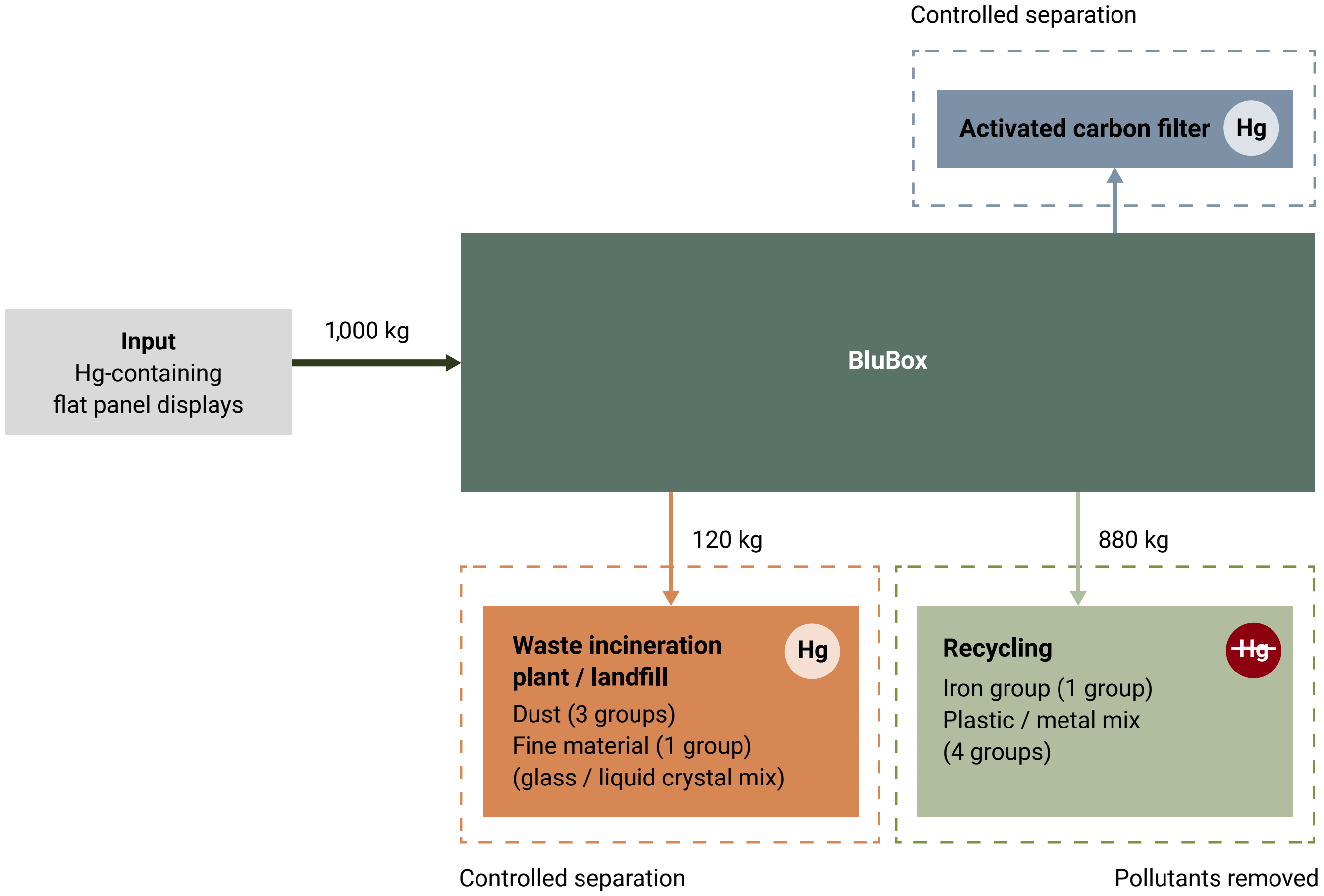
Introduction, optimisation and approval of a new recycling plant

Andreas Bill, Heinz Böni and David Wampfler

Backlights containing mercury pose a major challenge in the further processing of flat panel display units. The mercury is usually contained in delicate glass tubes. These are manually removed at the dismantling facilities throughout Switzerland, which involves a lot of work, and sent as a separate fraction for professional disposal. In search of a more efficient process, Roger Blesi, director of Thévenaz-Leduc SA, a subsidiary of the BAREC Group, commissioned a third-generation BluBox plant in 2020. This enables fully mechanical processing.

Figure SEQ figure * ARABIC 1: the THL BluBox plant in Moudon, Vaud

WEEE recycling in Switzerland is carried out in accordance with the SN EN 50625 standard. This stipulates that components containing pollutants must not be damaged or destroyed during the removal of pollutants, unless the released pollutants can be separated out into a distinguishable stream during processing. Mercury emissions in the form of gas or dust occur during the fully mechanical processing of flat panel displays. These are highly mobile and could end up in the environment or among the recyclable fractions. To prevent this, the screens are shredded under negative pressure at the new plant and the air flow is purified using activated carbon and HEPA filters. According to the manufacturer's information, this enables compliance with all standard specifications.



Independent conformity assessment
Approval of a new plant in the Swico-SENS recycling system is not only based on the information provided by the manufacturer, but also requires an inspection by the responsible conformity assessment body. The first audit with a batch test took place in September 2020. The operational specifications were checked during the audit, whereby SUVA, among others, was also involved. The batch test was run as a stress test. Only screens containing mercury (no plasma or LED screens) with a share of 75 percent by weight of TV sets were used as input material. This simulated an extreme situation to ensure that the plant can also handle an above-average input of pollutants. Samples from all initial groups were taken during processing and then sent to the laboratory for analysis. Two criteria were used to assess whether the pollutant was discharged in a compliant manner:

1. Pollutant limit of 0.5 mg mercury per kg in the finest, shredded mixed fraction where pollutants have been removed. According to the standard, this must be sampled as a reference fraction to check that the pollutant removal is sufficient.

2. Consistent separation of mercury in the intended target fractions via activated carbon filter, powdering and fine fraction (see Figure 2).

Results

Criterion 1: The results of the laboratory analyses showed that the Hg limit value of 0.5 mg/kg was exceeded in the finest and two other mixed groups where the pollutants had been removed.

Criterion 2: The efficiency of the activated carbon filter is continuously checked and ensured by measuring the exhaust air. However, it is not possible to balance the separation performance. To ensure consistent pollutant separation, the mercury that is not caught in the activated carbon filter must be concentrated in the intended fine fractions. An uncontrolled distribution to the recyclable fractions is not permitted. The inspection of the consistent pollutant separation is based on a comparison of the measurable mercury discharge in fractions where pollutants have been removed and fractions that contain pollutants (without activated carbon filter). The laboratory analyses showed that only 33% of the mercury that is not separated via the activated carbon filter is concentrated in the intended fine fractions, while 67% remains in the recyclable fractions.

Recycling and recovery rates: in addition to the pollutant removal performance, the recycling and recovery rates should also be calculated in the batch test to determine whether the fully mechanical process achieves the corresponding guide values. A recycling rate of 66.7% and a recovery rate of 84% were achieved during the batch test. These values are above the guide values for flat panel displays in the Swiss system (65% and 75% respectively).

The results of the batch test showed that the fully mechanical process has good recycling and recovery rates, but that the mercury-containing dust in particular is insufficiently concentrated in the intended fractions. As a significant mercury discharge occurs on the recyclable material groups, the plant could not be deemed compliant at this point in time.

Optimisation work
As of March 2021, under the direction of David Wampfler, Thévenaz-Leduc (THL) set about optimising and further developing the plant. Three months later, the plant was ready for another batch test. The air flow at material inlets and outlets had been optimised. Electrostatic charges could be neutralised, thereby removing adhered dust from the plastics. In addition, measures were taken to improve humidity control and other adjustments were made to the plant operation. In July 2021, another stress test was carried out on the optimised plant. The results were impressive: the Hg limit value was easily reached in all fractions where pollutants had been removed (0.15 mg/kg to 0.33 mg/kg) and the separation performance had been significantly increased. After the main pollutant removal via activated carbon filter, an additional 80% of the residual mercury could now be separated, compared to the previous value of 33%.

Approval and continuous monitoring
Based on the results of the second batch test, the plant was approved for regular operation in August 2021 by Swico's conformity assessment body. The prerequisite was that the plant be included in the annual audit process and that batch tests be carried out regularly. Since then, a joint Swico-SENS audit has been taking place in Moudon as the plant also processes lighting equipment containing Hg and LEDs in addition to flat panel displays. During the audit, the plant operator also communicates the latest findings from day-to-day operations and discusses these with the auditors.

THL's own tests had shown that the parallel processing of lighting equipment in the spatially separate mixer of the plant while the screens were being shredded could improve the pollutant removal from the lighting equipment. During the 2022 audit, it was agreed that this should be comprehensively examined through a joint Swico-SENS batch test. The batch test was, as before, carried out as a stress test in March 2023. As an addition, two tonnes of rod-shaped lighting equipment were processed in the mixer while the screens were being shredded. The recycling rate for flat panel displays was 68%; the recovery rate was 82%. Compliance with the mercury limit for the recyclable material fractions is also still achieved, but the values were slightly higher than in 2021. For a possible approval for parallel processing, it must be possible to rule out cross-contamination in the recyclable fractions of the flat panel display processing. With the current data, this cannot yet be conclusively assessed. Further clarifications are therefore currently taking place in close cooperation with the conformity assessment body.

Final fractions and primary material for further processing on the visual sorting plant

Conclusion
With the aim of full mechanical processing of mercury-containing flat panel displays, THL took on a major challenge. The road to the approval of the new plant by Swico's conformity assessment body was long and rocky as the plant did not meet the requirements of the SN EN 50625 standard in the condition in which it was purchased from the manufacturer. Thanks to a high level of dedication and numerous optimisations, the separation of pollutants could be significantly increased and the specially adapted BluBox started operation in mid-2021. This is a success for both THL and the Swico-SENS recycling system – thanks to its control mechanisms, the quality of the processing could be ensured without restricting innovation in recycling.

Complex processing for the recovery of climate-damaging gases from temperature exchange equipment

Niklaus Renner and Thekla Scherer

In 2022, more than one-third of a million temperature exchange equipment foamed with polyurethane (PU) were processed in an environmentally friendly manner at one of the three large recycling plants in Switzerland. In addition, around 50,000 'Stage 1' appliances such as non-insulated dehumidifiers or heat pump tumblers were processed.

Development of appliance types in recycling
Overall, the number of processed polyurethane-foamed appliances fell by 8% to 342,000 in 2022, while the number of 'Stage 1' appliances such as tumble dryers, dishwashers, dehumidifiers or air conditioners remained roughly constant compared to the previous year at 53,000.
A total of 18,800 tonnes of temperature exchange equipment was processed in an environmentally friendly manner.

High-tech processing in two stages
In the first stage, oil and the gaseous refrigerant in the compressor and refrigeration circuit of the temperature exchange equipment is extracted via suction with a tong or drilling head system. Capacitors and (now rare) mercury switches are removed manually. A plant module of the first stage essentially consists of vacuum pumps and chillers, an oil degassing unit and the compressed gas line system for transferring the refrigerant mixture to compressed gas tanks.

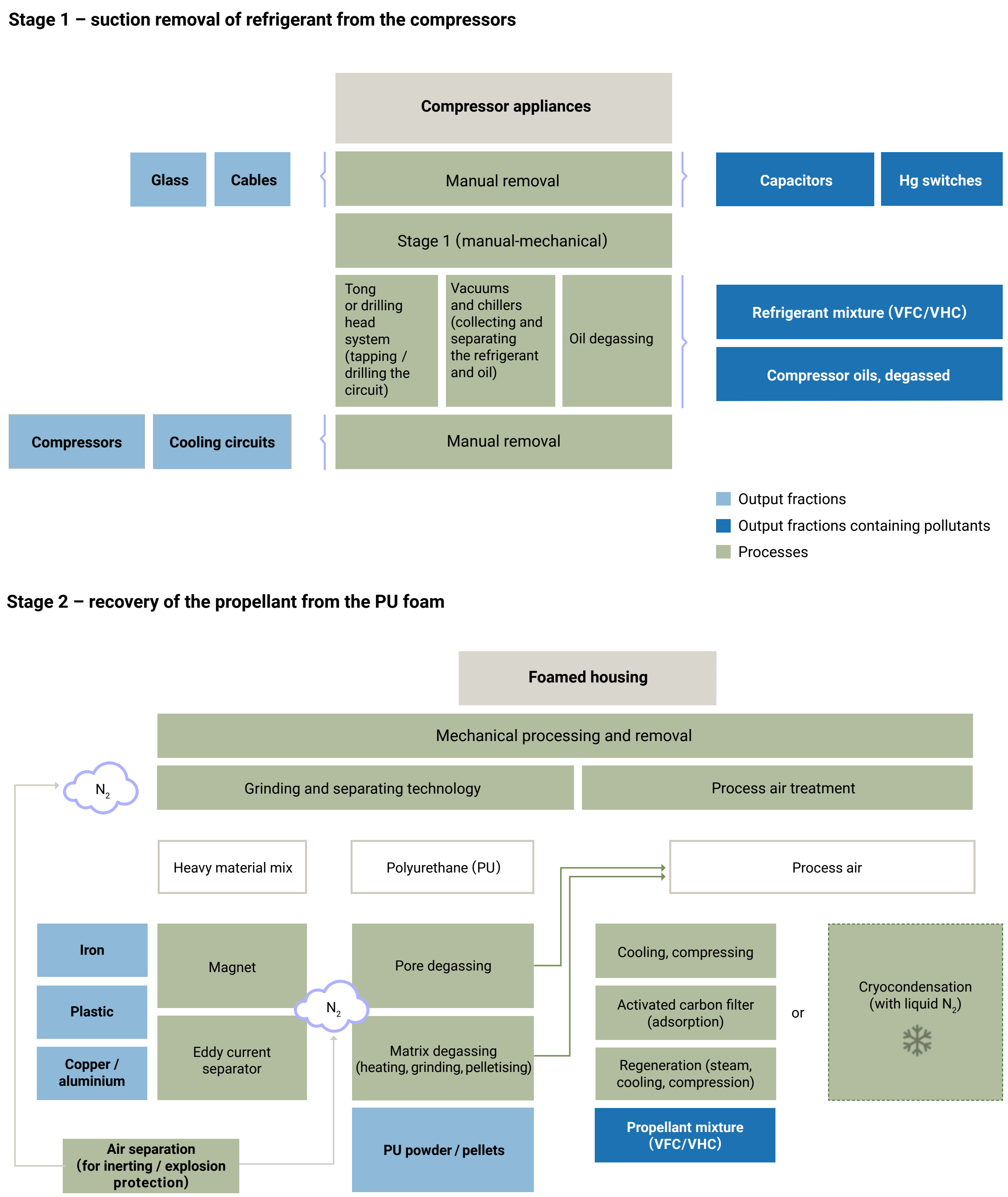
After the refrigerant has been extracted, non-foamed 'Stage 1' appliances are further processed in plants using conventional grinding technology (hammer mill, rotary shears, etc.).

After the suction extraction process, the foamed housings are sent to the second processing stage of the refrigerator recycling plant: this begins with mechanical grinding, whereby the material flow is guided through gas-tight shredders. State-of-the-art separation technology (cascade sifters, magnets, eddy current separators, etc.) enables separation into very pure ferrous metal, non-ferrous metal and plastic fractions as well as PU foam.

In the case of PU-insulated appliances, the focus is primarily on the controlled recovery of the propellant from the foam in addition to metal and plastic recovery. After the PU foam has been separated from the other shredder fractions as described, highly demanding PU processing with pore and matrix degassing is required as well as process air treatment with propellant collection and condensation. The PU foam is therefore pore degassed throughout the mechanical shredding, during which time the propellant in the foam cells is collected. This is followed by matrix degassing through the temperature effect, whereby the propellant molecules trapped in the polyurethane structure are also released. The extracted gas mixture is adsorbed on activated carbon filters, regenerated with the aid of steam and condensed using a chiller. The liquefied propellant mixture is pumped into compressed gas tanks to be disposed of in a high-temperature incinerator, just like the refrigerants. All mechanical processing steps take place in an inert atmosphere. The nitrogen required for this is usually generated on site via air separation (deoxygenation).
As an alternative to the described activated carbon filters, there are also so-called cryogenic systems where liquid nitrogen is used as a coolant for the cryocondensation, skipping an activated carbon filter stage. The plant of Kühlteg AG worked in accordance with this principle.

The schematic representation (Figure 1) shows an overview of the key process steps.

Figure 1: emperature exchange equipment processing: stage 1 and stage 2 process schemes.



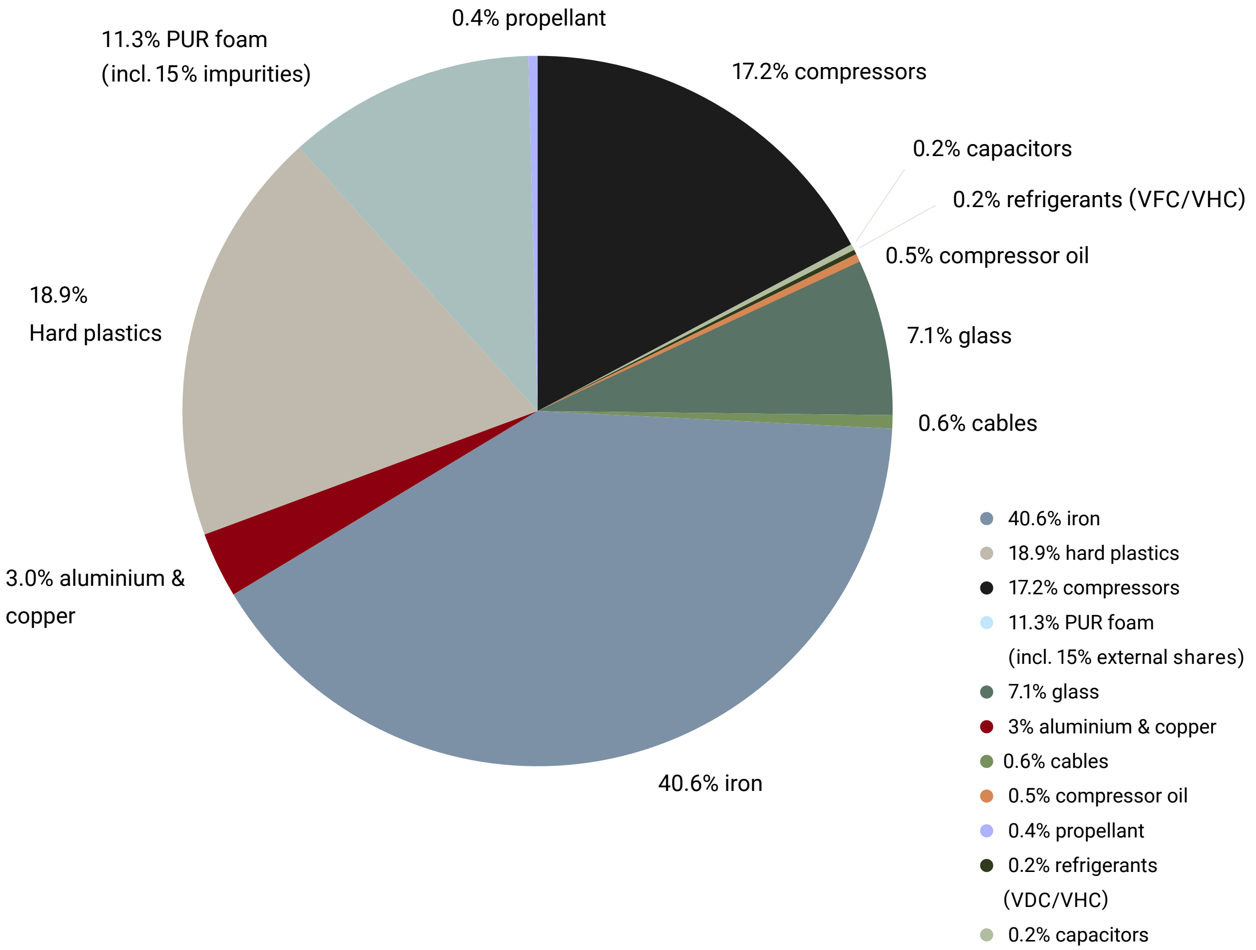


Figure 2: Average composition of a household refrigerator

Composition of a discarded refrigerator
Figure 2 shows an overview of the average composition of a discarded refrigerator, calculated using data from various performance tests at recycling plants over the past three years.

Proportions of VFC[1] / VHC[2] appliances
While the proportions of the two refrigerant types were exactly equal in 2013, the waste appliances processed at stage 1 in 2022 whose compressors were operated with the more climate-friendly hydrocarbons (VHC) accounted for 72%. At stage 2, the current proportion of appliances whose PU insulation has been foamed with VHC is already 80%. Both upward trends continue steadily.

Appliances with absorber systems containing ammonia continue to decline to a very low level (currently less than 2%).

Recovered gas quantities
In 2022, the following recovery quantities were achieved for the temperature exchange equipment processed at both process stages.

- Refrigerant: 53 grams per appliance (-13%)
- Compressor oil: 118 grams per appliance (-5%)
- Propellant: 35 grams per kilogram of PU foam (-1%)

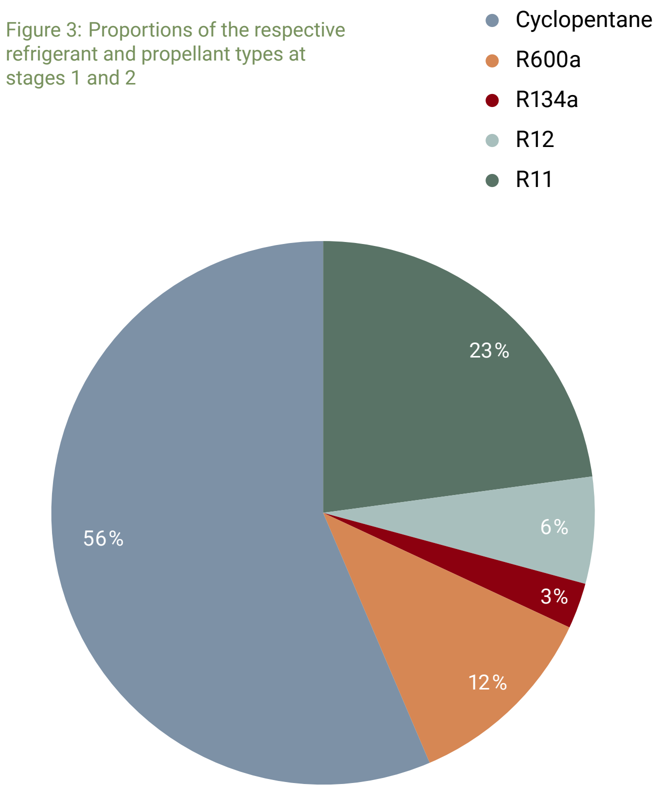
[1] VFCs: volatile fluorocarbons (e.g. R-11, R-12, R-134a, etc.)
[2] VHCs: volatile hydrocarbons (e.g. isobutane R-600a or cyclopentane)

One of the reasons for the observed declining quantities is the constantly decreasing density of the refrigerant and propellant mixtures. Another is the reduced performance of the two end-of-life plants, which will be out of operation by the time this Technical Report is published. (See the article on the two new plants on pages 28–31).

More than two-thirds of the refrigerants and propellants recovered from still-intact cooling circuits and the PU insulation of all foamed appliances (2022: around 80 tonnes) are now made up of climate-friendly gases (Figure 3).

This also means that around one-third of the recovered refrigerants and propellants still contain climate-damaging substances such as R-11 and R-12. The refrigerator recycling plants continue making an essential contribution to environmental and climate protection.

Figure 3: Proportions of the respective refrigerant and propellant types at stages 1 and 2



Temperature exchange equipment is prepared for the plant performance test.

Two brand-new plants for the recycling of refrigerators

Niklaus Renner

In last year's edition of the Technical Report, we provided information on significant changes to the Swiss plant fleet: two new refrigerator recycling plants from the companies Immark AG and E. Flückiger AG went into operation between autumn 2022 and spring 2023. Read on to discover where they're at today.

New production site of Immark AG Aarwangen BE.

Immark AG Aarwangen sets new standards throughout Europe

After a year of construction, Immark AG inaugurated the new site in Aarwangen, Bern in autumn 2022. Immark AG specialised there in the recycling of refrigerators and commissioned one of the most modern recycling plants in Europe for this purpose.

Immark AG is the Swiss market leader in the field of disposal and recycling of electronic waste and has been part of the Thommen Group since 2010. In autumn 2022, Immark AG opened its fourth site in Aarwangen. At the new location, the focus is on the proper disposal and recycling of refrigerators and other compressor appliances.

The plant was designed and constructed by the Bavarian company Erdwich Zerkleinerungs-Systeme GmbH with great support from experienced Immark specialists.

As a pioneer, Immark AG installed the first recycling plant for refrigerators in Switzerland back in 1991, then with a capacity of 20 appliances per hour. The new plant has ten times the capacity, so it can process up to 200 appliances per hour. This capacity is unique in Europe and was a prerequisite for being able to replace the two existing refrigerator recycling plants in Rothrist and Schattdorf. Work is carried out on two completely autonomous lines and in single-shift operation.

State-of-the-art recycling plant
During the first processing stage, the refrigerant-oil mixture is extracted under vacuum. The oil is separated from the refrigerant and additionally degassed. During the second stage, the appliances are shredded into 35 mm pieces using pre-shredders and hammer mills. The propellant contained in the polyurethane foam insulation (PUR) is released and extracted. The separated PUR foam is degassed via a pelletising plant.
The extracted propellant mixture is collected using an activated carbon system, condensed and rendered non-hazardous via high-temperature combustion. The nitrogen required for explosion protection in the plant is generated in-house.

Recovery of raw materials
The material released from the PUR foam is separated into metals and non-metals using a sophisticated system of magnetic separators, sieves, eddy current separators and density separation tables. According to the information provided by the manufacturer, all this ensures that the minimum values for gas recovery and recycling quotas required by Swico/SENS are achieved in accordance with SN EN 50625-2-3 and the supplementary technical regulations.

New production hall with its own power generation
The new processing hall offers a floor area of almost 3,000 m² and has a volume of around 40,000 m³. Thanks to a photovoltaic system measuring 2,400 m², Immark AG draws part of its electricity requirements from the sun and uses the heat recovery from the operating process for heating and hot water generation.

A beacon project
The construction of the new Immark AG site is the largest project in the history of the Thommen Group – and also one of the largest of the Bavarian family company Erdwich. Securing jobs in Switzerland and, above all, keeping the added value within the country is a major concern and a key aspect of the Thommen company philosophy. The implementation of the new recycling plant is like a beacon, says Sabine Krattiger, Managing Director of Immark AG. She adds: 'Many delegations of recycling companies from all over Europe have already announced that they wish to implement a project of the same magnitude.'

www.immark.ch

Erdwich refrigerator recycling plant of Immark AG. Middle: upper plant deck with extraction stations, left: appliance infeed in the second processing stage, with the N2 production plant in the background.

E. Flückiger AG refrigerator recycling plant from URT under construction. Left: eddy current separator, right: pellet cooler.

E. Flückiger AG: A new plant at the old site

After around 22 years of plant operation, the Board of Directors at Kühlteg AG had to consider building a new plant in 2020. The Thommen Group decided to set one up at the site in Aarwangen, Bern. E. Flückiger AG decided to continue with the Rothrist site – also with a new plant and under its own aegis.

Refrigerators have been recycled at the E. Flückiger AG site since the early 1990s. After an expansion and modernisation of the original plant in Rothrist, the merger with the recycling companies Immark AG Regensdorf and Kaufmann AG Thörishaus took place in 2001, thereby founding Kühlteg AG. To increase capacity and optimise the recovery of refrigerants and propellants, a high-performance plant from URT Umwelt- und Recyclingtechnik GmbH was put into operation in the same year. With the takeover of Immark AG and Kaufmann AG Thörishaus by the Thommen Group in 2009 and 2015 respectively, the Thommen Group now owned the majority of the Kühlteg shares. E. Flückiger AG remained a one-third co-owner. In 2020, the separation from the Thommen Group took place, and Kühlteg AG was history.

Higher performance, proven system technology
The construction of the new plant by the manufacturer URT Umwelt- und Recyclingtechnik GmbH at the Rothrist site will be completed in April 2023. With a capacity of 100 appliances per hour, it will be more efficient than the previous plant. As gases are trapped using activated carbon filters, the energy consumption is lower than in the cryogenic plant, which has been out of commission since September 2022. This greatly improves the CO_2 footprint per waste refrigerator. Plant safety and the degree of automation in the new plant are state of the art. Years of experience in the construction and maintenance of refrigerator recycling plants make the manufacturer one of the world's leading suppliers.

Energy benefits thanks to a single grinding stage
According to the manufacturer, the URT process enables the appliance casings to be efficiently separated into ferrous and non-ferrous metals, polyurethane foam and plastics with just one grinding stage. Purity requirements for the individual output fractions, as specified by SENS / SN EN 50625-2-3, can be reliably met according to the plant supplier. The specific grinding performance, the energy consumption per waste refrigerator, is low and amounts to approx. 1.8 kW per waste refrigerator. Furthermore, the use of only one grinding unit means the nitrogen requirement for inerting is also reduced.

Continuity in terms of site and staff
E. Flückiger AG is continuing its previous successful cooperation with URT Umwelt- und Recyclingtechnik GmbH. According to the Managing Director Janine Flückiger, the team is eagerly awaiting the start of operation of the new plant and is delighted about their autonomy and future-proofing in the field of refrigerator recycling. She also says: 'The ideal location in terms of transport – 5 minutes from the motorway exit plus its own rail connection – makes E. Flückiger AG an attractive recycling partner. The motivated staff, some of whom we were able to adopt from Kühlteg AG, has extensive experience in the disposal of refrigerators. Together, these factors create unbeatable value.'

www.flag.ch

E. Flückiger AG refrigerator recycling plant from URT under construction.
Left: pellet press, right: plastic/aluminium discharge belt on the eddy current plant.

Shortage of skilled labour and personnel in the disposal and recycling industry

By Stefanie Conrad and Anahide Bondolfi

The skilled labour shortage index reached a record high in 2022. The strong economic upswing following the coronavirus pandemic has led to an equally strong demand for personnel. Unemployment figures also fell considerably with this rising demand. This development poses major challenges for the disposal and recycling industry, which is particularly noticeable among the recycling companies of SENS and Swico as many SENS and Swico recyclers often work closely with dismantling facilities whose employees come from the secondary labour market.

Bottlenecks at dismantling facilities

The falling unemployment rate and socio-economic developments are happy news, but they often lead to staff bottlenecks at dismantling plants. This is particularly an issue because the manual removal of waste electrical and electronic equipment (WEEE) carried out at the dismantling plants is very labour intensive. The challenges and impacts in the recycling of WEEE associated with the current shortage of skilled workers and personnel are therefore considerable.

Adjustments at dismantling facilities

Like many other dismantling facilities, DOCK Gruppe AG creates jobs for people who have been unemployed for a long time. It offers an environment close to the labour market with honest work. As a partner of Solenthaler Recycling AG (SOREC AG), among others, Dock Gruppe AG dismantles WEEE at several facilities. Heinz Guntli, responsible for strategic corporate development at DOCK Gruppe AG, points out various reasons for the bottlenecks in dismantling capacities: 'The changes in the labour market also have noticeable effects on the companies of DOCK Gruppe AG. The coronavirus situation and the Ukraine crisis in particular have starkly revealed the challenges we must all face in terms of supply chains, demographic development, technical developments and understanding our own needs. Another key factor is the miniaturisation of electronic and electrical equipment, which is now often battery powered. The removal of pollutants from such equipment is thus becoming increasingly complex and expensive.' It is therefore largely only the absolutely necessary removal of pollutants that is carried out at the dismantling facilities of SOREC AG.

Manual dismantling as a core element of WEEE recycling

Due to the challenging economic situation and technical developments, there is a clearly visible trend towards optimisation and mechanisation in the sorting and dismantling of WEEE. However, given the current state of the art in WEEE recycling, manual dismantling work is still essential. Even the triage requires a trained human eye. If the personnel shortage persists or even increases, the optimisation of the manual processes in the dismantling of WEEE will also reach its limits.

Anne-Claude Imhoff, Co-Managing Director of leBird GmbH that oversees social dismantling facilities, also states: 'Our main partner had to adapt the capacity of the dismantling work to the personnel capacities.' The manual dismantling of WEEE is crucial for the recovery of valuable materials and the removal of pollutants. Anne-Claude Imhoff continues: 'Securing the general conditions for WEEE dismantling activities for the future is essential. This includes, in particular, the commitment of the social associations and their support from public funds as well as adequate remuneration from the institutions that administer the advance payments.'

Work in the dismantling facilities. (Photo: Swico)

Possible developments

However, there are more than just companies offering jobs in the field of WEEE dismantling for job seekers – there are also dismantling facilities that look after people with physical or mental disabilities, addicts or asylum seekers. Recent economic changes are also having a strong impact on the number of jobs in these areas. Greater public-private cooperation could better accommodate these developments and personnel requirements. Furthermore, these changes in the availability of skilled personnel raise the question of how to balance primary and secondary labour market jobs.

Dismantling demands a trained human eye.(Photo: Swico)

Circular economy for WEEE disposal – the FOEN enforcement guidelines on the state of the art set new standards

Heinz Böni

On 1 January 2022, the revised Swiss Ordinance on the Return, Taking Back and Disposal of Electrical and Electronic Equipment (ORDEE) entered into force. Article 13 stipulates that, as the supervisory authority, the Swiss Federal Office for the Environment must establish enforcement guidelines on the state of the art. On 3 March 2023, these went into the consultation as a draft among interested circles.

Enforcement guidelines are primarily aimed at the enforcement authorities. They specify the environmental regulations of the federal government and are intended to promote uniform enforcement practice. If the enforcement authorities observe these enforcement guidelines, they can assume that they are enforcing federal law in a legally compliant manner. Other solutions are also permissible as long as they are legally compliant.

According to Article 3 of the ORDEE, the state of the art describes the current development status of processes, facilities and operating methods that have been successfully tested in comparable plants or national/international operations, or which have been successfully implemented in trials. It can be transferred to other plants or operations according to the rules of technology. It is economically viable for a medium-sized and economically healthy company in the relevant industry.

Empa was entrusted with drafting the enforcement guidelines. In some aspects, it is based on the Swiss series of standards SN EN 50625 developed in 2014 on the collection, logistics and processing of waste electrical and electronic equipment. However, the requirements specified in the draft of the enforcement guidelines sometimes cover elements outside this series.

Functions must also be recovered
In terms of a sustainable circular economy, the enforcement guidelines specify three recovery goals and thereby go further than the SN EN 50625 series of standards with the disposal principles 'Scope of disposal'. The three goals are the recovery of the contained functions by preparing WEEE for reuse, the recovery of materials through recycling or other material utilisation, and the recovery of the contained energy through energy recovery.

In the SN EN 50625 series of standards, on the other hand, the focus is solely on the recovery of materials and energy. The preparation for reuse is counted towards the recycling rate. The duty of care when handling the equipment also includes the possibility of reuse.

Energy storage at the focus of operational risks
The improper handling of energy storage units has caused numerous fire incidents at recycling facilities. For this reason, clear provisions for dealing with the operational risks arising from energy storage units are laid down in the enforcement guidelines. The SN EN 50625 series of standards does not specify any requirements in this regard. In 2014, little significance was attributed to the risk of fire when handling energy storage units, especially during bulk transportation of equipment with lithium batteries.

No bulk transport of waste electrical and electronic equipment
In line with information regarding the topic of energy storage, the transport of bulk goods is explicitly prohibited. An exception is possible if a disposal company has first removed all hazardous components and substances (e.g. lithium-ion batteries) via state-of-the-art processes. The SN EN 50625 series of standards only stipulates that WEEE must be handled and stored with the necessary care. This prevents the release of pollutants into the air, water or soil as a result of damage and/or breakage.

Pre-processing valuable WEEE as non-destructively as possible
The aim of processing WEEE, in addition to removing components containing pollutants, is the highest possible yield of valuable materials. According to the enforcement guidelines, the processes involved should be designed and operated accordingly. Components containing valuable materials such as high-quality printed circuit boards, pure metals or parts with rare technical metals (e.g. neodymium magnets) or technical plastics (e.g. PMMA from flat panel displays) are separated as early and fully as possible. They are then sent for final recycling. This sometimes requires equipment-specific triage and non-destructive pre-processing. Mechanical processing of WEEE with similar compositions and behaviour in a joint processing flow in the same processing step is also conceivable. The SN EN 50625 series of standards does not specify any requirements in this regard either.

Recovering rare technology metals when processes are in place
The enforcement guidelines stipulate requirements for the recovery of rare technology metals and calls for their material recycling, provided that there are appropriate processes in place. The SN EN 50625 series of standards does not specify any requirements in this regard except for gold, silver, platinum, palladium and copper.

More detailed documentation and reporting obligations
The enforcement guidelines include detailed requirements for disposal companies with regard to the documentation of material flows on the basis of a uniform classification of inputs and outputs. These go beyond and are more detailed than the requirements listed in the SN EN 50625 series of standards. Recording all inputs and outputs creates complete transparency of the material flows. Materials accounting is used to calculate the operational key figures and to check the plausibility of adequate pollutant removal and resource recycling according to the current state of the art. This also enables the preparation for audits, the execution of studies and the creation of anonymous annual reports.

In contrast, the SN EN 50625 series of standards stipulates more general requirements for the documentation without establishing uniform classification of the inputs and outputs.

The enforcement guidelines will be finalised once the consultation is complete and are scheduled to enter into force on 1 January 2024.

EPR Grand Challenge – The WEEE Forum celebrates its twentieth anniversary

Pascal Leroy

On 7 December 2022, the WEEE Forum gathered over 170 professionals representative of the e-waste value chain at its EPR Grand Challenge Conference to discuss the next steps for EPR (extended producer responsibility). It was arranged for a double celebration: twenty years of WEEE legislation and twenty years of the WEEE Forum which was set up to represent European e-waste producer responsibility organisations but now speaks for 49 such not-for-profit companies across the world.

The keynote address was given by Virginijus Sinkevičius, European Commissioner for the Environment, who talked about the achievements in e-waste management in the EU. He thanked the WEEE Forum for its efforts over the years. He also noted that much remains to be done: «Right now, despite the improvements, too many waste appliances are failing to reach facilities for treatment or repair. They are forgotten at the back of a drawer, illegally exported, or scavenged for valuable parts which often leads to pollution. Turning this round is the grand challenge that we face. We will get there by working together and building a more circular economy.» The conference presented four challenges of the sector and each of these was discussed by expert panels to find solutions.

Delivering the Circular Economy
The worldwide societal challenge of e-waste calls for collective action. Many efforts are made by the collection schemes to get citizens to return their electricals. But the challenge of putting circular economy into practice and constructing circular societies where reuse, repair and recycling of electronic products become social norms needs a whole value chain approach with new business models and approaches. Valérie Guillard, Professor at Université Paris-Dauphine, questioned the psychological aspects of the transition to circular attitudes: «Why is it so difficult for consumers to change their way of consuming? Because consumption gives meaning to our lives, to what we do, and to our social relationships.» Bruno Vermoesen, representing BSH Home Appliances, described how much is already being done on the production side with the use of recycled materials and avoiding critical raw materials, for example.

Deploying producer responsibility internationally
E-waste is the fastest growing waste stream in the world and is, therefore, an issue of global concern. Jan Vlak, the president of the WEEE Forum, stated in his opening speech: «I am of the view that we need a Paris-type Agreement creating an international regime, a global secretariat, a partnership structure, a global treaty, or other UN initiative to cover several critical areas of e-waste management and related EPR programmes.» Vanessa Gray of the UN's International Telecommunication Union added: «Not only producers but all relevant actors, including regulators, consumers, and recyclers, must play a role in the EPR system in order to successfully increase the collection of e-waste.»

Transitioning to a low-carbon economy
Without secure and sustainable access to raw materials, Europe's ambition to become the first climate neutral continent is at risk. Guillaume Pitron, French journalist and author of the best-selling «The Rare Metals War», addressed the questions on how the e-waste collection sector can foster access to critical raw materials and make Europe less dependent on third countries. He also explained the economic, political, and environmental issues associated with the use of rare earth metals noting that «there has been no energy transition in history that has not required more metals and minerals, and the green energy transition is no different».

A new vision on EPR in future WEEE legislation
In Europe, 55 % of e-waste generated is officially collected and reported. Other parts of the world show much slower growth rates in its collection, and the global reported average collection rate is just 17 %. The e-waste that is collected in Europe is also treated to higher standards than in the rest of the world. That's largely thanks to twenty years of EPR legislation across Europe. However, legisla-

tion must be redesigned to make it fit for purpose for new market realities and based on the lessons learned in the past two decades. There was also agreement that all the players are committed to improving the legislation. There is sympathy for the view that a Regulation, rather than a Directive, would mean the playing field is more level across all member states with no differences resulting from transposition to national laws. It is felt that this will be one of the keys to ensuring future WEEE legislation has the desired impact.

WEEE Flows report launched
A publication, prepared in partnership between United Nations Institute for Training and Research and the WEEE Forum and its membership, was

also disclosed at the event. The paper provides key statistics of WEEE flows, collection rates in the EU-27, Norway, United Kingdom, Switzerland, and Iceland from 2010 to 2021. The study reveals, among others, that the amount of EEE put on market in these countries increased from 9.8 million metric tonnes (Mt) in 2010 to 13.3 Mt in 2019 (25.2 kg/inhabitant). The WEEE generated also shows an increase of 2.1 Mt, from 8.3 Mt in 2010 to 10.4 Mt (19.6 kg/inhabitant) in 2021. The documented formal collection of WEEE shows an increase of 1.8 Mt, from 3.8 Mt in 2010 to 5.6 Mt (10.5 kg/inhabitant) in 2021. More statistics can be found in the full document.

Learn more about the event and our vision. You can also find all our reports and publications here, including our 20 years on journey and the Response to the Call for Evidence in view of the evaluation of WEEE legislation.

For optimised, circular WEEE processing of the future

Andrea Wehrli, Kirsten Remmen and Heinz Böni

When WEEE is processed in a circular manner, natural resources are conserved and the environmental impact is reduced. Which factors must an assessment method include in order to promote and support a targeted, future-oriented and feasible circular economy for WEEE?

Goals for the circular processing of WEEE
The circular processing of waste electrical and electronic equipment (WEEE) requires a strategy that pursues three basic objectives: the creation of closed cycles, the prevention of damage to health and the maximisation of benefits.

Empa is carrying out the e-conseg project on behalf of the Federal Office for the Environment (FOEN). An assessment method is being developed that provides the basis for recording the degree of objective achievement in the most effective manner. The method should also be as practical as possible and applicable in the context of different technical, financial and regulatory framework conditions. The assessment method is based on the three processing objectives and includes assessment parameters that differ depending on the operational activities and the consideration of the system level (operational or national).

Closed cycles
The data on the mass flows of products, components and substances forms the basis for a comprehensive assessment. Input information allows the recovery potential to be estimated, while output information reveals losses and actual recovery opportunities. Content data is important for calculating loads and losses. Losses can be the result of various factors, such as incorrect sorting into other waste streams, separation into non-optimal processing streams, or emissions and losses during processing. The achievement of closed cycles must be assessed in the context of the other two objectives, namely preventing harm to health and maximising environmental benefits.

Pollutants must be prioritised
The separation and concentration of target substances with a high damage potential must be prioritised over valuable substances. In addition to the legally prescribed limits, the losses of pollutants in fractions that are not intended for this purpose must also be determined and assessed. Possible preventive measures could be determined from this data.

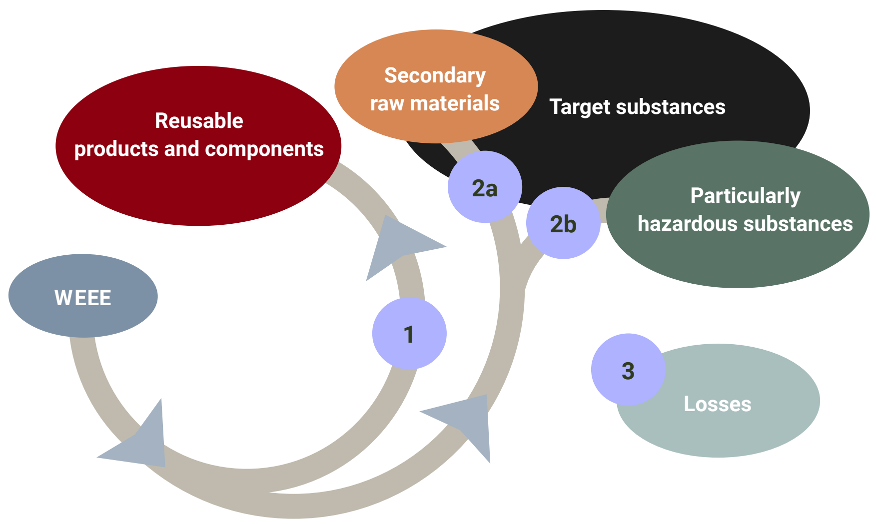
The complex world of environmental benefits
The generation of environmental benefits during the processing of WEEE is complex and depends on the entire value chain, including manufacturing and consumption. Ideally, products and components are (re)used for as long as possible and the substances are separated and concentrated during recovery in a sealed system in a way that prevents all losses, and these can be used again as high-quality substances in manufacturing.
To promote strategic decisions that would lead to environmental benefits, the material flows, among other things, are stored with environmental data to make the potential and creation of environmental benefits more transparent.

1 **Recycling path 1:** WEEE arrive as a product or as a component in preparation for reuse.

2a **Recycling path 2a:** A target substance in WEEE ends up in the recovery for secondary raw materials.

2b **Recycling path 2b:** A target substance in WEEE ends up in separate processing for material or energy recovery or disposal.

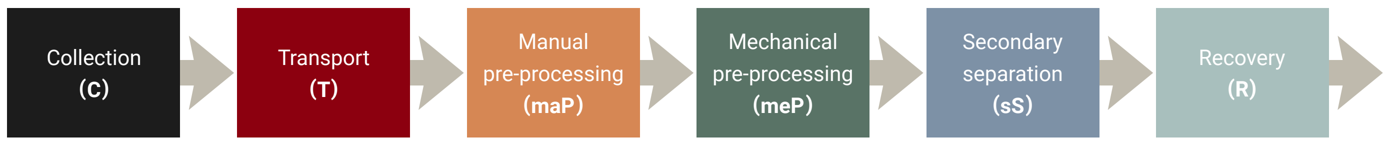
3 **Losses:** Substances in WEEE become lost in the recycling paths.



Assessment at business and national level
Optimising the recyclability of WEEE must be viewed holistically at the business and national level and the technical, economic and other relevant aspects must be considered. Another important approach for a useful assessment is the inclusion of continuous improvements and measures implemented by a business.
At the business level, the assessment value is based on the processes and possibilities as well as the limiting and non-controllable framework conditions. The focus is placed on exploiting the environmental potential against the background of an overall business perspective. This includes the energy-efficient recovery of as many target substances as possible, the prioritisation of environmentally significant substances and possibilities for recycling WEEE.

The assessment at the national level is based on the data from the individual processes and businesses. Here, it is essential for the input, the utilisation routes, the output and the losses to be recorded throughout the entire chain. This is the only way to obtain a realistic picture and to carry out a sound performance assessment at national level.

The new assessment method should aim to support businesses and authorities in identifying and implementing the right measures to continuously optimise the environmental benefits of the WEEE circular economy. The e-conseg project will last until mid-2024.



$$\text{Recyc.}_{\text{mat. recov.}}(t) = C(t) * T(t) * maP(t) * meP(t) * sS(t) * R(t)$$

The recyclability of a target substance (t) for material recovery (Recyc. mat. recov.) is based on the services of collection (C), transport (T), manual pre-processing (maP), mechanical pre-processing (meP), secondary separation (sS) and recovery (R).

Circular economy in the automotive sector –results from the EVA II project

Manuele Capelli and Charles Marmy

In a project of the Federal Office for the Environment (FOEN), Empa has been investigating the recycling of embedded electronic devices (EED) from vehicles for several years. The work is carried out in the context of the new Swiss Ordinance on the Return, Taking Back and Disposal of Electrical and Electronic Equipment (ORDEE). The costs and environmental benefits of dismantling EEDs and processing them separately in the electronic waste recycling system were investigated as an important element of the project.

As in many business areas, the trend toward more connected and smarter products is rising in the automotive sector. Modern passenger cars contain a large number of driving assistance, entertainment and comfort features. Just a few years ago, these could only be found in the premium segment. This trend results in a constantly growing number of embedded electronic devices (EED). Like other domestic electronics, EEDs in vehicles contain complex components such as printed circuit boards with processors or small electric motors for various movement functions. Some of the valuable metals contained in these components, such as copper or gold, are lost in the current recycling system because EEDs have not yet fallen within the scope of the ORDEE and are therefore not recycled separately in plants specialising in electronic waste.

Goals of the new ORDEE
During the revision of the ORDEE, the scope was extended and, according to Article 2, now also includes electronic components in vehicles (EEDs). This is, however, subject to two conditions. Firstly, the separate disposal of the EEDs must be possible with a reasonable amount of effort. Secondly, the associated material recycling should be environmentally sensible and economically viable according to the current state of the art. This was investigated as part of Empa's EVA II project.

Economically viable?
The costs are made up of three parts: the disassembly costs (i.e. the costs for removing the EEDs from the end-of-life vehicles), the costs of transport and the costs of recovering the raw materials. Due to the high labour costs in Switzerland, the disassembly costs are the most significant, particularly because a specialist is required who knows where the EEDs can be found in the vehicle. There are significant differences between the devices in terms of their value and removal costs due to their differing compositions and locations in the vehicles. The model calculations resulted in costs between CHF 3 and CHF 20, depending on the device type. The net costs for removing all EEDs from one end-of-life vehicle amount to around CHF 200. This already includes the income from the material value of all removed devices per end-of-life vehicle.

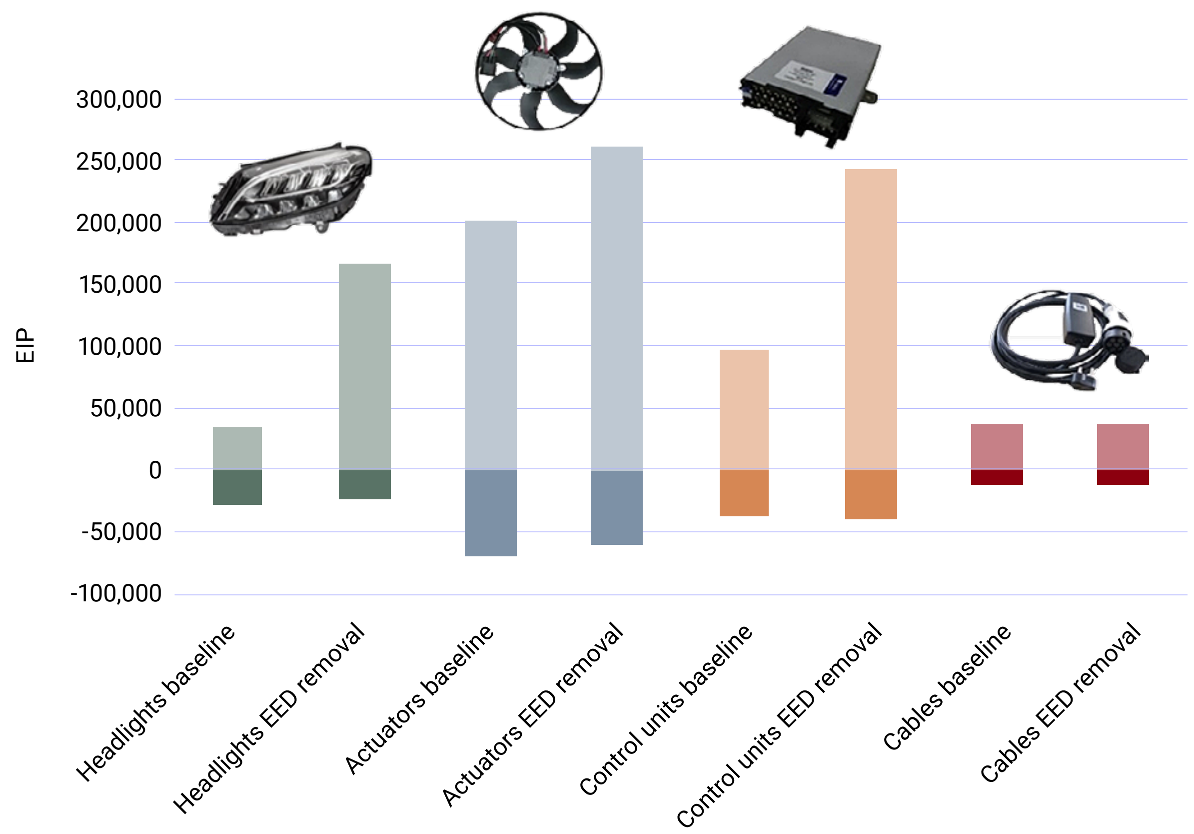
The ratio between material value and recycling costs varies due to fluctuating raw material prices and the development in the mix of end-of-life vehicles. The e-mobility trend could be positive for economic viability as electric vehicles are built more simply, thereby reducing removal costs. They also contain certain EEDs specific to electric cars that are considered particularly valuable.

Significant emission reductions
The life cycle assessment results show that the second requirement of the ORDEE – environmentally sensible – can be met. The environmental impact of the two scenarios 'no removal of the devices (baseline) and recovery of the raw materials' and 'separation of the EEDs (EED removal) and recovery of the raw materials' is compared across all processes. Due to the increased recovery rate as a result of lower losses of various metals such as gold, copper and aluminium, greenhouse gas emissions can be reduced by substituting primary materials. According to current data, the prevented environmental pollution is four to five times higher than the additional effort that arises when the EED is recycled separately (see figure).

On the path to a circular economy
With the expansion of the ORDEE to include electronic devices in vehicles, Switzerland is on the path to a circular economy in the vehicle sector. The results from the study show the improved recovery of various materials from EEDs when they are processed separately. The cost efficiency, expressed as environmental benefits per franc, is in a similar range to that of PET or domestic electronics. The system adjustment does not require a new processing infrastructure as the EEDs can be processed in the existing electronic waste recycling system in Switzerland. With the processing of EEDs, the environmental footprint of the vehicles decreases due to the increased recovery of valuable secondary resources.

Further information

↗ 'Recycling of electric components from passenger vehicles (EVA)'(pdf)
↗ 'Art. 13 Vollzugshilfe des BAFU'



Comparison of the ratio of environmental benefits (light bars) to recycling effort (dark bars) per kg for the various EED categories considered via environmental impact points (EIP).

[1] EVA = 'Elektronik-Verwertung Altfahrzeuge' [electronics recycling in end-of-life vehicles]

Lithium-metal batteries in WEEE Distinction and practical experience

Flora Conte

The dangers of lithium batteries in WEEE recycling have become well known. While a lot of experience can be gained from handling lithium-ion batteries, the topic of lithium-metal batteries raises questions among recycling partners for which there have not always been clear answers in the past. The exchange of knowledge within the industry to identify lithium-metal batteries and to protect against their risks is therefore very important.

Lithium-metal batteries (LiMe) are a subcategory of lithium batteries. These are primary cells, i.e. non-rechargeable batteries that have a high energy density[1] and are particularly durable. They are therefore used in areas where recharging or replacing batteries should be avoided. As the properties of LiMe batteries are associated with different risks in the context of collection, dismantling or recycling, it is important to be able to distinguish them from lithium-ion batteries in practice. After all, LiMe are highly reactive, produce toxic gases when damaged and behave differently to lithium-ion batteries under stress (short circuit, pressure). It's not just contact with water that can be problematic, the 'popcorn effect' can also lead to unpleasant surprises.

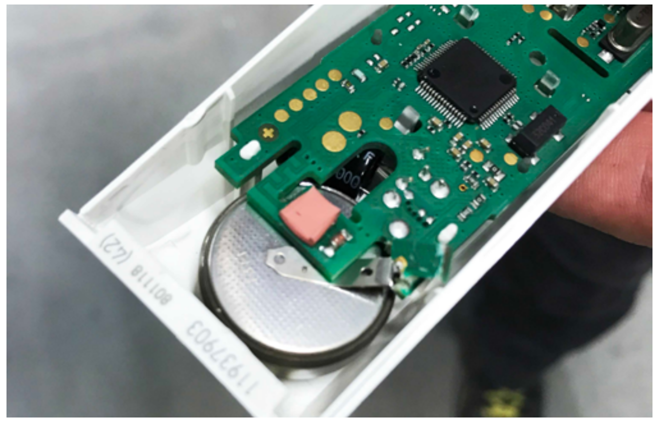
Very rare and very common?
In practice, the topic of LiMe batteries often leads to many questions and ambiguities. Are LiMe batteries so rare that you hardly ever come across them, or are they very common but much more harmless than we believe? The main reason for this question is that although the term 'LiMe batteries' is a subcategory of lithium batteries, it is also an umbrella term for different groups of batteries with varying properties. From the well-known lithium button cells to the extremely rare applications in the medical or military fields – the range of LiMe batteries is as huge as their array of dangers. In addition to the high energy density compared to lithium-ion batteries, the amount of energy and the general conditions are also important.

$LiMnO_2$ vs $LiSOCl_2$
Two categories of LiMe batteries are relatively common, so they end up in SENS and Swico collection points and with recycling partners: lithium manganese dioxide ($LiMnO_2$) and lithium thionyl chloride ($LiSOCl_2$) batteries.

$LiMnO_2$ batteries: these are often found in the form of button cells and AA or AAA batteries. They are used in cameras, watches or as backup batteries for memory chips, but also often in defibrillators. Dismantling facilities and collection points therefore encounter $LiMnO_2$ batteries every day. Although $LiMnO_2$ button cells are often well hidden, they are easy to identify due to their flat shape and silver colour. Cylindrical $LiMnO_2$ batteries are sold in Switzerland under well-known brand names such as Varta or Duracell as an alternative to classic alkaline batteries.

[1] 'Fire Hazard Analysis for Various Lithium Batteries' (pdf)

$LiSOCl_2$ batteries: these often cylindrical batteries are used in industrial, remote control and medical applications. They can be found in fire alarms, parking garage displays, as well as water, gas, heating or electricity meters. These are not particularly common devices, but when they land in recycling facilities, they often arrive in bulk, such as when an entire building has been renovated or refurbished. In the case of $LiSOCl_2$ batteries, frequently found brands include SAFT (white colour with green writing) and Tadiran (purple battery). Other brands of $LiSOCl_2$ batteries available in Switzerland are Jauch or EVE. $LiSOCl_2$ batteries are usually more hazardous than $LiMnO_2$ batteries because they contain a higher amount of metallic lithium and can quickly release highly flammable and toxic gases [2].



LiMe batteries from a wireless heat cost allocator (photo: Carbotech)

Other LiMe battery categories include lithium iron disulphide batteries ($LiFeS_2$) used in photography (e.g. Energizer brand). The highly hazardous lithium-sulphur dioxide ($LiSO_2$) batteries are mostly used in the military sector. The SAFT manufacturer also sells $LiSO_2$ batteries. In addition, lithium-iodine ($Li\text{-}I_2$) and lithium-carbon monofluoride ($Li\text{-}(CF)_n$) batteries are used in the medical sector.

Heat gauges are put aside and labelled. (Photo: GADPlus)

LiMe hazards during dismantling
For Sabine Krattiger, Managing Director of Immark AG, the main source of danger from LiMe batteries in practice is the dismantling of waste electrical and electronic equipment (WEEE). 'Mono groups' can arise there. A mono group refers to several similar or identical LiMe batteries stored together.

Ms Krattiger reports on a case at a dismantling plant that really influenced her and her employees: 'A large number of wireless heat cost allocators underwent pollutant removal at a dismantling plant, probably after a renovation of apartments. The dismantled, relatively small, cylindrical batteries were stored together in vermiculite layers within the battery container. Despite being layered in vermiculite, there must have been contact between the batteries. When the batteries reacted, the container remained closed. However, it became so hot that the wooden pallet holding the container caught fire. It wasn't the fire alarm that warned us, but rather the burglar protection, as there was a loud bang in the container. Fortunately, our employees had rightly carried out the important task of tightly closing the container lid as instructed.

[1] ↗ 'Amerex Lithium/Thionyl Chloride Battery (LiSOCl2) Safety Data Sheet' (pdf)

↗ 'BU-106a: Choices of Primary Batteries' (pdf)

This prevented the fire from spreading due to sparks jumping out of the container.' To prevent such incidents in the future, dismantling companies have started separating and clearly labelling multiple categories of WEEE containing lithium metal.

Masked off lithium button cells prevent short circuits in larger quantities (photo: soRec)

Flying button cells
As button cells are pervasive in electrical and electronic equipment, they can also be collected outside of dismantling plants. A supermarket reported that when replacing batteries in electronic price labels, many button cells were thrown together in a bucket. The 'popcorn effect' caused by short circuits quickly surprised the employees.

'That has also been our experience,' reports Dieter Offenthaler, former managing director of Batrec, now an independent consultant. 'When lithium button cells come into direct contact with each other and short circuits occur (e.g. in bulk), they jump around the room like firecrackers. Should there be any combustible material in the area, a large fire can quickly spread.' Combustible material is often found at a collection point or recycling facility: plastics, paper, wood, waste oil, etc. Although the amount of lithium per button cell is small and the energy discharged is correspondingly low, the 'exploding' button cells are very hot. Fire or personal injury can quickly occur wherever the button cells land.

Estimating hazards
For larger quantities of button cells collected at the same time, it is recommended across the board to mask off the button cells or store them in thick layers of vermiculite to avoid short circuits. In vermiculite, however, there is a risk that the small button cells will slip and come into contact during transport. In any case, it is very important to close the battery container to control the 'popcorn effect'.

For Dieter Offenthaler, however, it is not particularly worrying if cylindrical $LiMnO_2$ batteries end up in the mixed battery container together with alkaline batteries because, even in the event of a short circuit, there is no proximity to acutely combustible material.

However, he sees the situation completely differently when it comes to the often also cylindrical $LiSOCl_2$ batteries. These are the most dangerous in the everyday work of recyclers. A large amount of energy is released in the event of pressure from damage or a short circuit. This produces significant amounts of toxic gases such as sulphur dioxide (SO_2). 'You have to be very careful when sorting,' warns Markus Stengele (Head of Quality, Environment, Safety at SOREC Gossau SG). 'It's easy to get the symbols on the batteries mixed up. $LiSO_2$ batteries are commonly found in defibrillators and are labelled with the crossed-out wheeled bin symbol and Pb for lead. The labelling is provided in line with battery-related legislation because the battery contains more than 0.004 percent lead by mass. As a result, batteries with this label may be sorted into the lead-acid batteries group. The consequence of this is the transport of lead-acid batteries containing lithium batteries.' In case of doubt, the weight of the battery also provides an indication as to whether the battery may actually be a Pb battery – these are usually much heavier than other batteries.

Erring on the side of caution
The different types of LiMe batteries therefore increase the complexity of dealing with lithium batteries and the range of possible hazards and incidents. Understanding and identifying these can prevent damage.

Employees must remember one thing during collection and dismantling: better on the side of caution. Dieter Offenthaler states: 'If in doubt, it helps to insulate the LiMe batteries in sand or lots of vermiculite. Covering or masking off the exposed poles avoids short circuits, or the battery could also be packed individually in a plastic bag. A tightly closed container prevents uncontrolled projectiles. There must be no contact with water in the vicinity of people or combustible material, otherwise highly flammable or explosive hydrogen will form. The technique of using water to flood LiMe batteries and thus discharge them is only permissible at the battery recycler premises, in a controlled environment with professionals and using the corresponding transport method.'

$LiSOCl_2$ batteries of the brands SAFT and Tadiran (photo: Inobat)

The highly dangerous $LiSOCl_2$ batteries are more common than expected. It is important to remember the possible uses of these batteries and to identify WEEE that contain them before dismantling, and to treat them with suitable precautionary measures from the start.

The age of electronic equipment in recycling

Daniel Savi

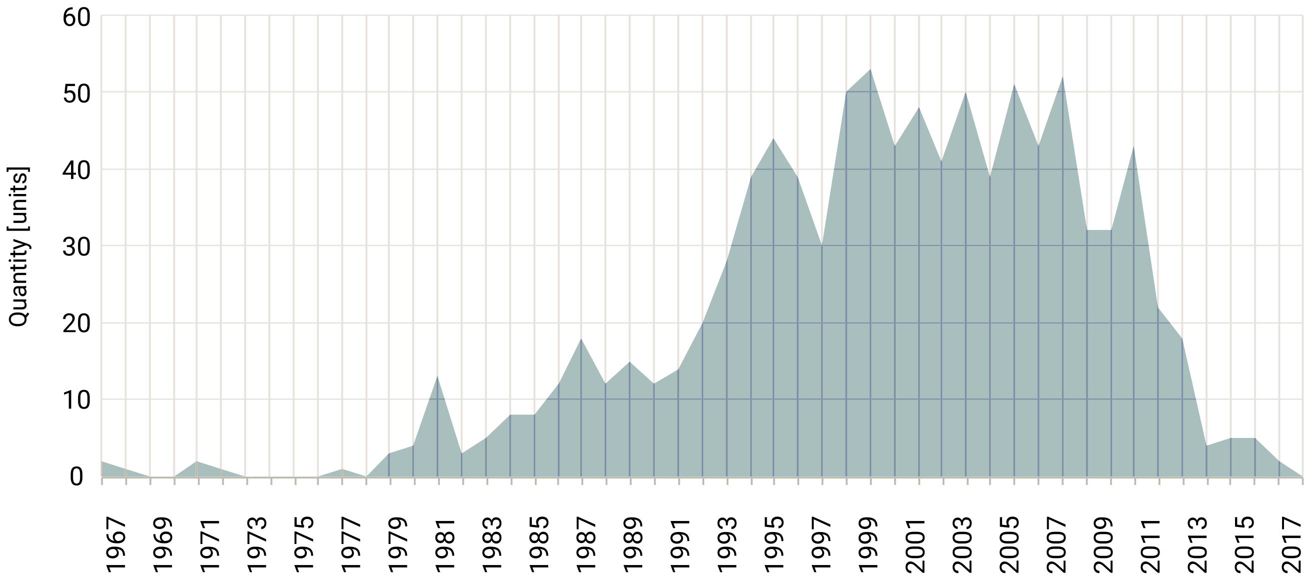
Over 3,000 capacitors from large household appliances, temperature exchange equipment and microwaves were collected and classified for the large-scale capacitor study by SENS and Swico. The data obtained enables, among other things, an age determination of the large household appliances and temperature exchange equipment being recycled.

Capacitors allow age determination
For the age determination, the age of 967 capacitors from large household appliances and 183 capacitors from temperature exchange equipment was determined. This is possible because the year of manufacture was often printed on these capacitors. In the manufacture of electrical and electronic equipment, it has been the practice for years to keep the bearings as small as possible. It is therefore plausible to assume that the appliances were not manufactured much later than the capacitors they contain. In the study, the year of manufacture of the appliance was therefore estimated to be the same as the year of manufacture of the capacitor.

Large household appliances are used for different lengths of time
The category of large household appliances includes cookers, dishwashers, washing machines, tumble dryers and other appliances of a comparable size. The capacitors mainly come from the first appliance types mentioned. Figure 1 shows the number of capacitors found for each year of manufacture. There is a peak from around 1994 to 2010. 75% of the assessed capacitors are from this period of time. The data shows an average capacitor age of 17 years. As the samples were taken in 2017, this results in an average manufacture date of October 1999. The oldest capacitor in the assessment was 50 years old. The data can be statistically analysed further. Figure 2 shows the data within a normal distribution. This makes it possible to estimate the uncertainty level in the age determination. The standard deviation of the data was calculated for this purpose. This is around eight years. Most large household appliances are therefore between 9 and 25 years old.

Quantity of capacitors from large household appliances

Figure 1: The years of manufacture of capacitors in large household appliances. The appliances were sent for recycling in 2017 .



Appliance age distribution among SENS household appliances

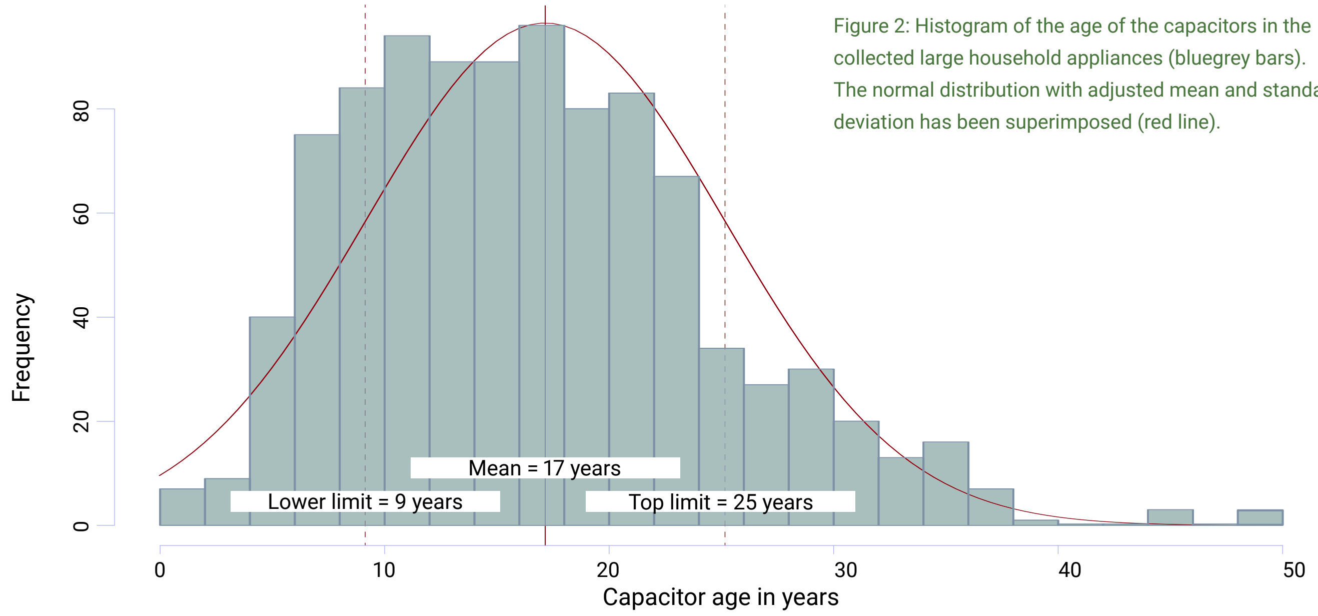


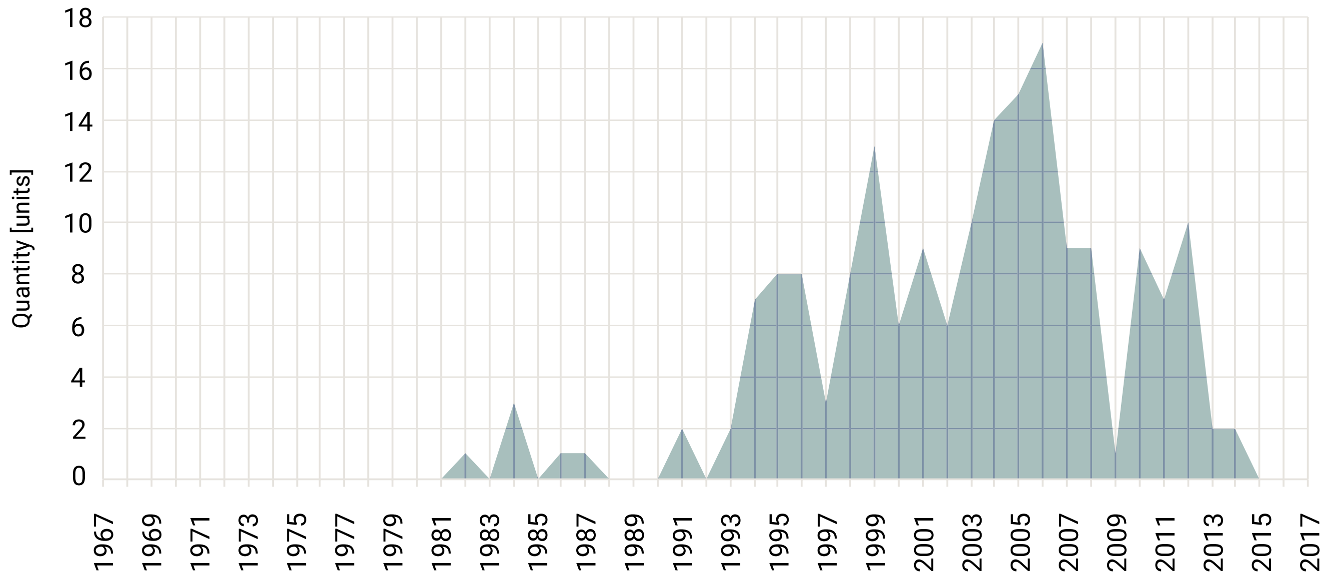
Figure 2: Histogram of the age of the capacitors in the collected large household appliances (bluegrey bars). The normal distribution with adjusted mean and standard deviation has been superimposed (red line).

For those interested in statistics, it should be mentioned that a log-normal distribution was also adapted to the data. However, the correlation was no better than for the normal distribution.

Refrigerators don't reach the same age as large household appliances
The second assessment was carried out with capacitors that had been installed in temperature exchange equipment. The temperature exchange equipment includes all appliances with a cooling circuit, i.e. mostly fridges and freezers. Heat pump tumblers and some air conditioning units also belong to this class, but the capacitors included in this assessment come almost entirely from refrigerators and freezers. That is why we will simply refer to refrigerators in the following. It has been shown that refrigerators don't reach the same age as other large household appliances such as washing machines or cookers. On average, they are decommissioned after 14 years. The calculation of the standard deviation results in an age range of 8 to 21 years before the appliances are replaced. Figure 3 shows the age of the removed capacitors. As the quantity is much smaller than for large household appliances, the reliability of the results is also lower. The oldest refrigerator in the collection of waste appliances was significantly younger than the oldest among large household appliances. It was taken to the SENS collection point after 35 years.

Quantity of capacitors from refrigerators

Figure 3: The years of manufacture of the capacitors in refrigerators from recycling in 2017. The youngest was three years old, the oldest was 35.



‘Pervasive electronics’ – the increasing pervasion of electronic components in our everyday objects

Heinz Böni

Electronic components are becoming increasingly common in our daily lives, often without being perceived as electronic products. E-cigarettes, to give just one example, contain rechargeable batteries. Their collection and disposal is currently causing plenty of work for take-back systems. ‘E-textiles’ and ‘smart textiles’ are finding their way into the textile sector. These contain electronics and conductive components.

The international initiative ‘Solving the e-waste problem’, i.e. StEP [1], was founded in 2004. It is exploring the topic designated ‘pervasive electronics’ in a working group. When disposed of, such items do not usually end up in the collection systems for electrical and electronic equipment, but are instead disposed of with household waste or via bulky waste collection in waste incineration plants where the raw materials contained in the electronics are lost.

We are all familiar with products containing ‘pervasive electronics’: greeting cards that play a melody when opened, children’s shoes that light up when they walk, ski boots that can be preheated, furniture that massages the body, and so on. The reasons for embedded electrical, electronic or conductive components are often additional or improved functionalities or the frequently invoked ‘consumer convenience’. This is intended to create market advantages for the supplier. In many cases, a clear distinction between products with ‘pervasive electronics’ and electrical and electronic equipment (EEE) is not possible. Most often, energy carriers and other electrical components are permanently integrated into new products so that they can no longer be removed or replaced. This type of design can be described as ‘disposable electronics’. The product is likely to be disposed of when the extra function no longer works. In addition, the design makes it difficult to identify these products as waste electrical and electronic equipment. As a result, end users end up disposing of them in the wrong waste stream. Furthermore, this product group lies in a grey area when it comes to legislative coverage.

It was possible to develop the initial groundwork via a master’s thesis carried out at the University of Natural Resources and Life Sciences in Vienna with the support of Empa in 2022 [2]. The product groups with integrated electronic components were identified and classified using a broad-based internet search on online sales platforms. A decision tree can be used to determine whether a product that has not previously been classified as electrical or electronic waste falls into the ‘pervasive electronic product’ category.

The ten product groups identified and their integrated functionalities are shown in Figure 1. Figure 2 shows the most common disposal routes.

[1] ↗ StEP - solving the E-waste Problem – StEP Initiative
[2] Master’s thesis at the University of Natural Resources and Life Sciences: Definition, classification, and mapping of pervasive electronic products; submitted by Helene Steiner (2023)

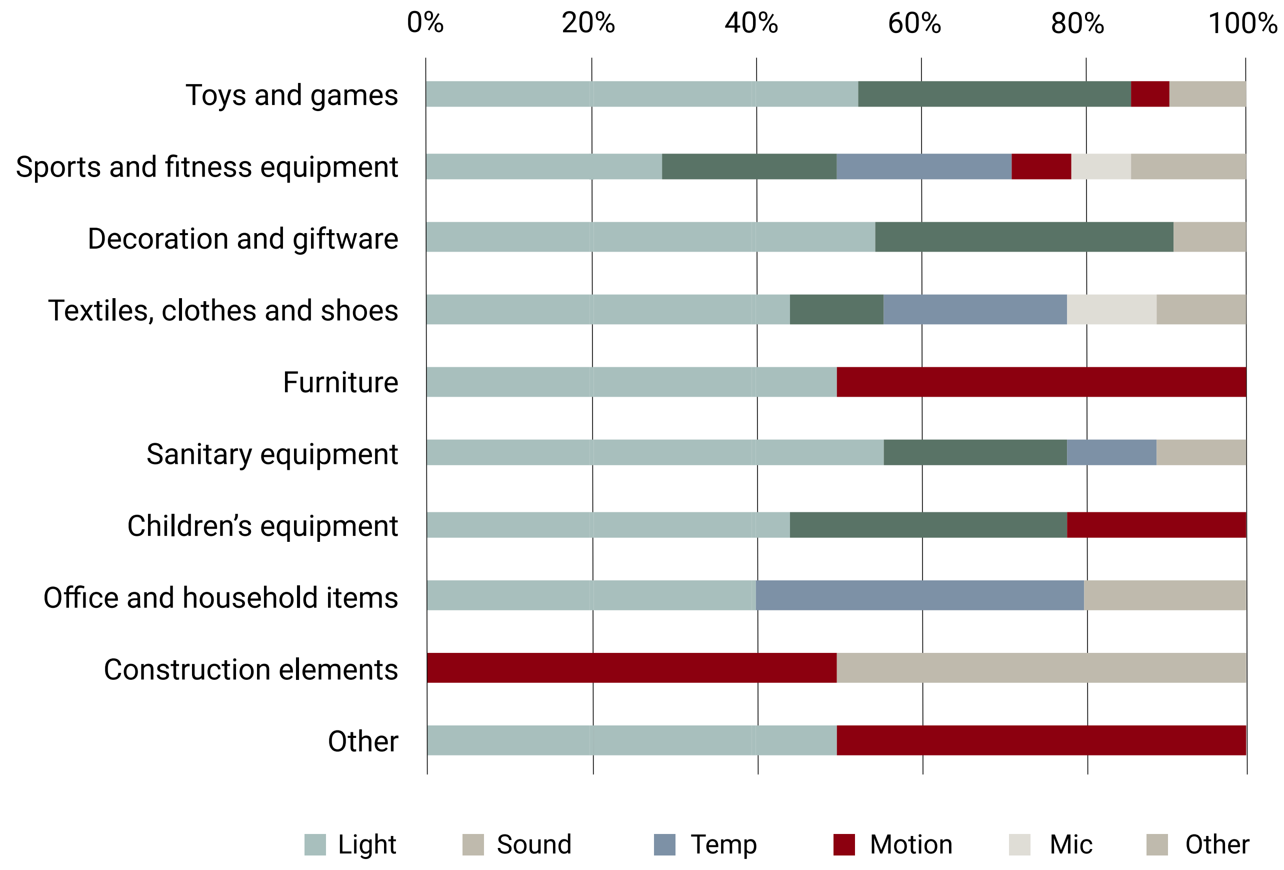


Figure 1: Product groups and integrated functionalities (from Helene Steiner’s master’s thesis)

The composition of a product with integrated electronics was determined using the example of children’s shoes. Around 8% of the shoe weight was made up of electronic components such as wires, LEDs, batteries, contacts and connectors. There are relatively few electronic components integrated in a single shoe. Such shoes are often only used for a short time. The high number of sales illustrates their relevance with regard to the careful use of finite resources.

StEP will continue exploring this topic [3], and another master’s thesis is planned. The collection and disposal of e-cigarettes is also currently a hot topic at the WEEE Forum.

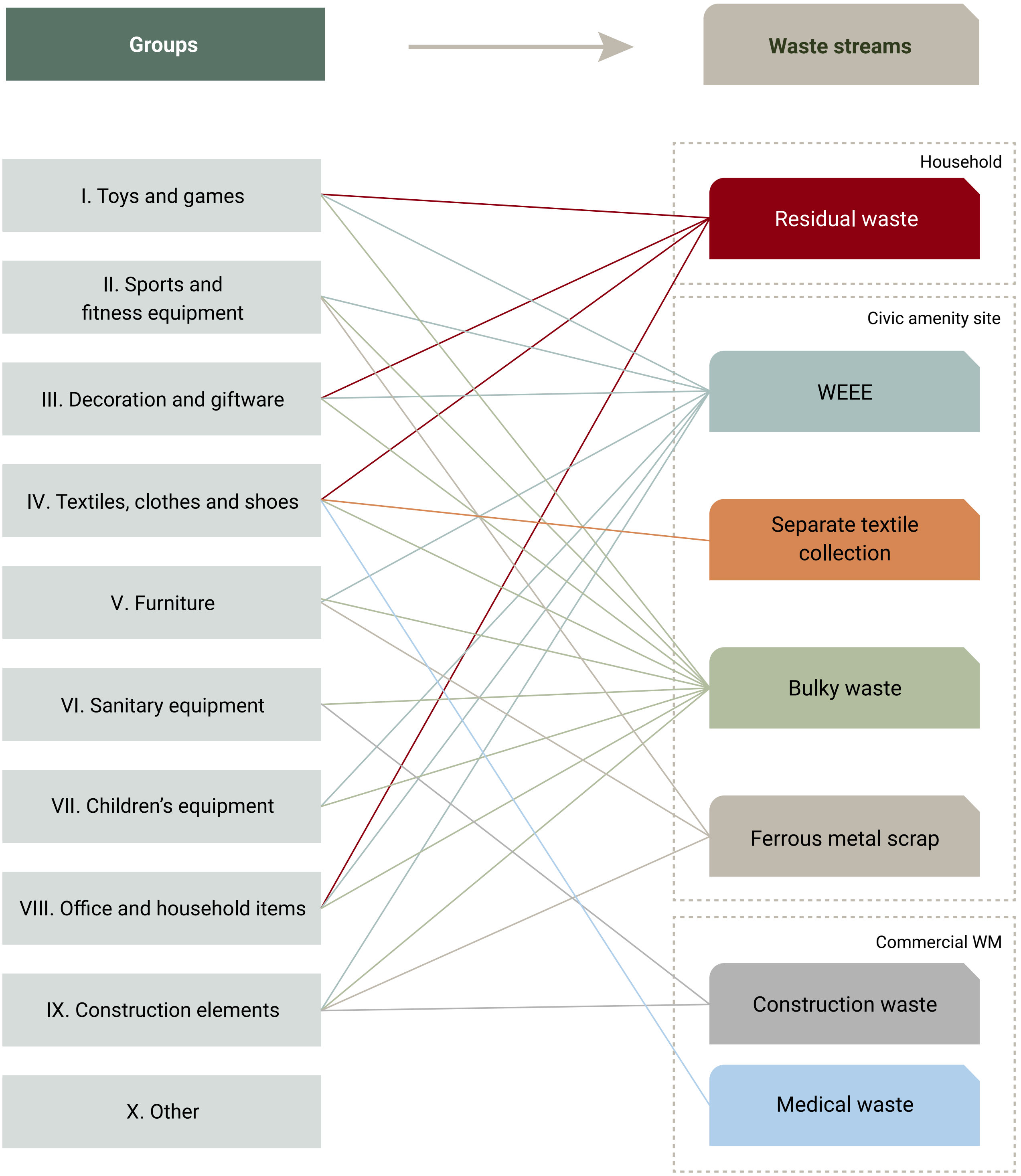
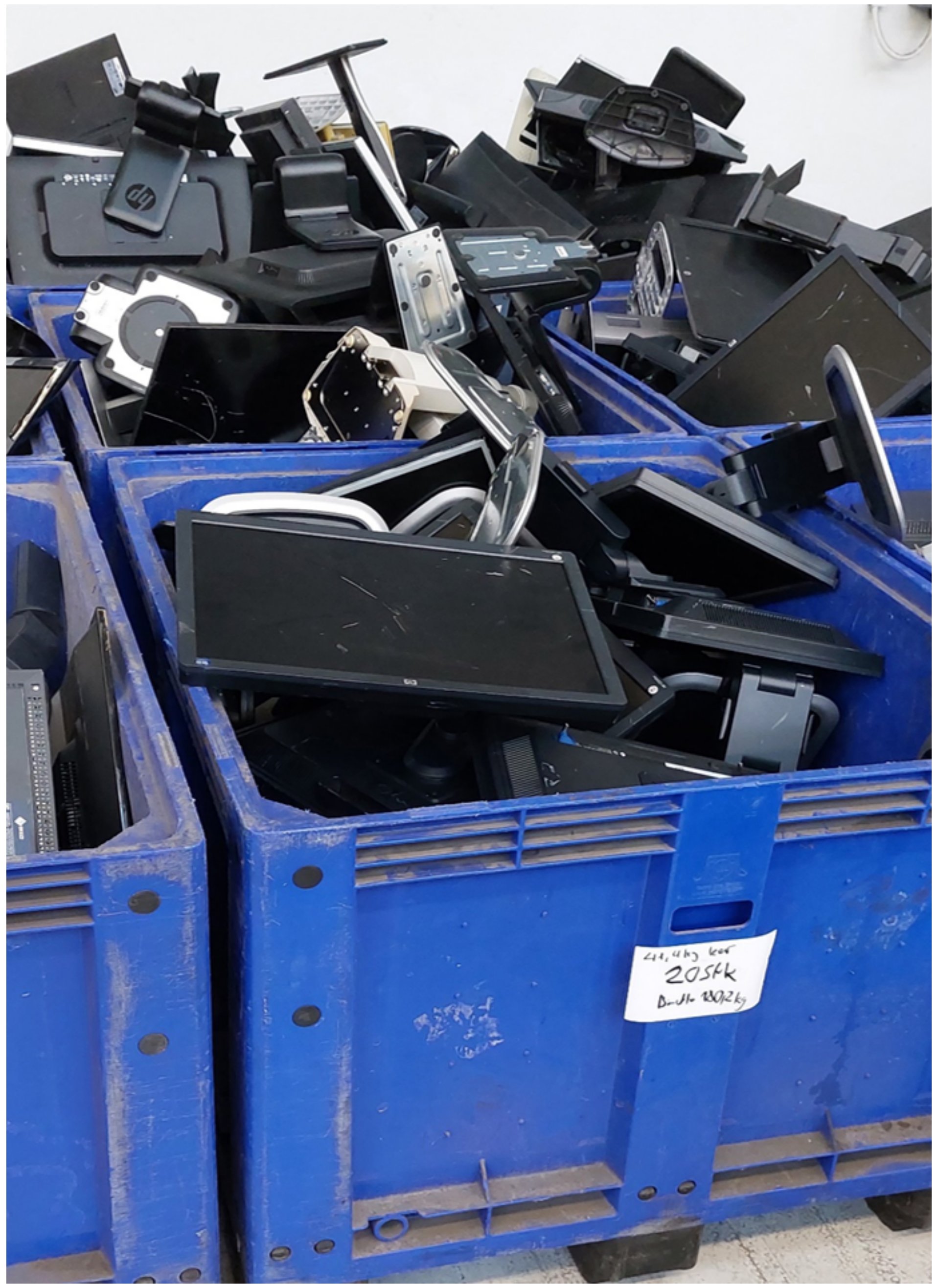


Figure 2: Disposal routes for products with integrated electronics (from Helene Steiner's master's thesis)



Material recovery and recycling rates for flat panel displays:
Figure SEQ figure * ARABIC 1: old PC monitors for further processing

Authors

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Anahide Bondolfi holds a Bachelor's degree in Biology and a Master's degree in Environmental Sciences from the University of Lausanne. She started working in the electronic waste sector in 2006 while writing her Master's thesis in South Africa, in collaboration with the Swiss Federal Laboratories for Materials Science and Technology (Empa). She then spent nearly 10 years working as an environmental consultant and project manager at two Swiss environmental consulting companies (leBird in Prilly followed by Sofies in Geneva). In January 2017, she founded Abeco Sàrl. She has been a member of the Swico/SENS Technical Commission since 2015. She is responsible for almost half of all the audits of the Swico and SENS dismantling facilities. Anahide Bondolfi has also been auditing several SENS recyclers and collection points since 2016.

Heinz Böni
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After graduating as a rural engineer at ETH Zurich and a post-graduate course in domestic water supply construction and water conservation (NDS/EAWAG), Heinz Böni worked as a research associate at Eawag Dübendorf. After holding the position of project manager at the ORL Institute of ETH Zurich and a stint at UNICEF in Nepal, Heinz Böni took up the position of Managing Director of the Büro für Kies und Abfall AG in St. Gallen. After that, he was a co-owner and managing director of Ecopartner GmbH St. Gallen for several years. He has been at Empa since 2001, where he is Head of the CARE (Critical Materials and Resource Efficiency) Group. He has held the position of Head of the Technical Audit Department of Swico Recycling since 2009 and has been an audit expert for Swico since 2007.

Stefanie Conrad
SENS TC, Carbotech AG
Stefanie Conrad completed a Master's degree in Environmental Science at ETH Zurich. After completing her studies, she worked on environmental projects focusing on remediation and decontamination, building pollutants and environmental audits. Stefanie has been working at Carbotech AG since 2020. Among other things, she deals with the topic of recycling and mobility in the field of life cycle assessments, advises companies on their sustainability strategy and carries out environmental audits. She has been a member of the SENS TC and an auditor for SENS and Swico dismantling facilities and collection points since 2021.

David Wampfler
E-Waste Manager & Site Manager Moudon / Groupe BAREC
David Wampfler grew up in a recycling family and became familiar with the craft of recycling at an early age. He has been working in the recycling industry since 2004 and has, among other things, completed his training as a recyclist. He gained experience in the areas of ferrous and non-ferrous metals, electrical and electronic waste, processing and treatment, as well as in retail. He has also continuously pursued further education, particularly in the metallurgical and environmental sectors and has lectured trainees and employees in the recycling industry. He has worked at Thévenaz-Leduc SA in Groupe BAREC since 2021, where he is responsible for E&E waste (processing of lighting equipment and flat panel displays containing Hg and LEDs).

Flora Conte
SENS TC, Carbotech AG
Flora Conte completed her Master's degree in Environmental Science, with a major in biogeochemistry and pollutant dynamics, at ETH Zurich. She has been working in the environmental consulting department of Carbontech AG since 2013. She manages various projects in areas such as renewable energy, recycling and entrepreneurship at a national and international level. Since 2015, she has been a member of the SENS and Swico TC and an auditor for SENS and Swico dismantling facilities and collection points. Flora Conte has been auditing SENS recyclers since 2016. In addition to her activities as an environmental consultant, she is involved in a non-profit organisation for access to solar power in developing countries.

Roman Eppenberger
Head of SENS Technical Inspection, Head of Technology and Quality at SENS
Roman Eppenberger completed his degree in electrical engineering at ETH Zurich. In tandem with his professional activities, he completed the post-graduate Executive MBA at the University of Applied Sciences of Eastern Switzerland (FHO). He gained his first industrial experience as an engineer and project manager in the field of medical and pharmaceutical robotics. As a project manager, he moved to the Contactless Division of the company Legic (Kaba), where he was responsible for the worldwide purchasing of semiconductor products. Since 2012, Roman Eppenberger has been a member of the management board of the SENS Foundation and is the Head of the Technology and Quality Division. In this position, he coordinates the Swico/SENS Technical Commission in conjunction with Heinz Böni.

Pascal Leroy
Director General of the WEEE Forum since 2007, oversees the general management of the association. He has been involved in all manner of e-waste programmes, policies and projects for twenty years. Formerly he was Government Affairs Manager on WEEE at APPLiA, the European home appliance manufacturing industry association. He also worked for five years in the European Parliament, as well as for Hill and Knowlton, one of the world's largest PR/PA firms. As a 26-year old, Pascal obtained a bronze medal from the Fondation du Mérite Européen in 1994 for European achievement. He speaks Dutch (native), English, French, Spanish and German.

Manuele Capelli
Swico Conformity Assessment Body SN EN 50625, Empa
Manuele Capelli studied environmental sciences and management, technology, and economics (MTEC) at ETH Zurich. Through a university internship at the World Resources Forum (WRF) with Empa, he gained initial experience in the field of electronic waste. He has been working at Empa as a research associate in the Technology and Society Department since 2021. His work involves projects on the circular economy and recycling systems as well as supporting projects to set up electronic waste recycling systems in developing and emerging countries. He is a member of the Swico TC and has been performing audits since 2022.

Daniel Savi
SENS TC, Office for Environmental Chemistry
After graduating as an environmental scientist from ETH Zurich, Daniel Savi joined SENS as Head of Collection Points and Head of Quality Assurance. He held these positions for seven years before joining Büro für Umweltchemie as a research associate, where he has been a partner and managing director since 2015. He focuses on the health hazards and environmental effects associated with construction work and waste recovery.

Charles Marmy
Swico Conformity Assessment Body SN EN 50625, Empa
After studying environmental engineering at the Swiss Federal Institute of Technology (ETH) in Lausanne, Charles Marmy began his professional career at a consulting engineering office in French-speaking Switzerland in 2016, where he initially worked as an employee and later as a project manager for projects in the environmental field. He focused on waste management and the issue of final disposal as well as the institutional and financial aspects of waste management in Switzerland and abroad. Since 2020, he has been working in Empa's Technology and Society Division, where he is involved in or carries out projects in the field of applied research. Waste management remains his specialism, now from the viewpoint of the circular economy and the recycling of rare metals recovered from batteries and electronic waste. He is a member of the SENS/Swico Technical Commission and has been an auditor for Swico recyclers since 2021.

Niklaus Renner
SENS TC, IPSO ECO AG
After completing his studies at the Lucerne School of Music, Niklaus Renner studied environmental sciences at ETH Zurich. Since 2007, he has worked at IPSO ECO AG in Rothenburg (formerly Roos + Partner AG in Lucerne). He deals with the issues of contaminated sites, soil protection and the environmental compatibility of various recycling processes and advises companies on questions relating to compliance with environmental law. Together with Dr Erhard Hug, he developed the mathematical evaluation model for the European refrigerator recycling standard CENELEC EN 50625-2-3. Niklaus Renner has been a member of the SENS Technical Commission and an auditor for recycling companies since 2017. His area of expertise includes audits and plant performance tests at refrigerator recycling companies.

Kirsten Remmen
Research Associate, Empa
Kirsten Remmen works as a research associate at Empa in the Technology and Society department. In this role, she deals with the availability and recyclability of secondary raw materials from various waste streams to enable a fact-based circular economy. After studying mechanical engineering at RWTH Aachen University, she developed membranes to recover resources from various acidic wastewater streams.

Andreas Bill
Swico Conformity Assessment Body SN EN 50625, Empa
Andreas Bill completed his Master's degree in Energy Management and Sustainability at the Swiss Federal Institute of Technology (ETH) in Lausanne and subsequently gained initial experience in the field of e-waste at Empa while completing his civilian service. He has been working as a research associate in the Technology and Society Department there since 2019. His core task is to support projects for the establishment of electronic waste recycling systems in developing and emerging countries. He is a member of the Swico TC and has been auditing Swico recyclers since 2020.

Fabian Elsener
Carbotech AG
Fabian Elsener completed his Bachelor's degree in Industrial Engineering at the Eastern Switzerland University of Applied Sciences in Rapperswil. He is currently completing his Master's degree in the Environment and Natural Resources with a focus on ecotechnology and life cycle assessment at the Zurich University of Applied Sciences in Wädenswil. He first came into contact with the recycling of electrical and electronic equipment during his internship at V-ZUG when he supported a batch test for them. He has been working in the Environmental Consulting department of Carbotech AG since the summer of 2021, where he mainly carries out life cycle assessments of technical products and systems.

Andrea Wehrli
Project Manager e-conseg, Empa
Dea Wehrli works as a research associate at Empa, where she mainly focuses on the topic of the circular economy including the e-conseg project and the development of the ISO standard 59014 on secondary materials. She is also a co-founder of E[co] work, which is establishing a co-working space for informal electronic waste dismantling facilities in India, and a bulk store in Zurich. Dea has a Master's degree in Environmental Sciences from ETH Zurich and, following her internship at Swiss Recycling, worked as a waste and recycling specialist for WEF. During her work for UN-IETC, ISWA and Sofies, she was also able to gain experience in the fields of CO_2 emissions from waste management, single-use plastic waste regulations and recycling systems.

Thekla Scherer
SENS TC, IPSO ECO AG
Thekla Scherer studied environmental sciences at ETH Zurich. After completing her studies, she worked in an engineering office for 10 years where she mainly focused on air pollution control and energy. She has been working at IPSO ECO AG in Rothenburg since 2016. As a project manager, she prepares environmental impact reports and travels as an environmental construction supervisor. She is an all-rounder who covers a wide range of environmental issues such as waste, environmentally hazardous substances and disposal. She has been a member of the SENS TC and an auditor specialising in refrigerator recycling facilities since 2021.

International links

↗ www.weee-forum.org
The WEEE Forum (Forum for Waste Electrical and Electronic Equipment) is the European association of 36 systems for the collection and recycling of electrical and electronic equipment.

↗ www.step-initiative.org
Solving the E-waste Problem (StEP) is an international initiative, which not only brings together key players operating in the fields of manufacturing, reusing and recycling electrical and electronic equipment, but also governmental and international organisations.
Three other UN organisations are members of the initiative.

↗ www.basel.int
The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal of 22 March 1989 is also known as the Basel Convention.

↗ www.weee-europe.com
WEEE Europe AG is an association comprising 19 European take-back systems. Since January 2015, it has been enabling manufacturers and other market participants to meet their various national obligations from a single source.

National links

↗ www.eRecycling.ch
↗ www.swicorecycling.ch

↗ www.swissrecycling.ch
As an umbrella organisation, Swiss Recycling promotes the interests of all of Switzerland's recycling organisations that are active in the separate collection industry.

↗ www.empa.ch/care
Since the start of Swico's recycling activities in 1994, Empa (the research institute of the ETH Domain for Materials Science and Technology) has been responsible for auditing recycling partners – as a conformity assessment agency for Swico Recycling's partners. The 'CARE – Critical Materials and Resource Efficiency' Group led by Heinz Böni is responsible for this.

↗ www.bafu.admin.ch
The Federal Office for the Environment (FOEN) offers a range of further information and news on the topic of recycling electrical and electronic equipment on its website under 'Waste'.

Cantons with delegated enforcement

↗ www.awel.zh.ch
On the website of the Office of Waste, Water, Energy and Air (WWEA), under 'Waste, raw materials and contaminated sites', you will find a range of information that is directly important to recycling electrical and electronic equipment.

↗ www.ag.ch/bvu
The website of the Canton of Aargau's Department of Construction, Transport and the Environment offers further information under 'Environment, nature and landscape'. This information also covers the topics of recycling and utilising raw materials.

↗ www.umwelt.tg.ch
On the website of the Canton of Thurgau's Department for the Environment, under 'Waste' you will find regionally relevant information on the recycling of electrical and electronic equipment.

↗ www.afu.sg.ch
The website of the St. Gallen Department for the Environment and Energy contains general information and data sheets on individual topics, plus information on current topics under 'Environmental information' and 'Environmental facts'.

↗ www.ar.ch/afu
On the website of the Appenzell Ausserrhoden Department for the Environment, you will find general information and publications relating to individual topics concerning the environment.

↗ www.interkantlab.ch
The website of the Canton of Schaffhausen's Intercantonal Laboratory offers further information on the topic of recycling electrical and electronic equipment under 'Information on certain waste'.

↗ www.umwelt.bl.ch
The website of the Canton of Basel-Landschaft's Department for Environmental Protection and Energy (DEE) provides information on recycling and utilising raw materials under 'Waste/waste that is subject to inspection requirements/electronic waste'.

↗ www.zg.ch/afu
On the website of the Canton of Zug's Department for Environmental Protection, under 'Waste management', you will find general information and data sheets on waste. Detailed information on the collection of the individual recyclable groups can be obtained from the Special-Purpose Association for Waste Recycling in Zug's Residential Communities (ZEBA) at ↗ www.zebazug.ch.

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