Study on the analysis of PCB and other potentially hazardous substances found in capacitors

June 2012

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1 Challenges and objectives

In France, as a precautionary principle, capacitors removed from WEEE listed in Annex II of the European Directive 2002/96/EC are currently disposed of using technology intended for treating waste containing PCB. **This specialised, high-temperature incineration technology is not only the most expensive but also excludes the possibility of recovering non PCB-containing materials found in the capacitors**.

This study, conducted by the OCAD3E (clearing house body gathering the 4 take-back organisations responsible for collecting and treating WEEE in France: Eco-Systèmes, Ecologic, ERP and Recyclum), aims at defining alternative sorting and treatment solutions for capacitors removed from WEEE regarding:

- **the analysis of different types of capacitors** found in WEEE as well as their quantity, the substances inside (PCB, other hazardous substances) and the possible capacitor sorting techniques which can be envisaged in relation to relevant criteria (visual recognition or other),
- **the technico-economic analysis of other existing treatment technologies**, suitable for treating these components and guaranteeing correct disposal of hazardous substances other than PCB.

This study provides decision support information to develop WEEE capacitor disposal processes with the aim of reducing costs in strict compliance with national or European environmental regulations.

2 Results

Types of capacitor in WEEE and substances identified inside them

The table below summarises all types of capacitors found in WEEE per treatment process stream (results obtained from a producer survey phase and a documentary research). The colours represent the level of potential presence of PCB and other hazardous substances.

2 Results

	Type of capacitor					LHA-excl. cold	LHA cold	SCREENS	SHA
	Category	Shape	External covering	Marks for differentiation	Size				
Within the scope Annex II of the Directive 2002/96/EC	Made of paper/film	Cylindrical, radial leads oblong 	Metallic or plastic	None / "no PCB" for some	h > 25 mm			not concerned	
		Parallelepiped with connection 	Plastic	None	h ≤ or > 25 mm			not concerned	
		Cylindrical, axial leads 	Plastic	None	h ≤ or > 25 mm				
		Small-sized rectangular/ "gum drop", with prongs 	Plastic	None	h > 25 mm		not concerned		
	Electrolytic Aluminium	Cylindrical, radial or axial leads soldered on/screwed in 	Metallic	"+" and/or "-"	h ≤ or > 25 mm				
		SMD (chip) 	Plastic	"+" and/or "-"	h < 25 mm				
Not within the scope of Annex II	Electrolytic Tantanlum	"Gum drop" 	No details given	No details given	h < 25 mm				
	Ceramic	"Gum drop" 			h < 25 mm				
	Mica	"Gum drop" 			h < 25 mm	not concerned	not concerned	not concerned	

Source: Terra SA

With potential presence of PCB.

Presence of hazardous substances other than PCB (PCB alternatives used in the film of film capacitors or substances in the electrolyte of electrolytic capacitors or brominated flame retardants in the plastic covering), potentially within the scope of Annex II of the 2002/96/EC Directive.

Having a potential presence of hazardous substances other than PCB but nevertheless outside the scope of Annex II of the 2002/96/0EC Directive (vol. < 12.3 cm^3).

Free of PCB and other hazardous substances.

Comments

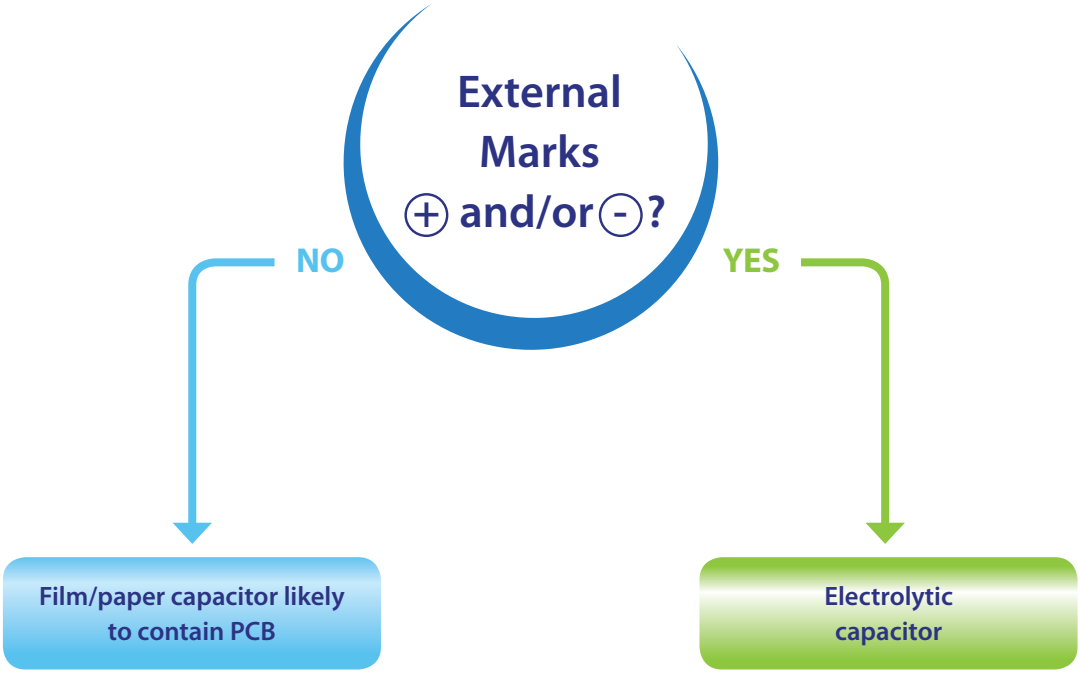
- Only film and aluminium electrolytic capacitors are included in the scope of Annex II of the 2002/96/EC directive.
- Film capacitors are likely to contain PCB (or PCB alternatives) within the internal film (dielectric). Due to their construction, electrolytic capacitors cannot contain any PCB as they don't have the same internal structure (source: capacitor manufacturers, printed matter).

Other than PCB, the other main hazardous substances found are biphenyl, naphthalene, di-butyl phthalate as well as dimethyl-biphenyl. Characterised by their toxicity, their hazardous nature for the environment and/or toxic to reproduction, these substances are mainly found in film capacitors.

As for electrolytic capacitors, these are mainly characterised by the presence of boric acid, ethylene glycol, di-methylacetamide and sulphuric acid. These substances can either be qualified as toxic, as irritant or as corrosive.

Using previous results and based on the external properties of capacitors, it is possible to sort them into categories by their type (for those listed in Annex II of the 2002/96/EC Directive).

Capacitor categories per type, visual recognition of cylindrical capacitors:



Properties/Characteristics:

- External metallic or plastic covering.
- Contains a film (or paper) which may be impregnated with a liquid (or none: this is then known as dry type).
- If it is impregnated, the impregnating liquid contains:
  - Either PCB,
  - Or PCB alternatives of a hazardous nature (see following table),
  - Or PCB alternatives of a non-hazardous nature (e.g. vaseline).
- May be marked "no PCB" (voluntary step taken by the manufacturer; marking is neither standardised nor part of a referential framework).

Properties/Characteristics:

- External metallic covering made of aluminium.
- Still remains PCB-free.
- Contains substances in the electrolyte likely to be hazardous

Source: Terra SA

Results of sampling and analysis of capacitors per stream

The tables and graphs below show the results from the sampling and the analysis of 5,554 capacitors (155 kg) removed from 4 treatment streams.

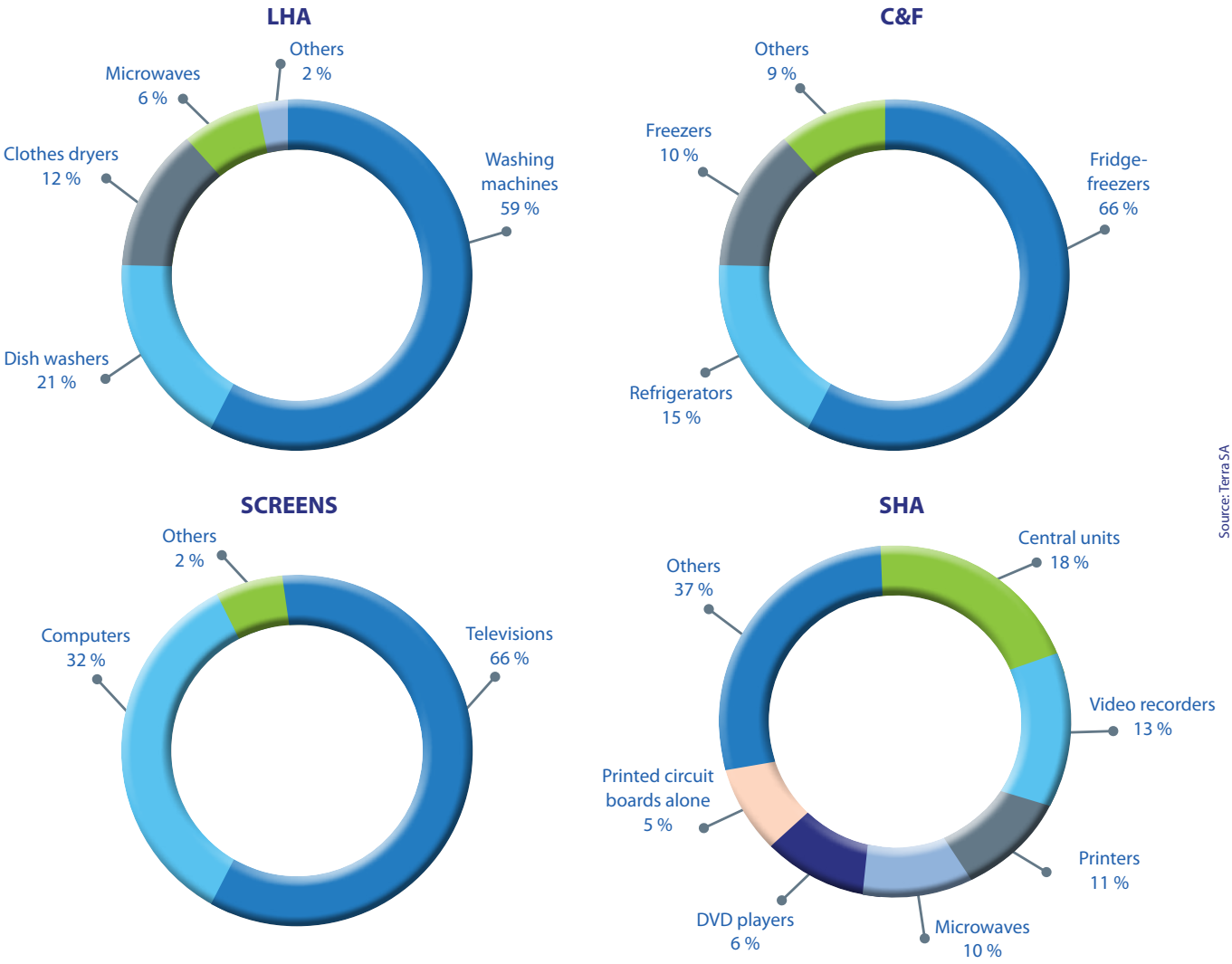
Quantities of capacitors sampled for analysis per treatment stream

Stream	Weight of analysed appliances	Quantity of capacitors (1)	
		Number	Weight
LHA	46,370 kg	833 units	69.6 kg
C&F	65,088 kg	108 units	6.5 kg
SCREENS	16,200 kg	2,577 units	37.3 kg
SHA	19,530 kg	2,036 units	41.5 kg
TOTAL 4 STREAMS	147,188 kg	5,554 units	154.9 kg

(1) Only capacitors included in Annex II of the Directive were sampled from the appliances.

Source : Terra SA

Results of capacitor distribution per number and type of appliance coming from each treatment stream:

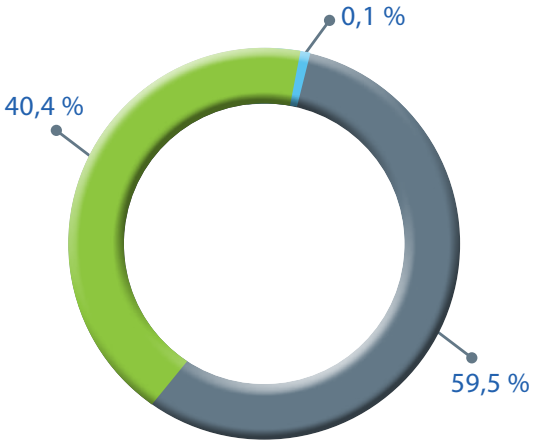


Source: Terra SA

130 capacitors from these samples were analysed in the laboratory for their internal PCB content. 82 had oil inside. No PCB content was detected in the oil in these capacitors. Note, nevertheless, that the small sample size having undergone chemical analysis does not guarantee a satisfactory level of representativeness.

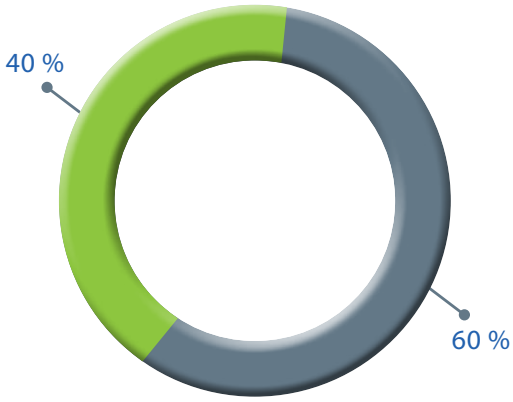
Results per stream of distribution of weight per type of capacitors:

LHA



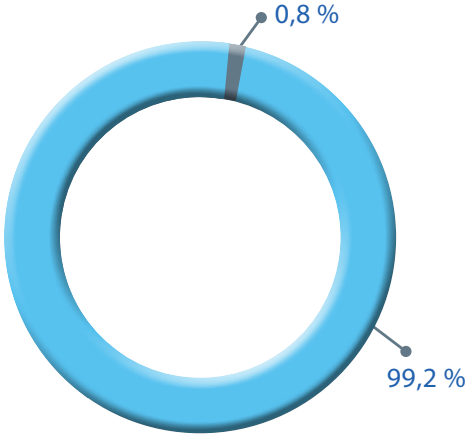
- Electrolytic capacitors (with +/- markings, no PCB)
- Film capacitors (without +/- markings, PCB suspected), with a plastic covering
- Film capacitor (without +/- markings, PCB suspected), metallic covering of which 16% marked "no PCB"

C&F



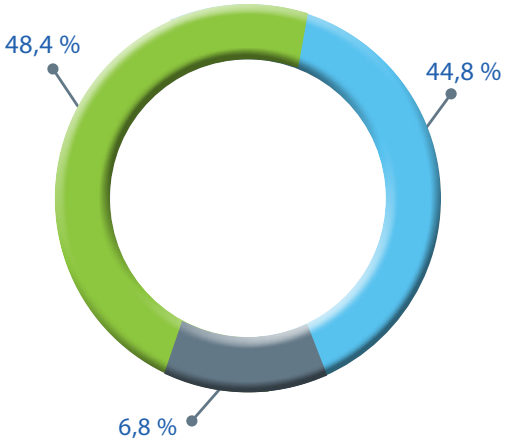
- Film capacitors (without +/- markings, PCB suspected), plastic covering
- Film capacitor (without +/- markings, PCB suspected), metallic covering

SCREENS



- Electrolytic capacitor (with +/- markings, no PCB)
- Film capacitors (without +/- markings, PCB suspected), with a plastic covering

SHA



- Electrolytic capacitors (with +/- markings, no PCB)
- Film capacitors (without +/- markings, PCB suspected), with a plastic covering
- Film capacitor (without +/- markings, PCB suspected), metallic covering of which 22% marked "no PCB"

Source: Terra SA

Analysis of determining sorting criteria and alternative treatment processes

Several visual recognition criteria enabling capacitor sorting by type, for differentiated further treatments were examined. The table below shows these different criteria and their relevance.

Criteria	Description / Comments	Relevance / Reliability
Criteria 1 **External marks + and/or -**	Characteristic marks for electrolytic capacitors. These types of capacitors are polarised and, due to the way in which they are made, are PCB-free *(source: printed matter and capacitor manufacturers)*	Relevant criterion for sorting by type for differentiated further treatments
Criteria 2 **Marks « no PCB »**	Marks intended to mean a total absence of PCB (only used for film capacitors, without +/- markings, mainly those coming from microwaves where internal voltage is high). It is voluntarily affixed by the manufacturer. Although the manufacturers surveyed say it is reliable, this marking is not covered by a standard or international reference framework. It is not checked by authorities.	This criterion is not considered to be 100% reliable. It has not been retained in the definition of the following sorting solutions.
Criteria 3 **Type of external covering (plastic/ metallic) for unmarked capacitors +/- (PCB suspected)**	For film capacitors (without +/- marks), a certain correlation appears to exist between the plastic covering and dry type (absence of liquid impregnating the film). On the whole, manufacturers who were surveyed confirm this trend, but some do not guarantee that this is 100% systematic. Internal analysis (1) conducted on about a hundred plastic covered capacitors from the SHA and C&F streams demonstrated that they were all dry. This is not the case for LHA, for which 7 out of the 54 plastic covered capacitors were analysed (1), i.e. 13%, were impregnated. The types of substances contained in the impregnation liquid were not analysed (note that the substances may be of an ordinary nature, as described in the tables above. Example: vegetable oil or minerals). The Spanish take-back company Ecolec carried out a study in 2007 on capacitors in which 1,674 LHA – were opened to see whether they leaked liquid. All plastic coated capacitors were described as dry (no liquid flowed from any of them).	Un-retained criterion at this stage for the definition of the following sorting solutions. (Potentially this should be studied more closely with a greater quantity of capacitors and in accordance with a detailed analytical protocol).
Criteria 4 **Density (kg/L) of capacitors**	Following density measurements on a sample of 400 capacitors, no significant differences in density were observed between the capacitor types (electrolytic, film, plastic/metallic covering). All densities measured are in the order of 1.2 to 1.5 on average. Mechanical densimetric sorting cannot therefore be considered.	Irrevelant criterion.

Source: Terra SA

(1) The capacitors were completely taken apart using a mini-cutter so as to be able to see the internal impregnation of the dielectric film.

Results of studies on alternative treatment processes

Following studies, alternative treatment processes were identified for aluminium electrolytic capacitors, in relation to the type of internal substances and their quantities as well as to the capacity of the process to be able to accept and treat these components in the correct way. Besides the disposal of substances some processes also allow the metallic part of the capacitor to be recovered.

The alternative processes identified for aluminium electrolytic capacitors are:

Possibility 1 : Disposal by specific hazardous waste incineration (hazardous waste incineration)

Possibility 2 : Landfilling in a hazardous waste landfill

Possibility 3 : Material recovery with disposal of internal substances in a specific process combining thermolysis and separation of metals (see details below). This process was tested by treating a 10t batch of electrolytic capacitors.

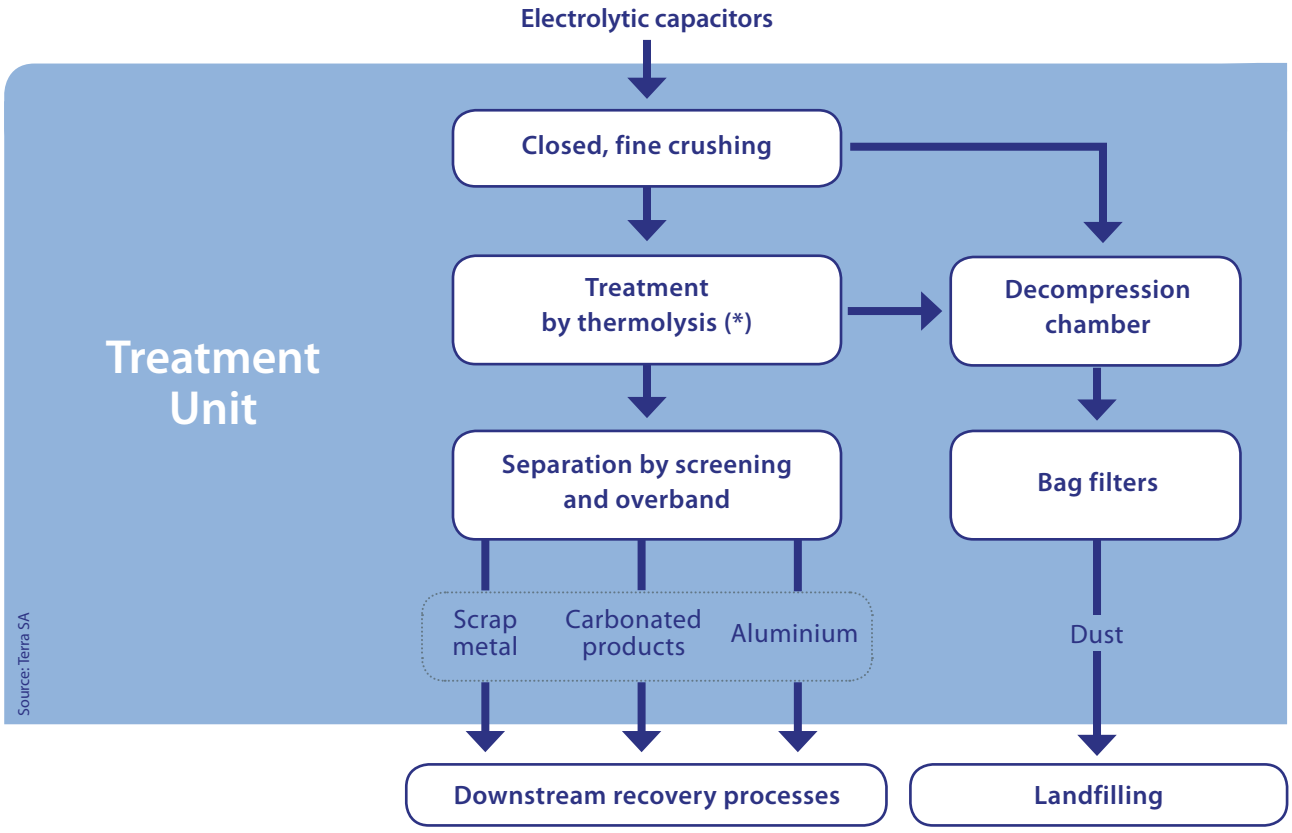
Comment

In the case of capacitors welded on electronic circuit boards (e.g. SHA streams), if these boards are managed by downstream companies (1) without prior crushing, a study carried out among those acceptors demonstrates that high-temperature processes (2) are able to correctly dispose of these capacitors (and the substances inside) when these have not been removed from the boards. Therefore, this would only concern some circuit boards from SHA, as the circuit boards from cathode ray tube screens, require in practice, crushing before being sent to downstream companies.

(1) Having a pyrolysis or pyro-metallurgy process

(2) Circuit boards acceptors using pyro-metallurgy or pyrolysis techniques state that they still accept boards with capacitors and are able to remove all internal organic substances (including PCB if necessary, but the boards' capacitors do not contain PCB in any case) through their high-temperature fusion process (~1200°C). Some smelters are authorised to generally receive waste contaminated with PCB.

Additional details of the electrolytic capacitor recovery process identified via thermolysis (possibility 3 described above)

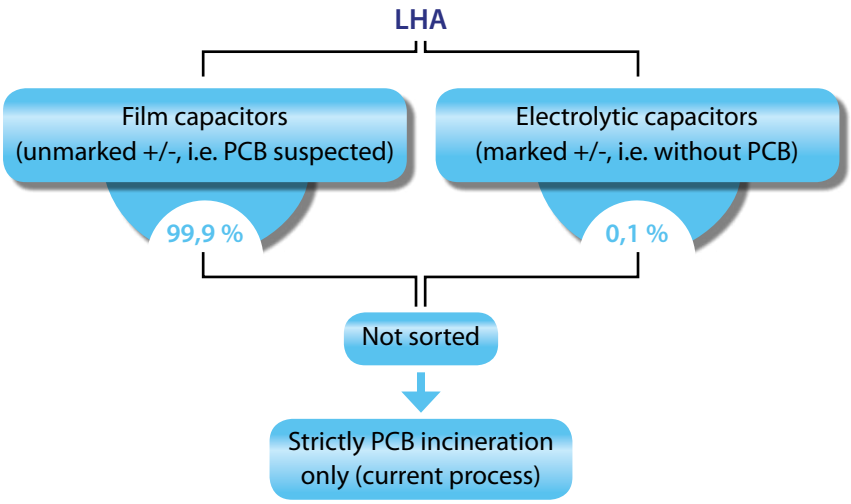


(*) The molecules of electrolytic substances are destroyed by thermolysis at 400°C and by gas passing through at 600°C for 1 to 2 seconds. The material recovery rate achieved by this process is over 40%.

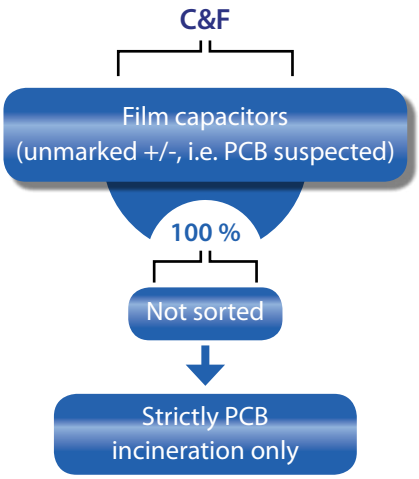
Solutions for sorting and processes per stream

Based on the results of the studies on above alternative processes, the following capacitor sorting and treatment processes per stream can be considered.

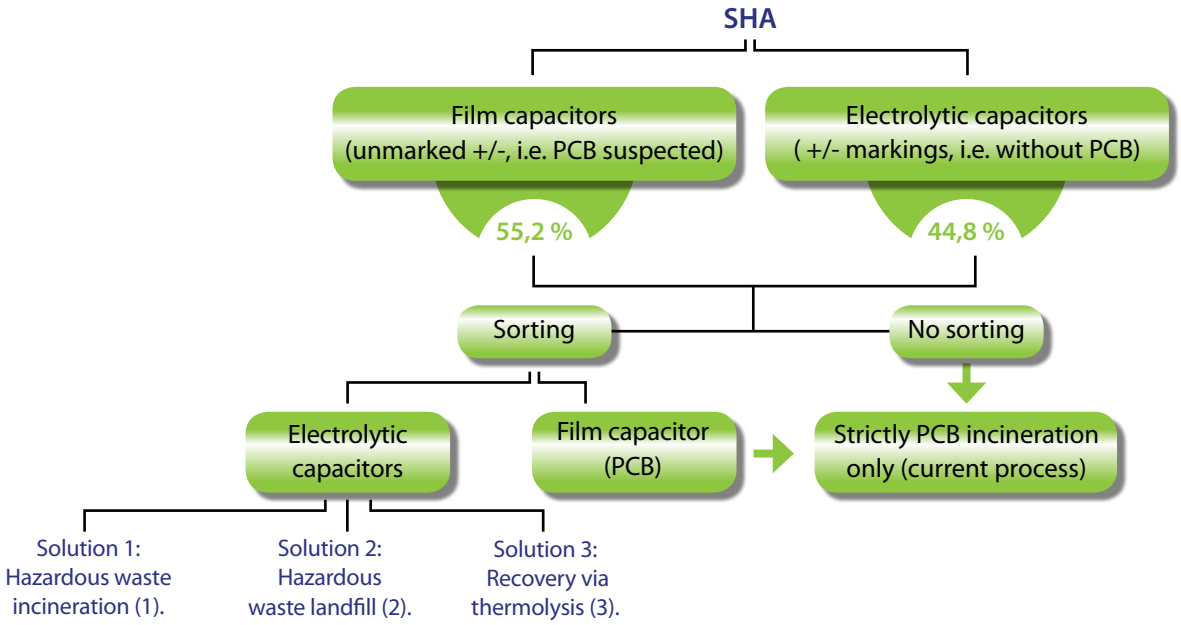
For LHA



For C&F

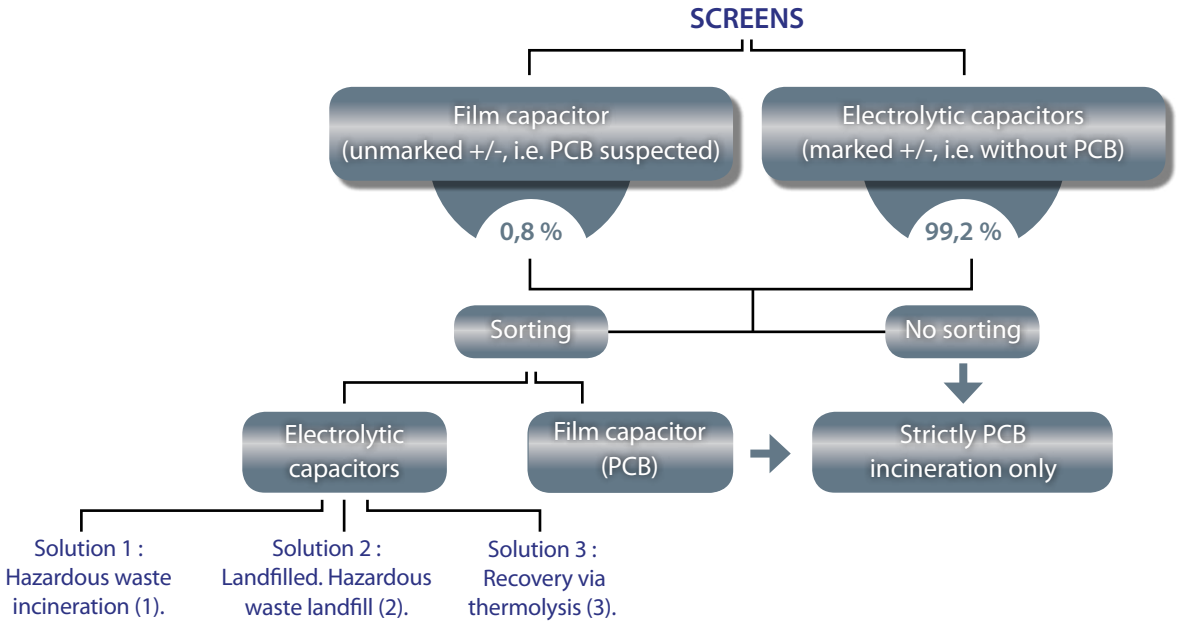


For SHA



Source: Terra SA

For screens



Source : Terra SA

(1) Savings made compared to current situation are around 600€/T.
(2) Savings made compared to current situation are around 1000€/T.
(3) Savings made compared to current situation are around 1150€/T.

Taking the results of this study into account, the French government decided that:

- It was necessary to continue to consider the C&F and LHA capacitors as susceptible to contain PCB and to treat them in a strictly PCB incineration process. This decision could be reconsidered after having obtained the analysis results from Spain regarding the correlation between capacitors with plastic envelope and the dry technology (characterized by the absence of hazardous substances according to the literature).
- Because the marking "No PCB" was not supervised by any regulation, it was not appropriate to take into account this criterion at the moment.
- It was possible to sort the SHA electrolytic capacitors and send them to a recovery via thermolysis process.

At the time this document is edited, the French Government has not decided anything yet about the capacitors in screens.

Case of SCREENS and SHA: electrolytic capacitor sorting for dispatch to an alternative treatment process.

NB: as stated in the previous paragraph, an additional saving could be made by not removing the capacitors present on electronic circuit boards from SHA that are being sent directly to final treatment processes (pyrometallurgy or pyrolysis).

3 Méthodology

The study was conducted in several stages:

› First, an overview was done regarding different capacitor types found in EEE, using information from documentary research as well as information gathered in interviews with a representative panel of electric and electronic equipment manufacturers. This overview enabled the capacitors found in each stream to be sorted into categories according to their type, external characteristics and substances present inside. It also gives details about capacitors which are or are not included within the scope of Annex II of the 2002/96/EC Directive.

› To quantify the actual distribution of capacitors in each stream by weight and by number in relation to the afore-mentioned categories, samples of capacitors removed from WEEE were taken in several dismantling and recycling companies in France. A total of 5,554 capacitors (155 kg) were sampled for all streams and for each one the following information was recorded: weight (g), stream and type of equipment from where it came from, presence of external marks "+/-" (detection of electrolytics), presence of external "no PCB" marks, brand, type of external covering (plastic or metal), height and diameter. Laboratory analysis of the presence of PCB on 130 capacitors was also carried out.

› Based on information gained in the previous phases, relevant visual recognition sorting criteria for each technology were established and tested.

› At the same time, based on the type of substances identified inside, studies were carried out in specialised hazardous waste treatment companies and smelters. This was conducted in order to examine the technical and environmental possibilities for each type of capacitor of treating these components with an alternative method in strict compliance with regulatory standards. Tests were also carried out on a 10 tons batch of aluminium electrolytic capacitors using an alternative treatment process by thermolysis, assessed as being capable of recovering these components.

Summary written by Eco-systèmes and Terra SA.

Study funded by take-back scheme organisations pro rata to tonnages of household electrical and electronic appliances marketed by member producers.
With financial support of ADEME.