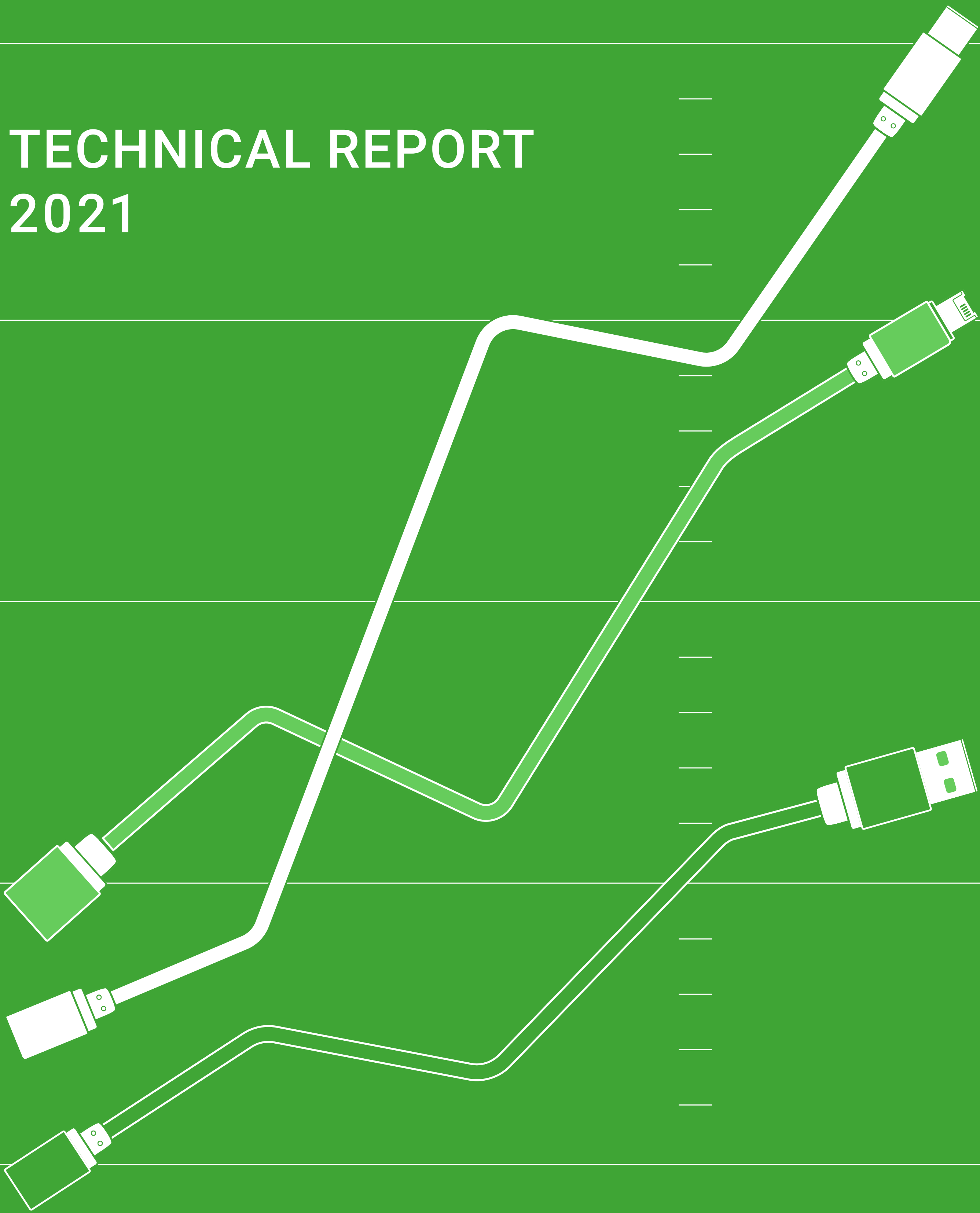
Swico, SENS and SLRS

News about electrical
and electronics recycling

TECHNICAL REPORT 2021



Contents

Stress test passed

The recycling systems Swico, SENS and SLRS are jointly presenting the technical and scientific findings of the past year, as they do every spring. And, like every spring, we can say with satisfaction that the recycling of waste electrical and electronic equipment is an ecological achievement and is greatly increasing year on year.

But the past year was unlike any before. It was characterised by lockdowns, uncertainties, alternating standstills and excessive backlogs. The year of the COVID-19 pandemic was extremely challenging and unstable for consumers, appliance manufacturers, trading companies, recycling companies and collection points alike. Systems demonstrate just how resilient they are in times of crisis – and we can proudly state that we passed the stress test.

Swico, SENS and SLRS are characterised by their tight-knit ecosystems of hundreds of contract and service partners, policies and management at all stages and, last but not least, consumers. This has resulted in a fine balance dedicated to the sustainability and consumer friendliness of recycling. The robustness of these systems is demonstrated not least through their financial endurance. Every single invoice was paid on time, index adjustments were implemented quickly, innovations were financed easily and special coronavirus-related compensation was even periodically given. Nevertheless, all the systems ended 2020 with balanced results and without dipping into their reserves.

The three systems are also confident in their outlooks. Not only are we well positioned in technical and financial terms; as this technical report shows, we have the innovative strength to cope with the future ecological challenges of the electrical and electronics industry. We look forward to tirelessly continuing our contribution to sustainability and to maintaining Switzerland's position as a world leader in recycling.

Judith Bellaiche
Swico

Heidi Luck
SENS

Silvia Schaller
SLRS

Swico, SENS Foundation and SLRS: competent and sustainable

For more than 20 years, Switzerland's three take-back systems Swico, SENS eRecycling and the Swiss Lighting Recycling Foundation (SLRS) have been guaranteeing resource-efficient return, reuse and proper disposal of electrical and electronic equipment.

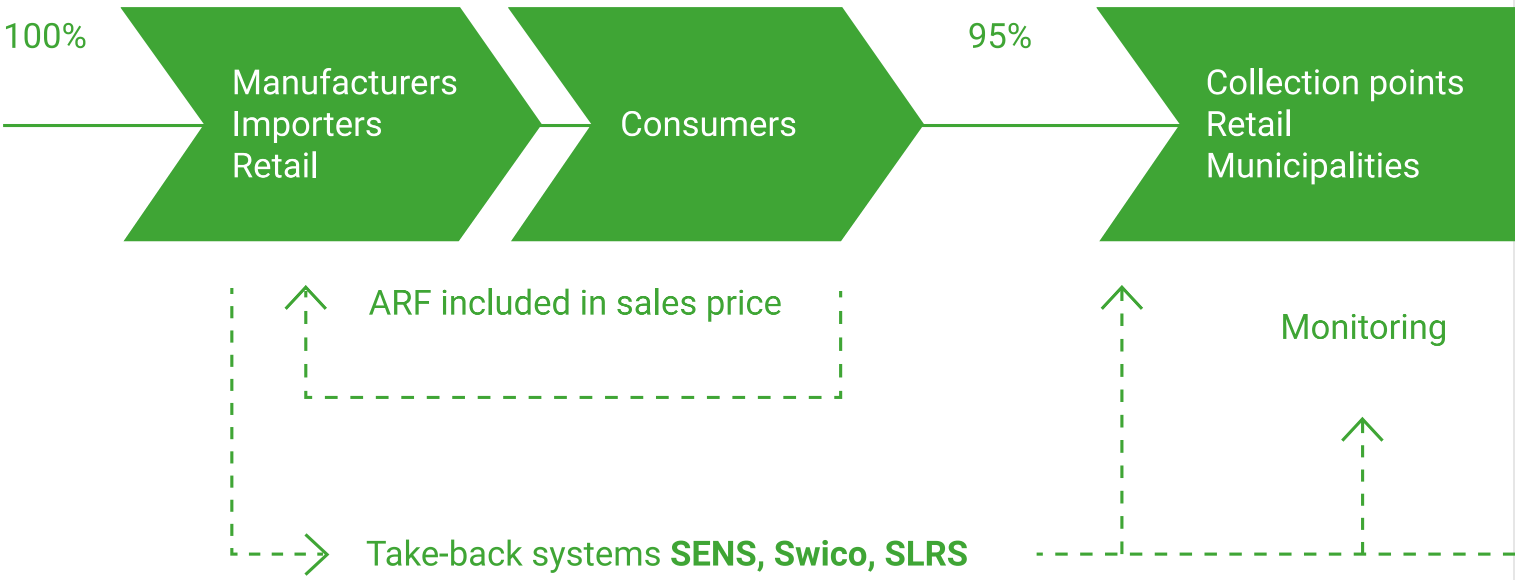
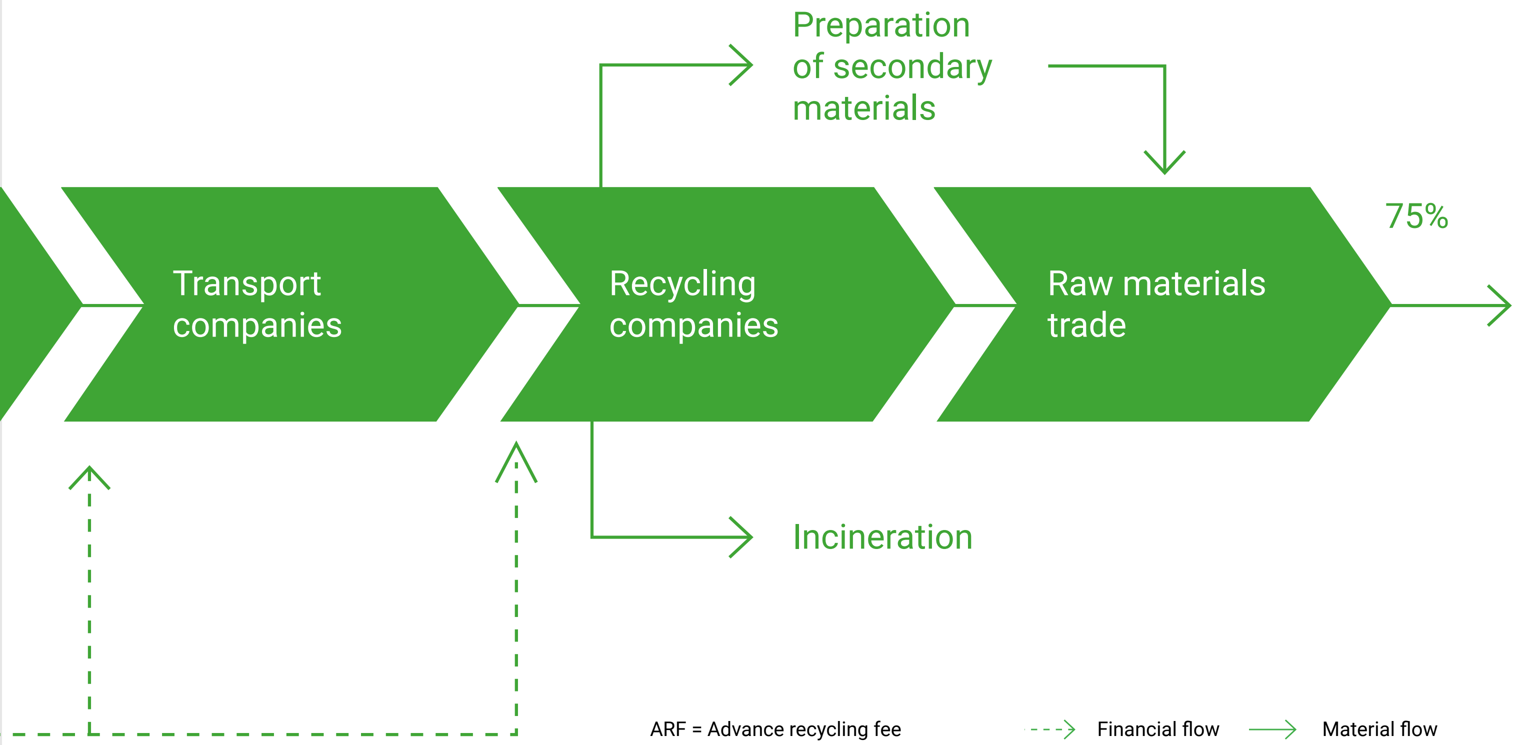


Figure 1: Overview of the take-back systems

There are historical reasons for the existence of three 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 to answer 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, SENS or the Swiss Lighting Recycling Foundation (SLRS) is now responsible for recycling. In 2020, the three systems disposed of around 129,800 tonnes of waste electrical and electronic equipment.

This means that Swico, SENS and SLRS have also made a significant contribution to the reintroduction of valuable resources into the production cycle. With the international networking of the three organisations at a European level – for example, as members of the Forum for Waste Electrical and Electronic Equipment (WEEE) – they also help to set cross-border standards for the recycling of electrical and electronic appliances.

The Ordinance on the Return, Take-Back and Disposal of Electrical and Electronic Equipment (ORDEE) obliges retailers, manufacturers and



importers to take back appliances they stock in their product range free of charge. To be able to competitively finance sustainable and environmentally responsible recycling of electrical and electronic appliances, an advance recycling fee (ARF) is included in the sale price of these appliances. The ARF is an efficient financing instrument that guarantees that Swico, SENS and SLRS can ensure proper processing of the appliances in their respective area and continue to face challenges in the future.

Swico

Swico Recycling is a special fund within the Swiss Industrial Association Swico 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. Swico's focus is on equipment in the fields of computing, consumer electronics, office equipment, telecommunications, the printing industry, measuring and medical instruments - copiers, printers, televisions, MP3 players, mobile phones, cameras, etc. Close cooperation with the Swiss Federal Laboratories for Materials Testing and Research (Empa), a research and service institute for material sciences and technology development within ETH, plays a crucial role in ensuring that Swico can enforce high and uniform quality standards throughout Switzerland with all waste management services.

SENS

SENS eRecycling is an independent, neutral, non-profit organisation that operates under the SENS eRecycling brand. It focuses on the return, reuse and disposal of electrical and electronic appliances from the small and large domestic appliance sector, as well as construction, garden and hobby equipment and toys. To this end, SENS works in close conjunction with specialist networks in which the parties involved in the recycling of electrical and electronic appliances are represented. In cooperation with its partners, SENS is geared towards ensuring that the recycling of these appliances is compliant with economic and ecological principles.

SLRS

The SLRS bears basic responsibility for lamps and lighting equipment. SLRS deals with the organisation of comprehensive waste disposal systems for lamps and lighting equipment across the whole of Switzerland. In order to finance these activities, SLRS administers a fund each for lamps and lighting equipment, which is fed from the relevant ARF. Training and sensitisation of market participants with respect to the recycling of lamps and lighting equipment and provision of information to all stakeholders also form part of SLRS's remit. SLRS maintains a close partnership with the SENS Foundation across all areas. For example, as a contract partner to SLRS, the SENS Foundation provides not only collection and transport via its take-back and recycling system, but also recycling, monitoring and reporting with regard to lamps and lighting equipment on an operational basis.

SWICO

SENS eRecycling

SLRS

Where is audit practice heading?

Heinz Böni and Roman Eppenberger

Many audit requirements have been expanded in recent years, making the audit processes longer and more laborious. The scope of the document review in the office has increased at the expense of the plant tour. The auditors agreed that they should go through the books on this. This is why the Swico/SENS Technical Commission held a closed meeting in mid-2020 and has made initial proposals.

The audit system, according to which Swico and SENS recycling partners are regularly reviewed based on technical and environmental requirements, has continuously developed over the last almost 30 years. Although the number of recycling companies to be audited – currently 18 direct recycling partners and 121 associated dismantling companies – has remained practically the same for years, the technical requirements have been continuously expanded. The audit scope increased in particular with the introduction of the SN EN 50625 standard, which was defined by Swico from 2017 and by SENS from 2019 as the technical basis for auditing. In some cases, this led to very long, extensive document reviews and obligations to provide evidence together with the plant management team, which significantly impaired the plant tour and thus the review of individual standard requirements on site. In numerous cases, this frustrated both the auditors and the audited companies.

The aim of the audit is to contribute towards the recycling systems' continuous improvement. This includes support in optimising operational processes and an assessment of resource efficiency when processing waste electrical and electronic equipment (WEEE). The latter focuses on the target substances of recycling: the most complete separation possible and environmentally friendly disposal of the pollutants contained in the devices, as well as a largely loss-free recovery of valuable secondary raw materials. With the auditors assessing the processes, the audits help to improve the state of the art in WEEE recycling.

What is changing?
Audit practice must be effective and efficient to meet these requirements. 'Effective' means 'doing the right thing' and 'efficient' means 'doing things right'. In an audit process, this is always a balancing act. Should documents primarily be checked to identify potential errors, weak spots or insufficient legal conformity? Or should the main focus be on operational practice to precisely identify what is perhaps well documented but inadequately implemented in practice? One thing is clear: an audit provides a very limited view of reality and the insight is limited to less than 0.5% of the annual working hours.

Against the backdrop of the still-unclear situation regarding the upcoming ORDEE revision, the Swico and SENS Technical Commission limited itself to making only small adjustments to the audit process for the time being. The key changes are that the document check should be performed long before the actual visit to the plant and some of the points should no longer be checked annually. This then allows for an extended tour of the plant. Further changes will be explored once the ORDEE situation has been clarified and no significant changes are made to the audit practice, e.g. by redefining the audit at national level. So there is a small revision due to the current change. It may not be a huge stride, but it is certainly a step in the right direction.

There have been some changes among the auditors:
Michael Gasser left the Swico audit team in late 2019. He will be replaced by Charles Marmy, who was introduced to auditing in 2020 and will work as an auditor starting in 2021. Stefanie Conrad joined the SENS audit team from Carbotech AG. During an initial phase, she will primarily be auditing dismantling plants. In addition, Erhard Hug permanently stepped back from his auditing activities as of late 2020. A special article has been dedicated to him (see page 46).

Balls of plastic stored on the Thévenaz Leduc S.A. premises until processing.

High collection quantities and composition continues to change

Michael Gasser

The processed quantities of waste electrical and electronic equipment remain in line with the long-term average. The composition according to individual categories is continuing to change. Quantities of electronic equipment continued to fall, which was offset by higher volumes of large household appliances and small household appliances.

In 2020, the Swico and SENS recyclers processed around 129,800 tonnes of electrical and electronic equipment (Waste Electrical and Electronic Equipment), a figure up slightly on the previous year, but still within the long-term average (Table 1 and Figure 1). The various categories continued to undergo long-term changes.
The volume of non-ORDEE equipment that is not included in the lists provided in the Swiss Ordinance on the Return, Take-Back and Disposal of Electrical and Electronic Equipment (ORDEE) and the volume of refrigerators and lighting equipment remained constant. The volume of electronic equipment processed is still dropping in line with the long-term trend (-1%) in part due to the decline in heavy CRT displays from computer monitors and televisions. With the almost complete disappearance of these types of screens, however, the decline appears to be slowing. In the case of large electrical appliances, an upward trend (+4%) is apparent again for the third year in a row following a change to the recording methodology in 2017. A further rise (+4%) could was also observed in the quantities of small electrical appliances, as was the case in the previous year.
The volume of processed photovoltaic equipment has declined slightly year on year, and its proportion remains small at 200 tonnes in total.

Year	Large household appliances	Refrigerators, freezers & air conditioners	Small household appliances	Electronic equipment	Lighting equipment	Photovoltaics	Non-ORDEE appliances	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	2,000	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
Change on previous year	**4%**	**1%**	**4%**	**-1%**	**0%**	**-33%**	**0%**	**2%**

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

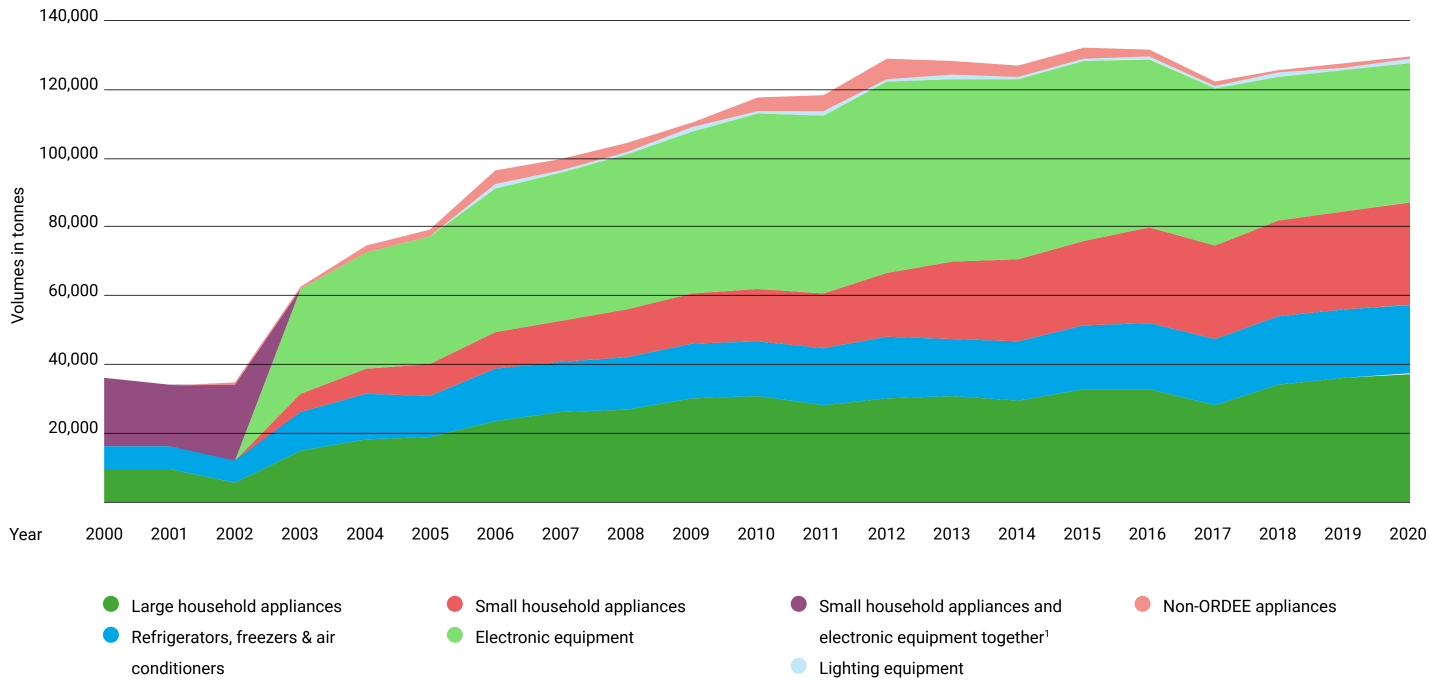


Figure 1: Total volume of processed electrical and electronic equipment in Switzerland in tonnes from the material flow recording system. Source: Toocy

Recovering recyclables

Recyclables are recovered from the processed waste electrical equipment and pollutants are separated by means of manual and mechanical processing (Figure 2). Metals make up the largest fraction of recyclable materials (62%). Plastic/metal mixtures (17%) and plastics (9%) are the next two largest fractions. The proportion of glass from cathode ray tube processing decreased by another 17% year on year and still amounts to 0.8%. The particularly valuable printed circuit boards account for only 1.4% of the total quantity. It is often worthwhile to remove these components manually before mechanical processing, so the precious metals they contain can be recovered in as complete a condition as possible. The fractions of recyclables are further processed in downstream plants and recycled or used to generate heat.

The fractions of recyclables from SENS and Swico recyclers are sent for further processing. The SENS and Swico recyclers have to provide evidence of material flows to prove and document the further processing of these fractions. Ferrous fractions are processed in Swiss steelworks, while non-ferrous metals are handled in European smelting works. Plastic/metal mixtures are separated further; depending on the separation process and composition, the metals and, in some cases, the plastics too are recovered. Certain mixed fractions are still directly used for energy recovery, although this proportion has fallen sharply in recent years thanks to new processing options for toner cartridges and sorting systems for plastics/metal mixtures. Glass fractions (screen glass, flat glass and recycled glass from illuminants), cables, printed circuit boards and batteries are also fed into special recycling operations.

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 Swiss recycling companies.
Most of the pollutants are removed manually in dismantling plants. Capacitors, for example, are removed from larger household appliances, batteries are taken out of electronic appliances and the mercury-containing backlights of flat-panel displays, scanners and photocopiers are disassembled. Pollutant removal and handling must be 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 undertaken by recycling companies and calls for high-calibre quality assurance systems.

Take-back and composition of electronic equipment

Swico Recycling regularly inspects the quantities taken back and the composition of electronic equipment. To this end, it conducts shopping basket analyses and performs product group processing tests (Table 2). In 2020, Swico Recycling took back 46,800 tonnes[1] of electronic equipment, the same as 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 average weights and quantities of FPD monitors and televisions continued to rise. While the number of mobile phones remains on the rise, the total volume increased only slightly due to the further decline in average weight.

A similar but less distinctive trend was also observed in the 'Consumer electronics, mixed' category, where the average weight can vary greatly year on year.

The composition of the individual equipment categories is determined by processing tests carried out by Swico recyclers and attended by Empa. During this process, 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.

[1] This figure is greater than the 40,600 tonnes of electronic equipment in Table 1, as it also includes equipment disposed of by A signatories under direct contracts.

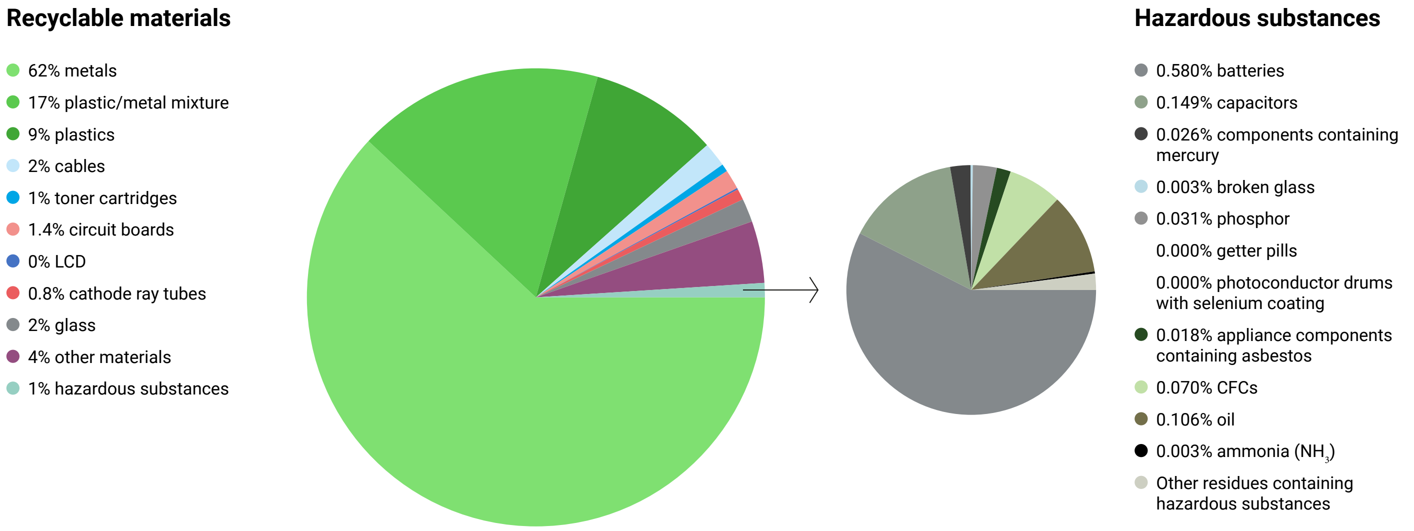


Figure 2: Composition of produced fractions in % in 2020. Hazardous substance breakdown, which make up around 1% of the total composition, are shown in the pie chart on the right (pollutants breakdown).

Appliance type	Quantity[4] in thousands	Average weight in kg	Metals in tonnes	Plastics in tonnes	Metal/ plastic mixtures in tonnes	Cables in tonnes	Glass and/or LCD modules in tonnes	Printed circuit boards in tonnes	Hazardous substances in tonnes	Others[5] in tonnes	Total in tonnes	Increase/ decrease compared to 2019
PC monitors, CRT	12	17.7	31	42	20	5	93	19	0	1	212	-65%[7]
PC monitors, FPD[1]	580	7.4	1,682	1,357	82	53	669	303	39	106	4,292	6%
PCs/servers	360	11.9	3,524	248	11	131		357	13		4,284	-9%
Laptops	480	2.5	353	349	123	6	106	174	83	5	1,200	-3%
Printers	460	11.5	1,874	2,846	326	29	36	92	2	86	5,290	2%
Large scale copiers and equipment	48	128.8	3,365	231	2,210	112	4	50	53	158	6,182	-2%
IT, mixed[2]	820	3.1	1,383	91	915	46	1	19	22	64	2,542	14%
CRT TVs	51	27.7	139	289	47	5	913	17	1	1	1,413	-50%[7]
LCD TVs	331	25.2	4,031	1,500	879	115	732	701	93	291	8,341	38%
Consumer electronics, mixed[3]	3,525	3.0	5,632	380	3,791	191	5	82	91	265	10,434	-5%
Mobile phones	904		23	48	–	–	7	30	27	–	136	10%
Remaining phones, rest	1,303		1,205	79	797	40	1	17	19	55	2,215	-9%
Photo/video	219		90	6	58	3	0	1	1	4	164	-2%
Dental											61	-3%
Total in tonnes			**23,333**	**7,468**	**9,259**	**734**	**2,568**	**1,864**	**445**	**1,037**	**46,766[6]**	**2.4%**
Total in pct.			**50%**	**16%**	**20%**	**2%**	**5%**	**4%**	**1%**	**2%**	**100%**	

1 FPD: flat-screen 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 41,000 tonnes of electronic equipment in Table 1, as it also includes equipment disposed of by A signatories under direct contracts
7 One-off correction: CRT monitors and televisions

Table 2: Swico volumes collected and composition by type of appliance (2020)
Source: Michael Gasser, Empa, based on Swico processing and market basket analyses (2020)

Highly developed processes for recovering refrigerants and propellants – a key contribution to climate protection

Geri Hug and Niklaus Renner

The recycling of disused temperature exchange equipment, i.e. compressor appliances such as domestic and commercial refrigerators and freezers, is essential for protecting the climate and the ozone layer. Tonnes of CO_2 in the single and double digits are saved with every kilogram of refrigerant and propellant recovered and rendered harmless in a controlled manner. Sceptics of the complex processes should note that the climate-related significance of recycling refrigerators decreases slightly year on year, as more and more appliances are produced with climate-friendly agents. However, until the last appliance with R-11, R-12 or R-134a (subsumed under the term 'VFC'[1] defined in the standard SN EN 50625-2-3) goes into reverse production, a timescale of 2030 is insufficient, and state-of-the-art processing together with newer appliances without climate-harming substances is the only ecologically acceptable way. SENS also recommends disposal via refrigerator recycling systems for the insulation foams from boilers.

Proportion of climate-friendly VHC[2] appliances practically unchanged
The long-standing trend towards ever-higher proportions of climate-friendly, VHC-operated compressors remains stable. In 2020, 66% of the appliances processed at stage 1 were the type with a VHC compressor (dark green line in Fig. 1), so there was practically no year-on-year change. However, 32% of the appliances still had a compressor filled with VFC. Absorber systems containing ammonia made up 2% of all processed appliances (this figure is also unchanged).

When it comes to insulation foams treated at stage 2, the data continues showing an analogous trend. However, this was noticeable earlier, since the VFC R-11 was replaced by the VHC cyclopentane directly (without an intermediate HCFC, as in the case of the refrigerants). In the current survey year, 75% of all recycled refrigerators were already insulated with cyclopentane-foamed polyurethane (PU) – a moderate year-on-year increase of + 2%.

Overall, the number of appliances processed in both processing stages by Kühlteg AG, Immark Schattdorf AG (formerly Ruag Environment AG) and Oeko-Service Schweiz AG dropped by 5% (from 390,000 appliances or 19,900 tonnes to around 370,000 appliances or 18,900 tonnes at present). See Fig. 1.

[1] VFCs: volatile fluorocarbons (e.g. R-11, R-12, R-134a, R-22, etc.)
[2] VHCs: volatile hydrocarbons (e.g. R-600a or cyclopentane)

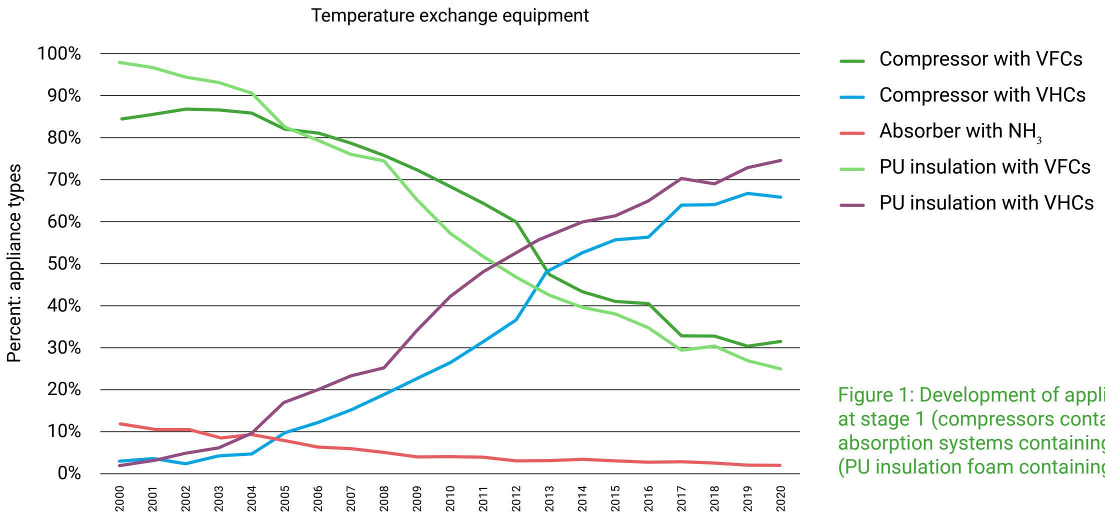


Figure 1: Development of appliance types processed at stage 1 (compressors containing VFCs/VHCs, absorption systems containing ammonia) and stage 2 (PU insulation foam containing VFCs/VHCs).

Recovery volumes slightly higher than expected

The recovery volumes have not changed much in the long-term trend. The volumes of recovered refrigerant and propellant mixtures continue to decrease as the ratio of the processed appliances shifts towards the VHC types, since their compressor filling quantities and the concentration in the PU foam are considerably lower than in the VFC appliances. The data concerning the assumed values for VFC and VHC filling quantities for domestic and commercial refrigerators going through both processing stages was collected from a wide range of sources and is, accordingly, reliable. In the case of appliances that are only processed only at the first stage (e.g. tumble dryers, mobile air conditioners, dehumidifiers), such assumptions exist to an imprecise degree, so the recovered quantities can be divided between the two fractions of processed appliances only with a degree of ambiguity. With such uncertainties in the evaluation method on the one hand and certain incoming goods reporting challenges on the other, the slight rise in refrigerant and propellant recovery compared to the previous year can likely be interpreted as: 63 g per appliance or 37 g per kg of PU foam (2019: 61 g/compressor or 34 g/kg PU[3]). This has little to do with the plant performance in and of itself. During performance tests, carried out exclusively with domestic refrigerators, constant recovery rates are also determined over the years.
See Fig. 2.

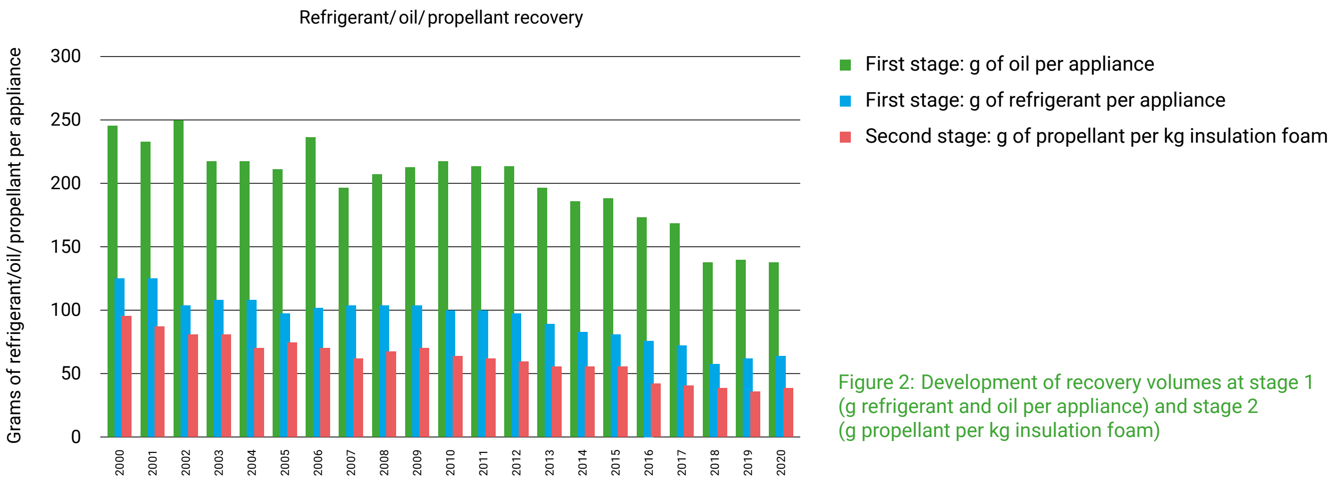


Figure 2: Development of recovery volumes at stage 1 (g refrigerant and oil per appliance) and stage 2 (g propellant per kg insulation foam)

[3] In last year's technical report, this value was incorrectly stated as 54 g/compressor.

CO_2 savings equivalent to several thousand gas storage tanks

The technically demanding target of 90% refrigerant and propellant recovery set out in the CENELEC standard is doubly relevant when it comes to environmental protection. On the one hand, the CFCs contained in older compressors and PU insulation foams have to be removed from the flow of old appliances due to their ozone depletion potential (ODP). At the same time, these substances have a global warming potential (GWP) that is 1,000 to 10,000 times greater than CO_2 (see Table 1). This is why recovering them and subsequently converting them into CO_2 as well as water, acids and salts (which have far less of an impact on the climate) in a controlled manner makes a key contribution to environmental protection.

In the current survey year, the volume of emissions avoided through controlled recovery of climate-changing gases was around 280,000 tonnes of CO_2 equivalents, which can be illustrated with the contents (compressed at 6 bar) of 5,600 typical spherical gas tanks measuring 20 m in diameter – the ones we all know from natural gas storage facilities (Fig. 3).

Taking a broader view: insulation foams from boilers

Refrigerators are not the only appliances that contain climate-changing gases; the foam insulation found in boilers and hot water tanks does too. Although this category does not include appliances returned as part of the SENS system, it is worth exploring at this point due to its climate impact and relevance to disposal.

Substance	Ozone depletion potential (ODP) R-11 equivalents	Global warming potential (GWP) with a timescale of 100 years CO_2 equivalents
Refrigerant (first stage)		
CFC-12 (R-12)	1	10,200
HFC-134a (R-134a)	–	1,300
Isobutane (R-600a)	–	3
Propellant (second stage)		
CFC-11 (R-11)	1	4,660
Cyclopentane (CP)	–	< 25

Table 1: Ozone depletion potential (ODP) and global warming potential (GWP) of refrigerants and propellants used in refrigerators.
Sources: FOEN (2013), EPA (2016), IPCC (2014).

Figure 3: Typical spherical gas tank for storing natural gas (source: Adobe Stock).

Exploratory analyses performed by SENS and a study conducted by the Öko-Institut Darmstadt (Darmstadt Institute for Applied Ecology) on behalf of the RAL Quality Assurance Association for the Demanufacture of Refrigeration Equipment (2020) revealed that VFCs/VHCs are still present in insulation foams found in boilers in concentrations comparable to refrigerators, even after use. Boilers built before the mid-1990s are generally considered to contain CFCs.

The conclusion from the studies mentioned above is that from an ecological standpoint, the only correct disposal route for boiler insulation foams (at least those containing CFCs) – or, for example, sandwich element insulation panels – is through stage 2 in refrigerator recycling plants. The people returning the appliances, the dismantling companies, the disposal companies and the cantonal offices frequently know far too little about this. Kühlteg AG and Oeko-Service Schweiz AG have been processing PU foam from supplied boilers in their stage 2 plants for many years. The insulation is manually removed and then processed together with the refrigerator casing. We hope that this best-practice approach to disposal will catch on!

Figure 4: Boilers for manual PU foam removal and processing in refrigerator recycling plants (picture used with the kind permission of the RAL Quality Assurance Association for the Demanufacture of Refrigeration Equipment, 2020).

Recycling fluorescent tubes: opportunities and challenges

Flora Conte

Around 800 tonnes of fluorescent tubes are processed in Switzerland every year. Compliance with the mercury limits must be strictly monitored, since the top priority is to protect both people and the environment. Thanks to conscientious work and efficient recycling processes, recycling is at over 90% despite the challenge posed by this volatile and toxic heavy metal.

SENS, SLRS and Swico promote the circular economy by recycling Waste Electrical and Electronic Equipment (WEEE). Protecting people and the environment from pollutants is a vital part of this. In Switzerland, numerous recycling companies specialise in the recovery of lighting equipment, particularly rod-shaped gas discharge lamps, also known as fluorescent tubes. Around 800 tonnes of fluorescent tubes are processed every year. Unlike most WEEE categories, pollutants in fluorescent lamps cannot be removed before mechanical processing. Mercury (Hg) that adheres to the components proves to be problematic during recycling. There is a health risk as soon as lighting equipment is damaged due to being handled incorrectly during the recycling process. Toxic mercury vapours form and escape even at room temperature, which is why mercury must be technically separated so that the limits and benchmarks are always adhered to. Hg values must be strictly monitored.

Four fractions are created when recycling fluorescent tubes: glass, aluminium end caps, magnetic metals and fluorescent powder. Although avoidance of mercury contamination is the top priority, the targeted 90% recycling rate is easily achieved in the recycling plants. The magnetic metals' and the fluorescent powder's mercury mass ratios are above the limits, so they can barely be used if at all. The fluorescent powder is disposed of in an underground waste site in the EU. For the glass and aluminium fractions, the limits of 5 or 10 ppm Hg are generally adhered to without any issues. So aluminium can be produced again from the aluminium fraction. However, glass is the material that contributes most to the high recycling rate. Almost 100% of the glass fraction, (i.e. most of the output volume) can be recycled. In the past, the glass was used to manufacture new fluorescent tubes. Demand for this application is decreasing with the transition to LED lamps. The glass is now used in, for example, glass wool production.

Almost 100% of the glass fraction,
(i.e. most of the output volume) can be recycled.

When recycling fluorescent tubes, it's fair to say that the amount of usable material is very high, but it must be handled with great care. This starts even when private individuals return fluorescent tubes at the collection point.

Batch tests: which indicators are relevant?

Anahide Bondolfi and Andreas Bill

**One of the key indicators used by the EN 50625 series of standards to assess the performance of a WEEE recycler is the recycling rate. However, since the recycling rate is influenced by the composition of the processed material and does not take the ecological value of the recovered or lost materials into account, this indicator is no longer satisfactory from today's perspective. With the new 'SENS and Swico supplementary technical regulations for the SN EN 50625 series', SENS and Swico have started the process of revising the recycling performance indicators.
In 2020, batch tests were carried out as pilots to test new approaches such as the consideration of potential base metals and recyclable plastic losses.**

Flaws of the recycling rate indicator
Swico and SENS monitor compliance with legislation and environmental regulations and assess recyclers' performance using various methods such as company audits, material flow checks and batch tests. One use of the batch test is to uniformly determine the recycling rate (i.e. the material recovery rate) for each recycler according to the treatment stream. But this indicator has two major flaws:

– The achievable recycling rate depends on the composition of the material processed in the batch test. This is variable and does not depend on the recycling performance.
– While the recycling rate provides volume-related information about the recovery rate of the most important materials, such as iron, aluminium, copper and plastics, it does not take their ecological value into account. In the case of technical metals, this value can be very high, even with smaller contents.

Recycling rate: benchmark instead of limit
With this in mind, the Swico/SENS Technical Commission (TC) adapted the specifications for batch tests and assessing them in the 'SENS and Swico supplementary technical regulations for the SN EN 50625 series' that have been applicable to Swiss recyclers since 1 January 2020. The recycling rates per appliance category are no longer set as a limit, but as a benchmark. This enables greater flexibility when interpreting the results of a batch test, particularly by taking the quality of the input material into account, and it also considers the technology's constant further development.
For small appliances without any screens and heat exchangers, the benchmarks for the recycling rate to be achieved have also been harmonised with Annex V of the European Directive on waste electrical and electronic equipment (WEEE Directive). European recyclers' targets were last adjusted there on 15 August 2018, so the recycling rate to be achieved for Swico small appliances was reduced from 65% to 55% and rose from 50% to 55% for SENS small appliances.

Benchmarks for large household appliances
The benchmark for large household appliances was adjusted in Switzerland after it came to light that numerous recyclers found meeting the requirements set out in the European Directive difficult. Instead of the 75% benchmark for all large household appliances that was valid previously, a quota was introduced for each of the four key appliance types in this category. The recycling rates per appliance type were calculated based on specific batch tests carried out at four Swiss recyclers between 2018 and 2020. The composition of each initial fraction was estimated through further separation steps or analyses, and the metal content was determined in order to calculate the recycling rate that could potentially be achieved. This was then introduced as a new benchmark for the appliance type in question. The benchmark for ovens, which contain large amounts of metals, has been increased to 86%. But lower benchmarks were set for washing machines (69%), dishwashers (68%) and tumble dryers (73%, once any compressors have been removed), since these appliances are increasingly made with ever more plastic. Although the recyclers' technologies tend to become more efficient and thus enable improved reusable material recovery, the recycling quota targets do not necessarily increase because the appliances' composition does not always develop in a manner that is beneficial to recycling.

Uncertainties in input-based recycling rates
While the new benchmarks for large household appliances, which are determined based on the mix of appliances processed, are more realistic, there are still considerable uncertainties. The metal content, which was calculated during the special batch tests to determine the four appliance types' recycling potential, varied between the individual batch tests with a 6% average standard deviation. The standard deviation was as high as 10% for washing machines and just 3% for ovens. This shows that the appliances' composition can vary a great deal, even within the same appliance type. A study on the material flow conducted by Swico Mix[1] in 2019 led to similar findings. Determining the recycling potential by extensively characterising the batch input material's composition is not sufficiently robust (degree of uncertainty surrounding the target substance balances > 50%) and the work required for this type of investigation is excessively high for regular implementation.

A new indicator: metal and plastic losses
In addition to the adjustments to the recycling rate benchmarks, the '2020 supplementary technical regulations' introduced a new indicator for assessing recycling performance: the amount of non-recycled metal (ferrous metals, copper and aluminium) and recyclable plastics – i.e. losses in the process chain. These losses usually arise in shredder light fractions or in mixed metal fractions that go to final processing where only one metal is recovered. Examples of such losses are copper contents in an iron scrap fractions used in steelworks, or ferrous metals in engines used in a copper smelter. These losses are estimated in kg per t total processed material, not according to the relative metal content per fraction, to take the total quantity of lost resources into account. For the new indicator, target values were proposed in the document for batch tests, but they have not been made binding yet.

[1] The Swico Mix is made up of Swico small appliances without Visual Display Unit and screens > 100 cm^2 (i.e. removable notebook screens, for example, are also diverted from the treatment stream).

Pilot phase: 2020 and 2021

The analysis of material losses seems to be more promising than adjusted recycling rates based on the relevant input composition, but experience is still needed. A Swico/SENS TC working group is therefore continuously working on further developing these indicators. During a pilot phase in 2020, additional analyses were carried out in the batch tests to determine metal losses in various fractions from mechanical processing. To this end, fractions in which the presence of a certain metal is expected but it is not recovered in a downstream process were selected. In addition to the base metals (Fe, Al and Cu), gold, silver and palladium were also sometimes analysed in these fractions, since loss of these precious metals is also a major loss in terms of ecological value. The results of this pilot phase revealed that the metal contents in the finest non-metal mechanical processing fractions, including the shredder light fraction (SLF), dust and filter fractions, varies greatly between recyclers and can sometimes be very high.

Further information

Quoted studies from earlier technical reports:

↗ Technical Report 2019, p. 43 - 44, Recycling rate of large household appliances, Geri Hug and Anahide Bondolfi

↗ Technical Report 2020, p. 32 - 33, Recycling quota of large household appliances – an update, Geri Hug and Anahide Bondolfi

↗ Technical Report 2020, S. 24 - 29, Are extended batch tests suitable for determining the recycling potential?, Roger Gnos, Rolf Widmer and Lorena Toledo Reyes

↗ Technical Report 2020, S. 40 - 41, A circular economy for WEEE recycling: Are we heading in the right direction?, Heinz Böni and Rolf Widmer

Benchmarks for recycling rates valid in Switzerland in 2021

For large appliances, these rates include only the recycling target for metals.

Treatment stream	Recycling rate benchmark
Temperature exchange equipment	80%
Visual Display Units	65%
Rod-shaped gas discharge lamps	90%
SENS large appliances: washing machines	69%
SENS large appliances: dishwashers	68%
SENS large appliances: tumble dryers	73%
SENS large appliances: cookers/ovens	86%
Swico large appliances	75%
SENS small appliances	55%
Swico small appliances (Swico Mix)	55%

Electronics in vehicles: an undiscovered gold mine?

Charles Marmy

Over the past few decades, there has been a spike in the number of electronic components in our cars and the boom in electromobility is only adding to this momentum. Just like smartphones, laptops, monitors and similar devices, these components contain rare and precious metals. But unlike domestic appliances, they are generally not recycled separately.

Have you driven a car today? If you have, then you will already have used countless electronic components: the smartphone-to-multimedia display connection, the GPS, the inside temperature controller, the automatic headlights, the electric windows, the cruise control, the rear view cameras, the obstacle detection sensors – the list goes on.

In recent years, the number of such components has risen rapidly. Just like consumer electronics (computers, telephones, printers, monitors, etc.), they contain a number of rare or precious metals, including gold, neodymium, copper and cobalt, that are essential for new technologies. Altogether, there are considerable amounts of metals like these in vehicles (see Fig. 1). In Switzerland, these quantities are roughly the same as those found in consumer electronics. But unlike consumer electronics, most vehicle electronics are not divided and recycled separately once the car has reached the end of its service life. The main aim of processes commonly used in the recycling of wrecked cars is to recover industrial metals such as iron, copper or aluminium. So rare and precious metals that are mainly found in electronic components are lost.

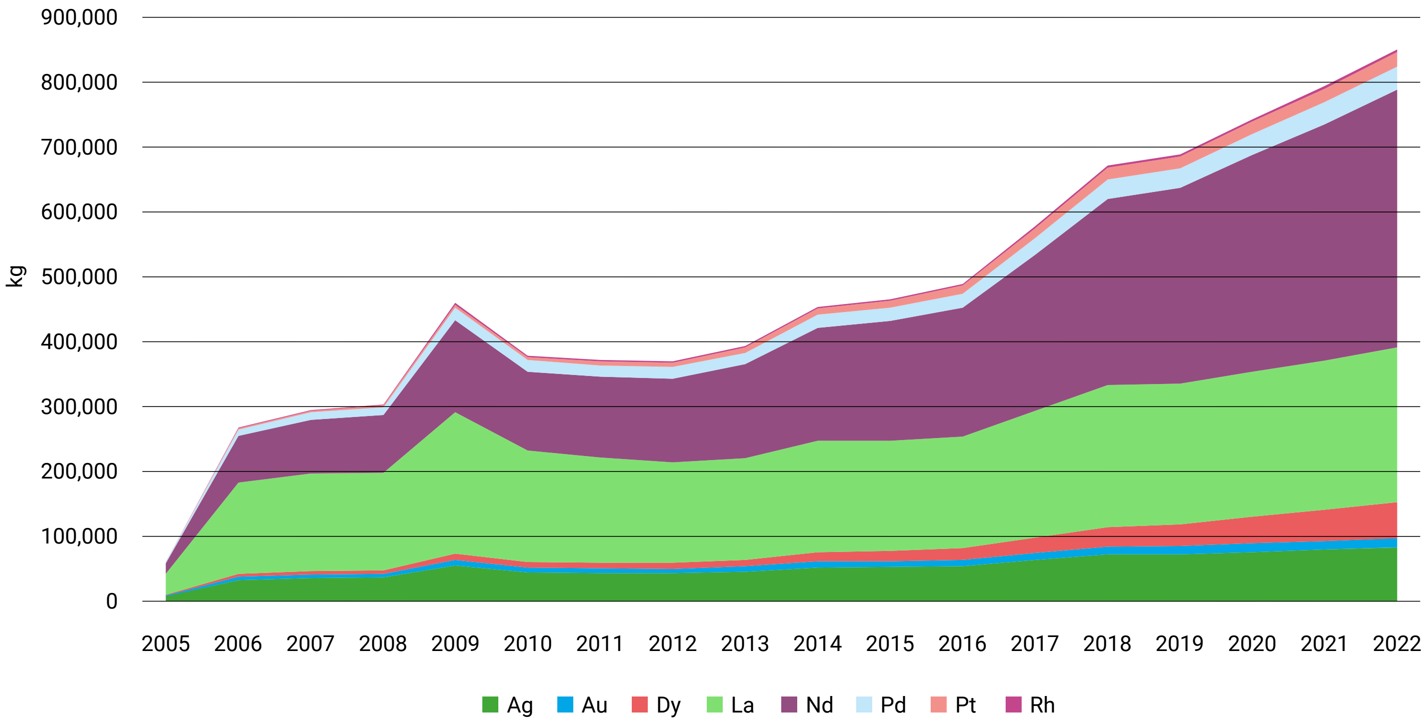


Figure 1: Annual total quantity of rare and precious metals in the car fleet in EU countries, the UK, Norway and Switzerland that potentially could be recycled, including a forecast for 2021 and 2022. (preliminary results, RMIS project, JRC)

What's more, the automotive industry has been undergoing profound changes in recent years. Electric vehicles' share of the market is booming. In 2020, one in four vehicles sold in Switzerland was partly electric at least (i.e. hybrid, plug-in hybrid or fully electric) and approximately one in 10 vehicles was fully electric. These drive types made up 3.8% of all Swiss vehicles in 2020, and this figure is likely to continue rising rapidly in the coming years. In the next decade or two, fully or partly electric cars will make up a significant share of end-of-life vehicles to be recycled.

This development has implications for the vehicles' composition and the materials they contain. Electric vehicles contain electronic components not found in vehicles with internal combustion engines, including lithium-ion batteries, electric motors and battery management systems (BMSs). And they weigh a fair bit to say the least. A fully electric car battery weighs around 500 kg, a great deal more than the engine's roughly 40 to 50 kg. What's more, these components contain raw materials rarely found in the electronic parts of conventional vehicles. Most lithium-ion batteries contain cobalt. Neodymium and dysprosium are needed to manufacture high-performance permanent magnets like those used in most electric engines, and copious quantities of copper are used to make their solenoids (see Figs. 2 and 3).

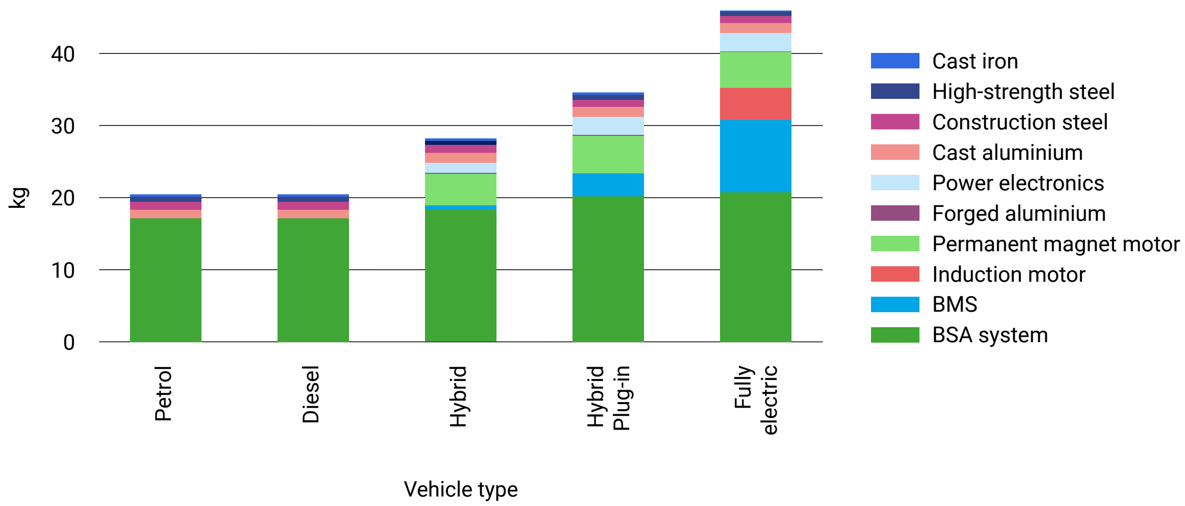


Figure 2: Average amount of copper per component and vehicle type (2020) (preliminary results, RMIS project, JRC)

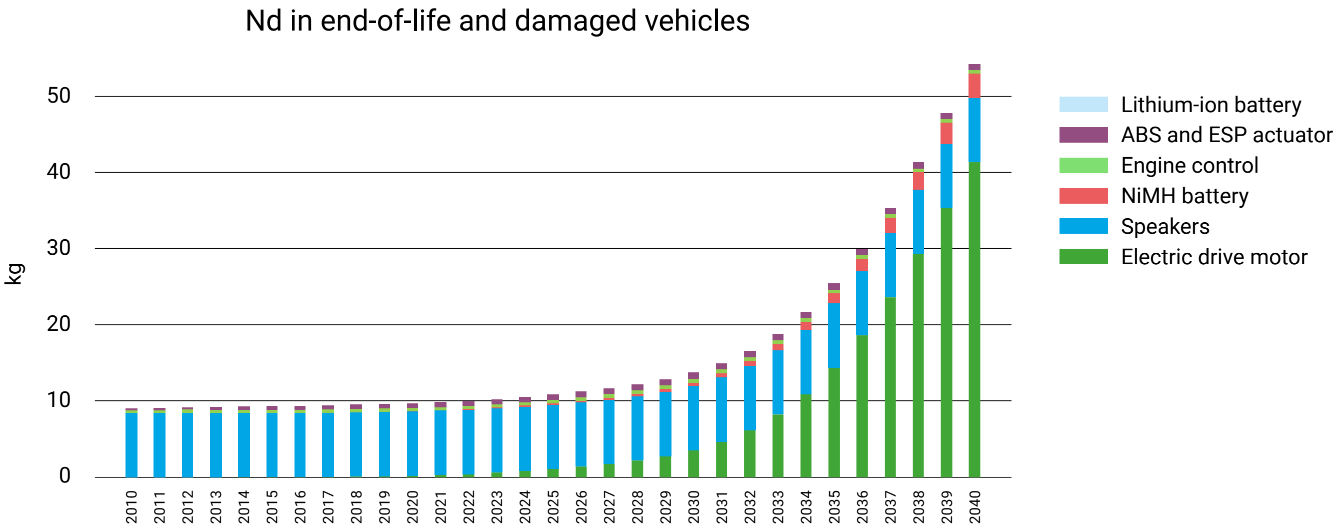


Figure 3: Amount of neodymium contained in end-of-life and wrecked vehicles in Switzerland (preliminary results, EVA II project, Empa)

Several scientific studies, including the EVA II study conducted by Empa across Switzerland and the RMIS study by JRC at European level, incorporate this development to make estimates and predictions about the amount of raw materials available in current and future end-of-life vehicles. Both studies aim to show that there is an interest in recycling these previously neglected electronic components; they also want to encourage the development of industrial recycling projects and support political measures. Society has become more dependent than ever on new electronic technologies, be it for convenience or security. This much is also true of various production and storage technologies in the field of renewable energy, which are crucial for a fast and efficient energy transition. In addition to their considerable economic value, these raw materials that are a vital part of modern-day technologies are also strategically important. Closing this recycling cycle, particularly through efficient and targeted recycling, must be a top priority. Switzerland is already doing a stellar job in this respect, largely thanks to organisations such as Swico, SENS and BATREC. However, electronic components from the automotive industry are still slipping through the cracks in this system.

Further information

- ↗ Raw Material Information System (RMIS) project, Joint Research Centre (JRC) of the EU Science Hub
- ↗ Recycling of electric components from passenger vehicles (EVA) project, Empa

Swico supports innovations in e-recycling

Roger Gnos

The Swico innovation fund was launched in 2019 and had invested CHF 384,000 in innovative projects by the end of 2020. Funding was provided for the construction of a toner recycling plant, for trials to improve cobalt and neodymium recovery and for a 'reuse before recycling' project. Other projects are in the pipeline.

The Swico innovation fund was launched by Swico Recycling and supports projects that boost the innovation of Swico Recycling's eco-system. The projects can take place throughout the entire recycling chain, from WEEE collection to the removal of hazardous and valuable sub-stances. Swico's contractual partners can also enter into collaborative relationships with start-ups or research institutes to kick-start projects that do not fall under the usual guiding principles.

Recycling companies, manufacturers and also other participants in the Swico ecosystem that have a contractual relationship with Swico can submit applications for funding projects.

The projects submitted must be innovative, provide relevant benefits for the Swico ecosys-tem, have good chances of success in terms of feasibility and be supported by applicants with the required qualifications.

The first funded project received a great deal of attention from professional circles: Swico supported the construction of a toner recycling plant to the tune of CHF 240,000. After all, over 1,700 tonnes of toner cartridges and refill containers are accumulated across Switzerland every year; at present, they are exported abroad and their transport negatively impacts the car-bon footprint.

Recycling toner in Switzerland – from project to full capacity

Submitted by Solenthaler Recycling AG based in Gossau, this project's original goal of commis-sioning a plant capable of safely removing and stabilising toner dust to ensure eco-friendly and sustainable processing by early 2021 could not be fully met due to the delays in the approval process, construction and test operation caused by the coronavirus. In December, Empa examined the plant in test mode, coming to the positive conclusion that the plant is running continuously and safely, and the output products are clean and sortable.

The members of the innovation fund's advisory board in front of the new toner plant; from left to right:
Heinz Böni, Empa; Marius Schlegel, Swisscom; Roger Gnos, Swico, Chairman of the Advisory Board

Since April 2021, the plant has run with a annual capacity of 1,500 tonnes in a single-shift operation. This is 1.5 times the amount originally planned, equating to a volume of four and a half Olympic swimming pools and saving around 150 tonnes of CO_2 per year. This innovative project means signatories of the Swico Recycling Convention, retailers and end consumers can rest assured that their components containing toner will be sustainably and efficiently disposed of in Switzerland.

Toner cartridges and refill containers can now be recycled in Switzerland.

The toner dust can be processed safely when securely bound.

Funding neodymium and cobalt recovery
Two other projects funded by the Swico innovation fund explore the increasing miniaturisation of lithium batteries and the related consequences for recycling. Safety-related aspects are the main focus, since many of these batteries are defective or stuck to the surrounding materials. But cobalt recovery is another focal point too. The feasibility study illustrated that this recovery is fundamentally feasible. Fortunately, it was also demonstrated that magnets containing neodymium are accessible in the resulting ground material. Neodymium is one of the rare-earth elements that is top of the list according to a FOEN study from 2011. To clarify in more detail whether and how the recovery of both raw materials is economically and ecologically viable, the Swico innovation fund made an additional CHF 24,000 contribution in autumn 2020. The first results were announced in early 2021.

Neodymium magnets

As Markus Stengele, a project manager at SOREC, explained, the selected test set-up achieved positive results and encouraged SOREC to apply for implementation as part of the lithium battery project.

Reusing before recycling
The best recycling is recycling that takes place as late as possible. That's why the Swico innovation fund supported a project by leBird Sàrl with funding of CHF 75,000 in 2020. The study evaluates the potential for reusing laptops, flat-screen TVs, mobile phones and other devices where applicable. The first step involved identifying the industry's needs, as well as the risks and opportunities.

The background to this study is an investigation by Empa that assessed the reuse of electronic devices, where most environmental pollution occurs during production, to be ecologically sound. However, the economic viability – i.e. how willing a buyer is to purchase a second-hand device – very much depends on its quality and the sales price, and too little is known about this at present.

Encouraging results
Based on leBird Sàrl's first test, a second step is now clarifying how reusable devices can be randomly identified, categorised and documented in a dismantling company. The focus then shifts to the aspects of functionality, data security and the development of a second-hand online shop with the corresponding specifications. Devices are not sold during this clarification and test phase, because the necessary guidelines are not currently available and the contracts with Swico Recycling exclude resale. Two experts from Empa are providing project support.

Conclusion after the Swico innovation fund's first 18 months

We are very satisfied with the projects submitted so far. They prove that Switzerland's recycling industry is both innovative and proactive. There is high level awareness of greater sustainability and an improved circular economy – and companies are extremely willing to carry out preliminary work. The fund is designed to push boundaries and, by doing so, turn visions into a reality.

Swico encourages all recycling companies, manufacturers and other participants in the recycling ecosystem that have a contractual relationship with Swico to submit innovative projects to the Swico innovation fund. You will find everything you need to know about the submission deadlines and the related process at ↗ www.swico.ch/innovationsfonds

'The Swico innovation fund supports promising recycling projects with financial support of up to CHF 300,000. Recycling is defined in the broad sense of the circular economy: logistics, monitoring and the life-time extension of devices are included too. Projects from areas such as of applied research and development or pilot tests are also awarded funding. Participants in the ecosystem that have a contractual relationship with Swico are eligible to apply. Cooperation and alliances with third parties (i.e. start-ups) are welcomed. We look forward to receiving your application by 15 February or 15 August every year."

Judith Bellaiche, Swico Managing Director

Quantitative and technology development and recycling requirements for flat-panel displays

Heinz Böni and Andreas Bill

Flat-panel displays have become an integral part of our everyday lives. The technology incorporated in these devices has seen significant development over the last decade. The trend is moving more in the direction of OLED, following a sharp drop in prices. How the devices develop in technological terms also influences the environmentally sound recycling requirements.

In 2019, around 1.4 million Visual Display Units (i.e. PC monitors, TVs and laptops) weighing 13,900 tonnes in total were disposed of in Switzerland. This figure corresponds to 30% of all devices collected and processed by Swico this year, with 5,830 devices processed per working day, and around 650 devices processed per hour. After the number rose sharply from around 900,000 devices to 1.5 million between 2006 and 2009, this figure has fluctuated surprisingly little since 2010, averaging at around 1.5 million devices from 2010 to 2019. In other words, the number of devices in use in private households and businesses has remained largely constant and quantities are no longer increasing – showing a typical picture of a saturated market (see Fig. 1).

The number of appliances containing CRTs has decreased from a peak of around 22,000 tonnes (2011/12) to around 3,500 tonnes (2019), while in the same period the amount of flat-panel displays increased from 4,000 tonnes to around 10,000 tonnes (see Fig. 2). The share of screens in the total number of devices recycled by Swico has dropped from 44% to 30%.

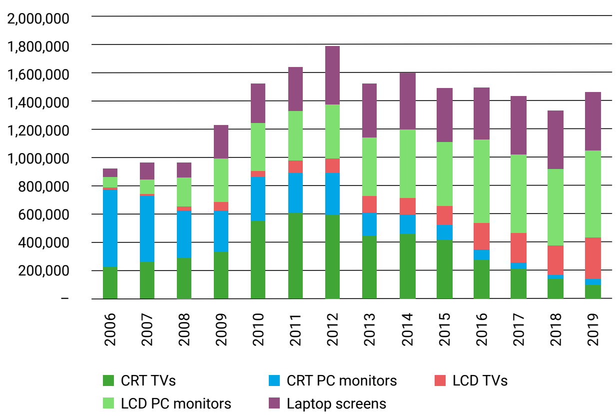


Figure 1: Development of the number of returned Visual Display Units from 2006 to 2019. Since 2013, the annual number has levelled off at around 1.4 – 1.5 million.

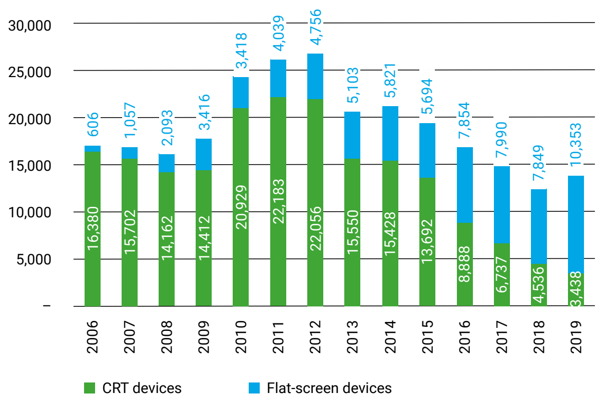


Figure 2: Development of the distribution of flat-panel and CRT display weights in tonnes (2006 – 2019). The volumes are currently approx. 14,000 t, almost 30% of the total recycled number of electronic devices from Swico.

Out of the number of devices disposed of in 2019, around 9% contained tubes (CRT devices) (see Fig. 3). Due to the different individual weights, the proportion of CRT devices was still 25% of the total amount of returned VDUs.

The proportion of devices with backlights containing mercury is decreasing among the returned flat-panel displays. In a non-representative random sample, it was determined in 2018 that 30% of TVs, 15% of PC monitors and 30% of laptops already had LED backlights. Based on these figures, the number of returned flat-screen devices with backlights containing mercury in 2018 can be estimated to be around 890,000 units or just under 6,000 tonnes in total. In other words, the backlights containing mercury would have to be removed from around 3,500 flat-screen devices every day and sent to a separate disposal facility for 250 working days.

Since the backlights make up 0.076% of TVs' weight and 0.248% of PC monitors' weight[1], the total volume of backlights to be removed in 2018 can be estimated to be around 10 tonnes, some of which includes the metal frames for the backlights from PC monitors.

LCD televisions with backlights containing mercury have 16 – 50 CCFL tubes. Assuming 4 mg of mercury per CCFL tube on average, the mercury levels in TVs vary between 64 and 200 mg Hg. PC monitors contain two to four CCFL tubes, and laptops one or two, so 8 to 16, or 4 to 8 mg Hg[2]. The amount of mercury that was separated and correctly processed by manually removing the backlights containing mercury from LCD screens in 2018 can be estimated to be 14 to 38 kg using these (rough) figures. While this appears moderate at first glance, it has a highly relevant environmental benefit: for every gram of mercury that escapes into the environment, 210,000 environmental impact points (EIPs)[3] are calculated. For comparison purposes: 26,000 environmental impact points are calculated for the extraction of one gram of gold, 2.2 points/gram for copper and just 0.0084 points/gram[4] for iron. So the environmental contribution of 14 – 38 kg of mercury discharged as a pollutant is equivalent to 113 – 307 kg of recovered gold, or 2,670 – 7,250 tonnes of copper or 350,000 – 950,000 tonnes of iron.

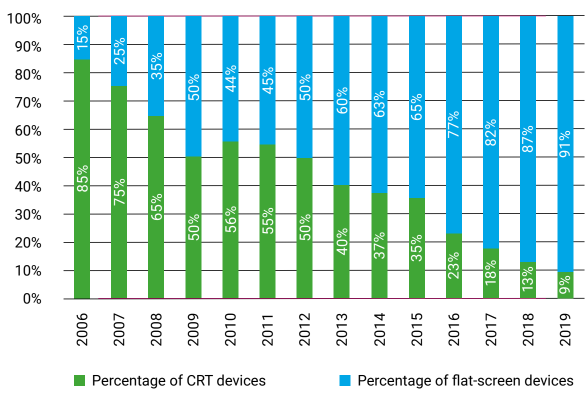
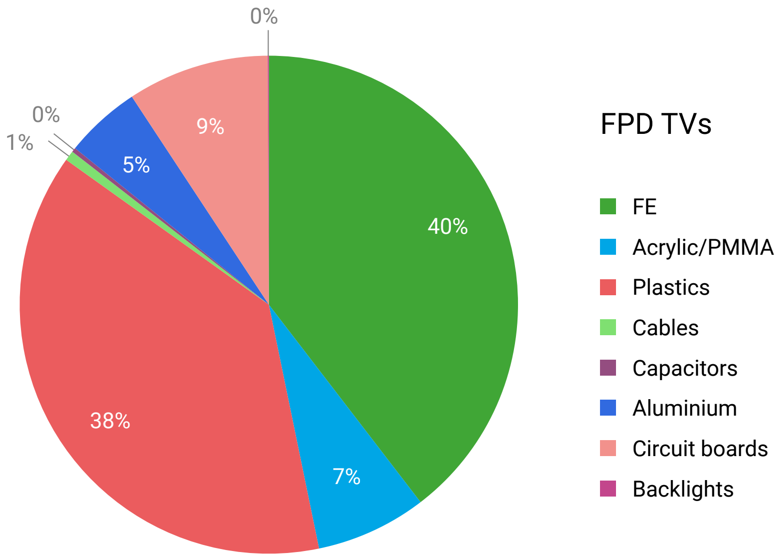


Figure 3: Distribution of the number of devices between flat-panel and CRT displays (2006 – 2019). More than 90% are flat-panel displays.

1 Determined by means of a batch test with 80 TVs and 150 PC monitors.
2 Source: Federal Office for the Environment: WEEE processing with regard to resource and pollutant aspects (Texts 31/2018) p. 122
3 'Environmental impact points' are used as an indicator to determine how much pollutant emissions pollute the environment and to quantify and compare resource extraction.
4 Source: Swiss Eco-Factors 2013 according to the Ecological Scarcity Method, Federal Office for the Environment (FOEN), Swiss Sustainable Business Network

9 Flat-panel displays

Figure 4 shows the composition of the flat-panel displays. Both LCD TVs and PC monitors each consist of approx. 40% iron, approx. 45 – 50% plastic (incl. PMMA panels) and approx. 5 – 6% aluminium. The proportion of printed circuit boards is 6% for PC monitors and 9% for flat-screen TVs.



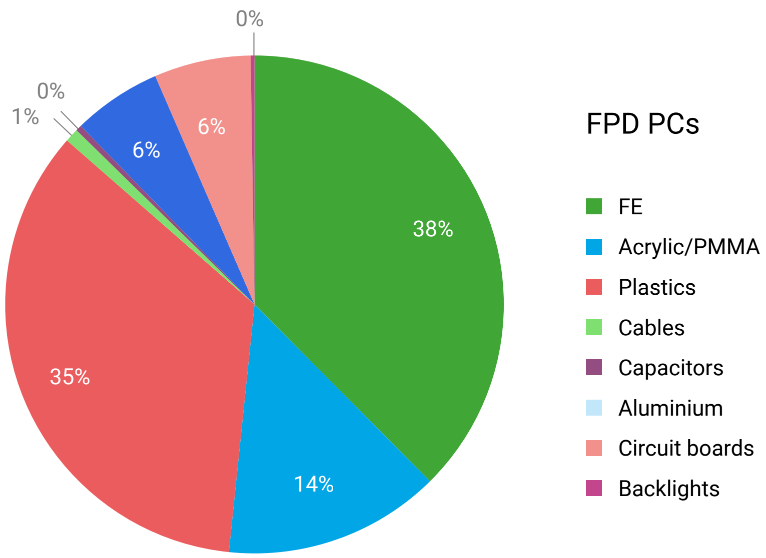


Figure 4: Composition of flat-screen televisions and PC monitors. Results of a batch test in 2020.

In the 2019 technical report, it was shown that trained employees can remove the backlights largely without causing any damage. Mercury measurements in the workplace confirmed that the maximum workplace concentration can be 20 to 30 times less.

With the alternative, fully mechanical processing of flat-panel displays containing mercury, the screens including the backlights are shredded under negative pressure. All the room air is extracted and purified using a filter system. The vast majority of the mercury is separated out by the air flow and concentrated in the activated carbon filter and dust. The mixed fractions resulting from the process are considered to have had their pollutants removed in accordance with the technical standard SN EN 50625, so no relevant mercury quantities may be carried over into and diluted in these fractions. The standard assumes that the mercury that is not separated by the air flow can mainly be found in the finest, shredded mixed fraction that the pollutants have been removed from. According to the standard, this is therefore determined as a reference fraction to check that the pollutant removal performance is sufficient and must be sampled. The maximum permissible mercury content is 0.5 mg/kg. This very strict requirement is a major hurdle for the mechanical processing of flat-panel displays without prior removal of backlights containing mercury.

Fire risk from lithium batteries – questions and answers

Flora Conte and Rolf Widmer

Damaged lithium batteries (LiBs) are an ever-present fire risk for all collection points, dismantling companies and recyclers. The hazardous situations vary a great deal, making fire protection a major challenge. Are all LiBs equally dangerous? What influence do the weather, handling and storage all have on the fire risk? What protective measures are in place?

Recent years have seen awareness of the fire risks associated with handling lithium batteries (LiBs) increase among all those affected. At the same time, the proportion of LiBs in the battery mix is continuously increasing, as is the distribution of LiBs in various waste electrical and electronic equipment (WEEE). The fires caused by LiBs at collection points, dismantling companies and recyclers both in Switzerland and globally illustrate that continuously adapted measures are required. Protection is provided by applying knowledge on the one hand and technical solutions on the other. This article provides an overview of the issue of fire risk and LiBs in a Q&A format. It does not replace advice from safety experts.

Question 1: Are there different types of lithium batteries?
In technical terms, we make a distinction between lithium-ion batteries (LIBs) and lithium-metal batteries, which are collectively referred to as lithium batteries (LiBs). LIBs are now available only as rechargeable batteries (secondary batteries). Li-metal batteries, on the other hand, are available exclusively as disposable batteries (primary batteries) – often button cells, but rarely also as large cells with a high energy density.

The lithium contained in Li-metal batteries (examples in this figure) is highly reactive. (Photo: INOBAT)

Question 2: Why is there an increased risk of fire when handling waste LiBs?
The risk of fire related to returning waste LiBs stems from the fact that they often contain a considerable residual charge (i.e. ignition energy), as well as an easily flammable liquid electrolyte or combustible metallic Li. This combination of

ignition energy and flammability can lead to spontaneous combustion if the batteries are improperly handled, but even the liquids that may leak out are not harmless. The lithium contained in li-metal batteries is highly reactive. If it comes into contact with water, among other things this leads to the formation of hydrogen (H_2), meaning it can trigger oxyhydrogen explosions[1].

Question 3: What main risk factors have to be taken into account when handling waste LiBs?

- The LiB's properties: The fire risk associated with LiBs depends on the condition (intact, defective), the protection (loose, installed), the capacity (in watt hours) and the Li metal content (in grams). Also see question 4.
- Mechanical impact: LiBs are sensitive to pressure. This is why LiBs and WEEE containing LiBs should not be stored and transported as bulk goods or circulated with gripper arms, excavators, etc., since the LiB cells could be exposed during the tipping process. They are not protected against damage and short-circuiting and are usually surrounded by flammable materials. The small containers recommended by SENS and Swico are more suitable. The thin-skinned pouch cells (in mobile phones) in particular are quickly damaged during dismantling.
- Weather: Heat from solar radiation can lead to temperatures exceeding 60°C, which in the case of LiBs can cause flammable gases to escape, cell fires to break out and even 'thermal runaway' to take place. Li-metal batteries also react on contact with water. So weather protection is very important.
- Short circuits: When stored in steel barrels, the plastic inliners prevent short circuits with the barrel. Short circuits must also be avoided between the LiBs (see question 8). Caution: Buffer and backup batteries, which are exempt from ADR, can also short-circuit themselves with their metal housings if they are dismantled and poured together.

Question 4: How do you identify LiBs that could be a fire hazard?
LiBs are a fire hazard in particular when they are defective. Defective LiBs can be identified by housing deformation ('inflated' LiBs), liquid leakage (smell of solvent gas) or increased temperature.

The risk of fire is increased particularly if LiBs are defective. (Photo: INOBAT)

LiBs should also always be classified as dangerous if they store a high mass or a lot of energy. For your guidance: ADR exemption limits for LiBs apply to LiBs < 500 g or with < 2 g Li, or with < 100 Wh energy content.

Question 5: What should you do if you find suspicious waste LiBs?
Suspicious LiBs should be isolated in suitable, closed containers (see question 8). Insulated LiBs must be protected from the weather and stored as far away from flammable materials and emergency exits as possible. Suspicious LiBs should ideally be fully discharged on site. For a partial discharge, at least, LIBs can be submerged in tap water or salt water for several days. Discharge works only if there is no battery management system present (e.g. for bicycle batteries). Water must not be used for Li-metal batteries.

↗ Inobat offers an emergency number that you can call if you suspect LiBs are defective. It also picks up dangerous LiBs if required.

[1] ↗ https://www.riskexperts.at/fileadmin/downloads/Publikationen/Lithiumbatterien__SicherheitsratgeberMaehliss__2016.pdf

Question 6: How can you fully protect yourself against LiB fires?
Companies that are frequently in contact with potentially defective LiBs or WEEE containing LiBs should ideally develop and implement a storage, safety and contingency plan with expert support. Among other things, it should be checked whether the necessary fire-extinguishing equipment is present and functional. Employees must be made aware of and trained in the hazards to ensure correct identification of suspicious LiBs and correct LiB handling during storage, sorting, dismantling and transport. Repeated training and fire protection exercises are very helpful in this respect. Quality assurance is particularly important in dismantling companies. Technology such as fire detectors or thermal imaging cameras are also a great help.

Question 7: In case of fire: what should you watch out for until the fire brigade arrives?
If a fire breaks out, it is important that the contingency plan is implemented correctly. Burning LiBs or WEEE containing LiBs should be removed and isolated if doing so is specified in the plan. It should be noted that LiBs can burn with a considerable time delay and breaks. This is due to the structure comprising several cells, their thermal inertia and uncertain short circuit development inside the cell. In addition to smoke in case of fire, the evaporating or vaporising electrolyte (white vapour) from overheated, non-burning LiBs is dangerous too. The utmost care is required, since it contains substances that are toxic to humans and the environment, including hydrofluoric acid.

Question 8: How should LiBs be stored?
For storing LiBs, Inobat recommends using Inobat steel barrels with the supplied plastic inliners and vermiculite (see figure). The vermiculite provides fire protection, thermal insulation, distance between the LiBs (preventing short circuits) and greater stability during transport.
If possible, tape or protect the LiBs' poles before storage. The barrel's lid should always be closed with the clamping ring. The barrels should not be stacked, since any excess pressure blown off will build up and the barrels on top may overheat.

INOBAT barrels for safe storage and disposal (Photo: INOBAT)

How should PCB-free capacitors be handled in future?

Daniel Savi

As already reported in the 2019 technical report, PCB-free capacitors also contain liquids that may be harmful to the environment or health. A total of 18 substances of concern were found and their properties were subsequently clarified in more detail. This research firstly led to an assessment of the suitable disposal methods for these substances and secondly to a list of substances of concern that were used as lead substances for sampling.

Five substances and one group of substances were identified as potential lead substances
Among the substances of concern, five substances and one group of substances that were classified as more critical for the environment than the others were identified. They were used for sampling and chemical analysis of fractions after mechanical processing. They are:

- N-methylpyrrolidone: Completely miscible in water and among the substances of concern in capacitors.
- Phenol: Most toxic to rats among all the substances of concern. The breakdown product, catechol, is carcinogenic.
- 2,2',5,5'-Tetramethylbiphenyl: There are indications that the substance can bioaccumulate. The proportion of the liquid mixture in microwave capacitors can be high. It was determined to be 80% in the laboratory analysis. However, the quality of the determination was only moderate. So it is not entirely clear whether the substance was correctly determined. Additionally, very few substance properties are known, making further assessment of the environmental performance impossible.
- 2,6-Diisopropylnaphthalene: There is evidence that this substance can bioaccumulate as well. Very few material properties are known for the substance. 2,6-Diisopropylnaphthalene is part of the diisopropylnaphthalenes (DIPN) isomer mixture.
- Benzyltoluene: This mixture of p-, m- and o-benzyltoluene is highly toxic to aquatic organisms and degrades very slowly in the environment.
- Four substances belong to the group of naphthalenes (see table on the right). They are highly toxic to fish and, according to model estimates, are not rapidly biodegradable. Naphthalene (CAS no. 91-20-3) is also thought to be carcinogenic.

Substance designation	CAS number	Capacitor type occurrence
Benzyltoluenes	27776-01-8	Non-polarised, cylindrical microwaves
Naphthalene		Non-polarised, cylindrical
Naphthalene	91-20-3	
1-Chloronaphthalene	90-13-1	
1-Methylnaphthalene	90-12-0	
2-Methylnaphthalene	91-57-6	
2,2',5,5'-Tetramethylbiphenyl	3075-84-1	Microwaves
2,6-Diisopropylnaphthalene	24157-81-1	Microwaves
N-Methylpyrrolidone	872-50-4	Electrolytic capacitors
Phenol	108-95-2	Electrolytic capacitors

The table lists the substances of concern with particularly noteworthy properties related to ecotoxicity. They were used as lead substances for a trial strategy in recycling.

Substances of concern can be destroyed in a waste incineration plant if they are sufficiently solubilised

In addition to the question of the impact of the substances of concern on the environment, their destructibility in disposal processes was also examined in more detail. First, relevant substance properties such as ignition temperature, boiling point and vapour pressure were researched. Furthermore, the operators at KEZO Hinwil were asked to assess the substances' destructibility in the waste incineration plant. For example, two of the aforementioned substances have properties that suggest they are easily destroyed through combustion: N-methylpyrrolidone has an ignition temperature of 265°C, phenol becomes gaseous at just 182°C and an ignitable gas mixture forms over the pure substance at just 80°C. The flash points of all the substances of concern were between 58°C and 263°C, below the burning temperature in a waste incineration plant. It must be noted, however, that the substance properties could not be determined for all substances of concern. Some substances are very poorly documented. The conclusions drawn here only reflect the current state of our limited knowledge about the environmental impact of the substances of concern. However, this always applies with respect to the substances' behaviour in the environment.

The assessment by the commissioned waste incineration plant matched the results of the literature research: if the substances are in a solubilised, easily flammable form, and if they occur in low concentrations on a flammable fraction, they should be fully destroyed in a waste incineration plant.

With regard to plastics recycling, there is potential for carry-over of substances of concern from capacitors. It should be noted in this respect that plastics also contain numerous additives. Some of the substances of concern are used as softening agents in plastics, and others as solvents in plastics production. This gives rise to a whole series of questions about the effects that substances of concern from capacitors have on plastics recycling. What substances of concern are also used in plastics? What substances of concern are unloaded in plastics recycling? What substances of concern are destroyed in plastics recycling? This recycling method should therefore be investigated further.

are particularly critical
A number of conclusions can be drawn from several years of research into the liquids in capacitors. Capacitors containing PCBs can still be found, particularly in lights and large household appliances (↗ see the 2020 technical report). They must be removed from the appliances before mechanical processing. Of the PCB-free capacitors, microwave capacitors contain by far the largest amount of substances of concern. They quickly lose absolutely all of their liquid when damaged. Microwave capacitors also have to be removed from the appliances before mechanical processing. For PCB-free, non-polarised, cylindrical capacitors and electrolytic capacitors, separation during mechanical processing with subsequent sorting is feasible if doing so does not cause excessive or frequent damage to the capacitors. An attempt was made to estimate how high the breakage rate could be during processing using model calculations for small SENS appliances. However, since there is insufficient data on the proportion of capacitors in the appliances, the results are unreliable. Nevertheless, it can be established that breakage rates in the very low double-digit percentage range should be tolerable.

The table on the right lists the 18 substances of concern found in PCB-free capacitors. The capacitor types follow the classification currently common in recycling. 'Non-polarised, cylindrical' capacitors are large capacitors over 2.5 cm in size that are often found in washing machines, for example. 'Microwave' capacitors are large, non-polarised capacitors with round narrow sides and are typically used in microwaves. 'Elcos' are cylindrical electrolytic capacitors used on circuit boards and in power supply units, for example.

As the dismantling shows, the microwave capacitor is heavily impregnated

Chemical designation	CAS number	Capacitor type occurrence
1-Chloronaphthalene (chlorinated naphthalenes)	90-13-1	Non-polarised, cylindrical
1-Methylnaphthalene	90-12-0	Non-polarised, cylindrical
1-methoxy-2-nitrobenzene/2-nitroanisole	91-23-6	Electrolytic capacitors
2-Methylnaphthalene	91-57-6	Non-polarised, cylindrical
2,2',5,5'-Tetramethylbiphenyl	3075-84-1	Microwaves
2,6-Diisopropylnaphthalene	24157-81-1	Microwaves
Benzyltoluenes	27776-01-8	Non-polarised, cylindrical, microwaves
Boric acid	11113-50-1	Electrolytic capacitors
Butyl hydroxyanisole	25013-16-5	Non-polarised, cylindrical
Di-p-tolylmethane	4957-14-6	Microwaves
Dibutyl phthalate	84-74-2	Non-polarised, cylindrical
Diethylhexyl phthalate	117-81-7	Non-polarised, cylindrical
Diisobutyl phthalate	84-69-5	Non-polarised, cylindrical
Dimethylacetamide	127-19-5	Electrolytic capacitors
Dimethylformamide	68-12-2	Electrolytic capacitors
N-Methylpyrrolidone	872-50-4	Electrolytic capacitors
Naphthalene	91-20-3	Non-polarised, cylindrical
Phenol	108-95-2	Electrolytic capacitors

Literature

- Daniel Savi, Ueli Kasser, Rolf Widmer (2020) Liquids in capacitors, Determining liquids in electrical capacitors, including the definition and classification of substances of concern, Behaviour in the recycling process, final report, SENS Foundation, Swico Recycling, Zurich

PCBs from electrical appliances remain under observation

Stefanie Conrad

PCBs remain an important focus of the SENS/Swico Technical Commission. Even small amounts of PCBs in the environment can accumulate in the food chain and cause considerable harm to health and the environment.

PCB contents and PCB loads are an ever-present topic in the SENS/Swico TC and during audits. In this article, we would like to recall the properties, applications and effects of PCBs that show just how important the correct removal of waste electrical and electronic equipment (WEEE) containing PCBs is.

Polychlorinated biphenyls (PCBs) form a group of different chlorinated hydrocarbons that have high thermal, chemical and biological stability and are flame retardant and electrically non-conductive. Since PCBs are persistent, evaporate easily and are toxic even in very small quantities, they still pose a challenge in WEEE recycling even today.

Although PCBs have been banned in Switzerland since 1986, PCB contents are still measured in fractions from WEEE recycling because small capacitors still contain PCBs in ballasts of fluorescent tubes and in long-life large household appliances. In addition to PCBs being used as insulating liquid and as cooling or dielectric liquid in transformers and in electric capacitors, they were also used as softeners in sealants, paints and varnishes or as corrosion and sealing protection.

PCBs still end up in the environment due to PCBs from old applications being disposed of improperly, leaks in landfills or evaporation. They then remain there for years and build up in the food chain. People ingest PCBs mainly through food, and even very small amounts can trigger harmful chronic effects. PCBs cause liver, spleen and kidney damage and weaken the immune system. They are suspected of being carcinogenic, of impairing the hormonal balance and of causing neonatal deformities.

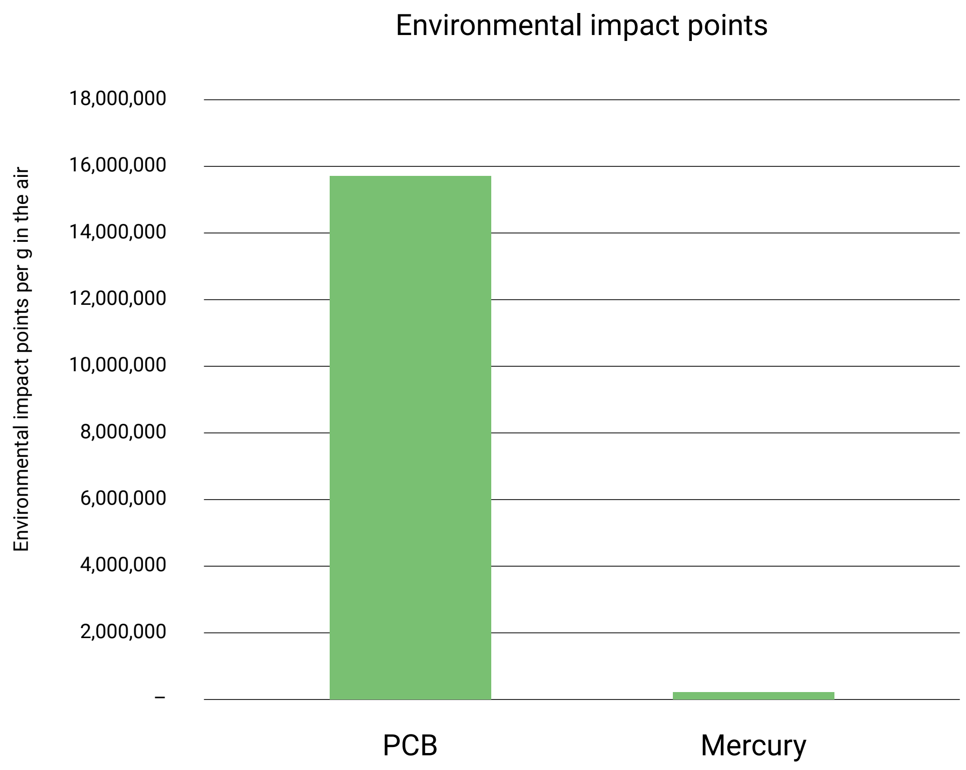


Figure 1: Environmental impact of 1 g PCB and 1 g Hg escaping into the air in EIPs/g.

To clarify the environmental impact of PCBs, the environmental impact points of 1 g PCB and 1 g mercury (Hg) that end up in the environment were calculated using the ecological scarcity method[1].

Figure 1 shows the environmental footprint of 1 g PCB, which is around 75 times greater than the environmental footprint of 1 g Hg.

Assuming a capacitor contains approximately 10 g of pure PCB, one capacitor alone that is overlooked during removal would have an environmental footprint of over 150 million environmental impact points – roughly equal to a car journey (with average load) of almost 500,000 km, i.e. almost 12 times around the world. These figures show the effects of PCBs and illustrate that even small amounts of PCBs have a significant impact on humans and the environment.

[1] The ecological scarcity method evaluates numerous environmental impacts and summarises them through full aggregation in an indicator (environmental impact points, or EIPs for short).

New international regulations on plastics

Andreas Bill and Heinz Böni

Waste electrical and electronic equipment (WEEE) contains 30 – 40% technical plastics, including ABS, HIPS, PC/ABS, PP and PS. The recycling processes result in plastic mixtures that are separated into individual polymers by downstream recipients abroad. Plastics containing particularly harmful substances are separated out and sent for thermal recovery, while the remaining plastics are reused as plastic granules in new products. Certain regulations on hazardous substance content and international transport have been tightened in the last year. These developments affect Swiss recycling companies too.

EU POPs Regulation recast
The transposition of the Stockholm Convention on Persistent Organic Pollutants (also known as the Stockholm Convention or the POPs Convention) is ensured within the EU by the POPs Regulation of 24 April 2004. It stipulates the rules for manufacturing, circulating and using the substances listed in the Stockholm Convention. On 15 July 2019, a new version of the POPs Regulation came into force, bringing with it an important innovation to the WEEE recycling industry. A total limit of 1,000 mg/kg now applies to the recycling of waste containing polybrominated diphenyl ethers (PBDEs), i.e. chemicals containing bromine that are used in particular as flame retardants in plastics. This means that plastic fractions from WEEE recycling may be recycled only if it can be ensured that the content of PBDEs is below 1,000 mg/kg. Individual limits of 1,000 mg/kg each for tetra-, penta-, hexa- and hepta-BDEs were previously in force, but there were no restrictions for the more frequently used deca-BDE. In accordance with Article 15 of the new POPs Regulation, a decision must also be made by 16 July 2021 with respect to whether the total limit of 1,000 mg/kg for PBDEs will remain in place or whether it will be reduced further to 500 mg/kg.

New rules set out in the Basel Convention
Until 2018, plastic waste from Europe and America was largely exported to China. But when China banned the import of such plastic waste in March 2018, major capacity bottlenecks developed, which were mainly absorbed by developing and emerging countries in South-East Asia developed. To prevent tough-to-recycle or contaminated plastic waste from entering these channels, new regulations for cross-border traffic with plastic waste were created in the Basel Convention on Norway's initiative; they came into force on 1 January 2021. According to these new regulations, only plastic fractions consisting of one, non-halogenated polymer and containing no relevant foreign substances may be exported without additional checks. Additionally, the export of mixtures of PE, PP and PET that do not contain any foreign or harmful substances is still permitted. The required degree of purity for such fractions is still under discussion. The EU proposes a 2% foreign matter content as a tolerance limit.

The 'Prior Informed Consent (PIC)' procedure now applies to export of other mixed or contaminated plastic fractions. Consequently, movement of such plastic fractions between two nations that have ratified the Basel Convention must be reported to the destination country's authorities and may leave the exporting country only when the corresponding permission has been granted. For countries that have also ratified the Ban

Amendment (including Switzerland and the EU), exports of such plastic fractions from OECD countries to non-OECD countries are also prohibited.

What will change for WEEE recycling in Switzerland?
The new rules set out in the POPs Regulation and the Basel Convention also have implications for the recycling of plastic fractions by Swiss WEEE recyclers. A relevant proportion of the plastic fractions from WEEE processing in Switzerland is recycled in neighbouring countries by recyclers specialising in WEEE plastics. They have the required processes for separating brominated plastics and can generally easily comply with the current limit of 1,000 mg/kg PBDEs. However, the effects of potentially reducing this limit further to 500 mg/kg in July this year are unclear. Due to the new rules set out in the Basel Convention, plastics recycled abroad are also subject to the PIC process. While this does not prevent the recycling of plastic fractions from WEEE processing, it does lead to additional administrative work, making plastic recycling – which is already not very profitable due to the low prices for primary plastics – even more difficult.

Swico and SENS join in the discussion
Swico and SENS are members of the WEEE Forum[1], which actively follows these international developments within a working group dedicated to the issue of plastics. Swico/SENS TC representatives regularly attend this working group's virtual meetings and support the WEEE Forum, particularly with technical issues by providing expertise and a large data pool developed through previous studies on brominated flame retardants and the associated monitoring.
By doing so, Swico and SENS can actively contribute to the way in which the WEEE Forum responds to these international developments.

↗ **Basel Convention::** The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was adopted on 22 March 1989 by the Conference of Plenipotentiaries in Basel, Switzerland, in response to a public outcry following the discovery, in the 1980s, in Africa and other parts of the developing world of deposits of toxic wastes imported from abroad. In total, 188 nations have ratified the Basel Convention to date.

↗ **Stockholm Convention :** The Stockholm Convention on Persistent Organic Pollutants is a global treaty to protect human health and the environment from chemicals that remain intact in the environment for long periods, become widely distributed geographically, accumulate in the fatty tissue of humans and wildlife, and have a harmful impact on human health and the environment. The Convention was adopted by the Conference of Plenipotentiaries on 22 May 2001 in Stockholm, Sweden, and entered into force on 17 May 2004. In total, 184 nations have ratified the Stockholm Convention to date.

[1] The WEEE Forum is the international association of WEEE take-back systems

The unquestioned authority of refrigerator recycling is retiring

Roman Eppenberger

In late 2020, Dr Erhard Hug, known as Geri Hug, stepped down from his long-term role as a technical advisor to the SENS and Swico Technical Inspection Body. With Geri Hug's departure, the SENS TC team is losing a figure who has shaped the development of refrigerator recycling from the very beginning. SENS and Swico would like to take this opportunity to thank Geri Hug for fostering such a successful cooperative relationship.

Geri Hug is the unquestioned authority of refrigerator recycling in Switzerland and one of the world's few refrigerator recycling experts. He not only worked in Switzerland; his remit extended into Europe and all over the world. It all started with a request from SENS' then managing director, Dr. Robert Hediger (†), to set up a model for recycling refrigeration appliances. With the emerging issue of global ozone depletion, the controlled disposal of refrigerators containing CFCs became a relevant one. Having obtained a PhD in chemistry, Geri was the perfect person to explore this topic. Full of vim and vigour, he got stuck right in and developed a model for assessing the quality of refrigerator recycling. This accumulated expertise is now integrated in EN 50625-x and lives on as an industry standard.

Further developing instead of just controlling
Geri Hug had always wanted to support recyclers as they strived not only to achieve conformity, but also to continuously improve. As an SGS auditor for ISO 14001, continuous improvement (CIP) is in his blood, so to speak. He doggedly pursued his values through tenacious discussions, but he was also prepared to make concessions if they helped move things in the right direction. He and Christoph Becker (RAL Quality Marks) held numerous discussions, and both pushed the title of the ultimate unquestioned refrigerator recycling authority towards one another. This is likely what happened in the Middle Ages, when a pope ruled in both Constantinople and Rome. We have heard that the two of them really grew fond of each other in the end.

The following is an excerpt from the long history of refrigerator recycling that he was so instrumental in shaping:

The story of ensuring eco-friendly recycling of refrigerators and freezers containing CFCs

In late 1991, SENS was looking for experts to develop requirements for eco-friendly recycling of refrigerators and freezers. They found the mechanical engineer Patrick Hofstetter (Office for Analysis & Ecology, now WWF Switzerland), who, as part of his Master's thesis, prepared a life cycle assessment for recovery of valuable and hazardous substances, especially CFCs from refrigerators, and the chemist Erhard Hug (Roos+Partner AG, now IPSO ECO AG), who, on behalf of a refrigerator recycler and SENS Foundation member, evaluated further recycling options for polyurethane foam from refrigerator insulation. Hofstetter and Hug were put to work by the then managing director Dr Robert Hediger (†), tasked with developing a test concept to determine the CFC quantities in the refrigerant circuits with a mixture of oil and CFC (R-12), plus the polyurethane insulation foams (PU foams) with the CFC propellant (R-11). The combination of knowledge about the composition of domestic refrigerators and freezers returned from the market, and particularly about the complexity of the PU foams they contained, proved productive from the very start. While implementing the concept in practice, it was found that emptying the refrigerant circuits through the plants that were already in operation barely caused any

Geri Hug
SENS TC, IPSO ECO AG

'It has been a pleasure working with you, our highly knowledgeable colleague, for over three decades. During this time, we have come to know and appreciate you as a strict but fair auditor. The disposal of refrigerators in Switzerland, Europe and in some cases worldwide has been shaped and further developed by your constructive, production-related solutions. I will never forget our visit together to a waste disposal company in Italy that, with great pride, presented its self-optimised 'Hugomat' to us – a plant capable of always meeting your refrigerator disposal requirements. I couldn't imagine a more fitting tribute than a waste disposal company naming their plant after you. We wish you all the best for your well-deserved retirement and hope you'll fill your new-found free time with lots of fun and happy moments.'

Patrik Ganz, Kühlteg AG

problems, whereas some plants for processing the PU foams failed miserably due to the complexity of the aged PU structure. At that time, SENS had five recycling companies under contract. Three of them operated plants of the failed type and thus needed replacements. As a result, the working group developed and implemented a routine test procedure to determine efficiency with regard to CFC recovery and thus continuously gained further knowledge and experience.

In 1995, the German Environment Agency (UBA) began to show interest in the SENS test methods and ultimately published the legally binding 'Guide for the disposal of refrigerators' in 1998, which was strongly based on the SENS standard.

Almost at the same time, the RAL Quality Assurance Association for the Demanufacture of Refrigeration Equipment published its corresponding standard (in force since 1997), which was also based on the SENS principles. It was reserved for RAL members and was therefore not widely accepted, but it was incorporated into waste legislation in Austria.

The WEEE Forum was founded in 2002. Erhard Hug was delegated a representative of SENS to the technical working groups for processing of E&E appliances. Since refrigerator recycling was so complex, a smaller working group spun off, with Erhard Hug as a technical expert on this matter. The SENS standard for the final processing of CFC devices (now VFC devices) was communicated to all participating member organisations in meetings held over several years.

Additionally, Erhard Hug managed prove the practicality of the requirements set out in the standard for various European clients by 2006 at a total of 14 plants in seven European countries. Until this point in time, only appliances containing VFCs had to be provided for the performance tests, which was made more difficult by an increased mix with VHC-foamed devices. To avoid sorting the appliances, Erhard Hug and Niklaus Renner (both of IPSO ECO AG) extended the original SENS methodology to include VFC and VHC recovery values. This meant the performance of systems with mixed VFC and VHC appliances could be assessed during normal operation.

Great resistance against this quickly developed, as it was believed that VHC appliances did not contain any refrigerants or propellants with a high ozone depletion potential, so they no longer needed to be processed using the enclosed plants. This point of view was to be manifested by the entire industry in Europe (EERA, WEEE Forum and CECED) in a common standard exclusively for VHC appliances in 2006, which was seen as a success by European committees. In late 2007, a corresponding standard for VFC appliances was published as an amendment.

The WEEELABEX project co-initiated by SENS within the WEEE Forum showed primarily the German manufacturers that, in a country without take-back systems, they stood apart from developments. Bosch Household Appliances quickly set up a working group to develop a European CENELEC standard for refrigerator and freezer recycling. The initial preliminary discussions took place in a small working group in Munich with Jan Bellenberg (B/S/H), Christoph Becker (RAL) and Erhard Hug (SENS). The work of the CENELEC Technical Committee 111X WG 4 officially started in January 2009. This was to be Hug's and Becker's opportunity to convince the entire industry, particularly manufacturers of refrigerators and freezers, that sorting VFC and VHC appliances into different channels would destroy the quality of the existing VFC channels, and conflicted with the legally anchored manufacturer responsibility.

As part of this work, Erhard Hug and Niklaus Renner used the Excel evaluation and calculation formulas developed for SENS to record mathematical descriptions of the entire test and evaluation procedures for stage 1 and stage 2 tests. During this time, Erhard Hug led the first auditor training course in Isernia, Italy, in 2010 for prospective WEEELABEX auditors from all over Europe.

The result of WG 4 from TC 111X was published in 2012 in the CENELEC standard EN 50574. The requirements formulated in the standard were so strict that the plans for sorting VFC and VHC appliances were soon taken off the table.

As part of an EU mandate to CENELEC, this standard was expanded and republished in line with the classification of the EN 50625-x series in 2017.

Erhard Hug did more than just exclusively look after the refrigerator and freezer recyclers; he also dealt with most of the relevant lighting equipment and large household appliance recyclers in German-speaking Switzerland during his employment from 1991 until his retirement in 2019.

In Switzerland, Erhard Hug was known as a strict but fair auditor who was also willing to give recyclers the time they needed to carry out repairs, adjustments and extensions. He repeatedly challenged recyclers and their plant suppliers to present correspondingly effective technical solutions in this regard.

He was also often tasked by recyclers with accompanying them during the new plant procurement process, thus ensuring that suppliers were aware of the strict requirements from the start. This prevented the procurement of plants that were clearly incapable of meeting the requirements, as was the case in 1990.

SENS and Swico would like to take this opportunity to thank Geri Hug for his invaluable contribution and hope he really enjoys the next stage of his life.

Authors

Anahide Bondolfi

SENS TC, Abeco GmbH

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). Ms Bondolfi has spent nearly 10 years working as an environmental consultant and project manager at two Swiss environmental consulting companies (leBird in Prilly and Sofies in Geneva). In January 2017, she founded Abeco Sàrl. Ms Bondolfi has been a member of the Swico/SENS Technical Commission since 2015. She carries out nearly half the audits on the Swico and SENS dismantling workshops. Ms Bondolfi has also audited some recyclers and collection points for SENS since 2016.

Heinz Böni

Head of the Swico Conformity Assessment Body SN EN 50625, Empa

After graduating as an agricultural 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 "Büro für Kies und Abfall" 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. Since 2009, he has held the position of Head of the Technical Audit Department of Swico Recycling and has been an audit expert for Swico since 2007.

Stefanie Conrad

SENS TC, Carbotech AG

Stefanie Conrad completed her Master's degree in environmental science, with a major in biogeochemistry and pollutant dynamics, at ETH Zurich. She then worked on environmental projects focusing on remediation and decontamination, building pollutants and environmental due diligence. Since 2020, she has been working in the environmental consulting department of Carbontech AG in the fields of life cycle assessments and audits, and has been a member of the SENS/Swico Technical Commission and an auditor for SENS and Swico dismantling companies and collection points since January 2021.

Flora Conte

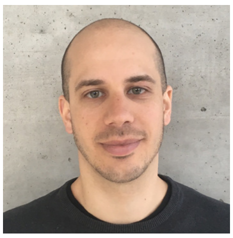
SENS TC, Carbotech AG

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 Carbotech 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 companies and collection points. Flora Conte has been auditing SENS recyclers since 2016. In addition to her activities as an environmental consultant, she is also 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 course 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.



Michael Gasser

Swico Technical Commission/ Michael Gasser Consulting

Michael Gasser completed a Master's degree in environmental science at ETH Zurich. He started working in the electronic waste sector in 2014 for an Empa project in India, where he later also worked as an auditor for Swico Technical Commission, in addition to supporting and managing various projects in the area of recycling. His areas of expertise include, in particular, the development and monitoring of recycling systems in Switzerland and in developing countries and emerging markets and the recovery of plastics. Michael Gasser has recorded the annual material flows as an independent consultant since 2021.

Roger Gnos

Technical Inspection, Swico Hazardous Materials Officer and Member of the TC

Roger Gnos has been heavily involved in recycling since 1991 and has experienced and helped to shape the evolution of waste electrical equipment recycling. He worked as a plant manager in an electronic waste processing company for almost 20 years. He has been working at Swico Recycling for 10 years, advising collection points. In 2019, he worked on the launch of the Swico innovation fund and has been the chairman of the advisory board since then. He is also fascinated by the technology and the people behind the recycling process.

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 various projects in the environmental field. He focused particularly 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 here too, 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 the 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.

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 Centres and Head of Quality Assurance. He held these positions for seven years before joining Büro für Umweltchemie GmbH as a research associate, where he has been a partner and managing director of the company since 2015. He focuses on the health hazards and environmental effects associated with construction work and waste recovery.

Rolf Widmer

Swico Conformity Assessment Body SN EN 50625, Empa

Rolf Widmer completed his studies to become a qualified electrical engineer (MSc ETH EE) and his postgraduate studies (MAS) at the NADEL Centre for Development and Cooperation at ETH Zurich, where he spent several years researching new manufacturing processes for semiconductor components at the Institute for Quantum Electronics. Today, he works in Empa's Technology & Society Lab, the materials research institute of the ETH Domain. Rolf Widmer is currently leading several projects in the field of electronic waste management and, in this respect, is researching closed material cycles for rare metals and problematic plastics and glasses.
Electronic waste increasingly also includes embedded electronic equipment for electromobility, energy systems and buildings. He has been a member of the Swico TC for many years.

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. Since 2019, he has been working there as a research assistant in the Technology and Society Department. 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.

Links

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/en/
↗ www.swico.ch/en/
↗ www.slrs.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 related 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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