SENS Swico SLRS

Technical Report 2016

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Ready, steady, think again!

“Swiss franc shock” is the financial expression of the year 2015. With the unexpected withdrawal from the euro minimum rate, the Swiss National Bank shocked the Swiss economy right at the start of the year and heralded a year full of challenges. This radical change in direction did not leave our industry unscathed. Commodity prices had already been moving in one direction for a longer period of time – downwards – and the strong Swiss franc only added to this effect in 2015.

However, it is not this single bombshell but the continuously changing political landscape in Switzerland that called for new approaches in terms of environmental matters. The recommendation to reject the Environmental Protection Act (EPA) and the popular initiative “Green Economy” are just two examples of this trend. The effects on the three take-back systems were surprising, especially in the revision of the Ordinance on the Return, Taking Back and Disposal of Electrical and Electronic Equipment (ORDEE). The Federal Office for the Environment (FOEN) completely unexpectedly withdrew the jointly developed financing solution, while work continued intensively on the development of the state-of-the-art technology based on the European CENELEC standard.

A rethink, however, also implies questioning what is familiar. The ecological assessment of household appliances revealed remarkable results: prevention of emissions impacts the environment much more than the recycling of materials. The strong focus on recyclables must therefore be critically examined in favour of a new vision.

In a sense, the Preisinsel Schweiz (Swiss price island) study initiated by Swico, SLRS and SENS came up with equally surprising results. A fair cost comparison of waste management services in Switzerland with selected European countries proved difficult due to the scarce amount of relevant data available. However, the explanations of the major differences and the revelation of a certain improvement potential encourage a new way of thinking.

And finally, new solutions are needed for the storage and transportation of hazardous goods. Switzerland has signed the international ADR agreement, which particularly concerns the handling of waste electrical and electronic equipment (WEEE) with regard to batteries containing lithium. Representative of the Swico/SENS Technical Commission are working in close collaboration with the authorities on the development of practical guidelines.

As unexpected as certain economic and political decisions and trends were in 2015, the direction in which we are heading is clear. SENS, Swico and SLRS intend to continue to lead the way in the disposal of waste electrical equipment. Here, a strong alliance between the three systems is equally important as transparent cooperation and constructive dialogue with our system partners.

Heidi Luck, SENS

Jean-Marc Hensch, Swico

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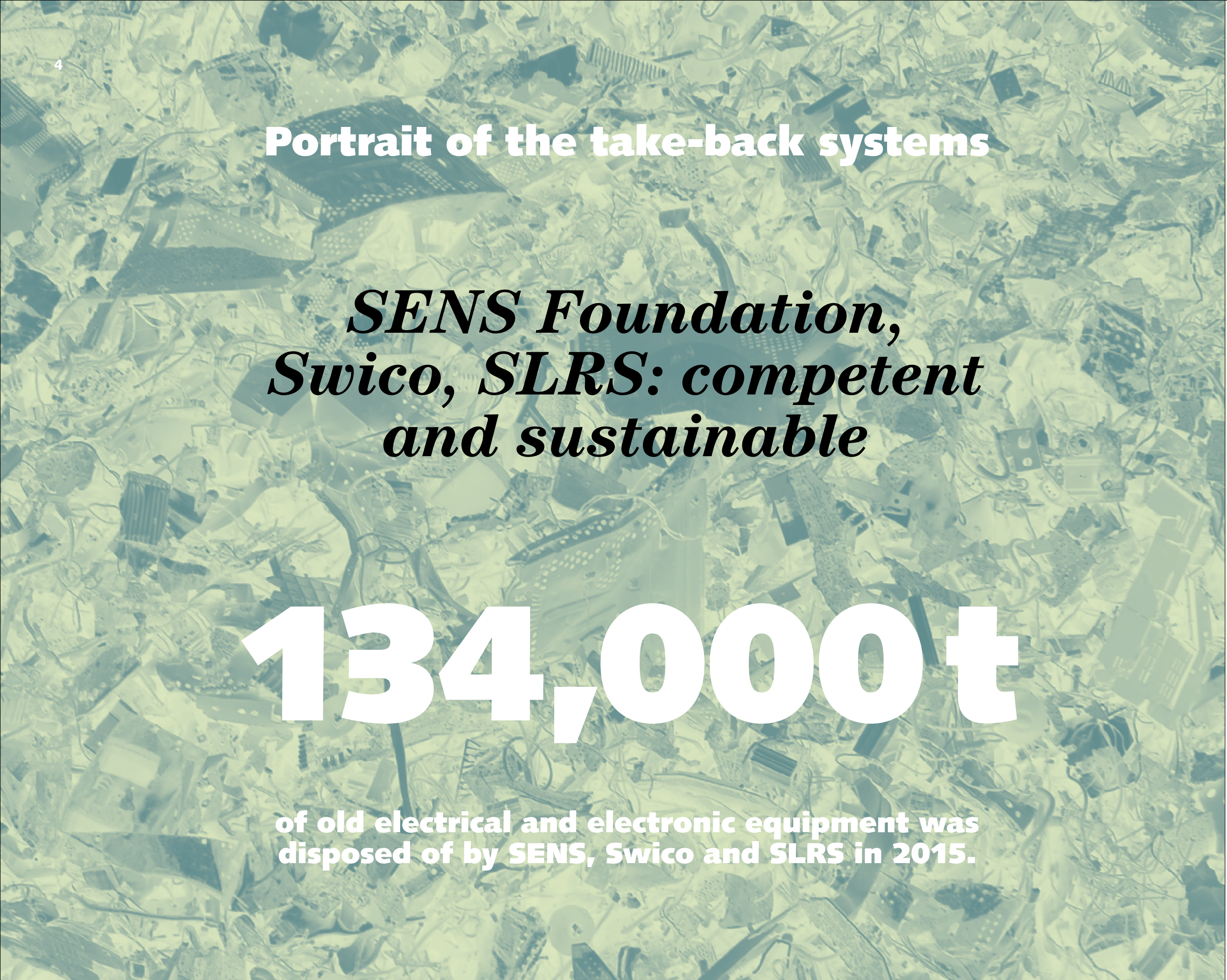


Portrait of the take-back systems

SENS Foundation, Swico, SLRS: competent and sustainable

134,000 t

of old electrical and electronic equipment was disposed of by SENS, Swico and SLRS in 2015.

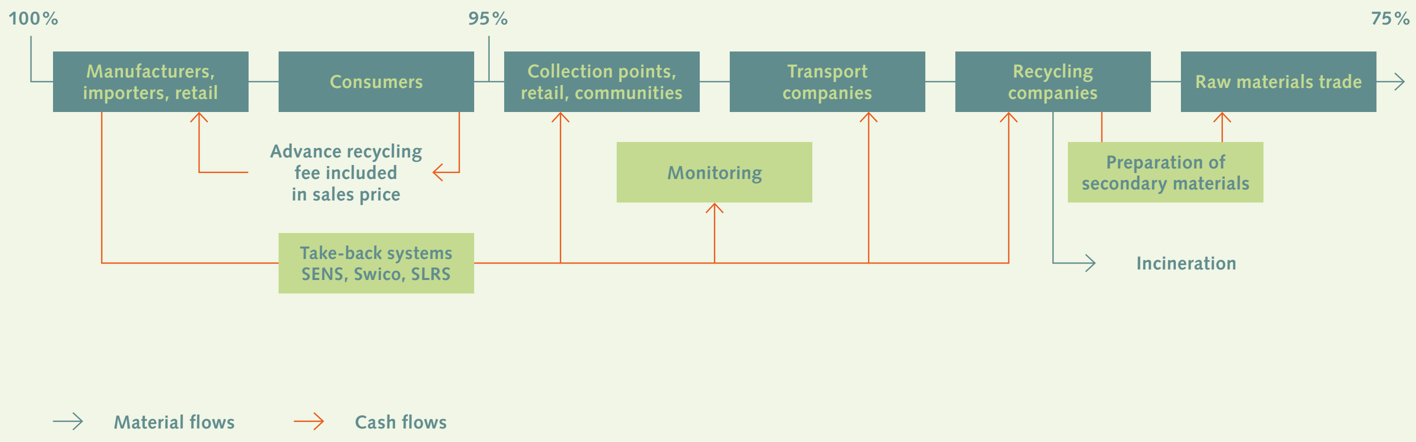
For more than 20 years, the three take-back systems of SENS, Swico and the Swiss Lighting Recycling Foundation (SLRS) have been guaranteeing the resource-efficient return and reuse and proper disposal of electrical and electronic equipment. Increasing take-back quantities bear witness to the success of the three systems.

In Switzerland, there are three take-back systems for electrical and electronic devices. There are historical reasons for the existence of three systems, as in the early years of institutionalised recycling, industry-specific systems were established. The aim of these was to guarantee proximity to the relevant industry in order to 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, the SENS Foundation or the Swiss Lighting Recycling Foundation (SLRS) is now responsible for recycling.

In 2015, the three systems disposed of around 134,000 tonnes[1] of old electrical and electronic equipment. This means that Swico, the SENS Foundation and SLRS have also made a significant contribution to reintroducing 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 equipment.

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

Overview of the take-back systems



SENS Foundation

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

Swico

Swico Recycling is a special fund within the Swiss Industrial Association Swico and deals exclusively with cost-covering recycling of old equipment. Swico aims to extract raw materials and dispose of pollutants in an environmentally friendly way. The focus of Swico is on equipment in the fields of computing, consumer electronics, office equipment, telecommunications, the printing industry as well as measuring and medical instruments, such as copiers, printers, televisions, MP3 players, mobile phones, cameras, etc. Close cooperation with Empa, a research and service institute for material sciences and technology development within the ETH, plays a crucial role in ensuring that Swico can enforce high and uniform quality standards throughout Switzerland with all waste management services.

Swiss Lighting Recycling Foundation (SLRS)

The Swiss Lighting Recycling Foundation (SLRS) bears the 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 the market participants with respect to the recycling of lamps and lighting equipment and providing information to 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 the recycling, monitoring and reporting with regard to lamps and lighting equipment on an operational basis.

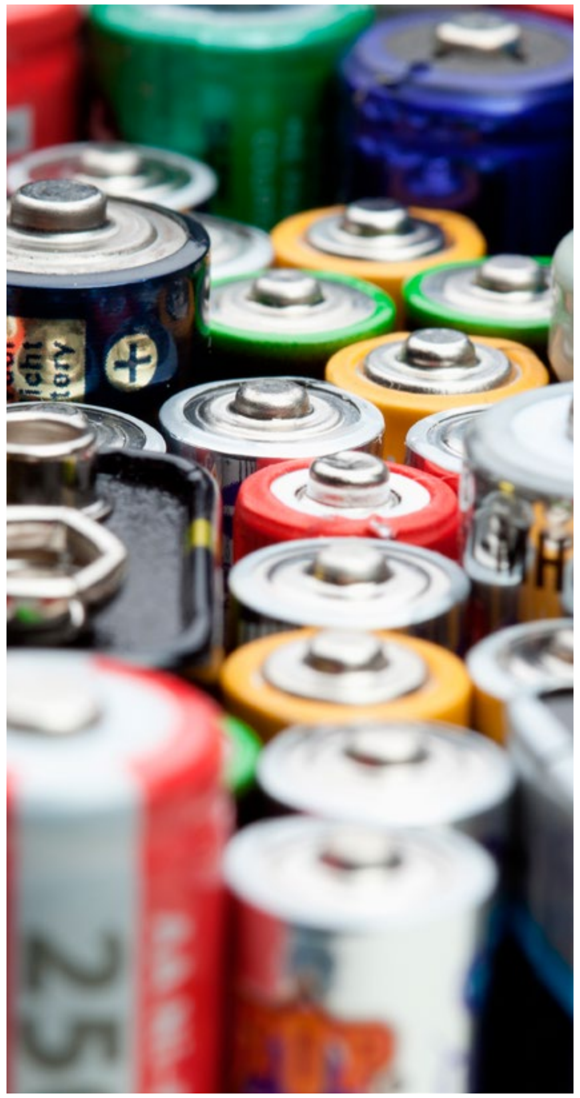
[1] This is the quantity confirmed by the material flow reports from the recycling companies. It is not the same as the quantity calculated in accordance with the annual and company reports for SENS and Swico Recycling.

Pilot audit according to CENELEC 50625

Roman Eppenberger & Heinz Böni

In 2015, the activities of the Technical Commission were clearly focused on the implementation of the CENELEC standard. Soon, the last documents of the CENELEC EN 50625 standard series will be available, and the CENELEC standard will become the state-of-the-art technology in Europe. This series of standards has its origin in the WEEELABEX standard, which in turn resulted from the technical regulations of SENS and Swico. Furthermore, the successor for the inspection of dismantling companies was defined, and four other cantons have chosen to adopt the delegated execution.

In February 2015, all of SENS and Swico's recycling partners were informed by letter of important information for the turn of the year. The permanent topic of lithium-ion batteries remains on the agenda, and the work group is still working on instructions for careful handling of appliances containing lithium-ion batteries. The Swico batch tests were conducted for the first time on specified and thus equivalent input quantities so that the performance of the commissioned recycling companies could be assessed better on the one hand in terms of recycling and recovery rates but also, on the other hand, be compared with one another. With Basel-Land, Appenzell Ausserrhoden, Schaffhausen and Zug, four more cantons have now signed the cantonal agreement on delegated execution. Thus, currently a total of eight cantons (including Aargau, Zurich, St. Gallen and Thurgau who were already participating) are part of the agreement.



The pilot audits included a total of seven companies. All inspectors took on the role of lead auditor at least once, which brought together the different experiences. Two audits were also accompanied by representatives from the cantonal environmental authorities who were able to take an active part in this pilot project and see for themselves the great attention to detail and the intensive inspections.

The successor for the inspection of dismantling companies has been assured since March. Silvan Rüttimann has passed on his responsibilities to female hands in the person of Flora Conte from Carbotech AG, Zurich, and Anahide Bondolfi of Sofies SA, Geneva. Both are fluent French and German speakers, which was a precondition on the part of the systems, in order to ensure the tasks in French-speaking Switzerland on a broader basis.

Given the currently very low commodity prices, the Technical Commission chose the topic of metal and scrap for its annual training in the autumn. The visit to Swiss Steel in Emmenbrücke (one of two steel plants in Switzerland) gave an interesting insight into a highly efficient system at the highest level. In an interview with the head of strategic sourcing, Daniel Jung, the inspection experts were able to discuss the challenges the metal recycling industry is currently facing.

The challenge of implementing EN 50625 in Switzerland

Ueli Kasser & Heinz Böni

At the end of 2014, the SENS and Swico foundations decided to implement the European series of standards EN 50625 on collection, logistics and treatment of waste electrical and electronic equipment (WEEE) in Switzerland on a mandatory basis. The idea is to measure the performance of the contract parties against European technological standards. This requires certain – mainly formal – adjustments to the inspections that were carried out as a pilot last year and will be improved and extended this year. From 2017 onwards, the new conformity assessment according to EN 50625 will become mandatory in all companies.

The Swico/SENS Technical Commission also wants to remain faithful to the guiding principle of "a level playing field for all recycling companies" in the future. As of 2017, however, this playing field will be measured according to the European Standard EN 50625. If everything goes according to plan, it will be adopted in all EU countries as of 2018 or 2019 as the binding state-of-the-art technology in the revised WEEE Directive.

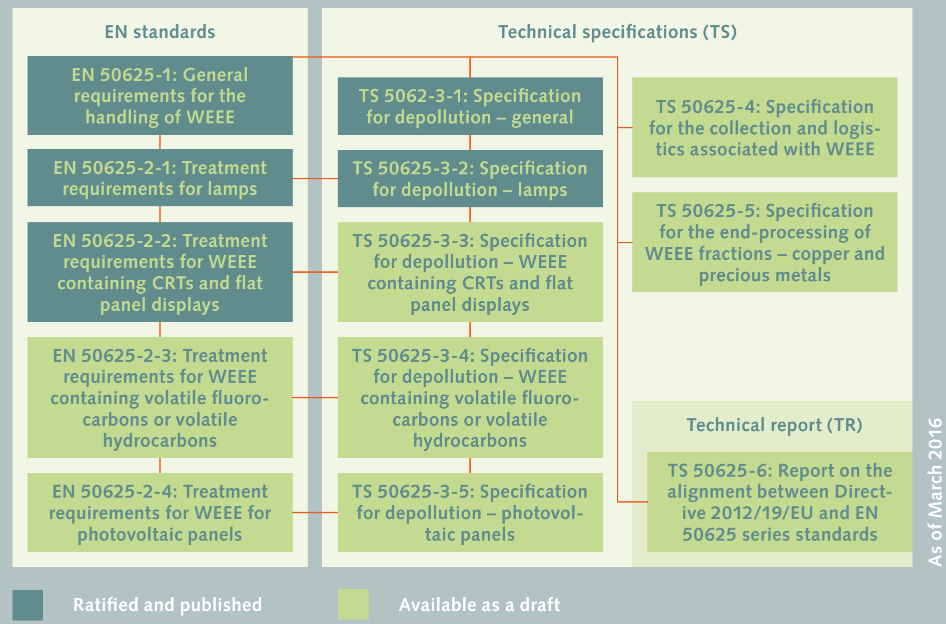
More or less complete

The European set of standards is highly advanced (Figure 1). It consists of a main standard that applies to all companies, as well as additional standards for those recycling companies specialising in lighting equipment, monitors, refrigerators, freezers and photovoltaic modules. There are seven technical specifications (TS documents) for the current standards (EN documents) containing limit values and specifying details such as sampling and analysis methods. The technical specifications can be revised more easily and more often (every three years) and are less complicated in terms of the consultative procedure and decision-making process in the European Standard Commission. The main standard, which applies to all WEEE recycling companies, has already been published, as have two special standards for lamps and monitors and two technical specifications. All other planned partial standards (Figure 2) and the outstanding technical specifications[1] are available as advanced drafts.

No major changes in Switzerland

As already detailed in the last two technical reports from 2014 and 2015, the remaining substantial differences between the European standards and the technical requirements, as developed by SENS and Swico, are minor. After all, the initiative for European standards originally came from Switzerland, at a time when most take-back systems in Europe were still busy setting up their organisational structure. The main services are the same: a recycling company must be able to prove that it carries out the removal of pollutants correctly and that its technology complies with the relevant recycling quotas[2], which

Figure 1: EN 50625 series – collection, logistics and treatment of waste electrical and electronic equipment (WEEE)



have become much stricter recently. In essence, compliance must regularly be demonstrated based on a representative batch (in the standard jargon: test batch processing). It must be ensured that the conditions during processing of the batch correspond to the typical daily business of the entire year.

Informative pilot phase

The differences between Switzerland and Europe are more formal. Good compromises were often found between typical Germanic thoroughness and the more laid-back, Latin approach. The European set of standards (statutory framework) is more comprehensive – it is more consistent and systematic in terms of its design and structure. The Swico and SENS report template, used for audits in Switzerland for nearly 10 years, has had to be adapted to the EN standard. A first draft of the report template was developed in the beginning of 2015 and tested as part of a pilot phase at seven Swiss recycling companies (see fig. 2). The experiences were quite uniform: the first draft was too wide-ranging and detailed, while the audits according to CENELEC took 9 to 10 hours, which did not leave enough time for observations and inspections of the companies. Most representatives of the cantons, with whom an agreement for the delegated execution is in place, responded positively, particularly with regard to the scope and detail of the report template. However, it also became clear that it would not be easy to align the expectations and requirements of the cantonal environmental protection agencies with the more extensive auditing according to CENELEC.

Streamlining and focusing

At the end of September 2015, over the course of one day, the Swico/SENS Technical Commission evaluated the experience using the new report template and decided on the following changes:

- By analogy with other conformity assessment systems, a distinction will be made between initial and subsequent audits every three years, with an additional monitoring audit to be carried out every year, focusing specifically on the treatment of waste electrical and electronic equipment and the visual inspection of the company. Evidence of legal compliance and company-specific risk analysis with appropriate prevention and mitigation measures is only to be inspected on a random basis during the monitoring audit, as required.

- ISO 14001 certified companies – i.e. the vast majority of Swiss recycling companies – will only be reviewed on a random basis with regard to legal compliance, continuous improvement and internal training.

- Predominantly bureaucratic information, such as the list of documents reviewed or authorised waste codes that can be viewed on VeVA-online, should be deleted from the record template.

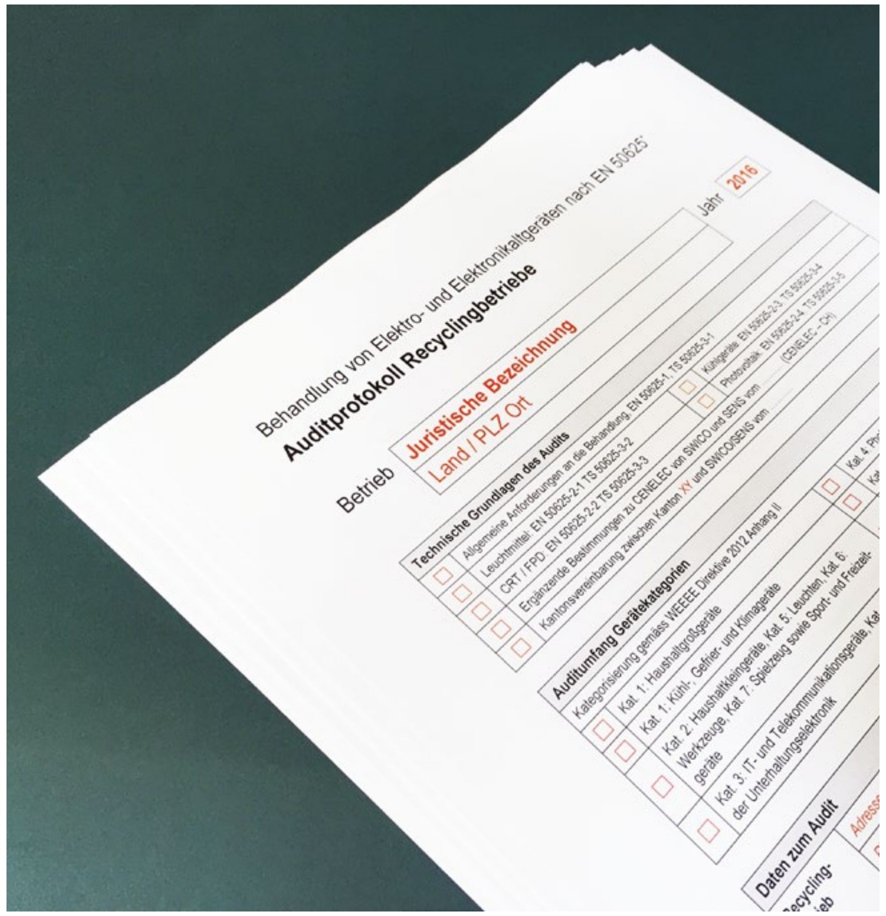
Based on these decisions and numerous detailed improvements, a second draft of the report template for conformity assessment in accordance with EN 50625 was agreed (Figure 2). This will be tested again during the current year, before it is finally revised and adopted on a mandatory basis for all businesses as of 2017. In addition, various other changes need to be made in order to satisfy the requirements of the European standard.

Table 1: Schedule for the implementation of EN 50625 in Switzerland

Tasks	2015												2016												2017		
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Report template for recycling companies	1st draft					1st pilot phase				Evaluation			2nd draft			2nd pilot phase						Finalisation					
Report templates refrigerators, lighting equipment and PV modules for recycling companies																						Drafts			Finalisation		
Report template for dismantling companies													Draft			Pilot phase						Finalisation					
Batch report template											1st draft					Pilot phase						Finalisation					
Technical questions / CENELEC plus													Draft			Pilot phase						Finalisation					
Handbook / guidelines																					Draft				Finalisation		

Handbook accessible to recycling companies

The report template for the inspection of dismantling companies is in progress and will also be tested as part of this year's pilot phase. It will be made leaner and be redesigned to take account of the principle of inspection. Templates are also to be produced for the lighting equipment and refrigerator PV module processing, in line with the EN standard and following the logic of the general template. The procedure for reporting on batch tests, which is strictly regulated in the European standard, is new as well. Towards the end of this year, the handbook for the monitoring experts also needs to be finalised. It contains a variety of practical information which is necessary to conduct consistent inspections. This includes an aid to interpretation for individual provisions, example assessments relating to certain situations in companies, examples of qualifications in the field of legal compliance, sample questions and criteria in the context of visual inspections in companies and summaries of legal regulations that may be relevant to recycling companies. Finally, it also provides information on how deviations from the standard are to be assessed in terms of severity. To create more transparency between monitoring experts and the inspected company, the handbook will also be made available to recycling companies as from 2017.



Some technical hot spots

The changeover from the Swiss to the European standard is an ideal opportunity to finally resolve recurring issues and implement them in all companies. These issues include:

- Should mixed processing together with non-WEEE waste be permitted? An interpretation of the EN provisions would allow this under certain conditions.

- To what extent should the dismantling of condensers and batteries by the cross-flow chip cutter or another pre-comminution technology be tolerated, meaning to what extent is manual removal of pollutants required prior to the initial mechanical treatment stage?

- To what extent can the release of the luminescent layer be tolerated when destroying, storing or transporting television/monitor screens?

- What demands need to be made on plastic fractions sent for recycling, where the removal of parts containing bromine is not guaranteed (e.g. China)?

Ensuring that these issues are assessed in the same manner by different monitoring experts in all companies concerned is a major challenge. If the change to the European standard can help to clarify these issues, then its introduction in Switzerland in 2017 will have already paid off.

[1] EN 50625-1, EN 50625-2-1, EN 50625-2-2, TS 50625-3-1 and TS 50625-3-2 can be ordered from: www.electrosuisse.ch

[2] According to the WEEE Directive on which the technical rules of SENS and Swico are based, the recycling and reuse rates from August 2015 increased by 5 per cent per device category (except lighting quipment).

SENS ecological audit

Prevention of pollutant emissions contributes substantially to the environmental benefits of SENS

Emil Franov

It is not the recovery of recyclable materials such as iron and copper from electrical and electronic equipment which has been responsible for the greatest environmental benefit of the SENS system over the past 25 years, but the separation and controlled disposal of pollutants. Of particular relevance to the environment is the toxin PCB which, as a dioxin, is among the twelve most harmful environmental pollutants. PCB is primarily found in condensers in ballast units for lamps and large household appliances, which will thus still have to be removed with the utmost care and properly disposed. Avoiding emissions of other pollutants such as CFC, brominated flame retardants (BFR) and mercury is also becoming proportionately more important, since these pollutants were banned later than PCB, meaning it will take longer for their levels in appliances to diminish.

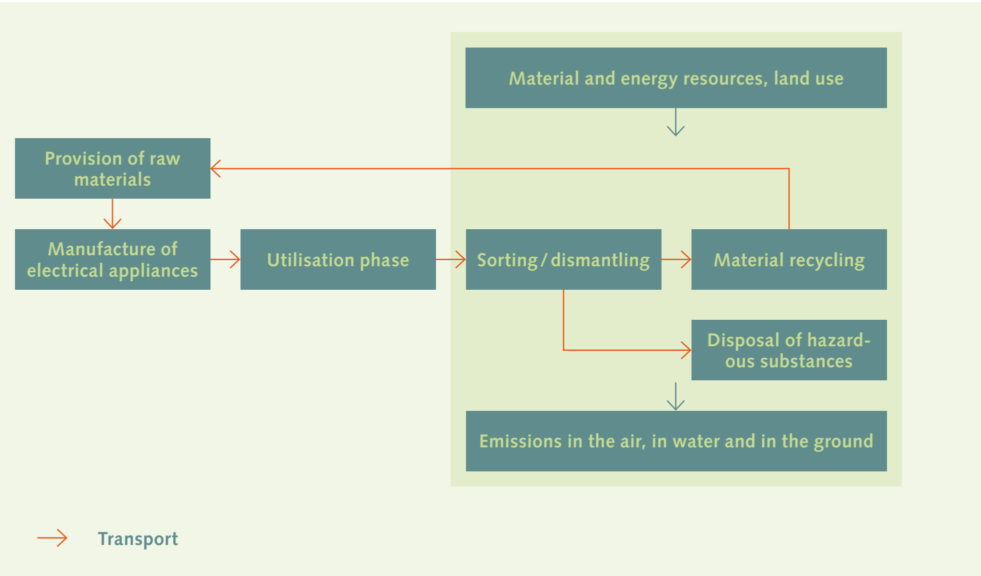
As part of its 25th anniversary in 2015, SENS commissioned an ecological audit to assess the environmental impact of 25 years of electrical and electronic equipment recycling by SENS and its partners – consumers, manufacturers/importers, retailers, service partners (such as collection points, carriers and recycling companies) and public authorities. In addition, the environmental benefits and the amounts of the main materials recovered were also assessed.

Before the SENS Foundation[1] was launched in 1990 and started work, small waste electrical and electronic equipment was usually disposed of together with household waste. Larger appliances containing a lot of metal, such as washing machines, were partly disposed of via companies specialising in metal recycling. However, little attention was paid to any pollutants found in these appliances. Only international agreements such as the decision to ban ozone-depleting substances in the medium term (Montreal Protocol, put into effect in Switzerland in 1988) focused attention on pollutants in waste electrical and electronic equipment. With the aim of disposing of the ozone-depleting substances contained in refrigerators and freezers in an environmentally friendly way, SENS consequently set up the first voluntary collection and disposal system. With the entry into force of the Ordinance on the Return, Taking Back and Disposal of Electrical and Electronic Equipment (ORDEE) in 1998, the SENS system was extended to include small electrical and electronic equipment (kitchen, gardening and hobby appliances, toys, etc.) and large electrical and electronic equipment (washing machines, ovens, etc.). In the 2005 revision, lamps and lighting equipment were also included.

A separate system (from Swico[2]) exists for the disposal of electronic devices. The ORDEE stipulates that dealers and importers must accept return of these devices free-of-charge and dispose of them in an environmentally friendly manner, with any hazardous substances in particular being disposed of properly. The SENS Foundation offers this service.

How was the environmental benefit calculated?

The environmental benefit results from the difference between the life cycle assessment of SENS and the life cycle assessment of the baseline scenario "without SENS" as a reference. The environmental performance of the SENS system thus consists of the environmental benefit beyond the reference scenario. The system boundary has been chosen as follows.



The basic data concerning the amounts of devices processed, the recyclable materials generated and the removed and properly disposed pollutants is mostly derived from the annual SENS statistics. Only older data for specific years (from 2006 and 2003) is available for the pollutants PCB and BFR. This explains why the historic content of these pollutants in appliances had to be extrapolated for the subsequent years.

The method of ecological scarcity 2013 (Frischknecht & Büsser Knöpfel, 2013) was used for the evaluation of the impact assessment. Evaluation using this method was developed in collaboration with the Swiss Federal Office for the Environment and is well established in Switzerland. One reason for choosing this method was that it takes into account both the environmental situation and the environmental objectives of Switzerland for the assessment and thus is widely respected with regard to sustainability. Another reason was that this method provides an actual evaluation of all important environmental aspects in this life cycle assessment, such as POP emissions and resource consumption.

The number of refrigerators, freezers, air conditioners, large and small electrical equipment and lighting equipment collected by the SENS foundation from 1990 to 2015 was selected as a functional unit.

Switzerland's reference scenario without SENS

For the scenario "without SENS", different variants are possible: from "nothing is going to be recycled and everything is dumped in open waste disposal sites or burned" to "handling of electrical equipment disposal in compliance with existing Swiss laws". For the purposes of this study, as realistic a scenario as possible "without SENS" was defined as a compromise, similar to the scenario in the Ecodom study on the environmental benefits of electrical equipment recycling in Italy (ECODOM, 2008). This is based on the following assumptions:

– Consumers return the same amount of appliances for recycling as with SENS.

– One half of the electrical equipment is economically optimised and recycled – in non-specific plants without compliance with specific environmental requirements – while the other half is recycled by specialist companies, albeit with a lower pollutants recovery rate due to the lack of external inspection.

– The following applies to all collected appliances: by way of economic optimisation, 50 per cent of iron and steel is recovered with full absorption of refrigerant, propellant and mercury. All other materials are disposed of.

– For the other half, all materials are recovered as described in SENS – 50 per cent of the refrigerant, propellant and mercury escape into the environment.

– With regard to PCB, the following assumptions were made based on measurements taken of the PCB content of various fractions of the sorting and dismantling process (Morf & Taverna, 2004):

  • 85 per cent of the PCB inputs can be found after decomposition in the ASR[3], which is disposed of in a waste incineration plant. 15 per cent can be found in recyclable materials: sooner or later, this PCB fraction will escape directly into the environment, either in the preparation for secondary materials or at the utilisation phase. Due to lack of data, it was assumed that 90 per cent of PCB content which ends up in a waste incineration plant will be destroyed and 10 per cent will be released into the environment.

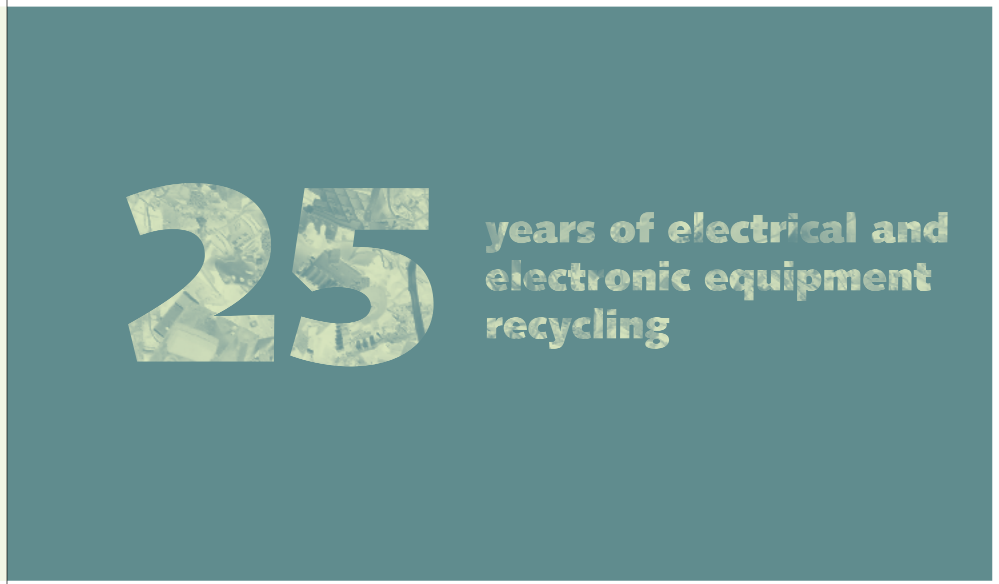
  • Overall, a total of 24 per cent of the PCB input will be released into the environment.

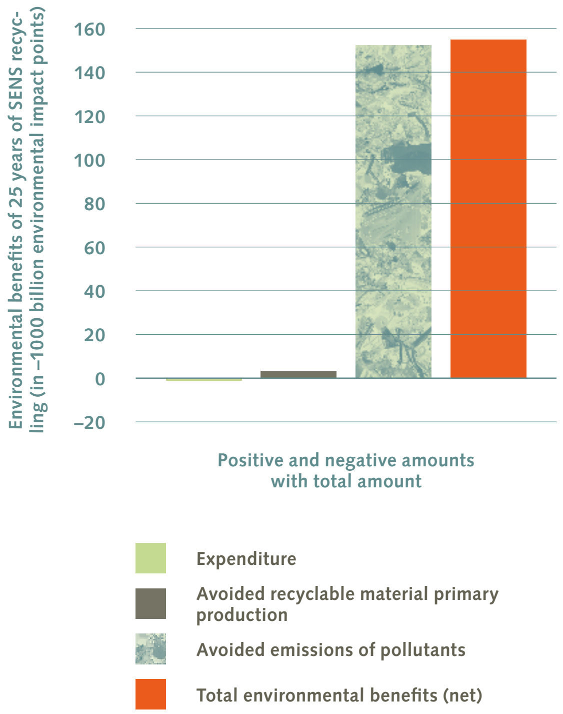
– With respect to BFR, the following assumptions were made based on Morf et al. (2002):

  • Half of the plastics containing BFR are not recycled due to the assumed economic optimisation and thus end up directly in the waste incineration plant where the BFR is destroyed almost completely.

  • The other half of the plastics containing BFR is recycled (abroad). It is assumed that these plastics emit BFR during their utilisation phase, that BFR gets into the environment through abrasion and that one half of the BFR eventually ends up in a waste incineration plant, while the other half finds its way to a waste disposal site, where part of the chemical leaches into the water.

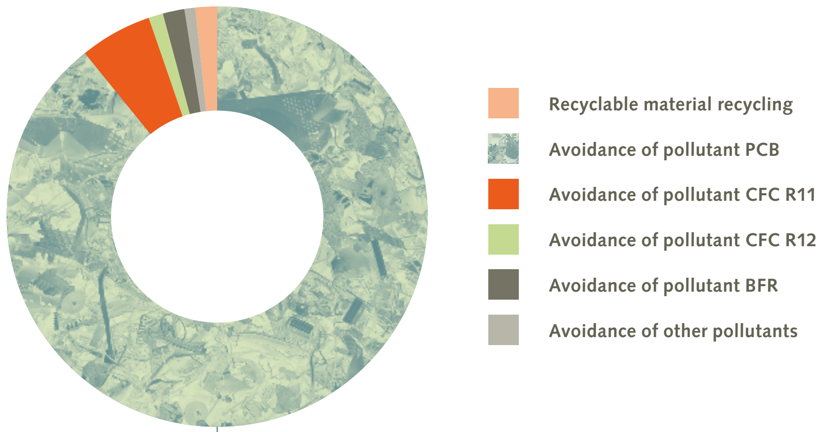
  • Thus, a further 1.02 per thousand of octabromodiphenyl ether (OctaBDPE), 0.94 per thousand of decabromodiphenyl ether (DecaBDPE) and 1.50 per thousand of tetrabromobisphenol A (TBBPA) get into the environment, as compared to the analysis of the current state of SENS.





The environmental benefits of the SENS electrical and electronic equipment recycling results from the total of positive and negative amounts.

Share of recyclable material recycling and avoidance of pollutants in the environmental benefits of SENS electrical and electronic equipment recycling



89.4%

avoidance of pollutant PCB

How has 25 years of SENS helped the environment?

Overall, the environmental benefits of 25 years of SENS electrical equipment recycling amount to net 155,000 billion avoided environmental impact points (UBP)[4] with almost all of the benefits (98.4 per cent) being due to the prevention of emissions of pollutants (see figure). The environmental benefits of recycled recyclable materials and the ecological burden of recycling (transport, energy consumption of recycling companies, etc.) are very small by comparison. The total environmental benefits of 155,000 billion UBP corresponds to approximately:

- the environmental footprint of the entire Swiss population (eight million inhabitants) in 11 months (equivalent to an annual reduction in the environmental pollution in Switzerland on average of about 4 per cent); or

- the environmental benefits generated by the use of unleaded petrol in Switzerland over nine years.

Among the emissions of pollutants prevented, correct disposal of condensers containing PCB makes the most important contribution to environmental benefits (89.4 per cent), followed by the correct disposal of CFC R11 (5.5 per cent), BFR (1.7 per cent) and CFC R12 (1.0 per cent).

The nine tonnes of PCB, which are also properly disposed of by the SENS system compared to the scenario “without SENS” and thus are not emitted into the environment, dominate the results, because PCB is classified as much more environmentally damaging than all other pollutants in electrical and electronic equipment. The PCB mainly stems from the condensers of small electrical and electronic equipment (especially the ballast units of lamps) and large electrical and electronic equipment.

The climate benefits of 25 years of SENS electrical and electronic equipment recycling is 7.1 million tonnes of global warming potential (GWP). The large part of the benefit stems from the correct disposal of CFC R11 (66.7 per cent) and CFC R12 (26.4 per cent). These greenhouse gases are mainly contained in the various cooling devices such as refrigerators, freezers and air conditioners.

Over the period of time observed, about 650,000 tonnes of recyclable materials were recovered on the one hand, and about 3,900 tonnes of pollutants were disposed of in a controlled manner on the other hand. Proportionally, the most important recyclable materials are iron (70.0 per cent), steel (10.9 per cent) and plastics (8.5 per cent). Much less significant are the quantities collected of copper (4.2 per cent), aluminium (2.6 per cent), zinc (2.5 per cent) and glass (1.2 per cent). Of the remaining recyclable materials, only very small quantities arose (less than 0.1 per cent). Proportionally, the main pollutants are CFC R11 (33.8 per cent) and oil (32.5 per cent). The quantities collected of BFR (14 per cent), CFC R12 (6.1 per cent), cyclopentane (6.0 per cent) and R600a (5.2 per cent) are much lower. Of the remaining pollutants, only small quantities arose (less than 2.1 per cent).

The life cycle assessment study showed that the SENS Foundation, in cooperation with its partners, generated very high environmental benefits during its 25 years of existence. Thanks to the environmentally friendly disposal of electrical and electronic equipment, the annual environmental impact on Switzerland was reduced by an average of about 4 per cent – a very significant value for a single measure.

What does this mean for the future?

Despite the fact that today fewer and fewer PCB condensers are contained in waste electrical and electronic equipment, this pollutant still has the highest potential to cause environmental damage according to our calculations. In particular, the condensers in ballast units for lamps and those in large household appliances must continue to be removed with the greatest care and disposed of properly. For a more accurate estimate of the actual environmental benefits, an update of the study of PCB levels in condensers from 2007 would be very helpful; it is also recommended to examine PCB substitute materials as to their potential to cause environmental damage.

Avoiding emissions of pollutants such as CFC, BFR and mercury by ensuring their controlled, proper disposal is becoming proportionally more important, since these pollutants were banned later than PCB, meaning it will take longer for their levels in appliances to diminish.

The contribution to the environmental benefits through the recycling of recyclable materials such as iron, copper and aluminium is still very low due to the dominance of the pollutants but continues to rise, especially as less PCB is contained in the appliances. Nonetheless, the recycling of such recyclable materials is useful from an environmental perspective since the environmental benefit (conservation of resources, etc.) from recycling is usually much greater than the cost of treatment (energy consumption, etc.). A potential assessment of the future recycling of existing traces of electronic metals has further shown that the environmental benefit thus generated is marginal, even if it is assumed that the metal contents in printed circuit boards of electronic devices would be similar to computer circuit boards.

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[1] Initially as Stiftung Entsorgung Schweiz (S.EN.S.)

[2] Abbreviation for Swiss Economic Association for the Suppliers of Information, Communication and Organizational Technology (Schweizerischer Wirtschaftsverband der Informations-, Kommunikations- und Organisationstechnik)

[3] Auto shredder residue (combustible waste)

[4] Shown as negative UBP in diagrams

Volumes

Increase in the volumes processed

Esther Thiébaud

After a slight decline in volumes over the last two years, in 2015, the quantities processed have risen significantly again and reached a new high. Around 73 per cent of the recyclable materials produced by the Swiss recycling companies enter the cycle.

In 2015, the Swico and SENS recycling companies processed around 132,200 tonnes of electrical and electronic (E&E) appliances. Compared to the previous year, this represents an increase of 4 per cent and a new record in volumes processed (table 1 and figure 1). The amount of large electrical appliances processed increased most significantly by 14 per cent. Refrigerators and small electrical appliances each increased by 5 per cent. The processing of electrical and electronic equipment, lighting equipment and non-ORDEE devices that are not included in the lists of the Ordinance on the Return, Taking Back and Disposal of Electrical and Electronic Equipment (ORDEE) hardly changed compared to 2014. Newly added to the lists is the processing of photovoltaic equipment, although the volumes are still small at 100 tonnes.

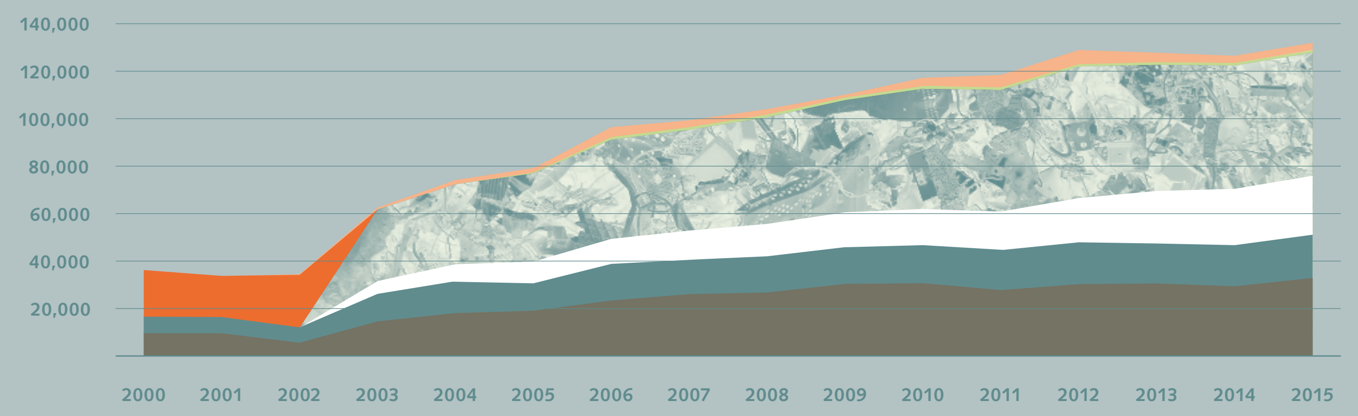
Materials recycling

Of the E&E appliances processed, the recyclables and hazardous substances are obtained through manual and automatic processing (figure 2). The largest recyclable materials group is that of metals, at 58 per cent. Compared to the previous year, the proportion of plastics-metal mixtures has increased from 11 per cent to 18 per cent, whereas the proportion of pure plastics groups has decreased from 13 per cent to 8 per cent. The proportion of glass from cathode ray tubes processing has dropped to 5 per cent, and the valuable circuit boards account for only 1.5 per cent of the total volume. Nevertheless, it is often worthwhile to manually remove particularly valuable materials before the automatic processing. The recovered recyclable materials are recycled or utilised thermally where possible. Metals are recovered in large, mostly European smelting plants. About half of the plastics-metal mixtures enter another processing stage, in which pure metal and plastics groups are separated. The other half is utilised thermally in incinerators. In 2015, plastics were recycled at about 64 per cent, corresponding to a volume of 7,300 tonnes. The previous year, 12,700 tonnes of plastics were recycled. This decrease of about 40 per cent could be related to the lower prices of raw materials for plastics. Glass groups (screen glass, plate glass and recycled glass from lighting equipment), as well as cables, circuit boards and batteries are processed further. The total recycling rate amounts to around 73 per cent.

Table 1: Total processed electrical and electronic equipment in Switzerland in tonnes from the material flow analysis

Year	Large electrical appliances	Refrigerators, freezers and air conditioners	Small electrical devices	Electronic devices	Lighting equipment	Photovoltaics	Non-ORDEE devices	Total tonnes / year
2009	30,400	15,300	14,900	47,300	1,100		1,200	100,200
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	980		6,000	129,100
2013	30,600	16,700	22,300	53,200	1,130		4,000	127,900
2014	29,400	17,200	23,900	52,000	1,060		3,000	126,600
2015	32,900	18,100	25,000	51,900	1,090	70	3,000	132,100
Change compared to previous year	**12%**	**5%**	**5%**	**–0.2%**	**0%**		**0%**	**4%**

Figure 1: Development of the volumes of appliances processed in Switzerland in tonnes



¹ Small electrical and electronic devices together: this number is larger than the 51,900 tonnes of electronic equipment in table 1, since this also includes electronic devices which A-signatories have disposed of via direct contracts.

Figure 2: Composition of the material groups generated in per cent in 2015

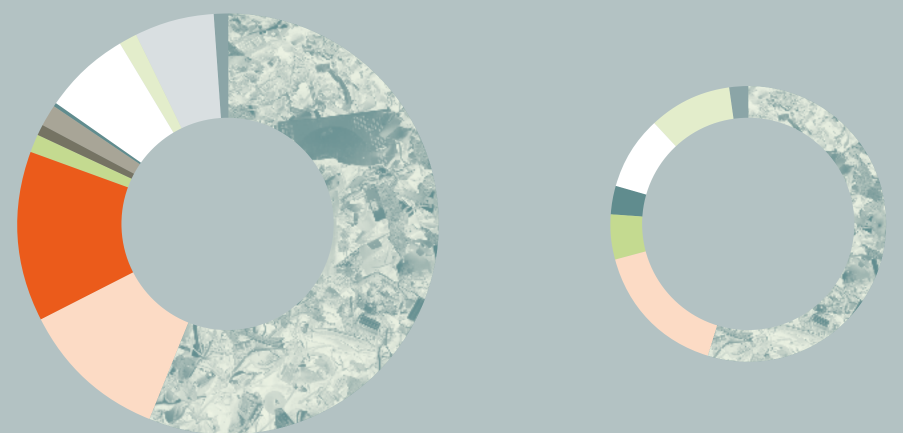


Table 2: Swico volumes collected and composition by type of appliance

	Number[3]	Average weight	Metals	Plastics	Plastics-metal mixtures	Cables	Glass and / or LCD modules	Circuit boards	Pollu-tants	Other[4]	Total	Increase / de-crease com-pared to 2014
PC monitors, CRT	121,000	17 kg	302 t	409 t	195 t	53 t	899 t	188 t	0.1 t	9 t	2,056 t	–11 %
PC monitor, LCD	513,000	8.5 kg	1,264 t	707 t		12 t	744 t	206 t	9.6 t	14 t	2,956 t	–4.9 %
PC / server	402,000	13 kg	4,377 t	306 t	14 t	163 t		443 t	17 t		5,320 t	0.6 %
Laptops	410,000	3 kg	369 t	343 t	124 t	6.2 t	107 t	177 t	84 t	5.1 t	1,214 t	–1.4 %
Printers	532,000	11 kg	2,161 t	3,280 t	375 t	33 t	42 t	107 t	1.9 t	99 t	6,099 t	27 %
Large-scale copiers / equip-ment	44,000	147 kg	3,504 t	240 t	2,301 t	116 t	4.3 t	52 t	56 t	164 t	6,439 t	–13 %
IT mixed[1]	503,000	4.1 kg	1,132 t	75 t	750 t	38 t	1.1 t	16 t	18 t	53 t	2,082 t	–47 %
CRT TVs	420,000	28 kg	1,146 t	2,379 t	387 t	40 t	7,523 t	142 t	11 t	6.3 t	11,636 t	–11 %
LCD TVs	161,000	15 kg	1,025 t	369 t		50 t	638 t	303 t	23 t	86 t	2,495 t	0.7 %
Consumer elec-tronics, mixed[2]	2,620,000	4.3 kg	6,112 t	405 t	4,048 t	204 t	5.7 t	88 t	97 t	284 t	11,243 t	–4.2 %
Mobile phones	704,000	0.21 kg	24 t	54 t			7.8 t	34 t	30 t		150 t	37 %
Remaining phones	1,460,000	1.9 kg	1,508 t	100 t	999 t	50 t	1.4 t	22 t	24 t	70 t	2,773 t	–4.8 %
Photo / video	324,000	0.54 kg	94 t	6.3 t	63 t	3.1 t	0.1 t	1.4 t	1.5 t	4.4 t	174 t	4.2 %
Dental											86 t	32 %
Total			**23,018t 42 %**	**8,673t 16%**	**9,256t 17 %**	**768t 1.4 %**	**9,975t 18 %**	**1,779t 3.3 %**	**372t 0.7 %**	**794t 1.5 %**	**54,721t 100 %**	**–6.6 %**

Hazardous substance removal
The proportion of hazardous substances generated is less than one per cent (figure 2). However, their removal is one of the most important tasks of the Swiss recycling companies besides reintroducing the recyclable materials in the cycle. Hazardous-substance removal is carried out manually to a large extent. For example, condensers in large household appliances are removed, as well as batteries from electronic devices or the background lighting of flat-screen displays, scanners and photocopiers. The removal of hazardous substances and the handling of these hazardous substances has to be constantly adapted to changing technologies and the latest state of the art. Nevertheless, companies must be able to take back appliances of all generations with their respective hazardous substances, to remove the hazardous substances and dispose of the appliances in an environmentally sound manner, which places high demands on the work of the recycling companies and requires robust quality assurance systems.

Take-back and composition of E&E appliances
Based on market basket analyses and targeted processing tests of certain product groups, Swico Recycling performed a detailed examination of the take-back amounts of E&E equipment and their composition (table 2). In 2015, Swico Recycling took back 54,721 tonnes[1] of E&E equipment, 6.6 per cent less than in the previous year. In terms of weight, the take-back of mixed IT and large appliances has decreased most significantly. The amount of CRT monitors and CRT TV sets taken back has also decreased by 11 per cent each, whereas the number of LCD monitors, LCD TVs and laptops has increased somewhat compared to 2014. As a slightly smaller average weight was taken as the basis in the market basket analysis in 2015, the volumes processed in tonnes remained almost unchanged. The number of mobile phones and smartphones collected increased by about 3 per cent; however, the average weight was somewhat higher than in 2014, leading to an increase in weight of 37 per cent.

The composition of the individual appliance categories is determined by means of processing tests carried out by Swico recycling companies and supervised by Empa. In this process, a previously defined number of appliances is collected and the resulting material groups are documented. The detailed volumes of E&E equipment taken back and their composition are shown in table 2.

[1] IT equipment, mixed, without monitors, PCs / servers, laptops, printers, large-scale copiers and equipment.

[2] Consumer electronics, mixed, not including televisions.

[3] Projection.

[4] Packaging and other waste, toner cartridges.

[5] This number is larger than the 51,900 tonnes of electronic equipment in table 1, since this also includes electronic devices which A-signatories have disposed of via direct contracts.

Swiss price island

Our way to the top

Deepali Sinha Khetriwal, Hannes Zellweger & Ulrike Voett

Fine balance
The three Swiss producer responsibility organisations (PROs) – SENS, Swico and SLRS – offer a powerful return system with an impressively high collection rate and strict take-back and disposal standards. They are among the international pioneers in the field of eRecycling. However, they are under pressure from different sides: on the one hand, the member companies demand a reduction in the advance recycling fee (ARF), on the other hand, the recycling companies are looking to offset their high operating costs. For this reason, in autumn 2014, the PROs commissioned Sofies SA to look into their cost efficiency, to find out where potential for optimisation exists. The aim was to achieve a better alignment between the charges paid by the member companies and the payments made to recycling companies.

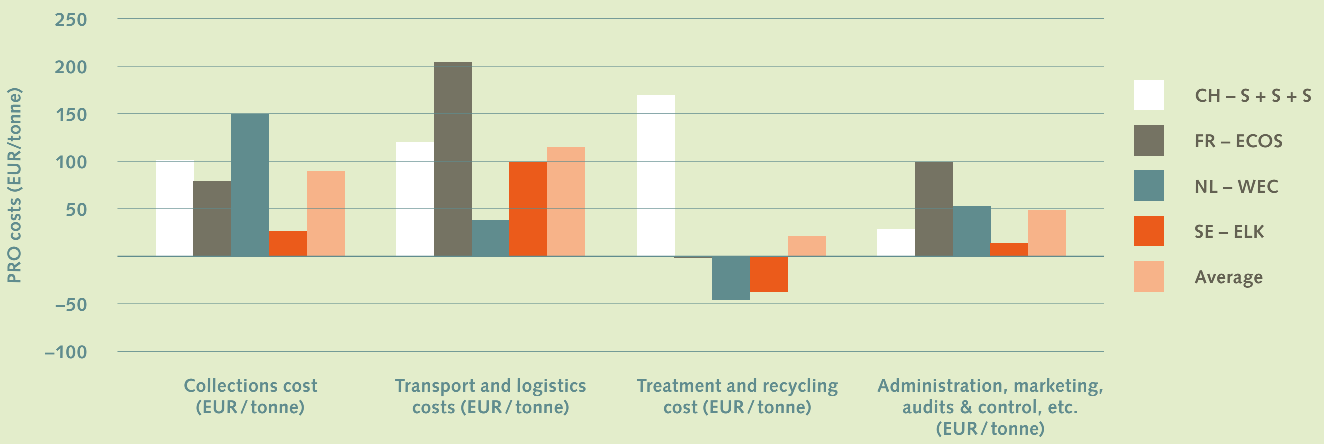
Methodological approach
A comparison of the costs of the Swiss PROs with those of selected European countries requires a structure that enables a reasonable comparison. Thus, the Sofies SA study initially focused on the overall costs of the systems and their subdivision into the major cost items. Then, the cost of the PROs in four European countries – France, Germany, the Netherlands and Sweden (chosen based on their performance or their geographical proximity to Switzerland) – were compared to the costs of the Swiss PROs. Sofies SA developed detailed questionnaires and carried out extensive surveys in order to gather detailed information about PROs, recycling companies and industry professionals. However, the intermediate results of the initial analysis showed that collection rate, recycling rate and recycling standards did not significantly affect the costs. Therefore, the experts decided to carry out more detailed quantitative and qualitative evaluations, in order to specifically identify the key cost drivers and thereby better understand their overall impact on the costs of the PRO.

Keeping track
As figure 1 shows, the Swiss PROs offer their services for a total of CHF 564 per tonne of collected electrical and electronic appliances[1]. The main cost items were expenditure for the collection of used electrical and electronic appliances, transportation and logistics, processing and recycling. These items represented 87 per cent of all expenses. The remaining factors had little impact on the costs of the Swiss PROs and could be largely summarised under the heading "administration, marketing and monitoring".

Table 1: Cost breakdown of the Swiss system

Cost item	Swico 2013	SENS 2013	SLRS 2013	Total Switzerland 2013
Total volume collected (in tonnes)	55,305	76,175	4,099	135,579
Collection costs per tonne (CHF / t)	111	144		126
Transport and logistics per tonne (CHF / t)	169	144		150
Recovery and recycling costs per tonne (CHF / t)	187	182	1,115	212
Costs for administration, marketing and monitoring per tonne (CHF / t)	29	29	268	36
Other costs – batteries – costs per tonne (CHF / t)	18	10		13
Other costs – packaging – costs per tonne (CHF / t)	64			26
Total costs per tonne (CHF/t)	**578**	**509**	**1,383**	**564**

Figure 1: Comparison of the main cost items



The costs of collection as well as transport and logistics for the Swiss PROs are typical for the European average. The costs of administration, marketing and raising awareness as well as for inspection and monitoring were below the average. Nevertheless, the overall costs of the Swiss PROs were significantly higher than those of comparable organisations in other European countries, with additional costs amounting to an average of about EUR 200 per tonne of collected electrical and electronic appliances. The main factor causing this huge difference was also ascertained: processing and recycling costs. Where other PROs were able to achieve net returns from processing costs, the Swiss paid high amounts for processing and recycling, as shown in figure 1.

Detailed evaluation of the cost driver "processing and recycling"

A detailed review of the various factors in the category "processing and recycling costs" showed that these costs can be further subdivided into:

- Country-specific costs which the PROs have no or little control over, such as national energy prices and living wage levels
- Costs which can be directly influenced by the PROs, such as through the agreements negotiated with the recycling companies for processing

Figure 2 shows the effect of various factors on the costs and the influence the PROs have over the cost.

Scandinavian ideals

The Swedish and Swiss systems are particularly suitable for comparison due to the countries' similarity in population size, comparable income levels and high collection rates for electrical and electronic appliances as well as well-established PROs. Comparison of the take-back and recycling systems in the two countries shows that up to 81 per cent of the cost differences can be attributed to five key factors:

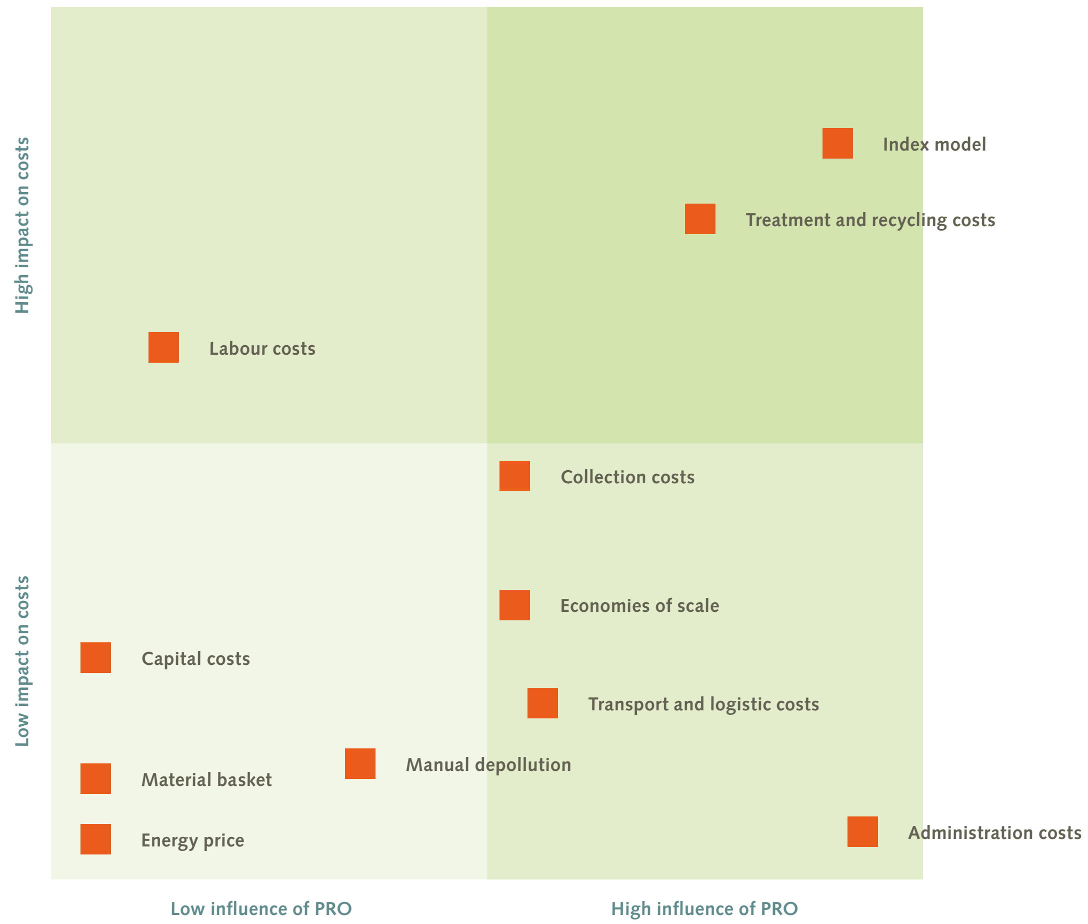
- In Sweden, the collection costs and costs for raising awareness are outsourced and borne by the municipalities, while in Switzerland, the PROs have to pay these costs.
- Furthermore, the Swiss recycling companies are more expensive because of their higher wages and capital and disposal costs. The reason for this are macroeconomic factors in Switzerland.
- In Switzerland, the transport and logistics costs are also higher due to different legal requirements and geographical circumstances.
- With recycling companies in Switzerland, the realisation of raw material value is lower not least because of the higher costs incurred when transporting the materials to the smelting works and reprocessing plants in Europe.
- The design of the material index model for calculating the remuneration of the recycling companies is another reason for the differences in costs.

Possible ways to proceed

When focusing on the cost-intensive factors which can be directly influenced by the PROs, two recommendations can be made to the PROs:

- Handling of the processing costs should be strictly separated from the revenues from material recovery. This would not only lead to greater transparency for the PROs and the recycling companies in terms of costs and revenues, but also make it possible to separate the highly volatile, market-dependent material revenues from the costs for processing and disposal which are independent of the market price.
- A more representative list of materials would be better suited to updating the index formula, including the metals which were previously not listed, as well as other material groups previously not accounted for. The objective here would be to make the sources of revenue and losses of a recycling company more transparent.

Figure 2: Effect and impact matrix



[1] All information on collected volume and costs relate to 2013.

Lithium-ion batteries

Handling lithium batteries

Rolf Widmer

The “LIB in WEEE”[1] work group convened by the three take-back and recycling systems Swico, SENS and Inobat in consultation with ASTRA develops explanations and recommendations for all those involved in the collection and transport of LIB-containing electrical devices, i.e. above all collection points but also traders that take back WEEE and the recycling companies that accept deliveries.

According to current legislation, LIB are hazardous goods and may not be transported unless they meet specific requirements and packaging instructions according to ADR 2015, especially for all LIB-containing WEEE

– which could contain clearly defective LIB (e.g. bloated mobile phones)[2];

– which only contain small LIB (up to 500 g gross mass, up to 20 Wh|100 Wh rated power or 1 g|2 g Li mass per cell|battery)[3];

– which contain large LIB[4].

As for WEEE containing LIB, the device takes over the function of packaging and the WEEE therefore may not be damaged. Furthermore, bulk goods, for example in bulk containers, are not provided for in ADR for WEEE containing LIB, and are therefore inadmissible.

WEEE containing LIB can thus be transported in accordance with SV 636 or SV 377. Both variants have advantages and disadvantages, in particular either “large” (SV 636) or “defective” (SV 377) LIB must be specifically sorted out.

Figure 1: Clearly defective and dangerous LIB in notebooks or mobile phones. Such WEEE must be sorted out.

From this follows that today it is mandatory for WEEE to be sorted at the collection centres or collection points before transport and to be protected and marked appropriately for transport. The “LIB in WEEE” work group recommends that the return systems affected be currently aligned with SV 377 for the collection and transport of small appliances, which requires pre-sorting of WEEE with defective LIB and hazard labels, UN numbers and transport documents for transport of the remaining, possibly LIB-containing WEEE. These WEEE must be transported in small packages, such as pallets and frames, just like screen devices.

These rules require fairly far-reaching and significant adjustments of the current practice across Europe. It is therefore not surprising that ongoing amendment proposals to the ADR rules are being received and forwarded to the respective committees in order to adapt the relevant regulations. In urgent cases, there is the opportunity of multilateral agreements to bring forward amendments so that they can be applied before the next general ADR revision. For example, the SV 636 is currently being revised so that all WEEE containing LIB – not just those with small LIB – can be transported unpacked. This would largely eliminate the need for sorting and labelling WEEE containing LIB.

Figure 2: Existing Inobat collecting box.

Figure 3: The UN-approved collection containers are lifted by harness into and out of the transportation containers.

Figure 4: UN-approved bags (silver) for transporting LIB in the usual INOBAT plastic drums or possibly new steel drums.

The decision for this review was taken in March 2016, and the earliest implementation date of this amendment could occur by multilateral agreement as early as summer 2016; otherwise at the beginning of 2017, together with the next ADR version. As soon as the SV 636 changes come into force, WEEE may be transported this way; however, until then the present rules apply.

Defective LIB (Figure 1) are considered a high risk and must be removed from goods returned. Although the new SV 636 will no longer prescribe rigorous sorting, in accordance with CENELEC 50625, the work group recommends still sorting out clearly defective LIB.

Inobat is currently testing various ways to transport defective LIB in UN-approved containers. The alternatives being considered include:

– Continued use of the existing INOBAT collection boxes (Figure 2). These collection boxes are then packed in an ADR-compliant INOBAT transport container (Figure 3).

– Using UN-approved bags (Figure 4) for LIB transport in the usual INOBAT plastic drums or new steel drums. Loose LIB, but also small WEEE, would be put in these bags where, in case of damage, the same thing happens as in the filler of the transport container: the evaporating electrolyte of outgassing LIB cells drives the oxygen out of the bag, and at the same time as it passes through the fabric, the vapour cools down below the flame temperature and as much vapour as possible is condensed and adsorbed in the fabric.

The completion of the evaluation of the alternatives and the introduction of the containers selected are expected this year.

[1] LIB stands for lithium metal or lithium ion cells and batteries, and WEEE stands for waste electrical and electronic equipment.

[2] SV 376 with P908 or LP 904.

[3] SV 636 with P909.

[4] SV 377 with P909.

Small volume – big impact

Ueli Kasser

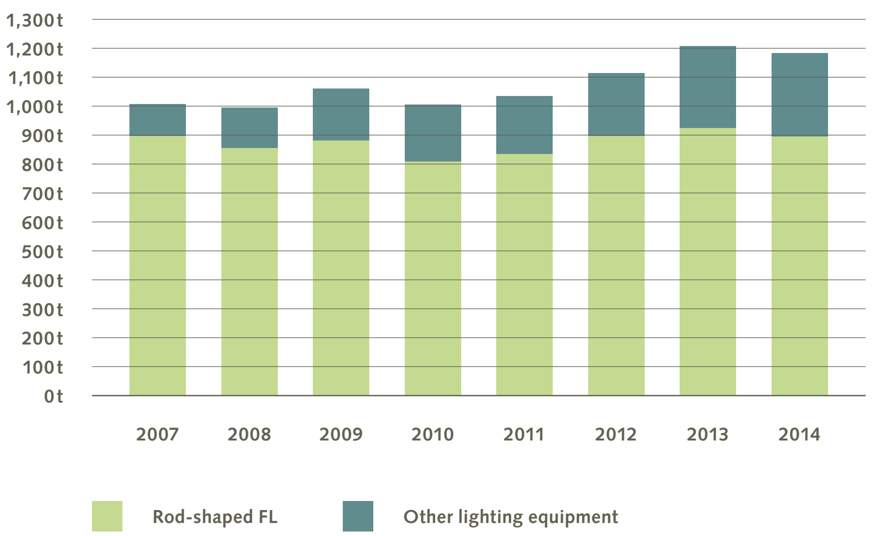
In the autumn of 2006, the advance disposal fee for fluorescent lighting (FL), energy-saving lamps and other gas discharge lamps was introduced. Since then, a total of a little over one kilogram per inhabitant of this toxic waste has been collected and recycled. Time to look back at what has happened with these roughly 10,000 tonnes of waste.

In recent years, the lighting market has undergone many changes. The phasing-out of traditional tungsten light bulbs because of their high energy consumption between 2010 and 2012 led, on the one hand, to a massive increase in energy-saving lamps, a further development of FL based on the mercury vapour discharge technology. However, this proved to be only a temporary solution with the advent of LED technology, which is both more energy-efficient and mercury-free. These developments on the lighting market also have a direct impact on the quantity and quality of the waste.

Significant increase in energy-saving lamps in the waste

Unlike traditional light bulbs, both gas discharge lamps – classified as hazardous waste – as well as LEDs, under the Ordinance on the Return, Taking Back and Disposal of Electrical and Electronic Equipment (ORDEE), must be returned separately, collected and disposed of in a controlled way. The take-back system of the Swiss Lighting Recycling Foundation (SLRS) has been funding the logistics and treatment of lighting equipment with the advance recycling fee since 2007. Figure 1 shows the volume of lighting equipment taken back by the disposal management companies since 2007 The data collection at the recycling companies only distinguishes between rod-shaped and non-rod-shaped lighting equipment. The volume of the classic FL has remained practically unchanged over the past eight years, while the volume of non-rod-shaped lighting equipment has increased from 110 tonnes to 280 tonnes per year.

Figure 1: Volume of lighting equipment taken back by Swiss lighting equipment recycling companies

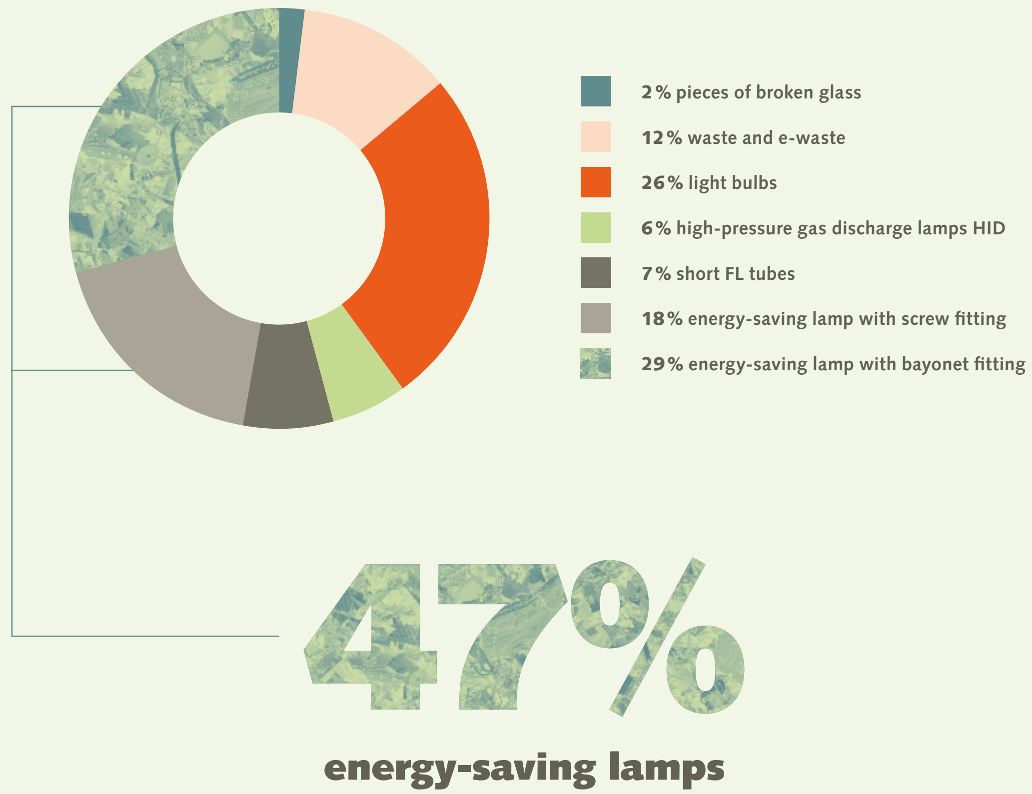


A lot of unfunded waste

The term "non-rod-shaped lighting equipment" refers to various different waste categories (see figure 2). On the one hand, consumers nowadays can no longer distinguish between conventional light bulbs, energy-saving lamps and LED retrofit lamps. On the other hand, there are high-pressure gas discharge lamps from street lighting, projectors and many other special applications among the non-rod-shaped lighting equipment as well as filter cartridges, thermometers and other waste which consumers and the collection points assume to contain mercury. The composition of the non-rod-shaped lighting equipment is known only from one random sample analysis of a Swiss recycler[1].

At that time, about two tonnes of non-rod-shaped lighting equipment were examined as they were delivered from the collection points to the recycler.

Figure 2: Composition of non-rod-shaped lighting equipment waste from a random sample analysis in 2010



The sample was not representative and provides only a blurred image, which since 2010 will probably have changed to a much larger proportion of energy-saving lamps. What is striking is the high percentage of light bulbs and other waste that is not financed through the system. Non-rod-shaped lighting equipment is of no interest to the recycling companies. The effort involved in sorting is considerable, and the added value of secondary raw materials is even smaller than for rod-shaped FL.

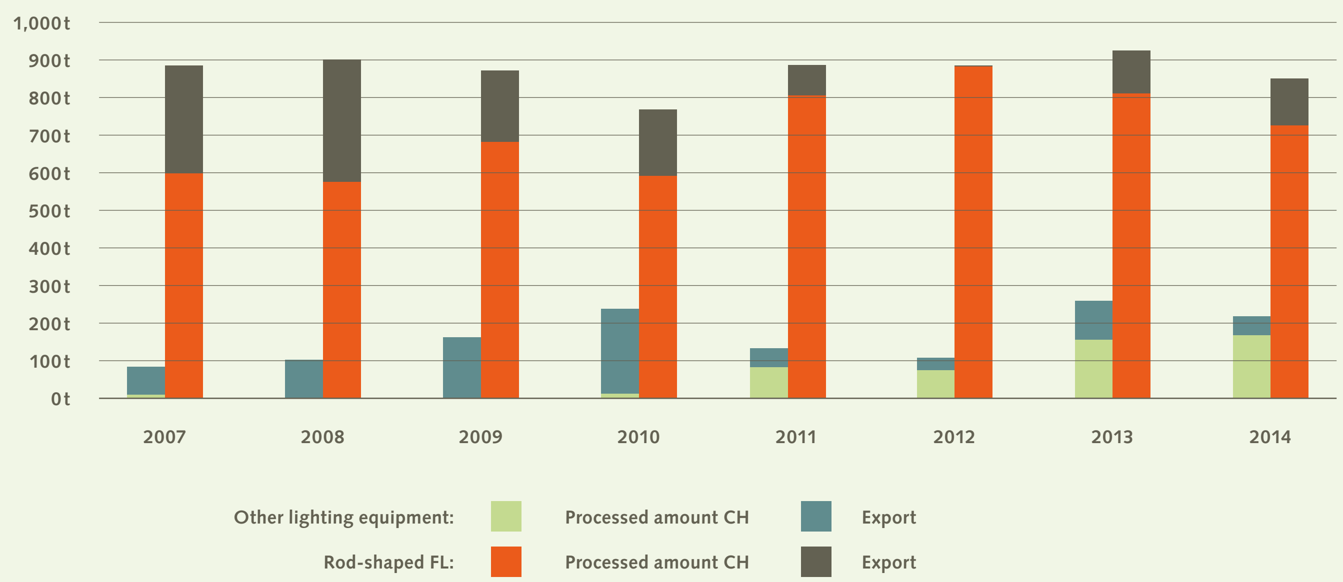
Increase in local processing

Figure 3 shows the volume of lighting equipment that was exported without processing and contrasts this with the volume processed in Switzerland. While between 2007 and 2010 up to 40 per cent of the lighting equipment collected were exported, this percentage declined in 2014 to 15 per cent. This is due to various factors. Until 2011, there was no proven technology for the efficient recycling of energy-saving lamps in Switzerland. In addition, initially, two SENS-licensed recycling companies did not have processing plants in Switzerland and only ensured the logistics for the export of the lighting equipment. Thus, FL, too, were exported to Germany and France, although even then Switzerland already had excess capacity. By 2014, only one company remained that exported all lighting equipment collected in Switzerland to France.

High mercury removal – little material profit

The primary aim in lighting equipment processing is to remove the mercury and permanently isolate the toxic metal from the biosphere. The total amount of mercury retrieved from the approximately 10,000 tonnes of lighting equipment processed in Switzerland since 2007 is around 1 tonne. Of this, about 90 per cent could be removed using state-of-the-art technology[2]. The larger proportion is absorbed in the activated carbon filters of the processing plants and recovered through regeneration or disposed of safely. The remaining part is in the fluorescent powder, which used to be exported and partially distilled to recover the mercury. Since the ban on exporting mercury from the EU and the closure of Dela GmbH in Germany, however, it now mainly ends up as a chemically stable compound in salt mines in Germany or at hazardous-waste sites in France. The preparation of the fluorescent powder for the recovery of rare earths[3] was practised for two years, but will be discontinued by the French operating company this year[4].

Figure 3: Unprocessed exported lighting equipment compared to the volume processed in Switzerland



From lamps to insulation

The glass group obtained from the lighting equipment processing across the entire material flow is about 80 per cent. Previously, a significant proportion of the glass was fed back again into the production of new lighting equipment. By ousting the end cap separation procedure and relocating lighting equipment manufacture to Asia, this closed-loop recycling has all but disappeared. The largest amount now goes into the production of glass wool for insulation. All other recipients – most of them abroad – use the broken glass from lighting equipment for industrial glass applications (e.g. ceramics). The metal groups that can be recycled directly account for about five per cent of the material flow. These enter the scrap metal cycle, with a focus on compliance with the mercury limit values. Thus, used lighting equipment represents a quantitatively insignificant waste stream, where separating and isolating of the mercury is paramount.

LEDs in the distant future

It makes no sense to recycle LEDs in technological systems designed for mercury removal. For the time being, these new kinds of waste are sorted out by the recycling companies and stored separately. According to insiders, about 15 tonnes of LED waste has accumulated in Switzerland this way in the past few years. Removing harmful substances is unnecessary according to most experts, and – given the small volume of toxic substances possibly present – would be disproportionate. Consequently, treatment will probably amount to recovering the rare metals on the valuable circuit boards of retrofit LED lighting equipment[5]. LEDs without integrated electronics will probably be burned.

[1] Nicht stabförmige Leuchtmittel – ein bunter Haufen; 2010 Technical Report of SENS, Zurich 2011, page 20.

[2] E. Hug, N. Renner; Erhebung von Quecksilberkonzentrationen in Fraktionen der Leuchtmittelverarbeitung unter Berücksichtigung von Aspekten zur Probenahme und Analytik; SENS/SLRS, 26 May 2010.

[3] U. Kasser, P. Wäger; Vom Sondermüll zur Rohstoffquelle – ein weiterer Kreislauf wird geschlossen; 2014 Technical Report of SENS/Swico/SLRS, Zurich 2014.

[4] Officially unconfirmed information by staff of Solvay Aroma Performance, February 2016.

[5] LEDs with screw base and integrated electronics.

Condensers containing PCB

How hazardous are condensers?

Daniel Savi

Condensers may contain polychlorinated biphenyls (PCB) if they are older than about 30 years. Since the general ban on PCB in 1986, it has become increasingly important to know how many condensers in today's returns still contain PCB. In future, the question that will have to be answered is whether newer condensers contain liquids that are hazardous to the environment or health in such amounts that further non-destructive removal is required.

Which condensers contain PCB?

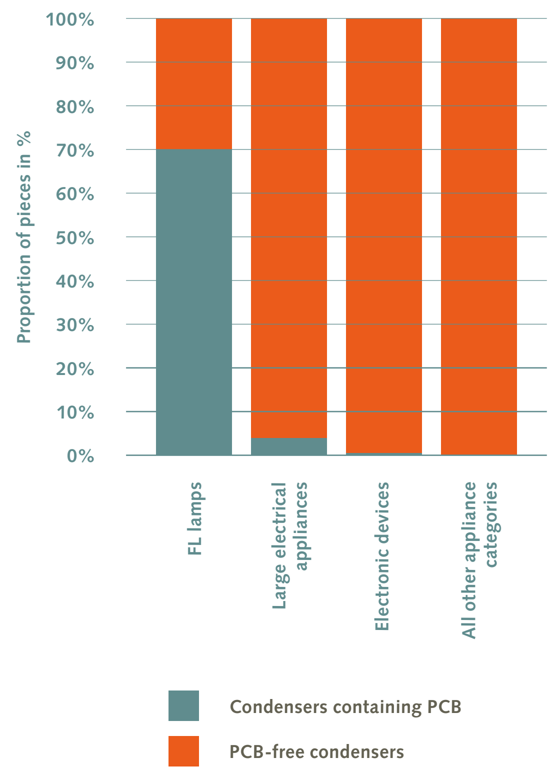
Condensers containing PCB are primarily metal-paper condensers that have been impregnated with PCB. After the ban on PCB in 1986, there were still leftovers of PCB used in the production of condensers, so that only from 1990 onwards could it be safely assumed that condensers from all key manufacturers were PCB-free. PCB are very stable in the environment and extremely toxic to fish. Since they are highly fat-soluble, they are concentrated in the food chain. PCB can lead to chronic diseases, especially liver cancer. Disposal management thus has to be organised in such a way as not to allow any loss of PCB as far as possible. According to the Chemical Risk Reduction Ordinance (ORRChem), condensers are considered as containing hazardous substances if they contain oils with more than 50 ppm PCB. The ban in the ORRChem refers not only to PCB but to all polyhalogenated aromatic substances. Consequently, a mixture of appliance condensers can be considered as PCB-free if the oil mixture of these condensers contains less than 50 ppm PCB. But how many condensers may still contain PCB for this condition to be met? Assuming that the oil is present as a pure PCB mixture in a condenser containing PCB, this question can be answered. Even one condenser containing PCB among 20,000 suffices for the oil mixture of all condensers to contain 50 ppm PCB. An extrapolation to cover the whole of Switzerland illustrates the magnitude of this requirement. Each year, Swiss recycling companies remove about 1.2 million condensers from electrical and electronic appliances. Of these, only 60 could contain PCB for the entire oil mixture of all condensers to contain less than 50 ppm PCB.

Figure 1: Mixed condensers from discarded electrical and electronic appliances.

How long will there still be condensers containing PCB?

It will still take some time before the number of condensers containing PCB drops to a level where removal becomes unnecessary. The few studies available show a decrease in condensers containing PCB in large household appliances, dropping from 8 per cent in 1994 to 4 per cent in 2008 and 0.4 per cent in 2013. Around 70 per cent of ballast units in fluorescent lighting both in 1994 as well as 2009 had condensers containing PCB. Small electrical appliances contained about 0.1 per cent of condensers containing PCB in 2008, and in 2013 about 0.4 per cent (Eugster et al., 2008; Gasser, 2009; Groen, 2013; Müller, 1994). Current figures are now extremely low but still above the one appliance per 20,000 units (0.005 per cent) which would need to be achieved to comply with the 50 ppm requirement. To forecast when this very low percentage of condensers containing PCB will be reached is very difficult due to the scarce data available. Nearly ten years after the last survey in Switzerland, the current situation needs to be re-examined. The combination of knowledge from experience and an analytical assessment of the components allows for a large number of condensers to be classified with reasonable effort regarding their PCB content.

Figure 2: Estimated proportion of condensers containing PCB > 2.5 cm according to appliance category (source: studies by SENS, Swico and SLRS in 2008 and 2009)



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Do PCB-free condensers contain any potentially harmful substances?

PCB-free condensers are not free of hazardous substances per se. According to the SENS and Swico technical regulations, even "electrolyte condensers containing potentially harmful substances (height > 25 mm, diameter > 25 mm or proportionately similar volume)" must be removed from waste equipment. Electrolyte condensers (elcos) are polarised condensers whose negative electrode consists of an electrically conductive liquid electrolyte. Non-polarised condensers can also contain liquid impregnations. To ensure an environmentally sound disposal, these liquids must be examined for any potentially harmful substances. The term "harmful substances" has not yet been precisely defined. In recycling practice, however, only substances can be referred to which are of particular concern in comparison to other substances in electrical and electronic equipment. For future technical regulations, a definition of this term must be found by TK-SENS Swico. Possible interpretations could be based on the Hazardous Substances Identification System and its H phrases, water toxicity or stability in the environment and fat solubility, etc.

In electrolyte condensers, the wet aluminium elcos are far more prevalent. According to the literature (Hering et al., 2014), electrolytes may be used in current aluminium elcos that could affect unborn children and be harmful on contact with skin or when inhaled. Condensers for power electronics are used wherever voltage peaks may occur. In electrical and electronic appliances, these include washing machines, dishwashers, photocopiers and microwave ovens. A possible design for such power condensers are MKV condensers. These condensers are composed of a two-sided paper vaporised with a metallic layer and an intermediate plastic film. The paper is impregnated with oil. From the PCB study carried out by Swiss take-back systems, we already know a number of possible ingredients of these oils. Among them are substances which may cause harm to unborn children or may be carcinogenic and very toxic to water.

It needs to be determined which substances qualify as "potentially harmful substances" that require special disposal treatment, and which categories correspond to the usual hazards when handling electronic waste. It is still too early to make a statement about what disposal practices will look like when there are no longer any PCB condensers. However, it is now time to lay down the necessary foundations for future decisions.

Photovoltaic module recycling

The problem with hazardous components

Ueli Kasser

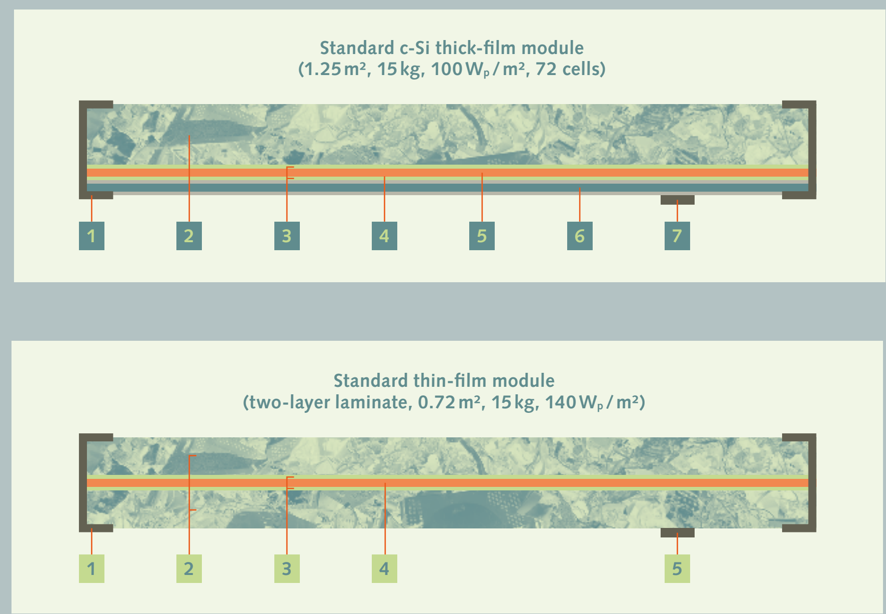
Generating power with solar cells is one of the most promising future technologies that will be promoted increasingly. Thus, it is surprising that there has been comparatively little research on and investment in the recycling of photovoltaic (PV) modules. Recycling is rendered particularly difficult by the fact that not all PV modules are free of hazardous components.

In Switzerland, recycling of PV modules was launched at the beginning of 2015 and is based on similar principles to those for other electronic waste. It is handled by the SENS OnlineSystem, with the technical requirements laid down by the European standard [1] and the logistics in Switzerland assured by two companies [2]. The volume is still insignificant, amounting to less than 50 tonnes last year. According to official forecasts, significant quantities are only to be expected in the medium term. Across Europe, around 20,000 tonnes of old PV modules are predicted for 2025 [3], while a total of around 7,500 tonnes of old PV modules was collected and processed in Europe during the seven years from 2010 to 2016 [4]. That equals less than one-tenth of one per cent of the total amount of e-waste. Despite this small volume, it is necessary to face the challenges associated with recycling.

Glass and hazardous substances

In terms of volume, the most important material in PV modules is plate glass, accounting for 60 to 75 per cent of the weight. The glass is essentially identical to window glass, the only difference being that antimony is added to the glass for PV modules as a clarifying agent additive. Standard designs of thick- and thin-film PV modules are shown in figure 1. The most valuable component in terms of present economic conditions is the aluminium frame, which accounts for about 20 to 25 per cent of the weight. However, the actual functional layer of films, semiconductors and the connection box with the electrical conductors contribute only little to the weight. The sandwich construction consisting of plastic films and glass complicates recycling. Separability is a challenge, similar to that with laminated safety glass from the construction or automotive industries.

Figure 1: Standard designs of thick- and thin-film PV modules



Thick-film module

1. Aluminium module frame, 20 %–25 %
2. Plate glass, 3-4 mm, 60 %-65 %
3. EVA film, 2 × 300 μm, 6,5 %–8,0 %
4. Conductor metals, 1 %
5. Silicon wafer semiconductor 300 μm, 4 %–5 %
6. Film on the back PET/PVF, 200 μm, 2,0 %–2,7 %
7. Socket, 0,8 %–1,4 %

Thin-film module

1. Aluminium module frame, 20 %
2. Plate glass, 2 × 3 mm, 75 %
3. EVA, PVB; PU, PE film 200–300 μm, 3 %–4 %
4. Thin-film semiconductor a-Si, Cd, In, Se, S, 3–8 μm, appr. 0,1 %
5. Socket, 0,8 %–1,4 %

Thick and thin

In order to carry out a risk assessment of PV modules, two systems must be differentiated by classifying them according to the thickness of the photoactive semiconductor layer (see figure 2). The terms “thick- and thin-film” are, admittedly, slightly confusing. They refer only to the semiconductor layer but not to the thickness of the entire module. Thick-film modules are composed of monocrystalline or polycrystalline silicon semiconductors, which can be identified by the typical wafer structure (see figure 3). The semiconductor layer consisting of pure silicon of about 300 to 400 micrometres (µm)[5] in thickness does not contain any hazardous substances. However, metallic copper and lead may be present from the conductors and solder joints, as is almost always the case in electrical and electronic devices. The PV modules with silicon-based cells are identified in Switzerland by the Waste Movements Ordinance (VeVA) code 16 02 16, “Without hazardous components”. Anyone who is able to distinguish thick-film solar cells from thin-film solar cells can be sure that it is only waste “Without hazardous components” in accordance with VeVA.

Not as clean as their image

The situation is different for thin-film modules. Thin-film modules containing the semiconductor types CdTe and CI(G)S must be marked as waste with hazardous components, i.e. with the [ak] code 16 02 97. The abbreviations stand for the chemical elements cadmium, tellurium, copper, indium, gallium and selenium. Their compounds are sometimes very toxic. Cadmium is prohibited in most applications[6]. The contents in thin-film modules are relatively high. In the literature, the content of cadmium is given as 500 ppm and of selenium as 100 ppm in relation to the entire module[7]. However, not all thin-film modules contain hazardous components. The modules based on amorphous silicon semiconductors (a-Si) are “Free of hazardous substances” according to the nomenclature of VeVA (see figure 2).

Recognising module types with hazardous substances via a network

While thick- and thin-film modules differ visually, a visual distinction within the thin-film module type between a-Si semiconductor modules and CdTe or CI(G)S modules is impossible, which complicates a clear separation into the two waste categories according to VeVA. This separation represents an important task for the Swiss recycling companies of PV modules as it determines to which foreign country a particular module type will be sent for recycling. The recycling company must identify modules with or without hazardous components based on the Photovoltaikforum module database[8]. This database lists about 86,000 types of modules by some 1,500 manufacturers worldwide. Of these, approximately 60,000 are no longer commercially available, yet still relevant for waste classification. For each type, the semiconductor material utilised is shown, so that a definite classification can be carried out. Besides, said classification is facilitated by the fact that PV modules of the same type generally accumulate in a large quantity.

Every sixth module type is [ak] waste

According to PV Cycle, the European organisation responsible for coordinating the national take-back systems, approximately 17 per cent of modules containing hazardous substances and about 81 per cent of silicon-based modules have been taken back and processed[9] between 2010 and 2016. However, according to the latest reports, the CI(G)S thin-film technology is becoming more important in the market[10]. The silicon-based modules that accumulate in Switzerland are processed by two plate glass recycling companies in Germany, which only utilise the separable plate glass and aluminium frame. The high-quality semiconductors are not recycled, although the high-purity monocrystalline or polycrystalline silicon could, in principle, be recovered[11]. Economic considerations currently offer little incentive to invest in recycling facilities that go beyond pilot scale. At the moment, the pure silicon crystals mainly end up in broken glass, which is then used in smelting plants, where the silicon does not interfere but is effectively worthless.

What to do with thin-film cells with hazardous substances?

Similar to flat-screen displays, several disposal issues are still unresolved for the CdTe and CI(G)S thin-film modules. Technologies are required that predominantly separate and isolate the toxic substances cadmium and selenium. Manufacturers in Germany, who, by law, are responsible for the disposal, are said to have already developed pilot plants for this purpose. However, there is still little knowledge in the industry about these technologies. Action must be taken over the next few years, as a number of CI(G)S waste modules has already been returned to a recycling company in Switzerland. For the time being, they are simply stored separately. The disposal of PV modules currently mainly consists of separating modules containing hazardous substances from those that do not, then storing the former and sending the latter to the plate glass recycling companies abroad.

Figure 2: PV module types and their potentially hazardous substances

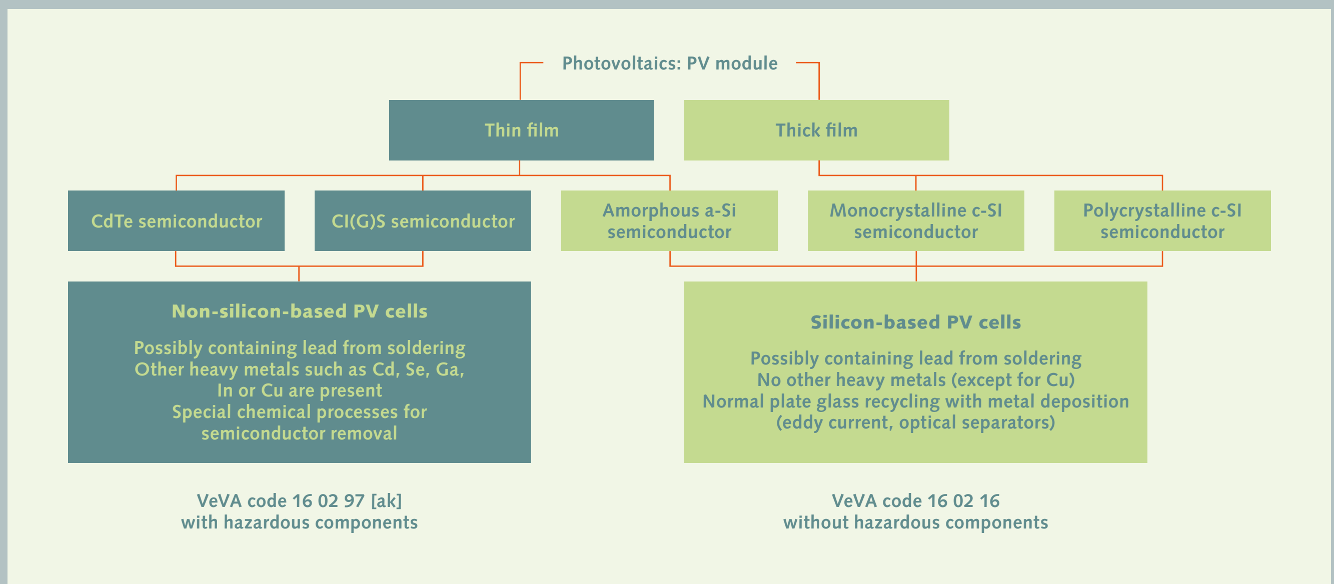


Figure 3: Visual distinction between thick- and thin-film PV modules is possible

Thin-film PV module.

Thick-film PV module.

[1] The EN 50625-2-4 “Treatment Requirements for Photovoltaic Panels” standard and the corresponding TS 50625-3-5 technical specification are at consultation stage within the national standard commissions.

[2] KWB Planreal in 9443 Widnau, Switzerland, and Glasverbund Zukunft (GVZ) in 6252 Dagmersellen, Switzerland.

[3] Recycling von PV-Modulen; Hintergrundpapier zum Round Table 2013; green jobs (ed.), Vienna, Austria, undated.

[4] Operational Status Report Europe – 01/2016; PV Cycle, www.pvcycle.org, 12 February 2016.

[5] This corresponds to 0.3 millimetres.

[6] Cadmium in PV modules in accordance with applicable regulations in Switzerland (ORRChem) and in Europe (RoHS Directive) is exempted from the ban.

[7] E.g. Studie zur Entwicklung eines Rücknahme- und Verwertungssystem für photovoltaische Produkte; Sander, K. et al., ökopol, Hamburg, November 2007.

[8] www.photovoltaikforum.com

[9] Operational Status Report Europe – 01/2016; PV Cycle, www.pvcycle.org, 12 February 2016.

[10] According to the report of the Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW) 2016, elmholtz-Zentrum Berlin, on solar-media.blogspot.ch, 26 January 2016.

[11] Tao, J.,Yu, S.; Review on feasible recycling pathways and technologies of solar photovoltaic modules; Solar Energy Materials & Solar Cells 141 (2015), 108–124.

Batch tests: Is a performance comparison possible?

Heinz Böni, Roger Gnos, Patrick Wäger & Rolf Widmer

With the objective of evaluating compliance with the recycling and recovery quotas specified in the Swico and SENS eRecycling technical regulations, regular batch experiments are conducted at the processing partners of Swico and SENS. To achieve better comparison, batch testing was carried out at Swico with a predetermined input amount in 2015. The aim is to find out how the quotas achieved by the various companies during recycling differ and to clarify whether a performance comparison is possible.

The demand on the input material of a batch test (test batch processing according to CENELEC 50625-1) is to process a representative amount of devices at goods-in. Due to the different compositions of the input at the various recycling companies, the results of these tests, however, are not fully comparable. Repeatedly, the poor quality of the material batch was given as a reason by the recycling partners for only just achieving the quota.

Since the introduction of the market basket analysis 2.0 (see Technical Report 2015), Swico has now been able to determine the composition of the market basket in detail. Thus groups, devices, components and even the condition of the devices (e.g. with/without the cable or battery) can now be recorded. The flow of goods can be directly assessed either at the collection point, at the recycling company or even customised (e.g. by manufacturer, product type, age, etc.). These analytical options permit tailoring the input of a batch test close to reality and thus carrying out closely equivalent batch test at the various processing partners (cf. “test batch processing” according to CENELEC 50625-1).

Input composition and processed quantities

In 2015, Swico, together with Empa, launched a pioneering project in Europe: the implementation of a batch test with customised input quantities. The mixture of different information and communication technology device types (Category 3 according to the WEEE Directive) as well as consumer electronics (Category 4, without photovoltaics) was defined so as to correspond roughly to the average composition of the material flow in the Swico system, whereby monitors are not included, since these are processed in a separate recycling channel. The resulting composition is shown in Table 1.

Recycling and recovery rates

In Switzerland, the existing legal requirements of the Ordinance on the Return, Taking Back and Disposal of Electrical and Electronic Equipment (ORDEE) of 14 January 1998 do not require minimum recycling and recovery rates. In the discussion paper for the revised ORDEE, no minimum quotas are given either. This is in contrast to its counterpart at European level, the WEEE Directive[1], which already provided such minimum quotas in its initial version of 2003.

The processing requirements of Swico and SENS have called for minimum recycling and recovery quotas since 2008. The recycling quota specifies the proportion of the material – relative to the total amount of devices processed – which is re-utilised (recycling), while, in addition, the recovery quota takes into account the portion which is thermally processed. According to the current version of the Swico and SENS Technical Regulations, a recycling quota (RQ) of 65 per cent and a recovery quota (VQ) of 75 per cent for Category 3 (IT and telecommunications equipment) and Category 4 (consumer electronics) must be achieved. These minimum quotas apply even if no monitors are currently included among the devices.

Since 15 August 2015, in accordance with the European WEEE Directive, stricter requirements apply. The minimum quotas were increased by 5 per cent so that the minimum quotas for Categories 3 and 4 now are 70 per cent for recycling and 80 per cent for recovery, respectively. Swico and SENS have not yet introduced the tougher quotas, so the previously existing minimum quotas still apply.

Table 1: Conditioning of the batch

Device types	Specification in t and %		Max. deviation *
PCs/servers	2,850	23.9 %	2.9 %
Printers	2,570	21.6 %	2.5 %
Radios	2,000	16.8 %	0.5 %
Boxes/loudspeakers	1,470	12.3 %	0.5 %
Landline telephones	750	6.3 %	5.3 %
Keyboards	630	5.3 %	0.7 %
Notebooks, laptops, PowerBooks	600	5.0 %	1.6 %
Switches	450	3.8 %	0.1 %
Routers/modems	300	2.5 %	0.1 %
Amplifiers	300	2.5 %	0.1 %
Total	**11,920**	**100%**	

* Maximum deviation from the specification for the respective device types (only five of six companies taken into account).

Implementation

For the assessment of the roughly 12 tonnes of input material, the material was composed over a period of about three weeks together with two employees from the appropriate disposal area of the recycling company. Subsequently, the waste electronic equipment was handed over to the respective recycling company. The recycling companies first had to dismantle the devices as in normal operation and then process a part of them mechanically. Empa was present for some of the initial dismantling and for the whole of the mechanical process. In each case, the entire processing procedure was mapped in a detailed process flow chart according to CENELEC 50625-1, Annex C. All internal and external material flows were recorded; at some recycling companies up to 50 fractions were identified. Of the total input amount, up to approximately 40 per cent was manually dismantled and did not undergo mechanical processing.

The experimental data was transferred to the RepTool[2] reporting tool developed by the European WEEE Forum for the evaluation of the RQs and VQs. With this tool, each fraction is assigned a processing procedure, which creates new fractions, which in turn are processed in other procedures. This process chain continues until all fractions have been recycled or disposed of. This also applies to the further processing by secondary purchasers, in particular to the treatment of mixed fractions for recovery of metals and plastics. Thus, it is vital to know how the external processes run and what quotas are achieved there. This information comes either from recycling investigations at the recycling company or the secondary purchaser, from material flow evidence, in which the purchaser declares the process and fractions, or, for known processes, from literature.

Batteries and capacitors

In addition to capturing the individual material flows, all batteries and capacitors removed were collected. For the battery mixture, the aim is to determine the mass fraction of the lithium batteries and their energy content and condition. For the capacitor mixture, analyses of the ingredients need to be carried out if required, in particular of the electrolytes. Furthermore, samples of the fine fraction (dust and ASR) were taken at the recycling companies. These were examined for PCB, copper, mercury and cadmium, allowing conclusions to be drawn regarding the removal of hazardous substances.

Results and outlook

The individual results are made accessible in the form of a report to the recycling companies but otherwise remain confidential. The detailed results will enable the recycling company to determine where it still has room for improvement and where it lies in comparison to other recycling companies. For the system operator Swico, it is important to know whether there are big differences between the individual recycling companies and whether the companies can meet the stringent regulations that apply in Europe.

Since not all the tests could be completed in 2015, the full results of the project are not yet available.

The cost of batch tests with conditioned input material are very high. It will thus hardly be possible to carry out annual compulsory tests in this way. However, it may be possible to repeat such tests every three to five years, in order to detect at least some trends in the comparable data.

Figure 1: Selection of fractions from manual pre-sorting.

[1] Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE).

[2] www.wf-reptool.org

Refrigerators (reporting period 2015)

Geri Hug & Niklaus Renner

Although no refrigerators are produced in Europe any more whose compressors or insulating foams contain climate-damaging chlorofluorocarbons, a large number of such devices are still sent for dismantling at the end of their service life. In 2015, 360,000 refrigerators or 18,000 tonnes of material were recycled by the four highly specialised Swiss recycling companies, which represents a further increase of four per cent. Around 40 per cent of these appliances are still of the old CFC/HCFC type. However, the proportion of the more environmentally friendly HC devices is steadily increasing.

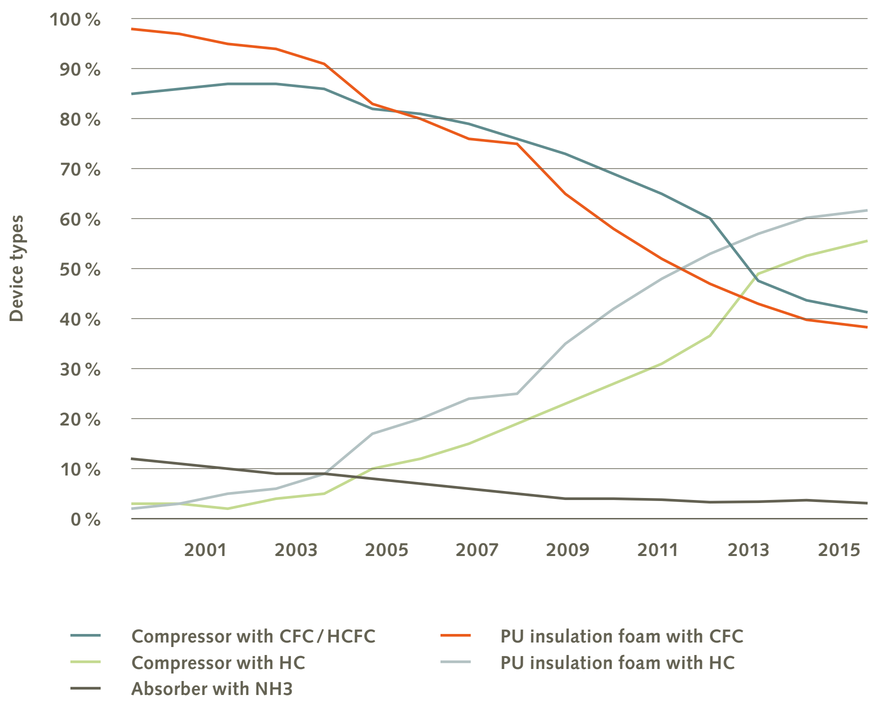


Figure 1: Development of the device types processed at stage 1 (CFC- / HCFC- and HC-containing compressors, ammonia-containing absorption systems) and stage 2 (CFC- and HC-containing PU insulation foam).

HC devices continue to gain ground

In 2015, too, the trend shifted further towards HC-driven compressors: in 2015, already 56 per cent (increase of six per cent compared to last year) of the appliances processed at stage 1 had HC compressors (solid red line in figure 1). Ammonia-containing absorption systems accounted for three per cent of all devices.

For the insulation foams, the survey data shows a similar trend. This became visible here even earlier, because the substitution of R11 by cyclopentane proceeded directly (without the halfway station of partially halogenated CFC as in the case of refrigerants). Currently, the insulation of 62 per cent of the refrigerators entering recycling is made of cyclopentane-foamed polyurethane (PU), so that the increase compared to the previous year too was in the predicted range (increase of two per cent).

As the input, so the output

Despite the continuing high quality of recycling plants, the amounts of recovered refrigerants and propellants is decreasing as more and more HC devices enter the dismantling process. Their compressor-filling quantities or concentration in the PU foam are well below half of that of CFC devices, which is why the absolute recovery quantities (but not the recovery rates) are declining.

Whereas in 2010, 99 grams of refrigerant could be extracted from each compressor at stage 1, last year it was 81 grams, and in the current survey period only 79 grams. Thus, the amount has fallen by 20 per cent since 2010. The amount of oil in 2010 amounted to 217 grams but decreased by 2014 to 186 grams. In 2015, it was 189 grams (–13 per cent compared to 2010). Since a decrease in the compressor oil could also be observed, it seems reasonable to conclude that on the input side, too, lower amounts of oil were used in the more modern appliances.

At stage 2, amounts of around 90 grams per kilogram of PU were still recovered around the turn of the millennium, since when this figure has dropped continuously. In 2014, the amount was 55 grams, while in the current survey year this value had hardly changed at 54 grams (see figure 2). The data is consistent with the moderate decline in the number of CFC housings and the aforementioned decrease in the specific weight of propellant recovered as a mixture of CFC, HCFC and HC.

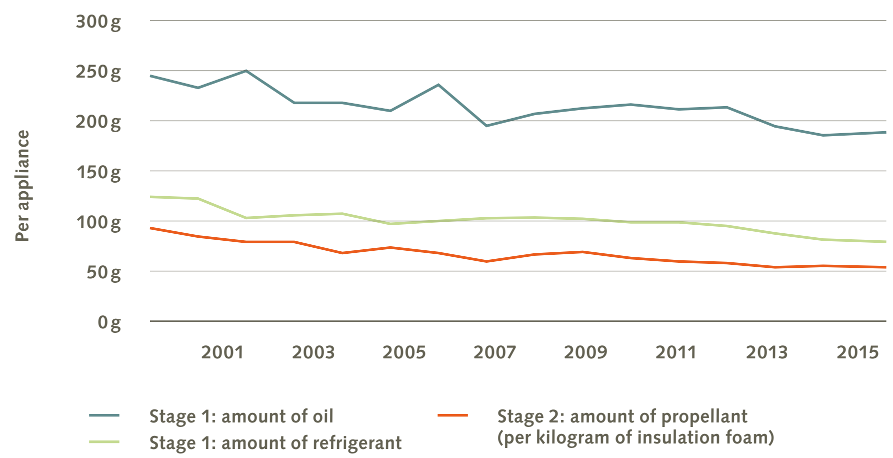


Figure 2: Development of recovery rates at stage 1 (grams of refrigerant, and oil, per appliance) and stage 2 (grams of propellant per kilogram insulation foam).

Recovery of CFC resulted in large CO_2 savings

The ambitious goal defined in the SENS specifications of 90 per cent recovery of refrigerants and propellants is doubly relevant in terms of environmental protection: on the one hand, the CFC contained in compressors and PU insulation foams must be removed from the waste because of their ozone depletion potential (ODP), while on the other hand these substances have a global warming potential (GWP) which exceeds that of CO_2 by one to ten thousand times (see table 1). For this reason, the recovery and subsequent controlled destruction of refrigerants and propellants (and their transformation into carbon dioxide, which is far less damaging to the climate, or dissolving in water as acids or salts) is an important contribution to environmental protection.

Substance	Ozone depletion potential (ODP) R11 equivalents	Global warming potential (GWP) with a time frame of 100 years CO_2 equivalents
Refrigerant (stage 1)		
CFC-12 (R12)	1	10,900
CFC-134a (R134a)		1,430
Isobutane (R600a)		3
Propellant (stage 2)		
CFC-11 (R11)	1	4,750
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 (2007).

Through controlled recovery of the respective substances at stage 1 (refrigerants) and stage 2 (propellants), the quantity of permanent climate-changing gases that the atmosphere was spared amounted to around 390,000 tonnes of CO_2 equivalents in the current survey year. This considerable amount is equivalent to a cube with a side length of approximately 600 metres consisting entirely of CO_2 (see figure 3). The side length of the cube would be over 4.5 times the height of the Zurich Prime Tower.

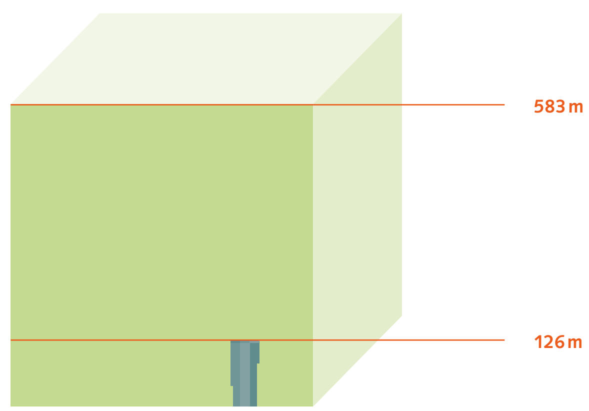


Figure 3: The equivalent amount of CO_2 saved through the controlled dismantling of refrigerators in 2015, represented as a cube of CO_2 (under normal conditions) – compared to the Zurich Prime Tower.

Cathode ray tubes

Future disposal of CRT devices in Switzerland

Rolf Widmer

Cathode ray tubes (CRTs), once widely used in TV sets and PC monitors, have in recent years been replaced by new flat-panel screen technologies such as liquid crystal displays. Thus, the demand for screen glass for the production of new cathode ray tubes has collapsed and closed-loop recycling from cathode ray tube to cathode ray tube is thus no longer possible. Therefore, alternative options are required for recycling them into other products (open-loop recycling) as well as for their environmentally friendly disposal.

In terms of weight, the cathode ray tube accounts for up to about 85 per cent of the mass of the monitor. It consists of about 65 per cent panel or front glass (a barium strontium glass), 30 per cent funnel or cone glass and 5 per cent necked glass (both lead glass). The open-loop recycling of front glass in products such as bottles (hollow container glass) is state of the art; therefore, no alternative applications were tested for lead-free front glass in the present study. By contrast, open-loop recycling of cone glass and necked glass is difficult due to its high lead content, as lead is undesirable in most glass applications. In the study, eight open-loop recycling and three removal alternatives for cone glass and necked glass were evaluated with regard to technical, health-related, environmental and economic criteria. In addition, the annual demand for CRT lead glass was estimated for each of these recycling options and compared with literature values for the worldwide discarded CRT monitors. All evaluated options could use CRT lead glass, without affecting the technical characteristics of the products. Four of the eight open-loop recycling options, however, would use lead glass in products for which lead is not necessary and released lead in leaching tests. Moreover, it appears that because of the wide spatial distribution of the products, for example lead glass as a sand replacement in concrete, the lead in these products would be irretrievably lost.

Based on the comparison of the various options, three appropriate recycling options were found: i) extraction of (metallic) lead from CRT lead glass for further use, for example in lead-acid batteries; ii) the use of lead glass as quartz flux in copper and lead smelters; and iii) the use of lead glass for glazing (vitrification) of waste. All three removal options are suitable, while limited interim storage time received the best assessment.

Above: The Brownian cathode ray tube from 1900 (http://www.crtsite.com/big/crt/braun%20tube-big.jpg); below: a CRT monitor storage place in Cape Town, South Africa (Empa 2006).

In Switzerland, the stock of screen glass reached its high of about 120,000 tonnes in 2000, with a maximum flow into recycling of about 11,500 tonnes in 2012. According to information from the recycling companies, the wide-ranging recovery options for cathode ray tubes, which still existed in 2008, were reduced mainly to a single foreign buyer for impure, mixed CRT glass shards by the end of 2015. This poses a considerable risk, especially since other known customers for Swiss CRT glass were forced out of business recently due to bankruptcy. From 2016, according to the model calculations, there are still some 30,000 tonnes of CRT glass (or about 10,000 tonnes of lead glass) in store, which, after 2020, will have been reduced at a rate of under 2,000 tonnes per year by 2025.

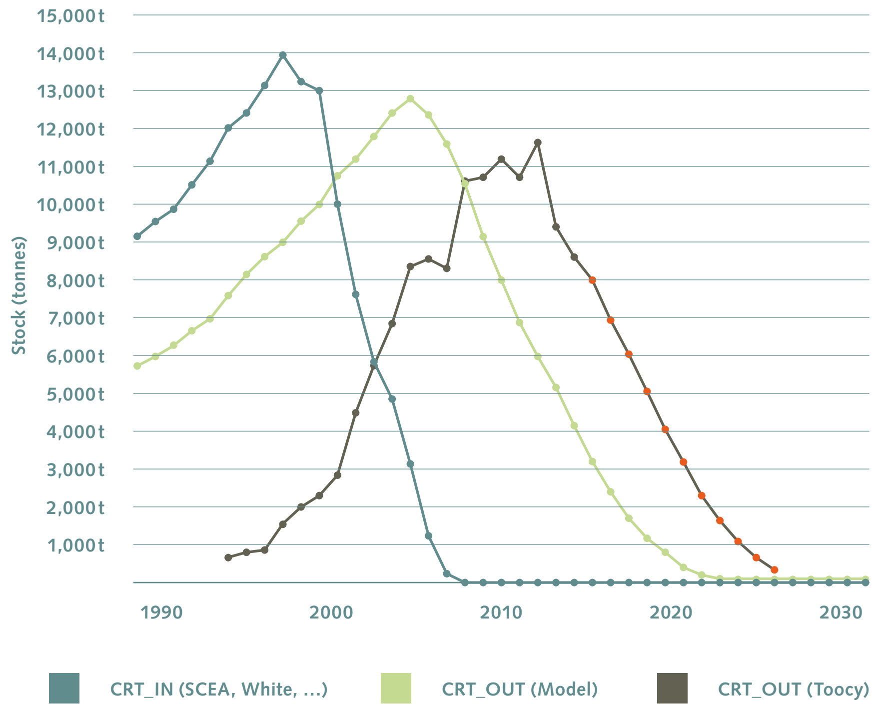
To handle these substantial amounts in an emergency requires an alternative solution, such as cleaning and interim storage of the shards in Switzerland.

The introduction of the European CENELEC standard EN 50625 requires changes to the current practice of CRT screen disposal in Switzerland:

- Handling of intact CRT devices must not result in any damage to the glass bulb. The necessary measures have to be documented.
- The release of hazardous substances (phosphorous and lead glass dust) must be prevented and explicitly documented.
- The effective separation of the tube from the monitor or of the lead glass and the light-emitting layer from the lead-free glass must be documented according to TS 50625-3-3.
- Broken CRT glass contaminated with phosphorous and glass dust must be considered as hazardous waste [S], classified accordingly and treated (this point is still to be agreed with the FOEN).

For the upcoming years, but especially for the development of state-of-the-art disposal within the ORDEE revision of the FOEN, the processing of CRTs must still be taken into account.

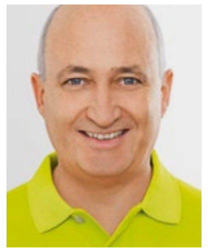
Figure 2: CH – CRT glass: stock and flows



Model and measurement data of Swiss CRT glass flows in tonnes per year. Data for the return "CRT_OUT (Toocy)" was collected up to 2014, from 2015 (•) onwards it was estimated. Data for "CRT_IN (SCEA, White, …)" concerns sales figures from 1995 (TVs) and from 1985 (PCs). "CRT_OUT (Model)" shows the return already simulated in 2006. The simulation used a Gaussian distributed market retention of CRTs to their final disposal ($\mu = 10$; $\sigma = 3$ for TVs, and $\mu = 7$; $\sigma = 1.5$ for PCs). The real return is delayed by around five years, and the mean retention time for TVs has been calibrated to 15 years ($\mu = 15$).

Authors

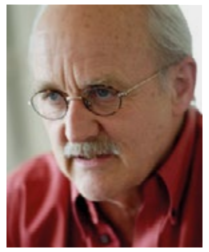
Heinz Böni
After graduating as a Rural Engineer at ETH Zurich and completing a postgraduate degree in Sanitary Engineering and Water Protection (NDS /EAWAG), Heinz Böni worked as a researcher at EAWAG Dübendorf. After working as project manager at the ORL Institute of ETH Zurich and at UNICEF in Nepal, Heinz Böni was appointed to manage the branch office of the engineering company Büro für Kies+Abfall AG in St. Gallen. He then spent several years as co-owner and managing director of Ecopartner GmbH in St. Gallen. Since 2001 he has been at Empa, where he heads the CARE group (Critical Materials and Resource Efficiency) and ad interim the Technology and Society Lab. He has been Head of the Conformity Assessment body of Swico Recycling since 2009 and an auditor for Swico and the SENS Foundation since 2007.



Roman Eppenberger
Roman Eppenberger graduated as an Electrical Engineer (dipl. El.-Ing.) at ETH Zurich. In tandem with his professional career, he completed the postgraduate Executive MBA at the East Switzerland University of Applied Sciences. He gained his first industrial experience as an engineer and project manager in the area of robotics in the fields of medicine and pharmacy. As a product manager, he joined the contactless division of the Legic company (Kaba), where he was responsible for global purchasing of semiconductor products. Since 2012 Roman Eppenberger has been employed by the SENS Foundation as an executive board member and heads up the Operations department. In this capacity he coordinates the Swico / SENS Technical Commission in conjunction with Heinz Böni.

Emil Franov
After studying Environmental Sciences at ETH Zurich with a focus on analytical environmental chemistry and aquatic systems, Emil Franov worked for five years as an environmental consultant in an international service company. Since 2001 he has worked at Carbotech AG in Basel as a consultant and project manager with a focus on environmental consulting, eco-balances and compliance with environmental requirements (environmental audits, environmental indicators, environmental law, etc.). He has several mandates for performing annual company eco-balances and environmental indicator surveys according to various international standards. Since 2002 he has been an inspector and member of the Technical Commission of the SENS Foundation. Emil Franov is Divisional Director and Member of the Executive Committee of Carbotech AG.

Geri Hug
After completing a degree in chemistry and a subsequent dissertation at the Organic Chemistry Institute of the University of Zurich, Geri Hug worked as a researcher and project manager at Roos + Partner AG in Lucerne. He was a partner at Roos + Partner AG from 1994 to 2011 and also managing director from 1997. He offers environmental consultancy in 15 industry sectors according to EAC codes, supports environmental audits and prepares environmental reports in accordance with the Ordinance on Environmental Impact Assessment (UVPV). Geri Hug prepares short reports and risk analyses pursuant to the Major Accident Ordinance (MAO) as well as operational and product life cycle assessments, and validates environmental reports. Geri Hug is the Control Officer of the SENS Foundation in the field of electrical and electronic waste disposal and lead auditor for environmental management systems pursuant to ISO 14001 at SGS. He is a member of the CENELEC Working Group on the development of standards for the environmentally friendly recycling of refrigerators.



Ueli Kasser
Graduate in Chemistry (Dipl. Chem.) / lic. phil. nat. at the University of Bern and ETH Zurich and graduate of INDEL (postgraduate course on problems of developing countries). After initially working as a freelancer in the fields of radioecology, ecotoxicology and occupational hygiene, he became co-owner of ökoscience – a consultancy office for applied ecology in Zurich - and project manager in the areas of air quality, environmental consulting and ecotoxicology. At this current time, Ueli Kasser is the owner of the Office of Environmental Chemistry in Zurich, which specialises in consulting in the fields of waste, chemicals safety, building materials ecology and indoor air quality. In addition to his teaching activity, he is an auditor for environmental management systems according to ISO 14001. Since the mid-nineties, Ueli Kasser has been an inspector of recycling operations on behalf of the SENS Foundation; he develops the standards and guidelines for the inspection activities, represents the SENS Foundation in the European association and acts as consultant in the European Standards project WEEE-LABEX.

Niklaus Renner
Niklaus Renner studied Environmental Sciences at ETH Zurich. Since 2007 he has worked as a research associate at Roos + Partner AG Lucerne. In the context of various studies, he is concerned with the environmental compatibility of scrap metal and waste equipment recycling. For the SENS and SLRS Foundations his involvement included a survey on the mercury content of fractions in the processing of lamps. In addition, Niklaus Renner's tasks include monitoring environmental law, maintaining the legal compliance tool LCS.pro and internal environmental law conformity audits. Operating inspections for the environmental inspectorate UPSA (Car Industry Association) and, since 2013, construction site soil analysis complete his profile.

Daniel Savi
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 focuses on the health hazards and environmental effects associated with construction work and waste recovery. He has been a partner and managing director of the company since 2015.

Deepali Sinha Khetriwal
Deepali Khetriwal received her doctorate from the University of St. Gallen with a thesis on forecasts of waste flows of end-of-life consumer goods. Prior to her doctoral studies, she gained an MBA in International Management at the University of St. Gallen. She began her work in the field of "e-waste" at Empa and worked on the Swiss electrical and electronic waste programme from 2004-2009. Since that time, Dipali Khetriwal has worked on various projects around the world that are related to electrical and electronic waste. In particular, she was instrumental in capacity building under the auspices of the "E-waste Academy" of the StEP initiative, which is a UN-supported forum for the field of electrical and electronic waste.

Esther Thiébaud
After graduating as an Environmental Engineer with an emphasis on Material Balance and Disposal Technology at ETH Zurich, Esther Thiébaud worked as a project manager in the area of contaminated sites at BMG Engineering AG in Schlieren. Since 2007 she has worked as a research associate in the CARE group (Critical Materials and Resource Efficiency) of Empa in the area of analysis and modelling of national and global material flows in connection with advanced technologies and the materials contained therein. Esther Thiébaud has been working on her dissertation since 2012.

Patrick Wäger
After studying chemistry at ETH Zurich and subsequently completing a dissertation at the Institute of Toxicology of the ETH and University of Zurich, Patrick Wäger worked for two years as an environmental consultant at the Elektrowatt engineering company in Zurich. Since then he has worked as a research associate and project manager at Empa in numerous research projects on waste disposal and the recovery of raw materials from end-oflife products; he works as an inspector for the SENS Foundation and Swico Recycling and was temporarily also lead auditor for environmental management systems pursuant to ISO 14001. Patrick Wäger has several teaching assignments in the field of environmental and resource management and among other activities is a member of the board of the Swiss Academic Society for Environmental Research and

Ecology (SAGUF). The current focus of his work lies in the exploration of strategies for more sustainable use of non-renewable resources, especially rare metals.

Rolf Widmer
Rolf Widmer graduated in Electrical Engineering (MSc. ETH EE) and completed his postgraduate degree on developing countries (NADEL, MAS) at the ETH in Zurich. For several years he carried out research at the Institute of Quantum Electronics of the ETH and today works at the Technology and Society Lab of Empa, the materials research institute of the ETH domain. Rolf Widmer currently directs several projects in the field of electronic waste management. In this connection he works on closed material cycles of electro mobility. His special interest is the recovery of rare metals, which are increasingly accumulating in "urban mines".

Hannes Zellweger
After training as an environmental engineer with a focus on Material Balance and Disposal Technology at ETH Zurich, Hannes Zellweger worked at Amstein + Walthert as a consultant on innovative networks of industry and residential areas for efficient, low-emission heating systems. He then spent three years working for the Swiss State Secretariat for Economic Affairs (SECO) and for Empa, St. Gallen, in Peru, where he was involved in various programmes in his core areas of resource and energy efficiency as well as recycling management. Since 2013, Hannes Zellweger has been working for Sofies where he is responsible for business development in German-speaking countries.

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International links

www.ewasteguide.info A collection of information and sources on all matters involving the recycling of electrical and electronic equipment.

www.weee-forum.org The WEEE Forum (Forum for Waste Electrical and Electronic Equipment) is the European association of 41 systems for collecting and recycling electrical and electronic waste.

www.step-initiative.org Solving the E-waste Problem (StEP) is an international initiative under the auspices of the United Nations University (UNU), which not only includes key players involving the manufacturing, reuse and recycling of electrical and electronic equipment, but also government and international organisations. Three additional 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, dated 22 March 1989, is also known as the Basel Convention.

www.weee-europe.com WEEE Europe AG is an amalgamation of 15 European take-back systems and, as of January 2015, will allow manufacturers and other market players to fulfil their various national obligations from a single source.

National links

www.eRecycling.ch

www.swicorecycling.ch

www.slrs.ch

www.swissrecycling.ch As the umbrella organisation, Swiss Recycling promotes the interests of recycling organisations operating in the separate collection sector in Switzerland.

www.empa.ch The Swiss Federal Laboratories for Materials Testing and Research (Empa) is a Swiss research institute for applied materials science and technology.

www.bafu.admin.ch In the "Waste" section of its website, the Swiss Federal Office for the Environment (FOEN) provides a range of further information and news on the topic of recycling electrical and electronic equipment.

Cantons with devolved powers

www.awel.zh.ch On the website of the Office of Waste, Water, Energy and Air (WWEA), the "Waste, raw materials and contaminated areas" section provides a raft of information of direct relevance to the recycling of electrical and electronic equipment.

www.ag.ch/bvu On the website of the Department for Construction, Traffic and Environment of the Canton of Aargau, the "Environment, nature and agriculture" section provides further information on the topics of recycling and reusing raw materials.

www.umwelt.tg.ch On the website of the Office for the Environment of the Canton of Thurgau, the "Waste" section provides relevant regional information about the recycling of electrical and electronic equipment.

www.afu.sg.ch The website of the Office for Environment and Energy St. Gallen contains general information, notices on individual issues and information on current topics, which can be found under "Environmental information" and "Environmental facts".

www.ar.ch/afu The website of the Office for Environment Appenzell Ausserrhoden contains general information and publications on individual issues and all matters involving the environment.

www.interkantlab.ch The website of the Intercantonal Laboratory of the Canton of Schaffhausen offers a wide range of information on recycling electrical and electronic equipment, which can be found under "Information on specific types of waste".

www.umwelt.bl.ch The website of the Office for Environmental Protection and Energy (AUE) of the Canton of Basel-Landschaft contains information on recycling and reusing raw materials in electrical and electronic equipment, which can be found under "Waste>Controlled waste>Electrical waste."

www.zg.ch/afu The website of the Office for Environmental Protection of the Canton of Zug contains general information and notices on the topic of waste, which can be found under "Waste management". Detailed information on the collection of individual recyclable materials is available from the Association of Local Authorities of the Canton of Zug for Waste Disposal Administration (ZEBA) at www.zebazug.ch.

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The technical report is published in German, English and French and is available for download as a PDF at www.eRecycling.ch, www.swicorecycling.ch and www.sirs.ch