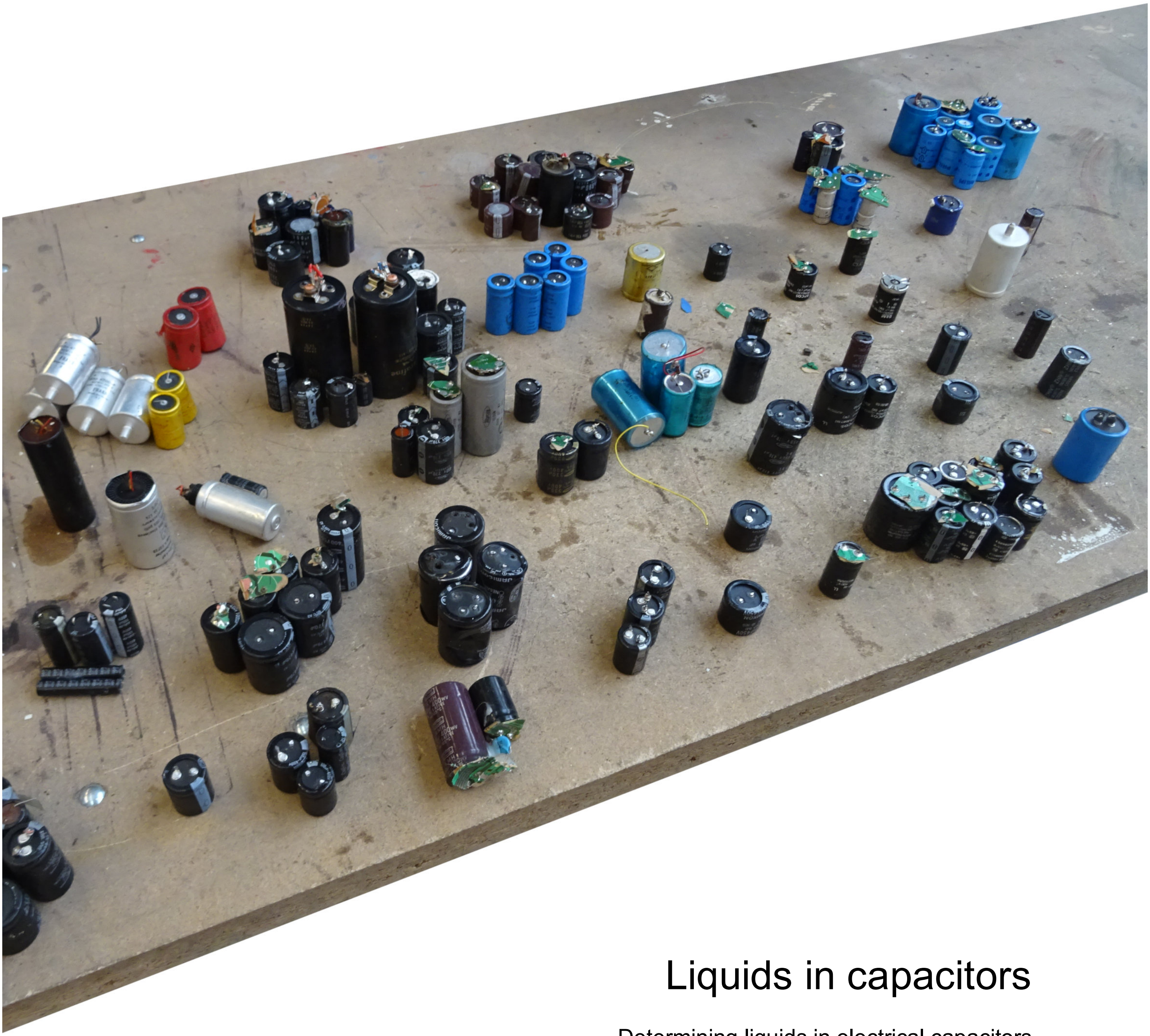

Liquids in capacitors

Determining liquids in electrical capacitors
including the definition and classification of substances of concern

Final report

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Authors

Daniel Savi, dipl. environmental scientist, ETH Zurich[1)]
Ueli Kasser, lic. phil. nat. (chemist)[1)]
Rolf Widmer, research associate[2)]

Organisation affiliation:

[1)] Büro für Umweltchemie, Schaffhauserstrasse 21, 8006 Zurich, Switzerland

[2)] Empa, Technology and Society Department,
Lerchenfeldstrasse 5, 9014 St. Gallen, Switzerland

Advisory group

Andreas Buser, Federal Office for the Environment, Industrial chemicals department, Bern

Markus Zennegg, EMPA Lab for Advanced Analytical Technologies, Dübendorf

Rolf Widmer, EMPA, Auditor Swico, St. Gallen

Emil Franov († 2017), Auditor SENS, Carbotech AG, Basel

Geri Hug, Auditor SENS, IPSO ECO AG, Rothenburg

Collaboration Technical Committee SENS-Swico

Heinz Böni, Empa St. Gallen

Anahide Bondolfi, Abeco, Aïre

Flora Conte, Carbotech AG, Basel

Roman Eppenberger, SENS, Zurich

Michael Gasser, EMPA, St. Gall

Roger Gnos, Swico, Zurich

Arthur Haarmann, EMPA, St. Gall

Niklaus Renner, IPSO ECO AG, Rothenburg

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List of abbreviations

Aluminium e-cap	Aluminium electrolytic capacitor
CE	Consumer electronics
C&L Inventory	ECHA database to classify substances in accordance with the Regulation (EC) No. 1272/2008 of the European Parliament and of the Council on classification, labelling and packaging of substances and mixtures (CLP Regulation)
CMR	Term for substances which have properties that are carcinogenic (C), mutagenic (M) or toxic for reproduction (R)
e-cap	Electrolytic capacitor
ECHA	European Chemicals Agency
GCMS	Gas chromatography – mass spectrometry
GHS	Globally Harmonised System of Classification and Labelling of Chemicals: classification of substance properties in accordance with the classification model of the United Nations which was developed by the Economic Commission for Europe (UNECE)
H-statement	Declaration of the hazard caused by a substance according to the GHS
ICP	Inductively coupled plasma
IT	Information technology
LCMS	Liquid chromatography – mass spectrometry
MS	Mass spectrometer
PCB	Polychlorinated biphenyls, substance group of 209 congeners
SDS	Safety data sheet
WEEE	Waste electrical and electronic equipment

1 Abstract

1.1 Issue

The reason behind this study was the fact that PCB-containing capacitors are becoming a smaller and smaller proportion of the collected capacitors from waste electrical and electronic equipment. Based on the results of other studies, according to which certain equipment categories are now free of capacitors containing PCBs, these results should be checked for the WEEE in Switzerland. For PCB-free capacitors, there was still no systematic work to determine which liquid substances they contain. According to the specifications of the relevant standards and regulations, PCB-free capacitors must also be removed from electrical appliances if these contain substances of concern. This led to the further question of how to define substances of concern.

1.2 Literature research

While researching literature at the beginning of the study, we evaluated accessible knowledge about liquid substances in capacitors. An attempt was first made to use literature and manufacturer inquiries to determine which types of capacitors contain liquids. It was found that aluminium electrolytic capacitors and the seldom used tantalum film capacitors always contain liquids, non-polarised cylindrical capacitors may but do not necessarily contain liquids, while other types are always completely dry.

The research on liquid substances proved to be challenging. Manufacturers do not provide a detailed declaration of the liquids in capacitors. The potentially contained substances were deduced via laboratory analyses of previous studies, patents and text books on electronics.

The term “substances of concern” was searched for in existing EU directives and national legislation in Switzerland. It became apparent that the term is not legally defined and that a definition must be developed for use in recycling.

1.3 Methods

Over 5 000 capacitors larger than 2.5 cm in at least one dimension were collected during an extensive collection campaign. These were assessed per appliance category with regard to their manufacturer, model number, production year, type of construction and PCB content according to the chemsuisse capacitor list. The PCB levels were determined in a laboratory for 21 capacitor models which could not be classified.

From the collected samples, eight mixed samples of PCB-free capacitors were prepared for laboratory analysis of the liquid substances. Capacitors from several appliance categories were combined for a mixed sample. For example, the capacitors from laptop power supply units and desktop computers were combined into one mixed sample. The liquids from non-polarised cylindrical capacitors were removed and mixed together to form mixed laboratory samples. The same method was applied to microwave capacitors. Although electrolytic capacitors contain liquids, these are absorbed in the blotting paper of the capacitor and thus do not leak. The coils were therefore removed from the housings and used to form mixed samples. The contents of the mixed samples were chemically analysed in a laboratory via gas chromatography–mass spectrometry (GCMS), and in the case of electrolytic capacitors, via liquid chromatography–mass spectrometry (LCMS).

1.4 Results and discussion

The 20 largest peaks from the chromatograms of the GCMS analyses were evaluated. To classify the substances as concerning or non-hazardous, we developed an evaluation scheme based on the H-statements of the GHS. The substances which were known from the analysis or the literature research were classified using the evaluation scheme. Nine substances of concern were found in non-polarised cylindrical capacitors, six in electrolytic capacitors and four in microwave capacitors.

No capacitors containing PCBs were found in any IT devices or consumer electronics. These types of appliances usually use electrolytic capacitors, which never contain PCBs. No capacitors containing PCBs were found in refrigerators, air conditioners or freezers. In large household appliances, 0.5 per cent of the capacitors contained PCBs and 1.7 per cent of the capacitors were suspected of containing PCBs. The figures for capacitors suspected of containing PCBs were based on the classification using the capacitor list. Laboratory analyses were used to analyse the PCB content of all capacitors suspected of containing PCBs from refrigerators and a significant proportion of the capacitors suspected of containing PCBs from large household appliances. All capacitors suspected of containing PCBs which were tested in the laboratory were found to be PCB-free. A great proportion of capacitors from fluorescent luminaires still contains PCBs. In our study, 55 per cent of the capacitors contained PCBs and another 21 per cent were suspected of containing PCBs. The results for small SENS appliances were not plausible and cannot be considered to be representative of returned SENS appliances. We speculate that the high proportion of PCB-containing capacitors arose because capacitors from household luminaires were included in the collection by mistake.

Further evaluations were made based on the acquired data. For example, we determined the proportion of dry capacitors in non-polarised cylindrical ones, the mass fractions of the electrolytic capacitors in IT devices and consumer electronics, as well as the division of electrolytic capacitors into those larger than 2.5 cm in one dimension and smaller ones. The average masses were calculated for all capacitor types.

1.5 Conclusions and recommendations

All liquids in the analysed capacitor categories could contain substances of concern as outlined in the established definition. The concentrations found were consistently low. Based on the data, the annual load of substances of concern in PCB-free capacitors was estimated to be between 500 and 1 000 kg for Switzerland.

A definition of substances of concern was developed within the scope of this study, the use of which we recommend.

The removal requirement stipulated in the CENELEC standard EN 50625 and the Directive 2012/19/EU of the European Parliament and of the Council on waste electrical and electronic equipment (WEEE Directive) should be revised to include all capacitors which contain liquids and are larger than 2.5 cm in at least one dimension. For PCB-containing capacitors which are still found in large household appliances and especially fluorescent luminaires, the existing removal regulations should remain. For PCB-free capacitors, removal must be carried out within a distinct stream that can be monitored as stipulated by the standard EN 50625.

2 Issue and approach

2.1 Issue

In accordance with the CENELEC standards series EN 50625,Annex VII of the WEEE Directive (European Parliament, 2012) and the SENS and Swico technical regulations (SENS et al., 2012), two types of capacitors must be removed from waste electrical and electronic equipment:

1. Polychlorinated biphenyls (PCB) containing capacitors
2. Electrolyte capacitors containing substances of concern (height > 25 mm; diameter > 25 mm or proportionately similar volume)

In practice in Switzerland and many European countries, the rule has been established that all capacitors with one dimension larger than 25 mm must be removed from all electronic appliances without destroying them: PCB-containing capacitors cannot be reliably distinguished from PCB-free ones during processing.

Over 30 years have passed since the PCB ban in 1986. The question has arisen regarding the proportion of PCB-containing capacitors in the current return of WEEE. Two studies conducted by SENS and Swico in Switzerland (Eugster et al., 2008; Gasser, 2009) showed that the proportion of PCB-containing capacitors is steadily decreasing and these are no longer found in certain appliance categories. Fluorescent luminaires are an exception to this as their ballasts still hold a large proportion of PCB-containing capacitors. A recent study was carried out on the proportion of PCB-containing capacitors on behalf of the Dutch take-back system for electrical appliances (Groen, 2013). The liquids in the collected capacitors were individually extracted to determine their PCB content. The study concluded that large appliances are virtually free of PCB-containing capacitors. However, the sample size of 268 units seems too small for such an assertion. In the case of luminaires, 10 per cent of the appliances examined had PCB-containing capacitors.

For the future, it will be important to determine whether PCB-free capacitors should also be removed without destruction. Substances of concern must therefore be defined and determined if these are found in electrolytic capacitors. Furthermore, the same question arose during the course of this study regarding non-polarised capacitors containing liquids. When it comes to recycling electrical appliances, there is also the question of which appliance categories involve capacitors which must be removed separately.

In order for Swico and SENS as well as the inspection experts from the technical inspection bodies of the two organisations to lay the groundwork for the future capacitor handling guidelines, the proportion of PCB-containing capacitors for disposal and the substances in liquid electrolytes and dielectrics of PCB-free capacitors for disposal must be clarified. A comprehensive list of possible substances in liquid electrolytes and dielectrics must be developed. It will also be clarified whether these substances require special treatment to prevent health or environmental hazards through recycling.

The study aims to clarify the following questions:

- What proportion of capacitors currently being removed from WEEE contains PCBs?
- Which substances are contained in liquid electrolytes and dielectrics of PCB-free capacitors?
- Which of these substances must be classified as “substances of concern” within the context of chemicals legislation?
- Does current WEEE in Switzerland contain capacitors with liquid electrolytes and dielectrics which must be classified as “substances of concern”?
- If yes, in which appliance categories and types?
- Does this lead to new recommendations for the removal of hazardous substances?

2.2 Interpretation of the removal requirement for capacitors

When it comes to disposal, the most relevant capacitors are those which contain liquids. These are not exactly the same as electrolytic capacitors. Within the category of electrolytic capacitors, aluminium e-caps have liquid electrolytes. Solid aluminium e-caps also exist for special applications which do not contain liquid electrolytes. Tantalum capacitors usually contain no liquids, only tantalum capacitors for medical and military special applications are produced with liquid electrolytes. Furthermore, numerous non-polarised cylindrical capacitors contain liquid oil impregnations as a dielectric. According to literature references, these are the types FK, MPK, MP, MK, MKV and MKK (see abbreviations, Table 1). These capacitors are not electrolytic capacitors according to the technical classification. Based on the usual classification of capacitors in electrical engineering, these capacitors would not have to be removed from WEEE if they contain no PCBs. The CENELEC standard EN 50625-1, the WEEE Directive (European Parliament, 2012) and the Swiss technical regulations (SENS et al., 2012), only demand for the removal of electrolytic capacitors containing substances of concern. This interpretation may be technically correct, but does not make sense in terms of environmentally friendly disposal and health protection. The aim is to prevent substances of concern from leaking out of capacitors and being distributed across all fractions in the recycling process without restriction.

Capacitors which only contain solid substances do not need special handling in electronics recycling. Solid substances with comparable toxic and physical properties are also used in other electronic components. Advance removal of capacitors with solid substances before treating electrical appliances to ensure environmentally friendly disposal is thus not productive. The focus should rather be placed on the liquid substances which are distributed in an uncontrolled manner across all fractions as adhesions during mechanical crushing. This study therefore examines the liquids in PCB-free capacitors regardless of whether they are electrolyte (polarised) or non-polarised capacitors.

2.3 The term removal in the standard EN 50625-1

The term component removal is defined in Annex A of the CENELEC standard 50625-1 as follows:

"Substances, mixtures and components shall be removed such that they are contained as an identifiable stream or identifiable part of a stream by the end of the treatment process. A substance, mixture or component is identifiable if it can be monitored to prove environmentally safe treatment."

Within the same point, the standard then requires that capacitors containing PCBs "shall be removed as a distinct step during the treatment process and prior to size reduction and separation (…)".

For electrolytic capacitors (> 25 mm or proportionally similar volume) containing substances of concern, the removal requirement is less strict: they "shall be removed as an identifiable (part of a) stream during the treatment process".

2.4 Approach

2.4.1 Overview

The project was divided into stages: first, the liquid substances in PCB-free capacitors were clarified according to literature and manufacturer information. During the first stage, we also developed a definition of the term substances of concern. A concept for the collection of capacitors from WEEE was developed using the acquired knowledge. We determined the manufacturer names and, where possible, the model names for the collected capacitors. The capacitors were classified according to their PCB content with the aid of the chemsuisse capacitor list (Arnet et al., 2011). The substances in the PCB-free capacitors were determined using a chemical analysis. To do this, mixed samples were prepared for a selection of appliance categories which were then examined in a laboratory. The substance list from the literature study served as the basis. The identified substances were classified using the definition of substances of concern.

2.4.2 Literature study and planning inventory and typology

The substances in capacitors were qualitatively analysed using screening tests in the study "PCB's in Small Capacitors from Waste Electrical and Electronic Equipments" (Eugster et al., 2008). Substance groups were identified there which could be expected in liquid substances.

Additional information about the electrolytes and dielectrics used in modern small capacitors was found in specialist literature. Patent specifications were another important source when searching for substances used. Manufacturers were also consulted.

2.4.3 Definition of substances of concern

Specialist literature was studied to find criteria for the term substances of concern. The results of this and considerations regarding the classification of substances under the GHS (European Parliament, 2008; UN, 2011) were used to develop a precise differentiation between concerning and non-hazardous substances.

2.4.4 Inventory and typology

The capacitors from WEEE were collected separately according to appliance categories. The acquired sample were manually pre-sorted according to capacitor manufacturers and models where possible. We classified the models as capacitors containing PCBs, capacitors suspected of containing PCBs, and PCB-free capacitors.

2.4.5 Chemical analysis

For the PCB-free capacitors, the liquid substances were analysed per appliance category in mixed samples for non-polarised and electrolytic capacitors. In non-polarised capacitors, the liquids flow freely. These capacitors could be cut open and the contained liquid flowed out. This method was used to prepare mixed samples for analysis from the liquids. Electrolytic capacitors contain impregnated paper. The liquids are largely bound there and cannot be removed by simple means. For this capacitor type, the coil was removed from the housing and numerous coils were combined into mixed samples. For the laboratory analysis, the liquid contents of the coil were dissolved once in cyclohexane and once in water for identical duplicate samples.

2.4.6 Evaluation of the substances

The substances which were known from literature or the analyses were presented per capacitor type. They were divided into substances of concern and non-hazardous substances in recycling according to the developed substance classification. Conclusions were drawn on this basis which should apply to future guidelines for handling capacitors in recycling.

3 Terms

3.1 Non-polarised cylindrical capacitors

Non-polarised capacitors form a large group of different construction types. In this case, non-polarised cylindrical capacitors refer to small capacitors which are not polarised and are integrated in cylindrical housing. These capacitors contain a coil comprising either two conductive films which are separated from one another by a dielectric film, or of two films, whereby a conductive layer is applied on one side of each film. They may contain liquids depending on the type. See also Table 1.

Figure 1: Non-polarised cylindrical capacitors with plastic or aluminium housing

3.2 Electrolyte

An electrolyte is, in a broader sense, a liquid which contains ions and thus conducts a current. Electrolytes are produced by dissolving salts or strongly dissociating acids or alkalis in water or an organic solvent.

In a narrower sense, the term electrolyte refers to a substance that supplies mobile ions. Starting materials for electrolytes in capacitors may be organic or inorganic acids or their salts or esters. In addition, alkaline additives such as ammonia are added to keep the pH value of the total mixture close to the neutral range.

3.3 Electrolytic capacitors

Electrolytic capacitors are usually polarised components with a negative and a positive pole. Non-polarised electrolytic capacitors are also available for special applications, particularly in the audio sector. These generally consist of two polarised electrolytic capacitors in series connection. Electrolytic capacitors are divided into aluminium electrolytic capacitors and tantalum capacitors. The term electrolytic capacitor is often shortened to e-cap. See also Table 1.

Figure 2: Different types of electrolytic capacitors

3.4 Dielectric

A substance which does not conduct electricity or does so poorly. A dielectric is an electrical isolator. Dielectrics can be solid, liquid or gaseous.

3.5 Microwave capacitors

The term microwave capacitors refers to impregnated plastic film capacitors of a common design typically used in microwaves. These non-polarised capacitors are integrated in a roughly hand-sized aluminium housing and are fully filled with liquid. The capacitors are made of aluminium film separated by several layers of plastic film. According to the classification model in Table 1, these are capacitors with metal and dielectric film with liquid impregnation.

Figure 3: Microwave capacitors from decommissioned microwaves

4 Literature research

4.1 Classification of capacitors

Capacitors are electrical components that can briefly store and release electrical energy. They consist of two differently charged conductive plates at a specific distance from one another. The capacity of the capacitor depends on the plate area and the material in the space between the plates (Kuchling, 1996).

Numerous different types of capacitors are possible in technical applications. These are divided into different classes in the specialist literature on electronic components. This classification is based on the materials used and the method of production. Table 1 shows the classification of the capacitors according to Hering (Hering et al., 2014). Missing information, particularly about tantalum capacitors, has been added from manufacturer documents. This study looks at capacitors with liquid electrolytes or with oil impregnation. The literature knowledge about these is listed in the “Dielectrics” column.

The recycling industry parlance uses a much simpler classification model for capacitor types which we also use for our study:

- Firstly, non-polarised cylindrical capacitors refer to all capacitors which have a more or less cylindrical shape and are not electrically polarised.
- Secondly, electrolytic capacitors refer to all aluminium electrolytic capacitors. These are cylindrical and have a positive and a negative pole, thus are polarised.
- Thirdly, microwave capacitors refer to the non-polarised capacitors with aluminium housing used in microwaves. These microwave capacitors are systematically a subset of the non-polarised cylindrical capacitors. The classification in a separate group based on the appliance type in which they are found causes a break in the classification. This is warranted by the large amount of liquids contained and the characteristic design which differs from all other capacitors.

Table 1: Classification of the capacitors

Construction	Plate material	Further division	Dielectric	Recycling capacitor type
Metal and dielectric film	Metal film	*According to material of the plastic film:* polycarbonate, polyphenylene sulphide, polypropylene, polystyrene, PET, power capacitor	Plastic film between metal film (usually aluminium), abbreviation denotes type of dielectric film	Non-polarised cylindrical
	Metal film		Two films between metal film: plastic film and paper or plastic film *Oil impregnation*	Micro-waves
Metal paper and dielectric film	Metallised paper		Plastic film between vaporised paper *Oil impregnation*	Non-polarised cylindrical
Metallised dielectric film	Metallised paper		Impregnated paper, metal layer evaporated For power capacitor, also impregnated paper in between Hard wax and *oil impregnation*	
	Metallised paper on both sides		Polypropylene film *Oil impregnation*	
	Metallised plastic film	*According to material of the plastic film:* polycarbonate, polyphenylene sulphide, polypropylene, polystyrene, PET, cellulose acetate (historically)	Plastic film, metal layer evaporated, no intermediate film Hard wax or *oil impregnation* possible	
Electrolyte	Aluminium		*With liquid electrolytes*: blotting paper impregnated with salt solution between aluminium film Generally polarised component, also non-polarised for special applications (audio)	Electrolyte
	Solid aluminium	Manufacturer Vishay	Manganese dioxide on glass fibre fabrics	
	Liquid tantalum	Historically and in the military: film capacitors with liquid electrolytes	Historically and in the military: paper strips impregnated with 55 per cent sulphuric acid between tantalum films Currently: tantalum sinter body surrounded by sulphuric acid as electrolyte, Teflon isolator (Wikipedia, 2016)	

Construction	Plate material	Further division	Dielectric	Recycling capacitor type
Electrolyte/ sinter	Solid tantalum		Tantalum sinter body moulded in manganese dioxide or conductive polymer; polypyrrole (PPy) or poly(3,4-ethylenedioxythiophene) PEDOT	
Sinter	Ceramic	Class 1: low, class 2: high, class 3: highest dielectric constant	Titanium dioxide, barium oxide	
Adjustable	Variable capacitor		Depending on model: vacuum, inert gas SF_6 or air	
	Air/ceramic trimmer		Depending on model: air, plastic films, ceramic	
	Integrated capacitor, MOS capacitor	metal insulator semiconductor structure	Silicon dioxide	

4.2 Liquid substances

4.2.1 Literature sources

The liquid substances in capacitors were deduced through numerous data sources. The capacitor study by (Eugster et al., 2008) on behalf of SENS and Swico provided a compilation of substances and substance groups which can be found in PCB-free capacitors. In Annex D, the study by (Chappot et al., 2007) provided possible compounds and substance groups for the substances through the screening analysis of ground capacitor samples from WEEE. Within the scope of the preliminary examination for the study mentioned above (Gloor, 2007), an examination report from the analysis laboratory Bachema provided analysis results for compounds from the GCMS analysis of crushed microwave capacitors. An internal compilation of Annex D from (Chappot et al., 2007) was made available with further analysis results for microwave capacitors (Eugster, 2007) by the elaboration of the study by (Eugster et al., 2008). These originated in part from (Gloor, 2007). However, the table also includes additional substances for which there are no analysis reports. The reference book *Elektronik für Ingenieure und Naturwissenschaftler* (*Electronics for Engineers and Scientists*) (Hering et al., 2014) references three additional possible electrolytes in aluminium e-caps. (Groen, 2013) carried out a study on the proportion of PCB-containing capacitors on behalf of the Dutch take-back system for electrical appliances. However, the study did not define any substances of the PCB-free capacitors. In France, the clearing house for all take-back systems OCAD3E carried out a large-scale capacitor study (eco-systèmes, 2012). The results include a classification of capacitors according to appearance and probability of occurrence of PCBs or other pollutants in each category. The study reports biphenyl, naphthalene, dibutyl phthalate and dimethylbiphenyl to be the most critical hazardous substances in PCB-free film capacitors. For electrolytic capacitors, the study lists boric acid, ethylene glycol, dimethylacetamide and sulphuric acid as hazardous substances. This list raises the question of whether it refers to the substance groups or individual substances. According to our own literature research, the strong sulphuric acid only appears as a main component in tantalum film capacitors which are used infrequently for special applications. In another study, (Mauro et al., 1999) analysed liquid dielectrics in large capacitors on behalf of the Electric Power Research Institute in California. Whether the substances in these mixtures are also used in small capacitors is not clear within the literature, so they were not included in the list of substances in small capacitors.

4.2.2 Manufacturer's specifications

Manufacturers sometimes declare the substances in their capacitors. EPCOS/ lists solvents, bases and acids in the electrolytes of aluminium e-caps in their material data sheets, but do not provide a complete declaration. The declared solvents are ethylene glycol and γ-butyrolactone, the weak base is N-methylpyrrolidone and acids are non-specifically declared as carboxylic acids (TDK, 2014). Another manufacturer of special capacitors also declared its electrolytes as γ-butyrolactone and ethylene glycol (Mundorf, 2016).

It proved difficult to find knowledgeable contact persons at the capacitor manufacturers. Consulting the contact persons listed by the manufacturer EPCOS on its technical data sheets led to a response from the product engineer at the Chinese factory (Werner, 2016). The response revealed that even capacitors with metallised plastic films can contain liquid impregnations. According to the response, more detailed information would only be available for specific capacitor models.

4.2.3 Patents

A German patent (Güntner et al., 1991) lists dimethylformamide, γ-butyrolactone, N-methylpyrrolidone and ethylene glycol as typical solvents for electrolytes. Aromatic carboxylic acids are mentioned as electrolytes in a narrower sense, specifically picric acid, salicylic acid, dihydroxybenzoic and trihydroxybenzoic acid, and phthalic acid. In addition, three example mixtures for electrolytes are specified, each consisting of five to six components. The patent holder is a factory for capacitors in power engineering. It therefore remains unclear whether the mixtures described are also used in small capacitors. An older patent from the USA describes a dimethylformamide electrolyte as a solvent and phosphotungstic acid as an ion donor (Hand, 1970). This acid is a heteropoly acid. Other substances from this group of substances can also be used in electrolyte mixtures, for example silicotungstic acid or molybdenum tungstic acid (Alwitt, 1977). An international patent describes two electrolyte mixtures of over a dozen components in detail: the main components are ethylene glycol, polyethylene glycol, ammonium pentaborate, ammonium salts of methylbenzoic acids and diammonium salts of various organic acids (Ebel, 2002).

Capacitors with metallised paper films and intermediate film layers for insulation are impregnated with liquids that are considered to be particularly insulating and stable up to temperatures in the range of 150°C. PCBs fulfilled this function in a practically ideal way. One possible substitute is vegetable oils. A US patent uses soybean oil with 0.05 to 10 per cent butylated hydroxyanisole and approximately 10 per cent "α-dodecene-tetradodecene" (Shedigian, 1985). The author presumably refers to a technical mixture of 1-dodecene and 1-tetradecene. Another patent mixes triacetin with epoxidised soybean oil (Shedigian, 1987). We also know from our own experience that castor oil can be used. In addition, mineral oils can also be suitable. A mixture of aliphatic and aromatic hydrocarbons is described specifically for plastic capacitors in a patent by Japanese authors (Sato et al., 1979). This is acquired directly by cracking petroleum and comprises numerous unspecified substances. Other possible impregnating agents include polymerised butenes and silicone oil (Eustance, 1970), as well as phthalates (Jay et al., 1979). (Schulz et al., 1980) describe an insulating oil made of paraffin oils and diarylalkanes. The term diarylalkanes refers to a group of substances consisting of molecules with two benzene rings, connected through a carbon atom. There is a group of atoms on both the rings and on the connecting carbon. According to the patent specification, carbon chains with up to eight carbons are possible here (alkyl groups). 1,1-di(4-methylphenyl)ethane and 1,1-di(3,4-dimethylphenyl)ethane are specified as the preferred diarylalkanes (Schulz et al., 1980). Microwave capacitors are sometimes labelled to contain diarylalkanes, indicating the use of the aforementioned substances in this product group. The analysis results of this study confirm this suspicion, see chapter 6.1.4.

4.3 Classification of the substances

4.3.1 The term substances of concern in literature

According to the CENELEC standard EN 50625-1, Annex VII of the WEEE Directive (European Parliament, 2012) and SENS and Swico technical regulations (SENS et al., 2012), “electrolytic capacitors containing *substances of concern* (height > 25 mm; diameter > 25 mm or proportionately similar volume)” must be removed from waste electrical and electronic equipment. The term “substances of concern” is not defined further in the basic principles. The WEEE Directive (European Parliament, 2012) also refers to these as substances of concern. No further definition of this term is provided.

A full-text search in European legislation on substances of concern results in hits within two regulations and four directives (EU, 2016). These are the Regulation (EC) No. 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH Regulation) and the Regulation (EU) No. 528/2012 of the European Parliament and of the Council concerning the making available on the market and use of biocidal products. The directives are the WEEE Directive, the Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy, the Directive 98/8/EC of the European Parliament and of the Council concerning the placing of biocidal products on the market, and the Council Directive 86/469/EEC concerning the examination of animals and fresh meat for the presence of residues.

None of the mentioned regulations or directives define the term substance of concern. The term is used in different ways. It is used in the sense of dangerous substance and in the sense of interesting substance, for example in an animal experiment.

In Switzerland, the Ordinance of 18 May 2005 on Risk Reduction related to the Use of certain particularly dangerous Substances, Preparations and Articles (ORRChem – *Verordnung vom 18. Mai 2005 zur Reduktion von Risiken beim Umgang mit bestimmten besonders gefährlichen Stoffen, Zubereitungen und Gegenständen,* *ChemRRV*) contains "Provisions relating to specific substances" in Annex 1 (Swiss Federal Council, 2005a). These provisions include prohibitions, exemptions and restrictions for groups of substances or individual substances. In addition, Annex 2 outlines "Provisions relating to groups of preparations and articles". Annex 2.14, on the other hand, defines pollutant-containing capacitors which are prohibited from being placed on the market or imported. Pollutant-containing capacitors are those containing "PCBs, halogenated diarylalkanes or halogenated benzenes". In addition, capacitors "containing substances or preparations containing more than 500 ppm monohalogenated or more than 50 ppm polyhalogenated aromatic compounds" are also considered to contain pollutants (Swiss Federal Council, 2005a). However, the term substances of concern is not used in the ORRChem. In addition, the Swiss Ordinance of 10 November 2004 on the Rotterdam Convention on the Prior Informed Consent (PIC) Procedure for Certain Chemicals in International Trade (Swiss Federal Council, 2005b) defines "Substances and preparations that are banned or subject to severe restrictions in Switzerland" and "Substances and severely hazardous pesticide formulations subject to the prior informed consent procedure".

The REACH Regulation (European Parliament, 2006) makes reference to restrictions on "dangerous substances and preparations". "Substances of very high concern (SVHC)" are also identified on which authorisation restrictions are then imposed.

For use in practice, it is essential to define the term "substances of concern" for the recycling of WEEE. Such a definition is suggested in chapter 7.1.

4.3.2 Classification of substances according to the GHS

The identified substances according to the discussion in chapter 7.2 are classified in terms of their danger to humans and the environment. To this end, the H-statements of the GHS were researched for all substances. As a source, we preferred to use the European harmonised classification as published by the European Chemicals Agency (ECHA, 2016a) according to Annex VI of the CLP Regulation (European Parliament, 2008). If there was no harmonised classification available for a substance, we used the manufacturer classifications as reported in the C&L Inventory. It is often the case that not all manufacturers classify a certain substance with the same H-statements. For each individual case, we included the H-statements in Table 2 which were mentioned in the majority of manufacturer reports. For individual substances, we adopted the classifications from the manufacturers' safety data sheets (SDS). For comparison, Table 2 also includes the classification of polychlorinated biphenyls (PCBs), which by definition are not found in PCB-free capacitors.

Table 2: GHS classification of the liquid substances in capacitors

Chemical designation	CAS No.	GHS labelling according to ECHA
1-Chloronaphthalene (chlorinated naphthalenes)	90-13-1	H302, H315, H319, H335, possibly H400 in 27 of 35 manufacturer reports
1-Decene	872-05-9	H226, H304, H400, H410
1-Dodecene	112-41-4	H304, H315, H411
1-Methyl-4-(phenylmethyl)benzene	620-83-7	H315, H319, H335
1-Methylnaphthalene	90-12-0	H302, H304, H315, H319, H334, H335 (lungs, respiratory tracts), H411
1-Tetradecene	1120-36-1	H304, H315, (H411)
1,1-Bis(3,4-dimethylphenyl)ethane	1742-14-9	No classification

Chemical designation	CAS No.	GHS labelling according to ECHA
1,1-Bis(4-methylphenyl)ethane	530-45-0	No classification, in Annex III list of the REACH Regulation
1,1-Diphenylethane, diarylethene	612-00-0	No information
1,1'-(1-Methylethylidene)bis(4-methylbenzene)	Unknown	No information
1-Methoxy-2-nitrobenzene/2-nitroanisole	91-23-6	H302, H350
1,2-Dimethyl-4-(phenylmethyl)benzene	13540-56-2	No information
1,2,3-Trimethyl-4-(1E)-1-propenyl-naphthalene	26137-53-1	No information
1,2-Benzenedicarboxylic acid	88-99-3	H315, H319, H335
1,3,5-Cycloheptatriene, 6-methyl-1-(6-methyl-1,3,5-cycloheptatrien-1-yl)-	Unknown	No information
1,5,6,7-Tetramethyl-3-phenylbicyclo[3.2.0]hepta-2,6-dien	126584-00-7	No information
1,3-Benzenedicarboxylic acid	121-91-5	No classification
2-Ethylhexanol	104-76-7	H315, H319, H332, H335
2-Hydroxybenzoic acid, salicylic acid	69-72-7	H302, H312, H315, H318, H319, H335
2-Methylnaphthalene	91-57-6	H302, H400, H410
2-Hydroxyethyl benzoate	94-33-7	No information
2,2'-Dimethylbiphenyl	605-39-0	No classification (SDS Sigma-Aldrich)
2,2',5,5'-Tetramethylbiphenyl	3075-84-1	H302, H319, H400, H410
2,3,4,4a-Tetrahydro-1α,4aβ-dimethyl-9(1H)-phenantron	94571-08-1	No information
2,4-Dihydroxybenzoic acid	89-86-1	H315, H319, H335
2,6-Diisopropylnaphthalene	24157-81-1	H302, H400, H410
3-Nitroacetophenone	121-89-1	H412
3,4-Epoxy cyclohexane carboxylic acid-(3,4-epoxycyclohexyl methyl ester)	2386-87-0	H317, H412
4-Isopropylbiphenyl	7116-95-2	No classification, in Annex III list of the REACH Regulation
4-Nitrobenzyl alcohol	619-73-8	H302, H315, H319, H332
4-Nitrophenol	100-02-7	H302, H312, H332, H373
5-Ethyl-2-methyl-4,4-diphenyl-3,4-dihydro-2H-pyrrole (EMDP)	102177-18-4	No information
Ammonium pentaborate	12046-04-7	H361
Benzoic acid	65-85-0	H315, H318, H372
Benzyl alcohol	100-51-6	H302, H332
Benzyltoluenes	27776-01-8	H304, H315, (p-,o-: H319), H332, (p-,o-: H335), H400, H410
Biphenyl	92-52-4	H315, H319, H335, H400, H410
Bis(7-methyloctyl)phthalate	20548-62-3	No classification (SDS Sigma-Aldrich)
Boric acid	11113-50-1	H360FD
Butyldiglycol	112-34-5	H319, H411, H336
Butylated hydroxyanisole	25013-16-5	H315, H319, H351, H361, H411
Di-p-tolyl-methane	4957-14-6	H302, H330, H413
Dibutyl phthalate	84-74-2	H360Df, H400, (H410/H411/H412)
Diethylamine	109-89-7	H225, H302, H312, H314, H318, H332, H335

Chemical designation	CAS No.	GHS labelling according to ECHA
Diethylene glycol	111-46-6	H302, H373 (kidney) (oral)
Diethyl phthalate	84-66-2	Not classified, up to H 400 in 7 of over 1 000 records
Diisobutyl phthalate	84-69-5	H360Df
Diisodecyl phthalate	26761-40-0	Not permitted in children's products (Annex XVII of the REACH Regulation, item 52), possibly H400, H410 or H411
Diisononyl phthalate	28553-12-0	Not permitted in children's products (Annex XVII of the REACH Regulation, item 52), possibly H400
Dimethylacetamide	127-19-5	H312, H332, H319, H360D
Dimethylformamide	68-12-2	H360D, H226, H332, H312, H319
Dinonyl phthalate	84-76-4	No classification
Ethyl(1-phenylethyl)benzene	18908-70-8	No information
Ethylene glycol, ethane-1,2-diol, monoethylene glycol	107-21-1	H302, H373
N-Methylpyrrolidone	872-50-4	H315, H319, H335, H360D
Naphthalene	91-20-3	H302, H351, H400, H410
Phenol	108-95-2	H301, H311, H314, H331, H341, H373
Polychlorinated biphenyls (PCB)	1336-36-3	H400, H410, H373
Polyethylene glycol	25322-68-3	No classification
Castor oil	8001-79-4	No classification
Soybean oil	None	No classification
Triethylamine	121-44-8	H225, H302, H312, H314, H332
Trioctyl trimellitate	3319-31-1	Possibly H361
γ-Butyrolactone	96-48-0	H302, H318, H336

5 Methods

5.1 Capacitor sampling

5.1.1 Scope of the analysis

The inventory and typology included all capacitors in the SENS and Swico take-back systems which are longer than 2.5 cm in one dimension. All aluminium e-caps smaller than 2.5 cm in all dimensions were also collected from Swico appliances.

5.1.2 Sampling concept

Capacitors were collected from SENS and Swico appliances over a specific period of time. Four recyclers or disassembly facilities were commissioned to collect the appliances. The appliance categories were chosen so that the capacitors could be analysed separately in groups of clearly distinguishable appliance types. The collection by categories also made functional differences in the used capacitor types visible. However, the number of categories should not be so large that only a handful of capacitors remain in each category. Excessively small samples do not enable a statistically reliable evaluation of the substances found. The final determination of the collection categories was carried out after preliminary tests at a disassembly facility which are documented in chapter 5.1.5. The capacitors for the appliance categories were collected according to Table 3. A collection of capacitors from cathode ray tube (CRT) computer screens was also intended. However, no appliances of this category arrived at the commissioned disassembly facility during the collection period.

Table 3: Appliance categories for the collection of capacitors

Appliances in the SENS system	Appliances in the Swico system
Large household appliances divided into: – Washing machines – Dishwashers – Other large household appliances	– PC flat screens – TV flat screens – CRT TV screens
– Refrigerators – Ballasts from luminaires	– Desktop computers including power supply units – External laptop power supply units – Uninterruptible power supplies (UPS)
SENS small appliances divided into: – Microwaves – Small household appliances with motors: coffee machines, vacuum cleaners, fans, electric drills, blenders, etc. – Other small household appliances	– Large-scale photocopiers – Multifunctional printers
	– Audio devices such as amplifiers, radios, compact systems – Loudspeaker boxes with at least 2 loudspeakers – Video cassette recorders

The 19 appliance categories for the collection according to Table 3 led to a great differentiation. For the laboratory analysis of the substances, mixed samples were formed across several collection categories based on the collection results, as shown in Table 10.

After collection, all non-polarised cylindrical capacitors and microwave capacitors larger than 2.5 cm were classified according to the following criteria:

1. Appliance category in which the capacitor was found
2. Capacitor manufacturer
3. Model designation from the manufacturer as printed on the capacitor
4. Number of capacitors found with the same model designation
5. PCB content (PCB-free, suspected of containing PCBs, PCBs contained) according to age and capacitor list (Arnet et al., 2011)
6. Declared substances (according to label)
7. Year of production according to printing on the capacitor
8. Construction type where possible (according to Table 1)

Figure 4: Example of two capacitors with the model designation MAB MKP 10/500

Aluminium electrolytic capacitors were classified in a much simpler manner. These capacitors are only labelled with the manufacturer and their capacity. Model names were printed on very few models in the collection. The classification could thus only be made according to the manufacturer:

1. Appliance category in which the capacitor was found
2. Manufacturer
3. Construction type (always aluminium electrolyte according to Table 1)

The classification was carried out by the study authors themselves. Without opening the capacitor, the construction type according to Table 1 could only be determined beyond doubt for aluminium e-caps. On other capacitors, the construction types were sometimes specified and could be recorded. It was often unclear if parts of the model designations should be understood as a construction type abbreviation.

Furthermore, the masses and unit quantities of electrolytic capacitors smaller than 2.5 cm were recorded for the Swico categories. It was hence possible to calculate an estimate of the mass fractions of small and large capacitors in the appliances, which are shown in chapter 7.6.2. The number and masses of the appliances from which the capacitors were taken could also be recorded for the Swico categories.

5.1.3 Representative sampling

To fulfil the requirement of representative sampling, every capacitor collected in Switzerland from WEEE must have the same chance of being included in the sample. This would be the case, for example, if all the disassembly facilities and recyclers collected a certain proportion of the capacitors separately throughout the year. However, such an approach is not feasible due to organisational, logistical and economic limits. As an alternative, some suitable disassembly facilities and recyclers have collected all the capacitors received during a specific time period. This sampling is random in that the period is not fixed from the outset. In principle, it could take place every week of the year. However, limiting the sampling time to a short period creates another problem: large equipment and luminaires, in particular, are often received in larger batches, for example from demolitions or renovations. Appliances from individual batches may thus be disproportionately represented in the sample. In addition, recyclers or disassembly facilities often do not process all appliance categories. For example, many facilities remove the capacitors from large equipment and pass on SENS small appliances and Swico appliances to other SENS or Swico facilities in an unprocessed state. To ensure a sample that is as representative as possible, several facilities should ideally be involved in the collection of each appliance category to limit the impact of larger batches and potential regional differences. Unfortunately, this was not always possible. In particular, the ballasts collected from fluorescent luminaires originated from a recycler who had received them from a few larger deliveries. This puts into doubt how representative this sample may be. The capacitors from refrigerators were also collected by only one recycler. However, since this recycler has a market share percentage in the double-digits for the processing of refrigerators, this could still be considered a representative sample.

5.1.4 Sample size

Certain statistical considerations are needed to determine the sample size. One of the study's questions is: "How large is the proportion of capacitors containing PCBs?" For a small proportion of PCB-containing capacitors in a sample to be verified at all, a sample of sufficient size is required. An estimate of the proportion of PCB-containing capacitors is therefore needed first. This estimate can be made using the data from the capacitor study (Eugster et al., 2008) and the luminaire study (Gasser, 2009). It must also be established how certain the fraction should be determined. In technical terms, how large the probability may be that the true value lies outside the permitted accuracy. In accordance with scientific practice, this value is set at 5 per cent. The third important figure is the desired accuracy. By what percentage may the sample result deviate from the true value? In technical terms, how big can the confidence interval be? Since this study aims to verify whether PCB-containing capacitors can still be found in relevant quantities, a very accurate result is not required. However, the confidence interval must be small enough that the expected proportion of PCB-containing capacitors can be measured.

In the 2008 PCB study, PCB mass fractions according to Table 4 were found in the shredded capacitor samples. In 2006, the disassembly of ballasts from luminaires resulted in shares of PCB containing capacitors according to Table 5.

Table 4: Mass fraction of PCB in capacitors – data from 2008 PCB study

Appliance category	PCB content from [g/kg]	to [g/kg]
Large household appliances	1.5	16.5
Dishwashers	0.17	0.22
Small household appliances	0.35	0.43
Microwave ovens	0.011	
Refrigerators	Under limit of quantitation	
Ballasts	24.3	247.7
IT/CE capacitors < 1 cm	Under limit of quantitation	
IT/CE capacitors < 1–2.5 cm	0.054	0.055
IT/CE capacitors > 2.5 cm	1.1	1.9
UPS systems	Under limit of quantitation	

Table 5: Share of capacitors containing PCB – data from 2009 luminaires study

Appliance category	Share of capacitors containing PCBs	
	Minimum	Maximum
Ballasts	60.5%	70.5%

From the data in the two studies, a correlation between the PCB content in the capacitors study (Eugster et al., 2008) and the share of PCB-containing capacitors in the luminaires study (Gasser, 2009) can now be established for capacitors from ballasts. An average value for the PCB content of each appliance category is calculated from the published PCB contents of a maximum of three laboratories in (Eugster et al., 2008). The ratio is then formed for ballasts between the minimum proportion of PCB capacitors and the average PCB content of the appliance category. This ratio is then multiplied by the average PCB content of the other appliance categories to obtain an estimate of the minimum proportion of PCB-containing capacitors in each category. To determine the upper limit, the ratio between the maximum proportion of PCB capacitors and the average PCB content is first determined for ballasts. Further calculations are then made analogously. The results of this estimation are listed in Table 6.

Table 6: Estimation of capacitors containing PCBs in quantities for all appliance categories

Appliance category	Average PCB content [g/kg]	Share of capacitors containing PCBs	
		Minimum	Maximum
Large household appliances	7.02	3.7%	4.4%
Dishwashers	0.20	0.1%	0.12%
Small household appliances	0.39	0.21%	0.24%
Microwave ovens[1]	0.01	0.006%	0.007%
Refrigerators	0	0%	0%
Ballasts	113.52	60.5%	70.5%
IT/CE capacitors < 1 cm	0	0%	0%
IT/CE capacitors < 1–2.5 cm[1]	0.055	0.03%	0.03%
IT/CE capacitors > 2.5 cm	1.5	0.81%	0.95%
UPS systems	0	0%	0%

The estimated shares already show that quantities of more than 1 per cent are only expected for large household appliances and ballasts. The other appliance categories already showed very low proportions which are likely to have reduced further since the capacitors study. The method according to (Rasch et al., 2011) is used to calculate the required sample size. The sample size to determine PCB-containing capacitors is calculated according to Formula 1.

$$n = \frac{p \cdot (1-p) \cdot u^2_{1-\frac{\alpha}{2}}}{\delta^2}$$

Formula 1: Calculation of the sample size for the share of PCB-containing capacitors

The maximum number of expected capacitors is used for p, u denotes the p-quantile of the standard normal distribution at the selected significance level, and δ denotes the permitted deviation. The trial use of some values now shows that very small proportions of less than 1 per cent can no longer be measured with reasonable effort. If, for example, 1 per cent is used as the upper limit and a deviation of ±0.1 per cent is permitted, the result is a sample size of 38 000 capacitors. If the accuracy is reduced to 0.5 per cent, the sample size drops significantly to a manageable 1,522 units. These calculations show that a more differentiated examination according to appliance categories is sensible for the experimental design.

For large household appliances, the examination must determine whether no PCB-containing capacitors are generally to be expected in SENS large appliances. The upper limit can thus be set to 4 per cent across all appliances and a permissible deviation of ±1 per cent can be tolerated. These specifications result in a required sample size for large household appliances of 1,476 units with a significance level α of 5 per cent.

The share of PCB-containing capacitors is expected to be largest in ballasts from fluorescent luminaires. Take stock of the situation is sensible but establishing a percentage with complete accuracy is not necessary. The proportion of PCB-containing capacitors is assumed to be 60 per cent. If an accuracy of ±5 per cent is

[1] Presumably a carry-over in the sampling.

tolerated, then a required sampling size of 369 capacitors ensues at the significance level of 5 per cent.

In order to determine the substances in PCB-free capacitors, requirements for the result must also be specified. The confidence interval can again be 5 per cent. When determining the concentration, we allow a deviation of ±5 per cent since we are particularly interested in the scale at which a substance occurs and not in determining the exact composition. To determine the liquid substances in PCB-free capacitors, the sample size must again be calculated according to Formula 1, whereby the permitted deviation is now set to ±5 per cent. The 5 per cent refers to the composition of the liquid substances in all capacitors as a total mixture. The worst-case value for p of 0.5 is used to calculate the sample size. A level α of 5 per cent results in a minimum sample size of 385 units. All statistical calculations were made using the statistics software R (R Development Core Team, 2018).

The statistical calculations lead to the following sampling programme: a total of 1,500 capacitors are collected from large household appliances. An assertion about the main components of the substances in all capacitors in an appliance category should be possible for the substances in PCB-free capacitors. Ideally, the substances of 400 PCB-free capacitors would be analysed individually. However, such an analysis programme would not be financially feasible. An analysis strategy with mixed samples will therefore be chosen which will be outlined in the methodology chapter for the analysis of the substances. The collection targets are shown in Table 7 per appliance category. In total, this results in a sample size of 5,250 capacitors

Table 7: Planned sample sizes per appliance category

No.	Appliance category systems	Collection category	Collection target, number of capacitors
11a	Large household appliances	Washing machines	1 000
11b	(total 1,500 capacitors)	Dishwashers	400
11d		Other	100
12	Refrigerators	Refrigerators	400
13	Ballasts from luminaires		400
14a	SENS small appliances	Microwaves	400
14b1		Appliances with motors	400
14b2		Vacuum cleaners and high-pressure cleaners	
14c		Other	400
21	PC monitors/Swico 010	PC flat screens	250
22	Office electronics, computing, communications/Swico 080	TV flat screens	
21	PC monitors/Swico 010	PC CRT screens	
22	Office electronics, computing, communications/Swico 080	TV CRT screens	
23a	PC/server/Swico 030	Desktop computers including power supply units	500
23b	Office electronics, computing, communications/Swico 030	Uninterruptible power supply (UPS)	
23c	Office electronics, computing, communications/Swico 030	External power supply units	

No.	Appliance category systems	Collection category	Collection target, number of capacitors
24a	Large-scale photocopiers, rollable plotters/Swico 060	Large-scale photocopiers	500
24b	Office electronics, computing, communications/Swico 060	Multifunctional printers	
25a	Remaining consumer electronics/Swico 130	Audio devices such as amplifiers, radios, compact systems	500
25b		Loudspeaker boxes with at least 2 loudspeakers	
25c		Video players (VHS)	
Total			5,250

5.1.5 Preliminary tests

Preliminary tests were carried out for disassembling SENS small appliances and electronic appliances at a disassembly facility. The appliance categories for sampling have been definitively determined based on the findings from these tests. During the disassembly tests, the appliances were disassembled according to Table 8. The table also lists which capacitors were found in the appliances.

Table 8: Appliances disassembled during the preliminary tests and capacitors found

Disassembled appliance	Electrolytic capacitors < 2.5 cm	Capacitors > 2.5 cm
Microwave	Several	1 unit
External power supply unit for laptop	Several	At least 1 unit
Internal power supply unit	Several	At least 1 unit
Coffee machine, flow	1 unit	None
Steam iron station	Several	None
Iron	None	None
Electric lawnmower	None	None
Large-scale photocopiers	Dozens	At least 5 units
Fluorescent luminaire ballasts, not electronic	None	0–1 units

The disassembly tests were documented as photographs below. Figure 5 shows an opened microwave with the typical microwave capacitor for increasing the voltage. This can be seen in the picture on the bottom right as a metal housing with rounded corners. Figure 6 shows the circuit boards of two internal power supply units, each with one or two large electrolytic capacitors. The three copper coils are also clearly visible on the right circuit board.

Figure 7 shows the opened power supply unit of a laptop. The inside of the plastic housing holds a metal sheet which shields the circuit board. The large electrolytic capacitor is visible in the middle of the circuit board itself. There are also other smaller electrolytic capacitors. Figure 8 shows the circuit boards of a large-scale photocopier. Many of these contain small electrolytic capacitors. The four circuit boards in the front to the right of the centre each contain a large electrolytic capacitor, as does the leftmost circuit board in the middle of the table.

The interior of a steam iron station can be seen in Figure 9. The water pump at the centre does not require a large capacitor. There are some smaller electrolytic capacitors on the top right of the circuit board. The brush motor of the electric lawnmower in Figure 10 does not require a capacitor.

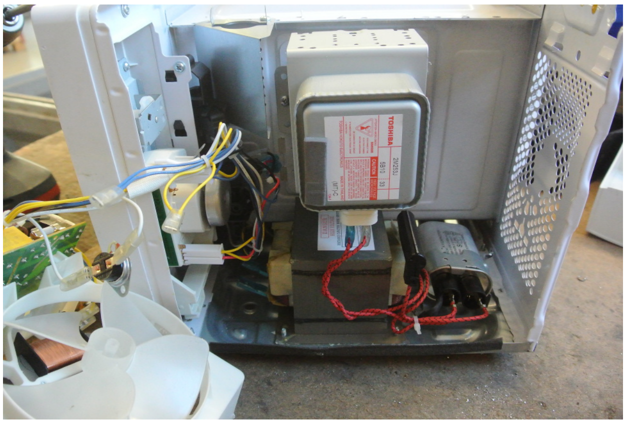


Figure 5: Microwave with typical capacitor in the bottom right of the picture

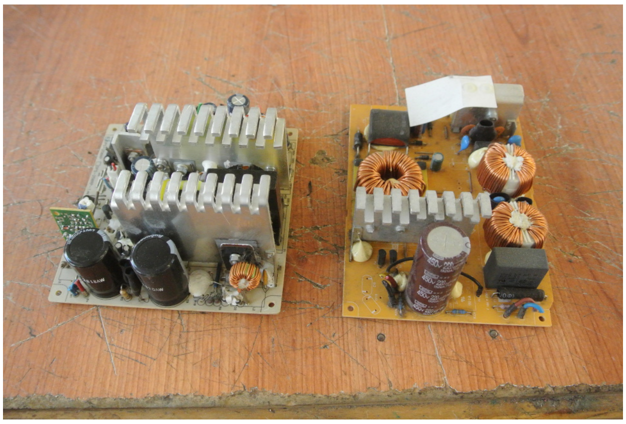


Figure 6: Internal power supply units from electrical or electronic appliances

Figure 7: External power supply unit to operate a laptop

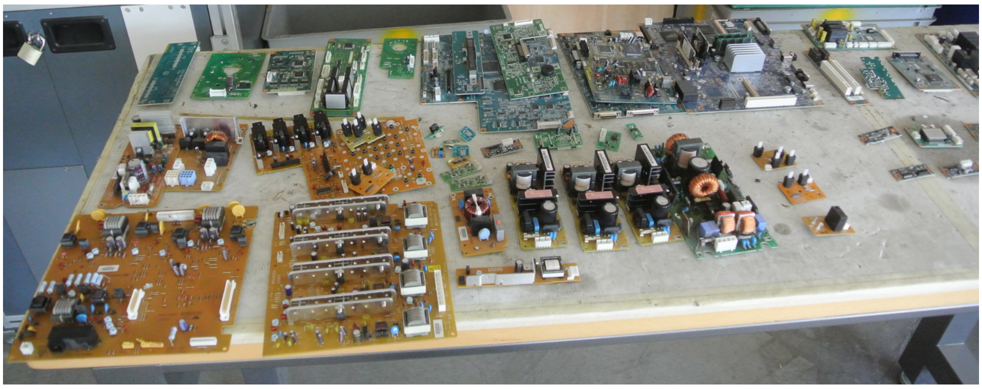


Figure 8: Circuit boards of a large-scale photocopier

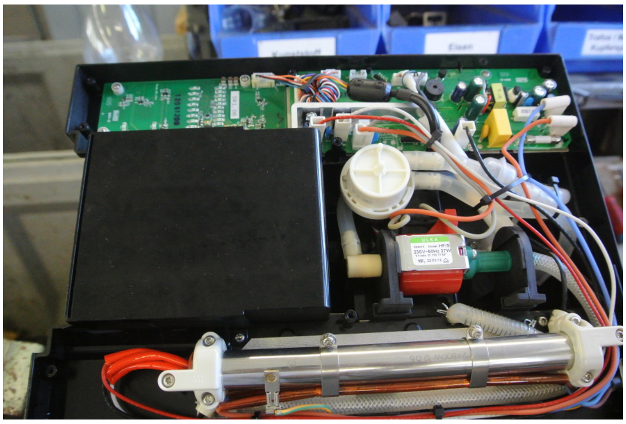


Figure 9: Interior of a steam iron station

Figure 10: Rotor of the brush motor of an electric lawn mower

5.2 Analysis of substances

5.2.1 Separation of liquids

5.2.1.1 Extraction of liquids for laboratory analysis

The liquids must be expelled from the capacitors for laboratory analysis. The best approach had to be found experimentally for each type of capacitor. The appropriate procedure was defined for each construction type. These are described in Table 9.

Table 9: Approach for separating the liquids per capacitor type

Capacitor type	Extraction method
Non-polarised cylindrical	Cut open the front end of the capacitor over the sampling vessel. Allow the escaping liquid to flow into the vessel. If necessary, cut the capacitor again on the other end to extract more liquid.
Electrolytic capacitor	Cut the capacitor open on both ends, pull the coil from the aluminium casing, separate the bitumen seal from the coil. Cut the coil down the middle and place the halves into two sampling vessels.
Microwave capacitor	Cut the front end of the capacitors over the sampling vessel. Collect plenty of the escaping liquid in the sampling vessel.

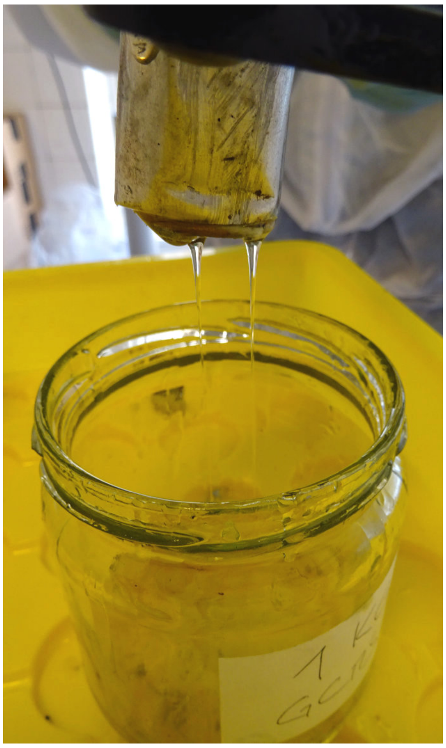


Figure 11: Liquid flowing from a non-polarised cylindrical capacitor after cutting

The liquids from the non-polarised cylindrical capacitors and microwave capacitors flowed out after cutting due to gravity alone, as can be seen in Figure 11. These were collected in a vessel and the liquid sample was then sent to the laboratory. The liquids in aluminium electrolytic capacitors are bound in the blotting paper between the aluminium films and do not flow out after opening the capacitors. The preliminary tests are described in the following chapter 5.2.1.2. The coil was therefore removed from these capacitors, halved and collected in two sampling jars. This resulted in two identical mixed samples which were supplied to the laboratory. One was used for extraction with an organic solvent, the other for extraction with water.

5.2.1.2 Separation tests in electrolytic capacitors

The liquid electrolyte is strongly bound to the impregnated paper in electrolytic capacitors. Attempts were first made to pierce the capacitors and leave the electrolyte to flow out into a container. This method proved ineffective. After a test period of 13 days, no liquids had flowed out of the capacitors. The containers were stored in the dark at room temperature during the test. See both photos in Figure 12.

Figure 12: Piercing the e-caps and dry containers after a 13-day test period

5.2.2 Analysability of the expected substances

Before planning the laboratory analyses, it was clarified with the commissioned laboratory which analytical methods could be used to detect the substances potentially found in capacitors. The substance lists of all possible substances known from the literature study were sent to the laboratory for this purpose (lists in Annex B). The laboratory management (Ruckstuhl et al., 2018) then informed the authors about which substances could be analysed through a GCMS analysis, headspace with GCMS analysis or LCMS analysis. In addition, they proposed analysing the elements tungsten and boron via inductively coupled plasma (ICP), as the desired tungstic and boric acids cannot be analysed in GCMS or LCMS. After consulting the advisory group, the analysis concept described below was adopted with this information.

5.2.3 Laboratory analysis concept

A mixed sample is created for the laboratory analysis from the collection categories of large household appliances, refrigerators, microwaves, SENS small appliances, flat screens, as well as desktop computers and external laptop power supply units. All liquid samples from non-polarised cylindrical and microwave capacitors are analysed via GCMS, and the PCB content of the samples is tested. Aluminium e-caps are analysed via GCMS and LCMS, and the elements boron and tungsten are detected via ICP. Table 10 shows the sampling programme in detail. For the microwave capacitors, the decision was made to analyse the models of the manufacturer BiCai separately. The models of this manufacturer accounted for about 50 per cent of all microwave capacitors.

Table 10: Laboratory analyses carried out per mixed sample

Appliance category	Includes capacitors from collection categories	GCMS analysis	LCMS analysis	PCB analysis	ICP analysis
Large household appliances	Washing machines, dishwashers, other large household appliances	X		X	
Refrigerators	Refrigerators	X		X	
BiCai microwaves	Microwaves	X		X	
Microwaves of other manufacturers	Microwaves	X		X	
SENS small appliances, non-polarised cylindrical	Small household appliances with motors, other small household appliances	X		X	
SENS small appliances, aluminium e-cap	Small household appliances with motors, other small household appliances	X	X		B, W
PC and TV flat screens	PC flat screens, TV flat screens	X	X		B, W
Desktop PC and laptop power supply units	Desktop computer, laptop power supply units	X	X		B, W

5.2.4 Creating the mixed samples

The mixed samples were designed so that at least 50 per cent of the capacitor models of an appliance category were represented in each liquid mixed sample of non-polarised cylindrical capacitors. In the mixed samples from aluminium e-caps, at least half of all manufacturers of capacitors in this appliance category should be represented. The samples must be representative in the sense that the models in the mixed sample should be represented in the same ratios as in the base sample. The samples were prepared and analysed in several batches. Following the analysis of the first aluminium e-caps, the sampling strategy was changed with the aim of covering all manufacturers in the mixed sample. The manufacturers whose models were only occasionally found in the sample were excluded. The reason for this was the insight after the first analysis that the peaks in the GCMS were cleanly separable and no noise was generated by mineral oils, which generate a signal in the GCMS over the entire retention period. The requirement for representative distribution of the capacitors for these samples was therefore abandoned. Table 11 shows the chosen test strategy and the desired coverage. In addition, the laboratory number of the mixed samples is identified.

Table 11: Mixed sample targets and strategies

Appliance category	Target coverage in the mixed sample	Mixed sample strategy	Reference	Sample No.
Large household appliances	50%	Representative	Models	6 HHG
Refrigerators	50%	Representative	Models	1 KG
BiCai microwaves	50%	Representative	Models	3.1 MW
Microwaves of other manufacturers	50%	Representative	Models	3.2 MW
Small household appliances, non-polarised cylindrical	50%	Representative	Models	5.1 HKG
Small household appliances e-cap	80–100%	Complete	Manufacturer	5.2 HKG
PC and TV flat screens	80–100%	Representative	Manufacturer	2 LCD
Desktop PC and laptop power supply units	80–100%	Complete	Manufacturer	7 Netz

During sampling, many capacitors were found to be dry, thus requiring continuous correction of the sampling programme while disassembling the capacitors.

5.2.5 Proportion of capacitors represented in mixed samples

The proportion of capacitors in the collection represented in the mixed sample was determined according to the following scheme: for each capacitor model represented in the mixed sample, the number of the same capacitor model in the capacitor collection was determined. The sum of these numbers provides the total number of capacitors represented in the mixed sample. This quantity is compared with all collected capacitors containing liquids. To this end, the total amount of capacitors must be corrected by the number of dry capacitors. Since this number is not precisely known, as described in chapter 6.4.1, the proportion of capacitors with liquids cannot be precisely determined either. However, the selected approach ensures a conservative estimate because more dry capacitors could be present among the collected capacitors, but not fewer. Table 12 shows the proportions of capacitors in the mixed sample compared to the amount of capacitors collected. It should also be noted that the reference variable varies. For non-polarised cylindrical capacitors, the proportion is shown at the model level (see also Table 11). For aluminium e-caps, however, it is shown at the manufacturer level. For flat screens, for example, this means that 87 per cent of the manufacturers of the collected capacitors were represented in the mixed sample. However, since aluminium e-caps have no type designations, an assertion cannot be made about what proportion of all models was represented in the mixed sample.

Table 12: Proportion of capacitors represented in the mixed sample

Appliance category	Number of capacitors opened for the mixed sample	Number of capacitor models represented in the sample	Maximum number of PCB-free capacitors containing liquids	Proportion represented in the mixed sample
Large household appliances	33	594	1,113	53%
Refrigerators	17	102	185	55%
BiCai microwaves	14	146	153	95%
Microwaves of other manufacturers	18	61	179	34%
Small household appliances, non-polarised cylindrical	13	18	23	78%
Small household appliances e-cap	23	324	400	81%
PC and TV flat screens	26	204	234	87%
Desktop PC and laptop power supply units	20	863	863	100%

5.2.6 Evaluation of the GCMS and LCMS analyses

The aim was to search for the main components in the mixed samples. The largest 10 to 20 peaks were evaluated in the GCMS chromatograms. These were compared to the laboratory's library of substance standards and the quality of the match was determined to be 1 to 100. Since mixed samples were created for cost reasons, liquids in individual capacitors could not be determined. Instead, the analysis provides a picture of the common substances in all capacitors of a mixed sample. The GCMS analysis also allowed for an approximate quantification by comparing the peak areas to those of the laboratory standard with known concentration.

The LCMS evaluation compares the atomic mass of the molecules found with a prescribed catalogue (target search) or in a generic search. For this study, the target search was carried out against the list of suspected substances according to Annex B. Hits with a matching atomic mass can be confirmed by comparison with a reference standard. The measured MSMS spectrum can be compared with the spectrum of a library, which then results in the identity being considered probable. The MSMS spectrum originates from the analysis of two mass spectrometers. The commissioned analysis laboratory uses a quadrupole MS, followed by a time-of-flight MS. The substance in the detector is divided into several fragments by inputting energy, and these then generate a characteristic pattern in the two MS. If the alignment of the MSMS spectrum is not successful, the identity is not confirmed. It could also be another substance with the exact same atomic mass.

5.3 Laboratory analysis of capacitors suspected of containing PCBs

After classifying the capacitors with the aid of the capacitor list, the proportion of capacitors suspected of containing PCBs was relatively high for large household appliances as well as refrigerators, air conditioners and freezers. Some of the capacitors from both appliance categories were analysed in the laboratory to verify their PCB content. The analysis programme was established so that the proportion of capacitors suspected of containing PCBs could be reduced to below 2 per cent for the category of large household appliances. The capacitor models with the highest quantities were chosen for the analysis to minimise the number of laboratory analyses needed. All capacitors suspected of containing PCBs were analysed for the category of refrigerators, air conditioners and freezers. For the laboratory analysis, the liquids were extracted as described under chapter 5.2.1.1. The laboratory analysis was carried out by determining seven PCB congeners and the summation was carried out in accordance with the ORRChem (Swiss Federal Council, 2005). No liquid leaked out of five capacitor models with black plastic housing, but they did contain moist blotting papers. The coils of these models were sent to the laboratory instead of the oils and the PCB content of the entire coil was determined. The PCB analysis was carried out for the same seven congeners as for the oils, but the summation was carried out in accordance with the Swiss Ordinance of 4 December 2015 on the Avoidance and the Disposal of Waste (ADWO – *Verordnung vom 4. Dezember 2015 über die Vermeidung und die Entsorgung von Abfällen, VVEA*) and the German Federal/state waste working group (*Bund/Länder-Arbeitsgemeinschaft Abfall/LAGA*).

5.4 Disassembly of electrolytic capacitors

To determine the mass fractions of the substances in an electrolytic capacitor, a unit about 2 cm in length and about 1.5 cm in diameter was disassembled into its components. The mass fractions obtained in this manner provide a first approximation of the proportions of solid and liquid substances. The disassembly of only one capacitor is insufficient for a representative determination of the mass fractions. This study, however, provides no elaborate disassembly of a larger number of electrolytic capacitors.

The aluminium electrolytic capacitor was disassembled as shown in Figure 13. The aluminium housing was cut open using a side cutter. The coil was then pulled out of the housing and the two films were fully unwound. All substances were weighed in a plastic cup whose mass was previously measured using the same scale. The scale used was a Mettler PC4000.

Figure 14 shows the components of the disassembled aluminium electrolytic capacitor. The following components can be seen:

- Left middle: unwound grey aluminium film
- Next to it is the green adhesive tape that surrounded the entire coil.
- Bottom left: black plastic housing
- Middle top: second unwound aluminium film
- Image middle: aluminium housing with cover
- Below: part of the bitumen seal
- Right: blotting paper soaked in liquid which was wrapped between the two films

The measured masses can be found in the results in chapter 6.6.

Figure 13: Aluminium e-cap, cover removed; view of bitumen seal and coil

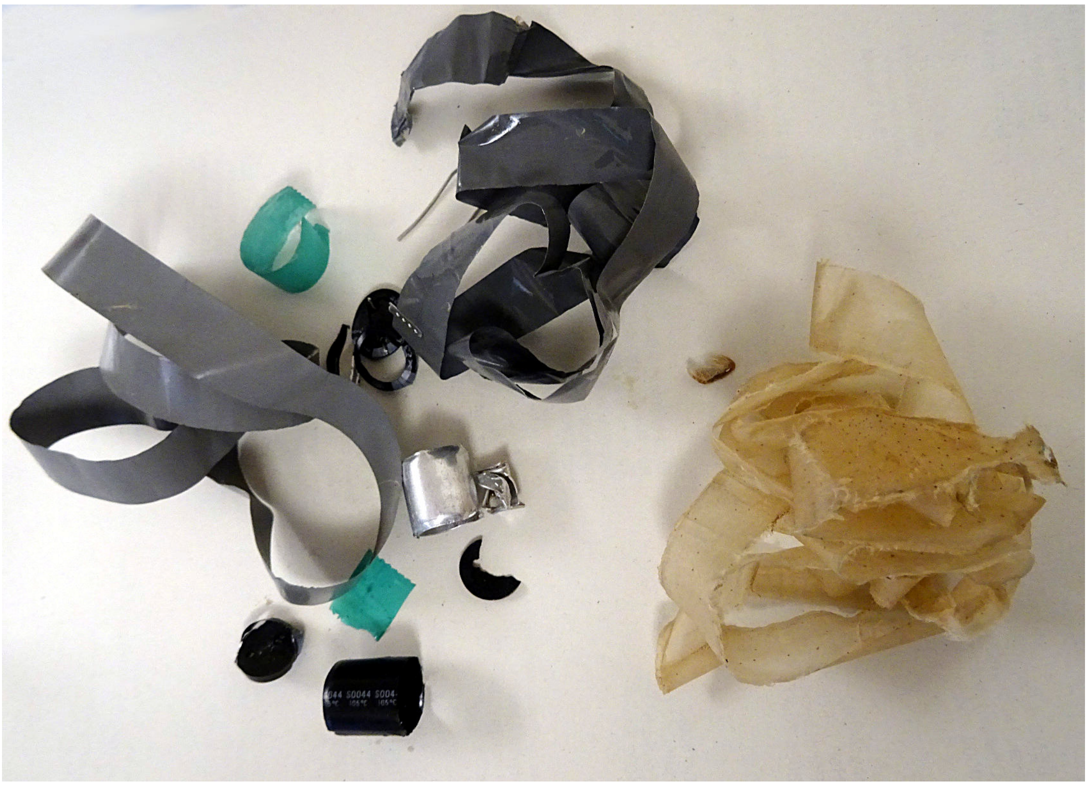


Figure 14: Components of the disassembled aluminium e-cap

6 Results

6.1 Analysis results of the liquid substances

6.1.1 General

For the GCMS analysis, the sample extraction was carried out with organic solvent. Analysis results from the GCMS analysis yielded results of varying grades ("fit"). For high grades, it can be assumed that the substance was actually present in the sample according to the evaluation. For moderate grades, it may be that the right substance was found, or it could be a structural isomer that cannot be distinguished in the GCMS analysis. It may also be the case that the right substance is not present in the laboratory library and a substance with a similar mass spectrum is obtained as a result. Low-grade results are uncertain and should not be considered as evidence of the substance being found. In the following, substances that could be verified with a very good match are always shown. Substances that have been analysed with moderate consistency are only shown if they appear plausible according to expectations from the literature or if the moderate fit can be explained. For these substances, however, it is important to note that similar molecules of the same substance group could also be present in the mixture. Unknown compounds are listed as a total in the result tables, and the substances that were not included in the result tables are also added to this total. All laboratory results can be found in Annex C.

All mass fractions were estimated based on the mass fraction of the internal laboratory standard. This makes them semi-quantitative and the measurement uncertainty could be in the range of 50 per cent to several orders of magnitude.

The eluate for the LCMS screening was prepared with water. The LCMS suspect screening results in hits with respect to the specified substance list according to Annex B. The identity of the substances found can only be confirmed for a few. The results table lists all substances found in the suspect screening.

The LCMS non-target screening provides possible molecular formulas for the detected molecules. The results depend on which atoms were included in the search. After an initial analysis with the atoms C, H, N, O, S, P, which yielded only hydrocarbons, a second analysis was carried out with the inclusion of B. This search also led to no useful hits.

The elemental analysis for tungsten and boron provides the mass fractions of these atoms in the sample, but no information about the molecules. This analysis was carried out for aluminium e-caps, as there was evidence in the literature for the presence of tungstic and boric acids. The coils were eluted in water for the analysis. The dissolved metals were determined. An internal control analysis at the laboratory showed that the levels in the suspended matter were extremely low (Maier, 2018).

The PCB content of the samples from non-polarised cylindrical capacitors was also analysed. This was done to check if the samples were extracts from PCB-free capacitors as requested.

6.1.2 Non-polarised cylindrical capacitors

The analysis results relate to the extracted liquid from non-polarised capacitors. They are mass fractions in the mixed samples from the liquids in the capacitors. The mixed samples all contained mineral oils which appeared as an area under all peaks in the chromatogram. This made it difficult to identify the individual peaks. It can be assumed that analyses of the liquids from individual capacitors would allow the determination of other substances lost in the mixtures. The chromatogram from the analysis of the capacitor mixed sample for refrigerators, air conditioners and freezers is shown as an example (Figure 15). The mineral oils contained are visible as peak 21; these are designated as hydrocarbon mixture in the result table.

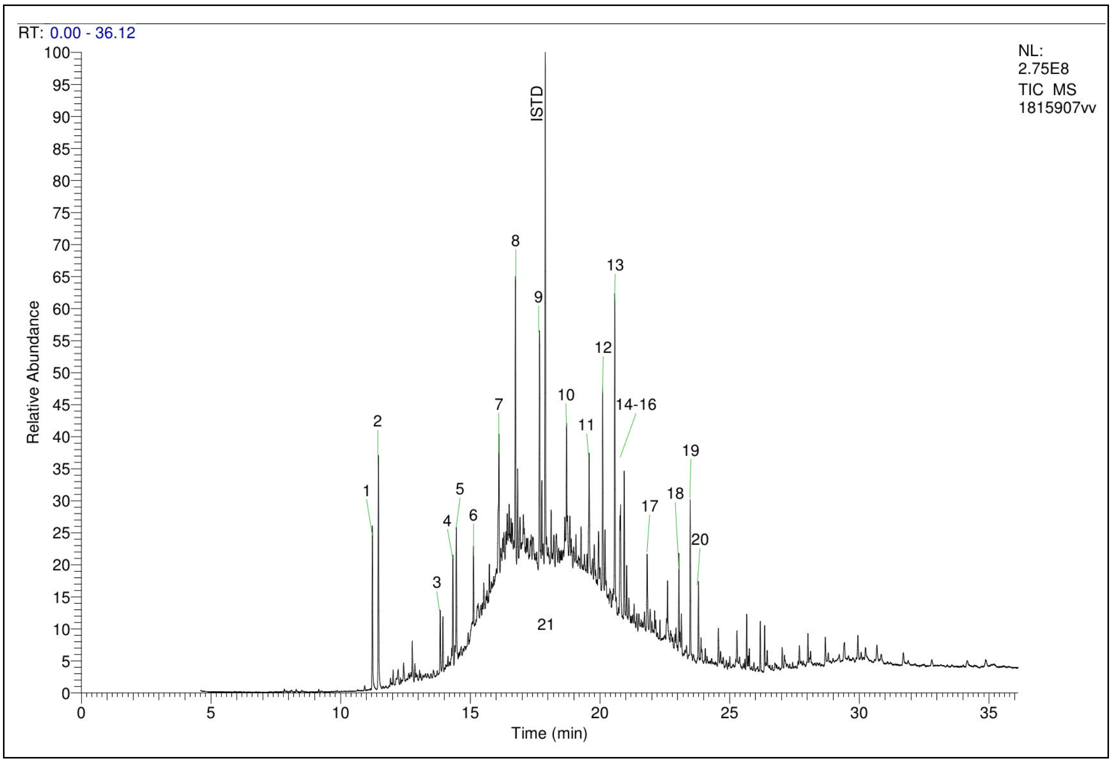


Figure 15: Chromatogram of the mixed sample from refrigerator capacitors

The results of the GCMS analysis of capacitors from large household appliances are listed in Table 13. The mixed sample of large household appliances comprised capacitors from washing machines, dishwashers and other large household appliances. Full laboratory results with the associated chromatogram are included in Annex C.3.6.

Table 13: GCMS analysis results of large household appliances (sample No. 6 HHG)

Chemical designation	CAS No.	Mass fraction [mg/kg]	Conformity
1-Methylnaphthalene	90-12-0	2 000	Very good
2,2,4,4,5,5,7,7-Octamethyloctane	5171-85-7	2 000	Moderate
2-Methylnaphthalene	91-57-6	1 000	Very good
2,2-Dimethyl-4-octen-3-ol	53960-44-4	1 000	Moderate
Di-tert-dodecyl disulfide	27458-90-8	1 000	Moderate
Sum of unknown compounds		28 000	
Hydrocarbon mixture		Not quantified	

The analysis results for the capacitors from refrigerators, air conditioners and freezers are listed in Table 14. The full laboratory reports can be found in Annex C.3.1.

Table 14: GCMS analysis results for refrigerators, air conditioners and freezers (sample No. 1 KG)

Chemical designation	CAS No.	Mass fraction [mg/kg]	Conformity
3,4-Epoxycyclohexylmethyl-3,4-epoxycyclohexane carboxylate or isomer	2386-87-0	16 000	Moderate
2-Methylnaphthalene	91-57-6	8 000	Very good
Benzyltoluenes (p- and m-)	27776-01-8	7 000	Very good
1-Methylnaphthalene	90-12-0	5 000	Very good
Triethylenglycolbis(2-ethyl hexanoate)	94-28-0	5 000	Moderate
Di-tert-octyl disulfide	29956-99-8	2 000	Moderate
Sum of unknown compounds		43 000	
Hydrocarbon mixture		Not quantified	

An overview of the analysis results for non-polarised cylindrical capacitors from SENS small appliances can be found in Table 15. For the complete results, please refer to Annex C.3.5.

Table 15: GCMS analysis results from SENS small appliances (sample No. 5.1 HKG)

Chemical designation	CAS No.	Mass fraction [mg/kg]	Conformity
1-Methylnaphthalene	90-12-0	4 000	Very good
Dinonyl phthalate	84-76-4	2 000	Very good
2-Methylnaphthalene	91-57-6	900	Very good
Sum of unknown compounds		14 000	
Hydrocarbon mixture		Not quantified	

Table 16 shows the results of the PCB analysis for the mixed samples from non-polarised cylindrical capacitors. The laboratory report can be found in Annex C.1. For the discussion on the determined PCB mass fraction in the sample from the SENS small appliances, please refer to chapter 7.8.1.

Table 16: PCB analysis results in mixed samples of PCB-free capacitors

Appliance category	Sample No.	Entire sample	PCB total in accordance with the ORRChem [mg/kg]
Large household appliances	6 HHG	Liquid from capacitors	< 20
Refrigerators	1 KG	Liquid from capacitors	< 20
Small household appliances	5.1 HKG	Liquid from capacitors	38

Figure 16: Some of the collected capacitors from SENS small appliances

6.1.3 Electrolytic capacitors

The analysis results refer to the mass of the extracted coils. The shown mass fractions thus relate to the whole coils consisting of films, separating papers and liquids. The results of the GCMS and LCMS analyses are presented below according to the prepared mixed samples. The analysis of the electrolytic capacitors did not face the issue of an all-concealing hydrocarbon mixture.

The analysis results of the mixed sample from flat screens are shown in Table 17 and Table 18. This mixed sample was created from aluminium e-caps in flat screens for use with computers and aluminium e-caps from flat screens for use as TV/video displays. The detailed laboratory reports can be found in Annex C.3.2.

Table 17: GCMS analysis results for e-caps from PC and TV flat screens (sample No. 2 LCD)

Chemical designation	CAS No.	Mass fraction [mg/kg coil]	Conformity
Butyldiglycol or isomer	112-34-5	1 000	Very good
1-Methoxy-2-nitrobenzene or isomer	91-23-6	100	Very good
4-Nitrobenzyl alcohol or isomer	619-73-8	70	Very good
2-Hydroxyethyl benzoate	94-33-7	40	Very good
Benzoic acid	65-85-0	30	Very good
Diethylene glycol	111-46-6	20	Very good
Phenol	108-95-2	20	Very good
3-Nitroacetophenone/m-nitroacetophenone	121-89-1	20	Very good
Dimethylbenzyl alcohol	617-94-7	10	Moderate
2-Ethylhexanol or similar compound	104-76-7	7	Very good
3-Aminoacetophenone or isomer	99-03-6	6	Moderate
Sum of unknown compounds	112-34-5	216	Very good

Table 18: LCMS analysis results for e-caps from PC and TV flat screens (sample No. 2 LCD)

Chemical designation	CAS No.	Qualitative mass fraction	Identity confirmed?
Triethylamine	121-44-8	In traces	No
Diethylamine	109-89-7	> 100 mg/kg entire sample	Yes
2,4-Dihydroxybenzoic acid	89-86-1	In traces, not confirmed	No
Polyethylene glycol	25322-68-3	Numerous different chain lengths, high intensities	No information

The second mixed sample with aluminium e-caps was created from the collected capacitors from laptop power supply units and desktop computers. Since the large e-caps over 2.5 cm in size in desktop computers are primarily found in power supply units, it can be assumed that the analysed capacitors from desktop computers mainly come from the integrated power supply units. The results of the laboratory analysis can be found in Table 19 and Table 20. For the complete laboratory report, please refer to Annex C.3.8.

Table 19: GCMS analysis results for e-caps from laptop power supply units and desktop PCs (sample No. 7 Netz)

Chemical designation	CAS No.	Mass fraction [mg/kg coil]	Conformity
Benzoic acid	65-85-0	200	Very good
Ethylene sebacate or similar compound	5578-82-5	200	Moderate
Diethylene glycol	111-46-6	200	Very good
3-Nitroacetophenone/m-nitroacetophenone	121-89-1	80	Very good
4-Nitrobenzyl alcohol or isomer	619-73-8	50	Very good
Phenol	108-95-2	50	Very good
Dimethylbenzyl alcohol or similar compound	617-94-7	50	Moderate

Chemical designation	CAS No.	Mass fraction [mg/kg coil]	Conformity
Azelaic acid monoethyl ester or similar compound	1593-55-1	50	Moderate
γ-Butyrolactone	96-48-0	40	Very good
3-Aminoacetophenone or isomer	99-03-6	30	Moderate
4-Nitrophenol	100-02-7	30	Very good
Decanedioic acid (sebacic acid or similar acid)	111-20-6	20	Moderate
1-Methoxy-2-nitrobenzene	91-23-6	10	Very good
1,4-Di-p-tolylbutane-1,4-dione	13145-56-7	10	Moderate

Table 20: LCMS analysis results for e-caps from laptop power supply units and desktop PCs (sample No. 7 Netz)

Chemical designation	CAS No.	Qualitative mass fraction	Identity confirmed?
Triethylamine	121-44-8	In traces	No
Diethylamine	109-89-7	> 100 mg/kg entire sample	Yes
Polyethylene glycol	25322-68-3	Numerous different chain lengths, medium intensities	No information
2-Hydroxybenzoic acid, salicylic acid	69-72-7	Medium intensity	No
1,2-Benzenedicarboxylic acid	88-99-3	Medium intensity	No
1,3-Benzenedicarboxylic acid	121-91-5	Medium intensity	No
1,4-Benzenedicarboxylic acid	100-21-0	Medium intensity	No

Sufficient large aluminium e-caps could be acquired from SENS small appliances to enable a laboratory analysis. This mixed sample comprises capacitors from the “Small household appliances with motors” and “Other small household appliances” appliance categories. The results of the laboratory analysis are summarised in Table 21, the detailed information can be found in Annex C.3.7.

Table 21: GCMS analysis results from e-caps of SENS small appliances (sample No. 5.2 HKG)

Chemical designation	CAS No.	Mass fraction [mg/kg coil]	Conformity
Butyldiglycol or isomer	112-34-5	3 000	Very good
Benzyl alcohol	100-51-6	2 000	Very good
Diethylene glycol	111-46-6	200	Very good
Phenol	108-95-2	30	Very good
Benzoic acid	65-85-0	20	Moderate
1-Methoxy-2-nitrobenzene	91-23-6	20	Very good
N,N-Diethylformamide	617-84-5	20	Moderate
3-Nitroacetophenone	121-89-1	10	Moderate
4-Nitrophenol or similar compound	100-02-7	10	Moderate
2-Ethylhexanol or similar compound	104-76-7	10	Very good
Sum of unknown compounds	112-34-5	70	

Table 22: LCMS analysis results from e-caps of SENS small appliances (sample No. 5.2 HKG)

Chemical designation	CAS No.	Qualitative mass fraction	Identity confirmed?
Triethylamine	121-44-8	High intensity	No, but likely
Diethylamine	109-89-7	> 100 mg/kg entire sample	Yes
2,4-Dihydroxybenzoic acid	89-86-1	In traces	No
Polyethylene glycol	25322-68-3	Numerous different chain lengths, high intensities	No information
Dimethylformamide	68-12-2	High intensity	Yes with high likelihood
Dimethylacetamide	127-19-5	Very high intensity	No, but likely

The results of the elemental analyses for tungsten and boron are outlined in Table 23. Boron can be found in the capacitors in a mass fraction of 1 to 2 g per kg of coil. As a rule of thumb, this equates to a mass fraction in the liquid of 1 to 2 per cent. Tungsten, on the other hand, is practically non-existent in the capacitors in a water-soluble form. The laboratory report for the elemental analysis can be found in Annex C.1.

Table 23: Results of the elemental analyses for tungsten and boron in aluminium e-caps

Appliance category	Sample No.	Entire sample	Tungsten [mg/kg coil]	Boron [mg/kg coil]
PC and TV flat screens	2 LCD	Coils from capacitors	< 0.05	983
Desktop PC and laptop power supply units	7 Netz	Coils from capacitors	0.0057	598
SENS small appliances	5.2 HKG	Coils from capacitors	0.0095	2,620

6.1.4 Microwave capacitors

The analysis results relate to the extracted liquid in each case. It is thus the mass fractions in the mixed liquids of the capacitors which were included in the mixed sample. The microwave samples are not masked by mineral oils (see Figure 17). Two mixed samples with microwave capacitors were analysed. One with capacitors from the manufacturer BiCai and one with capacitors from other manufacturers. The reason for this is that almost half of all collected capacitors originated from BiCai.

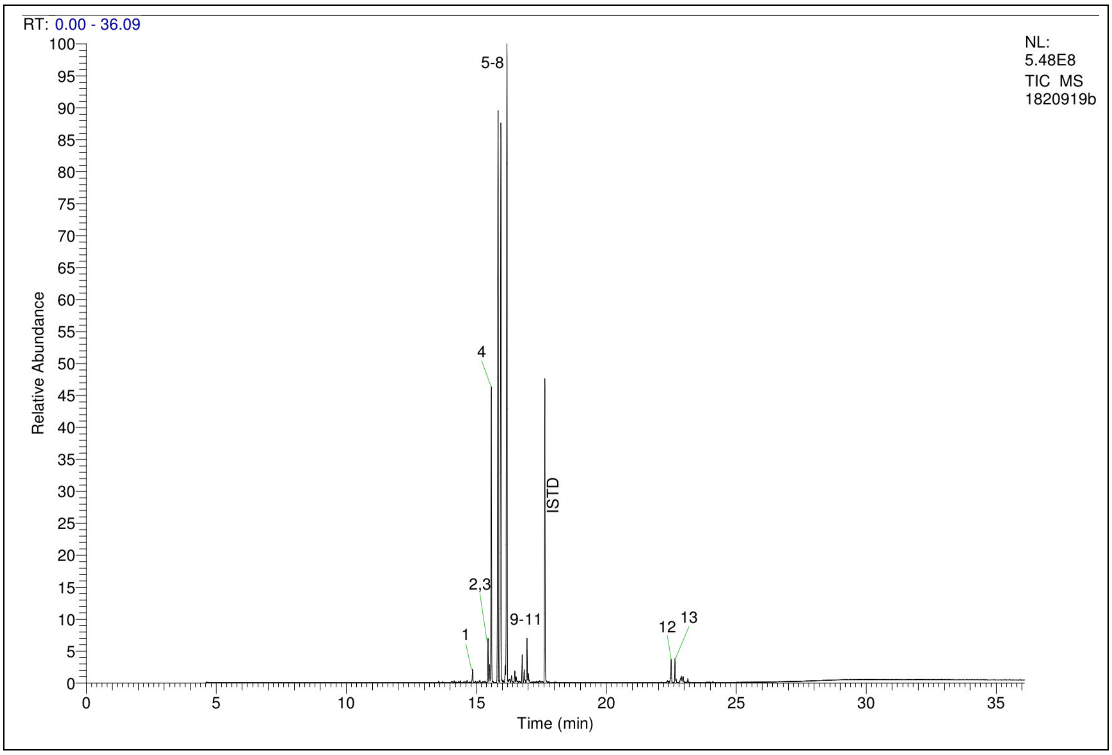


Figure 17: Chromatogram of the mixed sample from capacitors produced by BiCai

The analysis results for the mixed samples from the manufacturer BiCai are shown in Table 24. The detailed laboratory results are presented in Annex C.3.3.

The analysis results for the microwave capacitors from other manufacturers can be found in Table 25. The detailed laboratory results are presented in Annex C.3.4. The sum of all mass fractions in the mixed sample is 113 per cent. The mass fractions of the individual substances are estimated using the mass fraction of the internal laboratory standard. The true value may deviate from the value estimated in this manner by several orders of magnitude. These errors may lead to a total value over 100 per cent.

Table 24: GCMS analysis results of microwaves produced by BiCai (sample No. 3.1 MW)

Chemical designation	CAS No.	Mass fraction [mg/kg]	Conformity
2,2',5,5'-Tetramethylbiphenyl or similar compound	3075-84-1	800 000	Moderate
1,5,6,7-Tetramethyl-3-phenylbicyclo[3.2.0]hepta-2,6-dien or similar compound	126584-00-7	20 000	Moderate
1,1'-(1-Methylethylidene)bis(4-methylbenzene) or similar compound	N/A	15 000	Moderate
Ethyl(1-phenylethyl)benzene	18908-70-8	10 000	Moderate
1,2,3-Trimethyl-4-(1E)-1-propenyl-naphthalene or isomer	26137-53-1	6 000	Moderate
Di-p-tolyl-methane or isomer	4957-14-6	5 000	Moderate
5-Ethyl-2-methyl-4,4-diphenyl-3,4-dihydro-2H-pyrrole (EMDP) or similar compound	102177-18-4	5 000	Moderate
Sum of unknown compounds		18 000	

Table 25: GCMS analysis results of microwaves produced by other manufacturers (sample No. 3.2 MW)

Chemical designation	CAS No.	Mass fraction [mg/kg]	Conformity
2,2',5,5'-Tetramethylbiphenyl or similar compound	3075-84-1	800 000	Moderate
1,3,5-Cycloheptatriene, 6-methyl-1-(6-methyl-1,3,5-cycloheptatrien-1-yl)- or similar compound	N/A	200 000	Moderate
Benzyltoluenes (p-, m-, o-)	27776-01-8	46 000	Very good
1,2,3-Trimethyl-4-(1E)-1-propenyl-naphthalene or similar compound	26137-53-1	30 000	Moderate
5-Ethyl-2-methyl-4,4-diphenyl-3,4-dihydro-2H-pyrrole (EMDP) or similar compound	102177-18-4	30 000	Moderate
Ethyl(1-phenylethyl)benzene	18908-70-8	10 000	Very good
1,1-Diphenylethane	612-00-0	7 000	Very good
2,3,4,4a-Tetrahydro-1α,4aβ-dimethyl-9(1H)-phenantron or similar compound	94571-08-1	4 000	Moderate
Sum of unknown compounds		0	

The PCB content in mixed samples from microwave capacitors were also examined as a control. Both samples were free of PCBs as expected for these capacitors (see Table 26 and Annex C.1).

Table 26: PCB analysis results in mixed samples of PCB-free capacitors

Appliance category	Entire sample	PCB total in accordance with the ORRChem [mg/kg]
BiCai microwaves	Liquid from capacitors	< 20
Microwaves of other manufacturers	Liquid from capacitors	< 20

6.1.5 Substances not known from literature

The analysis results lead to certain substances which had not been described as substances within capacitors by the researched literature. These are listed in Table 27. The sample numbers are specified according to Table 11. Three of the substances found in microwave capacitors are diarylalkanes. These are the following: 5-ethyl-2-methyl-4,4-diphenyl-3,4-dihydro-2H-pyrrole (EMDP), di-p-tolyl-methane and ethyl(1-phenylethyl)benzene. 2,2',5,5'-Tetramethylbiphenyl can also be designated as a diarylalkane if the term is being used loosely.

Table 27: Analysed capacitor substances unidentified in literature

Chemical designation	CAS No.	Found in capacitor type	Sample No.
1,4-Di-p-tolylbutane-1,4-dione	13145-56-7	Aluminium e-cap	7 Netz
2-Ethylhexanol or similar compound	104-76-7	Aluminium e-cap	2 LCD, 7 Netz, 5.2 HKG
2-Hydroxyethyl benzoate	94-33-7	Aluminium e-cap	2 LCD
2-Nitroanisole/1-methoxy-2-nitrobenzene or isomer	91-23-6	Aluminium e-cap	2 LCD
3-Aminoacetophenone or isomer	99-03-6	Aluminium e-cap	2 LCD, 5.2 HKG
3-Nitroacetophenone	121-89-1	Aluminium e-cap	2 LCD, 7 Netz, 5.2 HKG
4-Nitrobenzyl alcohol or isomer	619-73-8	Aluminium e-cap	2 LCD
4-Nitrophenol or similar compound	100-02-7	Aluminium e-cap	5.2 HKG
Benzoic acid	65-85-0	Aluminium e-cap	2 LCD
Phenol	108-95-2	Aluminium e-cap	2 LCD, 7 Netz, 5.2 HKG
2,2-Dimethyl-4-octen-3-ol	53960-44-4	Non-polarised cylindrical	6 HHG
2,2,4,4,5,5,7,7-Octamethyloctane	5171-85-7	Non-polarised cylindrical	6 HHG
3,4-Epoxycyclohexylmethyl-3,4-epoxycyclohexane carboxylate or isomer	2386-87-0	Non-polarised cylindrical	1 KG
Di-tert-dodecyl disulfide	27458-90-8	Non-polarised cylindrical	6 HHG
Di-tert-octyl disulfide	29956-99-8	Non-polarised cylindrical	1 KG
Dinonyl phthalate	84-76-4	Non-polarised cylindrical	5.1 HKG
Triethylenglycolbis(2-ethyl hexanoate)	94-28-0	Non-polarised cylindrical	1 KG
1,1'-(1-Methylethylidene)bis(4-methylbenzene) or similar compound	N/A	Microwave capacitors	3.1 MW
1,2,3-Trimethyl-4-(1E)-1-propenyl-naphthalene or isomer	26137-53-1	Microwave capacitors	3.1 MW, 3.2 MW
1,3,5-Cycloheptatriene, 6-methyl-1-(6-methyl-1,3,5-cycloheptatrien-1-yl)- or similar compound	N/A	Microwave capacitors	3.2 MW

Chemical designation	CAS No.	Found in capacitor type	Sample No.
1,5,6,7-Tetramethyl-3-phenylbicyclo[3.2.0]hepta-2,6-dien or similar compound	126584-00-7	Microwave capacitors	3.1 MW
2,2',5,5'-Tetramethylbiphenyl or similar compound	3075-84-1	Microwave capacitors	3.1 MW, 3.2 MW
2,3,4,4a-Tetrahydro-1α,4aβ-dimethyl-9(1H)-phenantron or similar compound	94571-08-1	Microwave capacitors	3.2 MW
5-Ethyl-2-methyl-4,4-diphenyl-3,4-dihydro-2H-pyrrole (EMDP) or similar compound	102177-18-4	Microwave capacitors	3.1 MW, 3.2 MW
Di-p-tolyl-methane or isomer	4957-14-6	Microwave capacitors	3.1 MW
Ethyl(1-phenylethyl)benzene	18908-70-8	Microwave capacitors	3.2 MW

6.2 Literature references to liquid substances

6.2.1 Introduction

This chapter lists all substances (by capacitor type) which can be found in small capacitors according to literature research. Only those substances whose use in small capacitors is considered assured are listed. We assume assured use if the substance has been detected in a laboratory analysis of small capacitors, if it is described in a patent for the production of small capacitors, if it is declared by capacitor manufacturers or mentioned in several independent literature sources.

6.2.2 Non-polarised cylindrical capacitors

For the non-polarised cylindrical capacitors, the literature research leads to the 13 substances in Table 28 whose use we consider assured.

Table 28: Substances in non-polarised cylindrical capacitors known from literature

Chemical designation	CAS No.	Sources
1-Chloronaphthalene (chlorinated naphthalenes)	90-13-1	(Chappot, 2007), (Eugster, 2007), (Straimer, 1939)
1-Decene	872-05-9	(Shaw, 1980)
1-Dodecene	112-41-4	(Shedigian, 1985)
1-Methylnaphthalene	90-12-0	HHGG laboratory analysis, (Chappot et al., 2007), (Mauro et al., 1999)
1-Tetradecene	1120-36-1	(Shedigian, 1985)
2-Methylnaphthalene	91-57-6	HHGG laboratory analysis, (Mauro et al., 1999)
Biphenyl	92-52-4	(Chappot et al., 2007), (Gloor, 2007), (Eco-systèmes, 2012)
Butylated hydroxyanisole	25013-16-5	(Shedigian, 1985)
Dibutyl phthalate	84-74-2	(Eco-systèmes, 2012)

Diisobutyl phthalate	84-69-5	(Jay, 1979)
Naphthalene	91-20-3	(Chappot et al., 2007), (Eco-systèmes, 2012), (Mauro et al., 1999)
Castor oil	8001-79-4	(Chappot et al., 2007), capacitor overprint
Soybean oil	None	(Shedigian, 1985)

6.2.3 Electrolytic capacitors

For electrolytic capacitors, the literature research lead to 15 substances with reliable literature reference.

Table 29: Substances in electrolytic capacitors known from literature

Chemical designation	CAS No.	Sources
1,2-Benzenedicarboxylic acid	88-99-3	Patent DE3930310C1, Netz laboratory analysis
1,3-Benzenedicarboxylic acid	121-91-5	Patent DE3930310C1, Netz laboratory analysis
2-Hydroxybenzoic acid, salicylic acid	69-72-7	E-cap HKG and Netz laboratory analysis , (Chappot et al., 2007), (Güntner et al., 1991)
2,4-Dihydroxybenzoic acid	89-86-1	FPD and Netz laboratory analysis, Patent DE3930310C1
Ammonium pentaborate	12046-04-7	(Chappot et al., 2007), (Ebel, 2002)
Benzyl alcohol	100-51-6	E-cap HKG laboratory analysis, (Chappot et al., 2007)
Boric acid	11113-50-1	(Eco-systèmes, 2012)
Diethylamine	109-89-7	FPD, E-cap HKG and Netz laboratory analysis, (Chappot et al., 2007)
Dimethylacetamide	127-19-5	E-cap HKG laboratory analysis, (Hering et al., 2014), (Eco-systèmes, 2012)
Dimethylformamide	68-12-2	E-cap HKG laboratory analysis, (Hering et al., 2014), (Güntner et al., 1991)
Ethylene glycol, ethane-1,2-diol, monoethylene glycol	107-21-1	(Chappot et al., 2007), (Güntner et al., 1991), (TDK, 2014), (Mundorf, 2016), (Eco-systèmes, 2012)
N-Methylpyrrolidone	872-50-4	(Güntner et al., 1991), manufacturer
Polyethylene glycol	25322-68-3	FPD, e-cap HKG and Netz laboratory analysis, Patent WO2002061775
Triethylamine	121-44-8	FPD, e-cap HKG and Netz laboratory analysis, Patent DE3930310C1
γ-Butyrolactone	96-48-0	(Hering et al., 2014), (Güntner et al., 1991), (TDK, 2014), (Mundorf, 2016)

6.2.4 Microwave capacitors

The literature research for substances in microwave capacitors is summarised in Table 30 with 13 substances.

Table 30: Substances in microwave capacitors known from literature

Chemical designation	CAS No.	Sources
1-Methyl-4-(phenylmethyl)benzene	620-83-7	(Eugster, 2007)
1,1-Bis(3,4-dimethylphenyl)ethane	1742-14-9	(Schulz et al., 1980)
1,1-Bis(4-methylphenyl)ethane	530-45-0	(Schulz et al., 1980)
1,1-Diphenylethane, diarylethene	612-00-0	(Eugster, 2007), declaration on capacitors
1,2-Dimethyl-4-(phenylmethyl)benzene	13540-56-2	(Eugster, 2007)
2,2'-Dimethylbiphenyl	605-39-0	(Chappot et al., 2007), (Gloor, 2007), (Eco-systèmes, 2012)
2,6-Diisopropylnaphthalene	24157-81-1	(Eugster, 2007)
3,4-Epoxy cyclohexane carboxylic acid-(3,4-epoxycyclohexyl methyl ester)	2386-87-0	(Eugster, 2007)
4-Isopropylbiphenyl	7116-95-2	(Eugster, 2007)
Bis(7-methyloctyl)phthalate	20548-62-3	(Eugster, 2007), Patent DE3930310C1
Diethyl phthalate	84-66-2	(Chappot et al., 2007), (Eugster, 2007)
Diisodecyl phthalate	26761-40-0	(Chappot et al., 2007), (Gloor, 2007), patent DE3930310C1
Diisononyl phthalate	68515-48-0	(Chappot et al., 2007), (Gloor, 2007), patent DE3930310C1
Trioctyl trimellitate	3319-31-1	(Eugster, 2007)

6.2.5 Unknown capacitor type

There are reliable literature references indicating that dimethylbenzyl alcohol is used in capacitors in Table 31. However, it is not clear from the sources in which types of capacitors this substance is used.

Table 31: Substances known from literature of unknown allocation to a capacitor type

Chemical designation	CAS No.	Sources
Dimethylbenzyl alcohol	617-94-7	FPD and Netz laboratory analysis, (Chappot et al., 2007)

6.3 Proportion of capacitors containing PCB

6.3.1 Non-polarised cylindrical capacitors

6.3.1.1 Large household appliances

Large household appliances are an important source of non-polarised cylindrical capacitors. The proportion of capacitors containing PCBs is reported separately for the appliance categories from the sampling. In the last column, Table 32 also shows the totalled values from the first three columns for all large household appliances. These values apply to the collection category of the take-back system called household appliances.

Table 32: Occurence of capacitors containing PCBs in large household appliances

	Washing machines		Dishwashers		Other		All large household appliances	
Classification	**Units**	**Per-centage**	**Units**	**Per-centage**	**Units**	**Per-centage**	**Units**	**Per-centage**
PCB-free	905	97%	795	99%	326	98%	2 026	98%
PCBs suspected	27	2.9%	5	0.6%	3	0.9%	35	1.7%
PCBs contained	5	0.5%	1	0.1%	4	1.2%	10	0.5%
Total	937		801		333		2,071	

Based on the sample size and the share in the sample, the range can be determined in which the true value will lie with a probability of 95 per cent. These confidence intervals were calculated for the results of the entire sample of large household appliances and are shown in Table 33 after the result as ±x per cent.

Table 33: Share of PCB-containing capacitors in large household appliances with confidence intervals

Classification	**Units**	**Share ± confidence interval 95%**
PCB-free	2 026	97.8% ±0.63%
PCBs suspected	35	1.7% ±0.56%
PCBs contained	10	0.5% ±0.30%
Total	2 073	

6.3.1.2 Refrigerators, air conditioners and freezers

After large household appliances, refrigerators, air conditioners and freezer are the second most important source of non-polarised cylindrical capacitors. The share of capacitors are shown in Table 34 according to PCB content. No capacitor clearly contained PCBs in the sample. Fifteen were suspected of containing PCBs after the classification according to the capacitor list (Arnet et al., 2011). All capacitors suspected of containing PCBs were examined in the laboratory to check their PCB content. No evidence of PCBs was found. All tested capacitors from refrigerators were thus free of PCBs.

Table 34: Occurence of PCB-containing capacitors in refrigerators, air conditioners and freezers

Classification	Units	Percentage
PCB-free	410	100%
PCBs suspected	0	0%
PCBs contained	0	0%
Total	410	

6.3.1.3 Ballasts from fluorescent luminaires

The share of capacitors containing PCBs, capacitors suspected of containing PCBs and PCB-free capacitors are shown below in Table 35 for capacitors from ballasts. It is important to note that these proportions apply to the capacitors but not to the ballasts themselves. The majority of ballasts do not contain large capacitors. A large capacitor was only integrated into some ballasts for technical reasons.

Table 35: Occurence of capacitors containing PCBs in ballasts

Classification	Units	Percentage
PCB-free	58	24%
PCBs suspected	50	21%
PCBs contained	130	55%
Total	238	

Based on the sample size and the share in the sample, the range in which the true value will lie can be determined with a probability of 95 per cent. These confidence intervals were calculated for the results of the capacitors from ballasts and are shown in Table 36 after the result as ±x per cent.

Table 36: Proportion of PCB-containing capacitors in ballasts with confidence intervals

Classification	Units	Share ± confidence interval 95%
PCB-free	58	24.4% ±5.5%
PCBs suspected	50	21.0% ±5.2%
PCBs contained	130	54.6% ±6.3%
Total	238	

If the sample was representative, this means that between 49 and 61 per cent of the capacitors from ballasts contain PCBs. The results are very similar to those from the luminaires study by (Gasser, 2009). It determined 60 per cent PCB-containing, 10 per cent PCB-suspected and 29 per cent PCB-free capacitors.

6.3.1.4 SENS small appliances

As with large household appliances, the results for SENS small appliances are shown for the sampling in Table 36 per collected category, and the total values for SENS small appliances are shown in the last column.

Table 37: Occurence of capacitors containing PCBs in SENS small appliances [2]

	Small household appliances with motors		Other small household appliances		Total small household appliances	
Classification	**Units**	**Per-centage**	**Units**	**Per-centage**	**Units**	**Per-centage**
PCB-free	73	87%	35	70%	108	81%
PCBs suspected	7	8%	2	4%	9	7%
PCBs contained	4	5%	13	26%	17	13%
Total	84		50		134	

The calculation of the confidence interval is shown with a likelihood of 95 per cent for SENS small appliances in Table 38 after the results as ±x per cent.

Table 38: Share of PCB-containing capacitors in small household appliances with confidence intervals [2]

Classification	**Units**	**Share ± confidence interval 95%**
PCB-free	108	80.6% ±6.7%
PCBs suspected	9	6.7% ±4.2%
PCBs contained	17	12.5% ±5.6%
Total	134	

The capacitor collection from SENS small appliances is not beyond doubt. It must be assumed that capacitors from mobile lamps are included in the sample. The result should be interpreted with caution and should not be cited. See also the discussion in chapter 7.4.1.5.

6.3.2 Electrolytic capacitors

Electrolytic capacitors are always free of PCBs. PCBs are not used as this would not be technically useful. PCBs act as insulators, but electrolytic capacitors require conductive liquids. In a customer order for a Swiss recycler, we analytically determined the PCB content of a sample of 11.4 kg electrolytic capacitors all smaller than 2.5 cm. This corresponds to an estimated number of approximately 5,400 units. The sample contained no PCBs as was to be expected (Savi, 2018).

6.3.3 Microwave capacitors

Microwave capacitors are generally deemed to be free of PCBs. The laboratory analyses from this study confirm that microwave capacitors do not contain PCBs (see also chapter 6.1.4).

[2] The results in this table are doubtful and should not be cited.

6.4 Share of capacitors with liquids

6.4.1 Share of dry non-polarised cylindrical capacitors

During the examination, we tested numerous capacitors to see if they contain liquid substances. For the laboratory analysis, the capacitors were cut open and the liquid was poured out. All capacitors without liquid leakage were recorded. This evaluation involves non-polarised cylindrical capacitors. Electrolytic capacitors always contain an impregnated spacer film, meaning they are never dry. Microwave capacitors are always filled with liquid.

Table 39 shows the total number of dry capacitors by appliance category and their proportion in all non-polarised cylindrical capacitors. The identified proportion represents a minimum number. It was determined so that all models without liquid leakage were recorded in the preparation for analysis. With the total number of units of the corresponding models in the collection, it was possible to count back to the number of units in the whole sample. It was also found that all cut-open capacitors in white or coloured plastic housings were dry. Two examples of this type are shown in Figure 18. After this finding was confirmed for 19 units, all capacitors of this type were classified as dry and included in the total.

Figure 18: Opened plastic capacitors without liquid substances

There are also numerous capacitors in aluminium housing which turned out to be dry once opened. These models were also considered in the total number of dry capacitors, whereby the results as per Table 39 were produced.

Motor start capacitors packaged in black plastic housings are another group. These were common in the refrigerator sample. These capacitors contain impregnated blotting paper. An excess of liquid was sometimes found in the housing. Technically, these are electrolyte capacitors and not counted as dry capacitors. Examples for this housing shape are shown in Figure 19.

Figure 19: Motor start capacitors in black plastic housings

Table 39: Share of dry capacitors in the non-polarised cylindrical capacitors

No.	Appliance category systems	Collection category	Total number in collection	Dry capacitors [units]	Proportion of dry capacitors
11a	Large household appliances	Washing machines	937	440	47%
11b		Dishwashers	801	344	43%
11d		Other	333	90	27%
12	Refrigerators	Refrigerators	410	126	31%
13	Ballasts from luminaires		238	0	0%
14a	SENS small appliances	Microwaves	343	0	0%
14b		Appliances with motors	280	42	15%
14c		Other	256	7	3%

6.4.2 Fluid leakage when disassembling capacitors for the analysis

The amount of liquid which leaked out from the samples was recorded for the analysis. The qualitative categories “a lot”, “a few drops”, “slightly damp” and “dry” were created for this purpose.

Non-polarised cylindrical capacitors were filled with liquids to very different extents. The open models yielded results according to Table 40.

Electrolytic capacitors were consistently slightly damp (67 units), only 2 units lost a few drops of liquid when opened. Microwave capacitors were all filled with a lot of liquid.

Table 40: Fluid leakage during sampling for the analysis in quantity of capacitor models

Capacitor type	A lot	A few drops	Slightly damp	Dry
Non-polarised cylindrical capacitors	54	6	6	53

6.5 Collection result

6.5.1 Capacitors > 2.5 cm in one dimension

Table 41 shows how many capacitors larger than 2.5 cm in at least one dimension should be collected per appliance category and how many were actually collected by the commissioned facilities. Figure 20 shows an overview of the collected units.

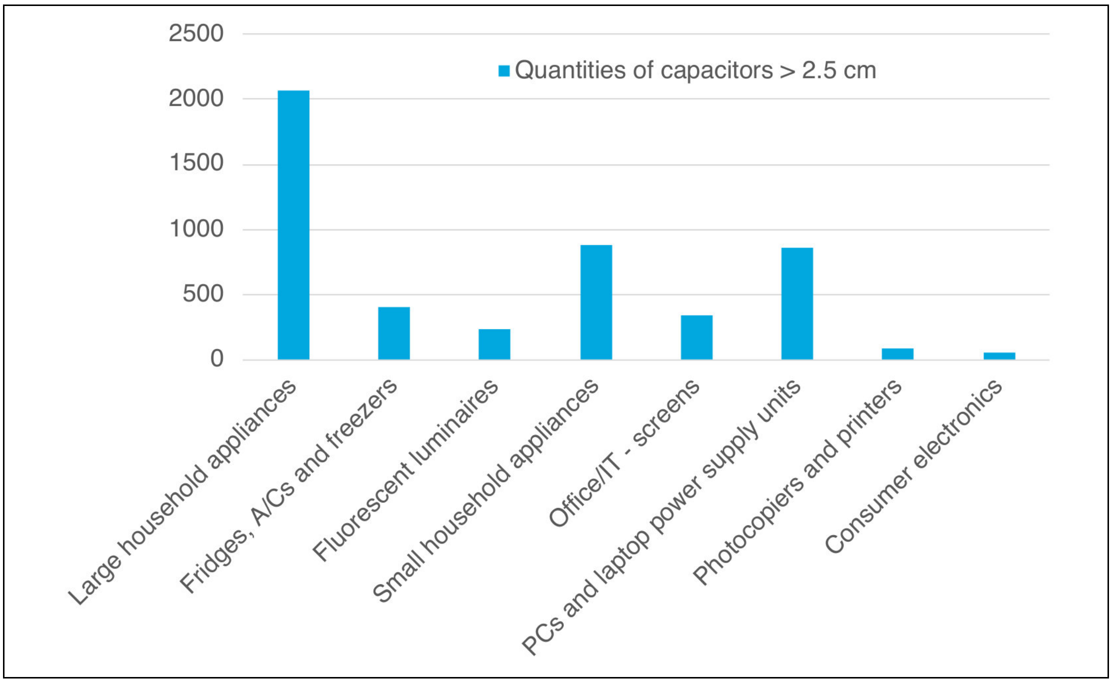


Figure 20: Collected capacitors > 2.5 cm per appliance category

For the individual categories, there were sometimes significant deviations between planning and results. This was to be expected. Collecting facilities were only able to collect capacitors for a limited time, relying on the delivered appliances. The quantities of capacitors collected reflect the mix of appliances that collecting facilities received during the sampling period. The collection result largely corresponds to the planning. In total, 6 per cent fewer capacitors were collected than planned, whereby the collection result for Swico appliances was just under a quarter below the planned level. However, around 11 000 smaller aluminium e-caps were also collected, as shown in the following chapter. The collection of large capacitors for photocopiers and audio electronics was particularly challenging. For the first category, the collection result was 83 per cent below and the second category was 89 per cent below the planned quantity. From desktop computers and power supplies, however, 73 per cent more capacitors were collected than planned. For screens, the collection result was 37 per cent above what was planned. Significantly more capacitors than planned were also collected from large household appliances, with collection levels 38 per cent above target in this sector. The collection of capacitors from ballasts was more difficult, with the result coming in at 41 per cent below target. The collection quantity was also below target for SENS small appliances, in this case by 27 per cent. Table 41 also shows the masses of the collected capacitors per appliance category. Capacitors were weighed per appliance category while determining the models.

Table 41: Comparison between collection planning and actually collected capacitors

Appliance category systems	Collection category	Planned number of capacitors > 2.5 cm [units]	Collected number of capacitors > 2.5 cm [units]	Mass of collected capacitors > 2.5 cm [kg]
Large household appliances	Washing machines	1 000	937	96.2
	Dishwashers	400	801	43.1
	Other	100	333	24.4
Refrigerators	Refrigerators	400	410	29.0
Ballasts from luminaires		400	238	26.9
SENS small appliances	Microwaves	400	343	39.2
	Appliances with motors	400	280	22.7
	Other	400	256	10.7
Office electronics, computing, communications/Swico 01	PC flat screens	250	24	0.280
	PC CRT screens		0	0.000
Office electronics, computing, communications/Swico 08	TV flat screens		210	2.689
	TV CRT screens		108	1.500
Office electronics, computing, communications/Swico 03	Desktop computers including internal power supply units	500	589	4.407
	Uninterruptible power supply (UPS)		0	0.000
	External power supply units		274	3.161
Office electronics, computing, communications/Swico 06	Large-scale photocopiers	500	46	0.515
	Multifunctional printers		38	0.597
Consumer electronics and cameras/Swico 10	Audio devices such as amplifiers, radios, compact systems	500	17	0.269
	Loudspeaker boxes with at least 2 loudspeakers		21	0.183
	Video players (VHS)		15	0.131
Total		5,250	4,940	305.9
Total SENS		3,500	3,598	292.2
Total Swico		1,750	1,342	13.7

6.5.2 Aluminium electrolytic capacitors smaller than 2.5 cm

All aluminium electrolytic capacitors were removed from the appliance categories of the Swico collection system, regardless of their size. For the evaluations, the collected capacitors were then sorted into those with a dimension larger than 2.5 cm and smaller ones. For the smaller capacitors, the number of units and the mass per appliance category were determined. The collected capacitors smaller than 2.5 cm in all dimensions are documented in Table 42 below.

Table 42: Collection result of capacitors smaller than 2.5 cm

Appliance category systems	Collection category	Total collected < 2.5 cm [units]	Mass of collected capacitors < 2.5 cm [kg]
Office electronics, computing, communications/Swico 01	PC flat screens	404	0.337
	PC CRT screens	0	0
Office electronics, computing, communications/Swico 08	TV flat screens	1,307	1.434
	TV CRT screens	1,438	0.959
Office electronics, computing, communications/Swico 03	Desktop computers including internal power supply units	5,979	4.729
	Uninterruptible power supply (UPS)	0	0
	External laptop power supply units	874	1.243
Office electronics, computing, communications/Swico 06	Large-scale photocopiers	35	0.052
	Multifunctional printers	417	0.380
Consumer electronics and cameras/Swico 10	Audio devices such as amplifiers, radios, compact systems	345	0.176
	Loudspeaker boxes with at least 2 loudspeakers	9	0.014
	Video players (VHS)	645	0.277
Total		11,453	9.6

6.5.3 Comparison of capacitor quantities in all size classes

Based on the presented collection numbers, we created the evaluation according to Figure 21. It shows the numbers of different capacitor types per appliance category. Capacitors > 2.5 cm were divided into “Non-polarised cylindrical capacitors”, “Electrolytic capacitors” and “Microwave capacitors”. Capacitors < 2.5 cm were divided into “Electrolytic capacitors” and “Film/ceramic capacitors”. The latter category refers to dry non-polarised capacitors that have been removed and collected along with the other types of capacitors by mistake rather than systematically.

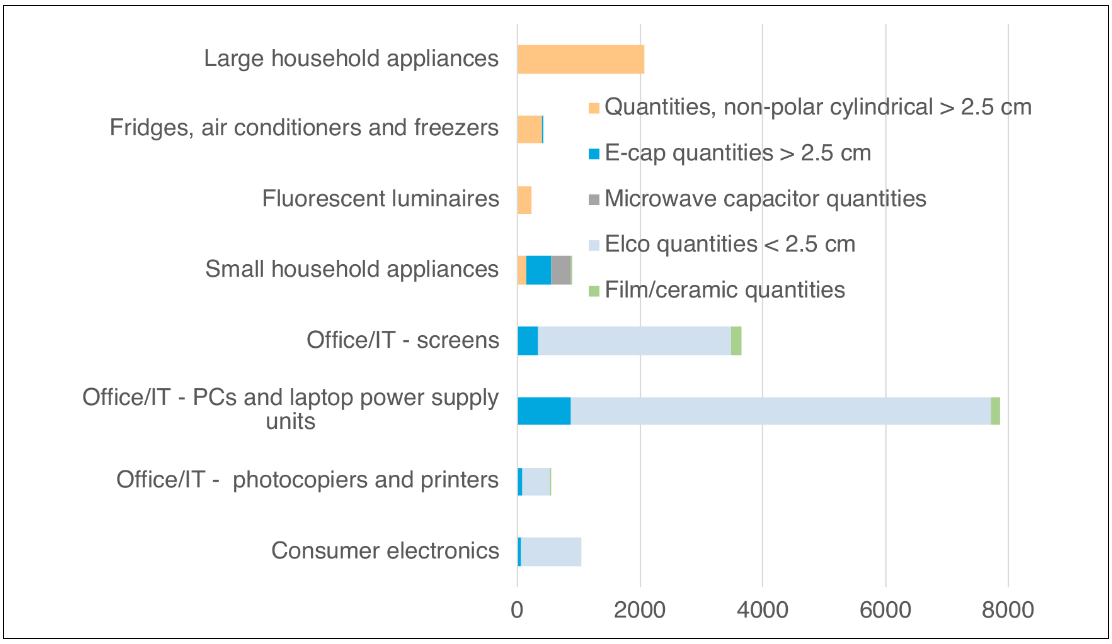


Figure 21: Numbers of collected capacitor classes per appliance category

6.5.4 Appliances

For Swico appliances, the collection facility recorded the number and mass of appliances from which the capacitors were taken. This data can be found in Table 43.

Table 43: Number and mass of appliances from which the capacitors were removed

No.	Appliance category systems	Collection category	Number of disassembled appliances [units]	Mass of disassembled appliances [kg]
21a	Office electronics, computing, communications/Swico 01	PC flat screens	15	103
21b		PC CRT screens	0	0
22a	Office electronics, computing, communications/Swico 08	TV flat screens	29	547
22b		TV CRT screens	17	349
23a	Office electronics, computing, communications/Swico 03	Desktop computers including internal power supply units	133	804
23b		Uninterruptible power supply (UPS)	Approx. 20	Not determined
23c		External laptop power supply units	219	63
24a	Office electronics, computing, communications/Swico 06	Large-scale photocopiers	2	157
24b		Multifunctional printers	17	162

No.	Appliance category systems	Collection category	Number of disassembled appliances [units]	Mass of disassembled appliances [kg]
25a	Consumer electronics and cameras/Swico 10	Audio devices such as amplifiers, radios, compact systems	6	28
25b		Loudspeaker boxes with at least 2 loudspeakers	26	171
25c		Video players (VHS)	11	28
Total	(without UPS)		475	2,411

6.6 Mass fraction after total disassembly of electrolytic capacitor

The disassembly of an electrolytic capacitor measuring approximately 2 cm in length without external contact pins and with a diameter of approximately 1.5 cm resulted in masses according to Table 44. The mass of the blotting paper was determined immediately after opening the capacitor and again after a storage period of eight months. In the methodology chapter 5.4, the disassembly is illustrated with images.

Table 44: Masses from the disassembly of an electrolytic capacitor

Weighing	Mass [g]	Mass fraction [%]
Whole capacitor without contact pins	7.6	100%
Aluminium and plastic housing with bitumen seal	3	39%
Aluminium films with internal contacting	2.8	37%
Blotting paper without liquid	0.6	8%
Liquid in blotting paper	0.8	10.5%
Losses (difference between fractions and mass of the whole capacitor)	0.4	5%

7 Discussion

7.1 Definition of substances of concern

Electronic components consistently contain toxic substances, such as copper in cables, lead in solder joints or flame retardants in plastics. Since the definition of substances of concern is used in connection with the advance removal of capacitors, care should be taken to ensure that the definition of substances of concern in capacitors covers only those substances which require separate treatment during processing.

All substances classified by the REACH Regulation (European Parliament, 2006) as substances of high concern and thus listed in Annex XIV are considered substances of concern in recycling. All substances listed in Annex III of the Rotterdam Convention (UNEP/FAO, 2017) are considered substances of concern in recycling.

Substances that are banned or subject to severe restriction according to national laws are considered as substances of concern. For Switzerland, this is the case for substances which cannot be used in capacitors according to the ORRChem, Annex 2.14 (Swiss Federal Council, 2005a) and all substances listed in the annexes of the ChemPICO (Swiss Federal Council, 2005b).

All chemicals put on the market must be classified with H-statements according to the specifications of the CLP Regulation (European Parliament, 2008). These H-statements are progressively harmonised in Europe under the CLP Regulation. The H-statements offer a relatively comparable and above all easily available source of information for defining the term substances of concern. The disadvantage of the H-statements is the very rough classification of the environmental hazards in only five classes for risk to aquatic life and one for gases that deplete the ozone layer, which is not relevant for capacitors.

We determined the H-statements for all liquid substances in capacitors found during the literature research and laboratory analyses. The results of this research have been recorded in Table 2. Table 45 shows all H-statements of the liquid electrolytes and dielectrics found. The following criteria were used to classify the substances as substances of concern or not of concern using the H-statements:

- Substances with chronic effects on organisms even in small concentrations are classified as substances of concern. These include classifications as carcinogenic, mutagenic, fertility-impairing and with unspecific chronic effects.
- All substances that are toxic or very toxic to aquatic life are considered substances of concern.
- Substances with fatal effects are regarded as substances of concern. Substances which are classified as toxic or harmful to health according to the GHS are not regarded as substances of concern in recycling. Substances with the classification H304 are an exception. This is because these substances can reach the lungs when swallowed due to their low viscosity and can thus cause pneumonia. This hazard is not relevant if the substances are highly diluted in mixtures. In addition, the oral route of exposure is not relevant in recycling.
- Substances which are potential allergens are not classified as substances of concern. These hazards are not uncommon for substances in WEEE and must be considered in the recycler’s workplace health and safety practices.
- Physical hazards do not qualify a substance as a substance of concern.

Table 45: H-statements for liquid substances and classification as substances of concern

H-statement	Hazard	Qualifies a substance as CMR	Qualifies a substance as a substance of concern
H220	Extremely flammable gas	No	No
H225	Highly flammable liquid and vapour	No	No
H226	Flammable liquid and vapour	No	No
H300	Fatal if swallowed	No	**Yes**
H301	Toxic if swallowed	No	No
H302	Harmful if swallowed	No	No
H304	May be fatal if swallowed and enters airways	No	No
H310	Fatal in contact with skin	No	**Yes**
H311	Toxic in contact with skin	No	No
H312	Harmful in contact with skin	No	No
H314	Causes severe skin burns and eye damage	No	No
H315	Causes skin irritation	No	No
H317	May cause an allergic skin reaction	No	No
H318	Causes serious eye damage	No	No
H319	Causes serious eye irritation	No	No
H330	Fatal if inhaled	No	**Yes**
H331	Toxic if inhaled	No	No
H332	Harmful if inhaled	No	No
H334	May cause allergy or asthma symptoms or breathing difficulties if inhaled	No	No
H335	May cause respiratory irritation	No	No
H336	May cause drowsiness or dizziness	No	No
H340	May cause genetic defects	**Yes**	**Yes**
H341	Suspected of causing genetic defects	**Yes**	**Yes**
H350	May cause cancer	**Yes**	**Yes**
H351	Suspected of causing cancer	**Yes**	**Yes**
H360D	May damage the unborn child	**Yes**	**Yes**
H360FD	May damage fertility May damage the unborn child	**Yes**	**Yes**
H360Df	May damage the unborn child Suspected of damaging fertility	**Yes**	**Yes**
H361	Suspected of damaging fertility or the unborn child	**Yes**	**Yes**
H361d	Suspected of damaging the unborn child	**Yes**	**Yes**
H370	Causes damage to organs	**Yes**	**Yes**
H372	Causes damage to organs through prolonged or repeated exposure	No	**Yes**
H373	May cause damage to organs through prolonged or repeated exposure	No	No
H400	Very toxic to aquatic life	No	**Yes**
H410	Very toxic to aquatic life with long-lasting effects	No	**Yes**
H411	Toxic to aquatic life with long-lasting effects	No	**Yes**
H412	Harmful to aquatic life with long-lasting effects	No	No
H413	May cause long-lasting harmful effects to aquatic life	No	No

If a substance is classified as concerning according to its H-statements, we must also check whether the substance is sufficiently stable in the environment to have a harmful effect. Rapidly biodegradable substances are eliminated in the environment so rapidly that the hazard they present to ecosystems is locally limited. This restriction does not apply to CMR substances which are carcinogenic, mutagenic or teratogenic. These substances can have a direct impact on humans via the recyclable material chain without first ending up in open systems. We clarified the environmental stability of all non-CMR substances that may be considered potentially concerning after classification using the H-statements. We used the EPI Suite software from the United States Environmental Protection Agency (US EPA, 2012) for this purpose. It calculates a model prediction of the biodegradability of substances with known chemical properties. The results of this prediction were checked with the information in the substance registration dossiers according to the REACH Regulation (European Parliament, 2006).

There is currently no ecotoxic classification for substances listed in the Annex III directory of the ECHA. However, data from model predictions indicate that these substances may have toxic or ecotoxic properties. These substances are therefore listed in the aforementioned directory. Manufacturers must state whether their properties need to be clarified in accordance with the REACH Regulation. These substances are not currently classified as substances of concern in recycling, but must be observed further and reclassified as more information becomes available.

7.2 Liquid substances in PCB-free capacitors

7.2.1 Introduction

Substance lists of the known liquid substances in capacitors can be created using the results of the laboratory analyses and the literature research. These are presented separately below by capacitor type. The tables contain all substances that were analysed in the GCMS laboratory analysis with a very good correspondence to the substance library. Substances are taken over from the LCMS analysis if their identity is confirmed or classified as likely. All substances considered to be guaranteed from the literature research are listed. The tables indicate in the penultimate column whether a substance was found in the GCMS or LCMS analysis of this study or if it is reliably mentioned in the literature. The last column also shows the classification as a substance of concern according to the evaluation scheme in chapter 7.1.

7.2.2 Non-polarised cylindrical capacitors

The substances in Table 46 were identified in PCB-free non-polarised cylindrical capacitors. A total of 9 out of 15 are substances of concern.

Table 46: Known substances in non-polarised cylindrical capacitors

Chemical designation	CAS No.	How was it found?	Substance of concern?
1-Chloronaphthalene (chlorinated naphthalenes)	90-13-1	Literature	Yes
1-Decene	872-05-9	Literature	No
1-Dodecene	112-41-4	Literature	No
1-Methylnaphthalene	90-12-0	GCMS analysis and literature	Yes
1-Tetradecene	1120-36-1	Literature	No
2-Methylnaphthalene	91-57-6	GCMS analysis and literature	Yes
Benzyltoluenes (p- and m-)	27776-01-8	GCMS analysis	Yes
Biphenyl	92-52-4	Literature	Yes
Butylated hydroxyanisole	25013-16-5	Literature	Yes
Dibutyl phthalate	84-74-2	Literature	Yes
Diisobutyl phthalate	84-69-5	Literature	Yes
Dinonyl phthalate	84-76-4	GCMS analysis	No
Naphthalene	91-20-3	Literature	Yes
Castor oil	8001-79-4	Literature	No
Soybean oil	None	Literature	No

7.2.3 Electrolytic capacitors

In addition to the substances listed in Table 47, it has emerged from the laboratory analyses that boron-containing compounds are also found. The boron content in the samples was between 0.5 and 2.5 g/kg with regard to the coil mass. Furthermore, boric acid is described as a substance in aluminium e-caps multiple times within the literature.

Table 47: Known substances in electrolytic capacitors

Chemical designation	CAS No.	How was it found?	Substance of concern?
1-Methoxy-2-nitrobenzene or isomer	91-23-6	GCMS analysis	Yes
1,2-Benzenedicarboxylic acid	88-99-3	Literature	No
1,3-Benzenedicarboxylic acid	121-91-5	Literature	No
2-Ethylhexanol or similar compound	104-76-7	GCMS analysis	No
2-Hydroxybenzoic acid, salicylic acid	69-72-7	Literature	No
2-Hydroxyethyl benzoate	94-33-7	GCMS analysis	Suspected
2,4-Dihydroxybenzoic acid	89-86-1	Literature	No
3-Nitroacetophenone/m-nitroacetophenone	121-89-1	GCMS analysis	No
4-Nitrobenzyl alcohol or isomer	619-73-8	GCMS analysis	No

Chemical designation	CAS No.	How was it found?	Substance of concern?
4-Nitrophenol	100-02-7	GCMS analysis	No
Ammonium pentaborate	12046-04-7	Literature	Suspected
Benzoic acid	65-85-0	GCMS analysis	No
Benzyl alcohol	100-51-6	GCMS analysis and literature	No
Boric acid	11113-50-1	Literature (and boron analysis)	Yes
Butyldiglycol or isomer	112-34-5	GCMS analysis	No
Diethylamine	109-89-7	LCMS analysis and literature	No
Diethylene glycol	111-46-6	GCMS analysis	No
Dimethylacetamide	127-19-5	LCMS analysis and literature	Yes
Dimethylbenzyl alcohol	617-94-7	Literature (and moderate consistency with GCMS analysis)	No
Dimethylformamide	68-12-2	LCMS analysis and literature	Yes
Ethylene glycol, ethane-1,2-diol, monoethylene glycol	107-21-1	Literature	No
N-Methylpyrrolidone	872-50-4	Literature	Yes
Phenol	108-95-2	GCMS analysis	Yes
Polyethylene glycol	25322-68-3	LCMS analysis and literature	No
Triethylamine	121-44-8	LCMS analysis and literature	No
γ-Butyrolactone	96-48-0	GCMS analysis and literature	No

7.2.4 Microwave capacitors

The analysis results of the microwave capacitors show numerous biaryls, diarylalkanes or arylalkanes (Table 48). These substances are described in little detail in the literature. For many of the observed substances, compounds with similar absorption spectra could also be present in the GCMS analysis. The consistency between the measured spectra and the spectra in the substance library is often only moderate. Applying the rule that only substances with very good consistency are classified as known from the analysis would lead to very few substances, which were also measured in fairly low concentrations. The substances with very good consistency are benzyltoluenes, ethyl(1-phenylethyl)benzene and 1,1-diphenylethane. All major components would be left out of the list. Since it is reliably evidenced that the analysed or similar compounds from the mentioned substance groups are present, the substances with moderate consistency are included in the list of known compounds for microwave capacitors.

For some of the substances found, a classification was not possible because no information on the toxicity of the substance could be found.

Table 48: Known substances in microwave capacitors

Chemical designation	CAS No.	How was it found?	Substance of concern?
1-Methyl-4-(phenylmethyl)benzene	620-83-7	Literature	No
1,1-Bis(3,4-dimethylphenyl)ethane	1742-14-9	Literature	No
1,1-Bis(4-methylphenyl)ethane	530-45-0	Literature	No, observe
1,1-Diphenylethane, diarylethene	612-00-0	GCMS analysis and literature	Assessment not possible
1,1'-(1-Methylethylidene)bis(4-methylbenzene) or similar compound	N/A	GCMS analysis	Assessment not possible
1,2-Dimethyl-4-(phenylmethyl)benzene	13540-56-2	Literature	Assessment not possible
1,2,3-Trimethyl-4-(1E)-1-propenyl-naphthalene or similar compound	26137-53-1	GCMS analysis	Assessment not possible
1,3,5-Cycloheptatriene, 6-methyl-1-(6-methyl-1,3,5-cycloheptatrien-1-yl)- or similar compound	N/A	GCMS analysis	Assessment not possible
1,5,6,7-Tetramethyl-3-phenylbicyclo[3.2.0]hepta-2,6-dien or similar compound	126584-00-7	GCMS analysis	Assessment not possible
2,2'-Dimethylbiphenyl	605-39-0	Literature	No
2,2',5,5'-Tetramethylbiphenyl or similar compound	3075-84-1	GCMS analysis	Yes
2,3,4,4a-Tetrahydro-1α,4aβ-dimethyl-9(1H)-phenantron or similar compound	94571-08-1	GCMS analysis	Assessment not possible
2,6-Diisopropylnaphthalene	24157-81-1	Literature	Yes
3,4-Epoxy cyclohexane carboxylic acid-(3,4-epoxycyclohexyl methyl ester)	2386-87-0	Literature	No
4-Isopropylbiphenyl	7116-95-2	Literature	No, observe
5-Ethyl-2-methyl-4,4-diphenyl-3,4-dihydro-2H-pyrrole (EMDP) or similar compound	102177-18-4	GCMS analysis	Assessment not possible
Benzyltoluenes (p-, m-, o-)	27776-01-8	GCMS analysis	Yes
Bis(7-methyloctyl)phthalate	20548-62-3	Literature	No
Di-p-tolyl-methane or isomer	4957-14-6	GCMS analysis	Yes
Diethyl phthalate	84-66-2	Literature	No
Diisodecyl phthalate	26761-40-0	Literature	Suspected
Diisononyl phthalate	68515-48-0	Literature	No
Ethyl(1-phenylethyl)benzene	18908-70-8	GCMS analysis	Assessment not possible
Trioctyl trimellitate	3319-31-1	Literature	Suspected

7.3 Classification of the substances in capacitors

7.3.1 Substances of concern

Applying the selected classification from the previous chapter results in 19 substances of concern in capacitor liquids. This number also includes the group of PCBs. For PCB-free capacitors, there are thus 18 substances of concern that can be found in the capacitors which are currently being recycled. The list of these substances can be found in Table 49.

Table 49: Substances of concern in capacitor liquids

Chemical designation	CAS No.	Substance of concern based on H-statements	Easily biode-grad-able?	CMR?	Substance of concern in recycling	Capacitor type occur-rence
1-Chloronaphthalene (chlorinated naphthalenes)	90-13-1	Yes	No	No	Yes	Non-polarised cylindrical
1-Methylnaphthalene	90-12-0	Yes	No	No	Yes	Non-polarised cylindrical
1-Methoxy-2-nitrobenzene/2-nitroanisole	91-23-6	Yes		Yes	Yes	E-cap
2-Methylnaphthalene	91-57-6	Yes	No	No	Yes	Non-polarised cylindrical
2,2',5,5'-Tetramethylbiphenyl	3075-84-1	Yes	No		Yes	Micro-wave
2,6-Diisopropylnaphthalene	24157-81-1	Yes	No	No	Yes	Micro-wave
Benzyltoluenes	27776-01-8	Yes		No	Yes	Non-polarised cylindrical, micro-wave
Biphenyl[3]	92-52-4	Yes	No	No	Yes	Non-polarised cylindrical
Boric acid	11113-50-1	Yes	No	Yes	Yes	E-cap
Butylated hydroxyanisole	25013-16-5	Yes	No	Yes	Yes	Non-polarised cylindrical
Di-p-tolyl-methane	4957-14-6	Yes	No	No	Yes	Micro-wave
Dibutyl phthalate	84-74-2	Yes	Yes	Yes	Yes	Non-polarised cylindrical

[3] The properties of biphenyl are currently being clarified in the REACH Regulation (ECHA, 2013) as it is suspected of being persistent, bioaccumulative and toxic.

Chemical designation	CAS No.	Substance of concern based on H-statements	Easily biode-grad-able?	CMR?	Substance of concern in recycling	Capacitor type occur-rence
Diisobutyl phthalate	84-69-5	Yes	Yes	Yes	Yes	Non-polarised cylindrical
Dimethylacetamide	127-19-5	Yes	Yes	Yes	Yes	E-cap
Dimethylformamide	68-12-2	Yes	Yes	Yes	Yes	E-cap
N-Methylpyrrolidone	872-50-4	Yes	Yes	Yes	Yes	E-cap
Naphthalene	91-20-3	Yes	No	Yes	Yes	Non-polarised cylindrical
Phenol	108-95-2	Yes	Yes	Yes	Yes	E-cap
Polychlorinated biphenyls	1336-36-3	Yes	No	No	Yes	Containing PCBs

7.3.2 Potentially concerning substances

There are indications for the four substances in Table 50 that they could meet the criteria for substances of concern. All four substances are classified with different H-statements depending on the manufacturer and there is no harmonised classification at the European level. For both ammonium pentaborate and trioctyl trimellitate, some manufacturers declare H-statement 361 ("Suspected of damaging fertility or the unborn child"), but some manufacturers do not declare this H-statement. Diisodecyl phthalate and diisononyl phthalate are not permitted in items for children (Annex XVII of the REACH Regulation). In some cases, the manufacturers declare the H-statements 400, 410 or 411 for diisodecyl phthalate. One manufacturer declares H400 for diisononyl phthalate. Some manufacturers do not declare any of the H-statements mentioned above. For diisononyl phthalate, the model estimate indicates ready biodegradability. However, due to the listing in Annex XVII of the REACH Regulation (European Parliament, 2006), the classification as a suspected substance remains.

Table 50: Potentially concerning substances in capacitor liquids

Chemical designation	CAS No.	Substance of concern based on H-statements	Easily biode-grad-able?	CMR?	Substance of concern in recycling	Capacitor type occurrence
Ammonium pentaborate	12046-04-7	Suspected	–	Yes	Suspected	E-cap
Diisodecyl phthalate	26761-40-0	Suspected	No	No	Suspected	Microwave
Diisononyl phthalate	28553-12-0	Suspected	Yes	No	Suspected	Microwave
Trioctyl trimellitate	3319-31-1	Suspected	–	Yes	Suspected	Microwave

7.3.3 Non-classifiable substances

It was not possible to classify the dozen substances in Table 51 found in capacitor liquids. This is because there is no classification with H-statements for these substances.

Table 51: Substances in capacitor liquids which could not be classified

Chemical designation	CAS No.	Substance of concern based on H-statements	Substance of concern in recycling	Capacitor type occurrence
1,1-Bis(4-methylphenyl)ethane	530-45-0	Assessment not possible	Assessment not possible	Microwave
1,1-Diphenylethane, diarylethene	612-00-0	Assessment not possible	Assessment not possible	Microwave
1,1'-(1-Methylethylidene)bis(4-methylbenzene)	Unknown	Assessment not possible	Assessment not possible	Microwave
1,2-Dimethyl-4-(phenylmethyl)benzene	13540-56-2	Assessment not possible	Assessment not possible	Microwave
1,2,3-Trimethyl-4-(1E)-1-propenyl-naphthalene	26137-53-1	Assessment not possible	Assessment not possible	Microwave
1,3,5-Cycloheptatriene, 6-methyl-1-(6-methyl-1,3,5-cycloheptatrien-1-yl)-	Unknown	Assessment not possible	Assessment not possible	Microwave
1,5,6,7-Tetramethyl-3-phenylbicyclo[3.2.0]hepta-2,6-dien	126584-00-7	Assessment not possible	Assessment not possible	Microwave
2-Hydroxyethyl benzoate	94-33-7	Assessment not possible	Assessment not possible	E-cap
2,3,4,4a-Tetrahydro-1α,4aβ-dimethyl-9(1H)-phenantron	94571-08-1	Assessment not possible	Assessment not possible	Microwave
4-Isopropylbiphenyl	7116-95-2	Assessment not possible	Assessment not possible	Microwave
5-Ethyl-2-methyl-4,4-diphenyl-3,4-dihydro-2H-pyrrole (EMDP)	102177-18-4	Assessment not possible	Assessment not possible	Microwave
Ethyl(1-phenylethyl)benzene	18908-70-8	Assessment not possible	Assessment not possible	Microwave

7.3.4 Substances not of concern

Table 52 shows all liquid substances in capacitors which can be considered not of concern in recycling based on the developed classification.

The examination of the registration dossiers of all non-CMR substances only led to information on degradation pathways in the environment for 1-dodecene (ECHA, 2017a) and biphenyl (ECHA, 2017b). Both substances are rapidly biodegradable according to this information. For biphenyl, this classification is in conflict with the fact that its persistent, bioaccumulative and toxic properties are currently being clarified. Biphenyl was therefore not classed as rapidly biodegradable in this study. The classification in the dossier for 1-dodecene can also be applied to 1-decene, meaning it can also be considered rapidly biodegradable. For 1-tetradecene and benzoic acid, the model estimation with EPI Suite (US EPA, 2012) showed that they are rapidly biodegradable. The same result was obtained for 1-decene and 1-dodecene. These four non-CMR substances are thus concerning or suspected with regard to their H-statements, but readily biodegradable. As a result, these substances should not be classified as substances of concern in recycling.

Table 52: Non-hazardous substances in capacitor liquids

Chemical designation	CAS No.	Substance of concern based on H-statements	Easily bio-degrad-able?	CMR?	Substance of concern in recycling	Capacitor type occur-rence
1-Decene	872-05-9	Yes	Yes	No	No	Non-polarised cylindrical
1-Dodecene	112-41-4	Yes	Yes	No	No	Non-polarised cylindrical
1-Methyl-4-(phenyl-methyl)benzene	620-83-7	No	–	No	No	Micro-waves
1-Tetradecene	1120-36-1	Suspected	Yes	No	No	Non-polarised cylindrical
1,1-Bis(3,4-dimethyl-phenyl)ethane	1742-14-9	No	–	No	No	Micro-waves
1,2-Benzenedicarboxylic acid	88-99-3	No	–	No	No	E-cap
1,3-Benzenedicarboxylic acid	121-91-5	No	–	No	No	E-cap
2-Ethylhexanol	104-76-7	No	–	No	No	E-cap
2-Hydroxybenzoic acid, salicylic acid	69-72-7	No	–	No	No	E-cap
2,2'-Dimethylbiphenyl	605-39-0	No	–	No	No	Micro-waves
2,4-Dihydroxybenzoic acid	89-86-1	No	–	No	No	E-cap
3-Nitroacetophenone	121-89-1	No	–	No	No	E-cap
3,4-Epoxy cyclohexane carboxylic acid-(3,4-epoxycyclohexyl methyl ester)	2386-87-0	No	–	No	No	Micro-waves
4-Nitrobenzyl alcohol	619-73-8	No	–	No	No	E-cap
4-Nitrophenol	100-02-7	No	–	No	No	E-cap
Benzoic acid	65-85-0	Yes	Yes	No	No	E-cap
Benzyl alcohol	100-51-6	No	–	No	No	E-cap
Bis(7-methyl-octyl)phthalate	20548-62-3	No	–	No	No	Micro-waves
Butyldiglycol	112-34-5	No	–	No	No	E-cap

Chemical designation	CAS No.	Substance of concern based on H-statements	Easily bio-degrad-able?	CMR?	Substance of concern in recycling	Capacitor type occur-rence
Diethylamine	109-89-7	No	–	No	No	E-cap
Diethylene glycol	111-46-6	No	–	No	No	E-cap
Diethyl phthalate	84-66-2	No	–	No	No	Micro-waves
Dinonyl phthalate	84-76-4	No	–	No	No	Non-polarised cylindrical
Ethylene glycol, ethane-1,2-diol, monoethylene glycol	107-21-1	No	–	No	No	E-cap
Polyethylene glycol	25322-68-3	No	–	No	No	E-cap
Castor oil	8001-79-4	No	–	No	No	Non-polarised cylindrical
Soybean oil	None	No	–	No	No	Non-polarised cylindrical
Triethylamine	121-44-8	No	–	No	No	E-cap
γ-Butyrolactone	96-48-0	No	–	No	No	E-cap

7.4 Share of capacitors containing PCB

7.4.1.1 Overview

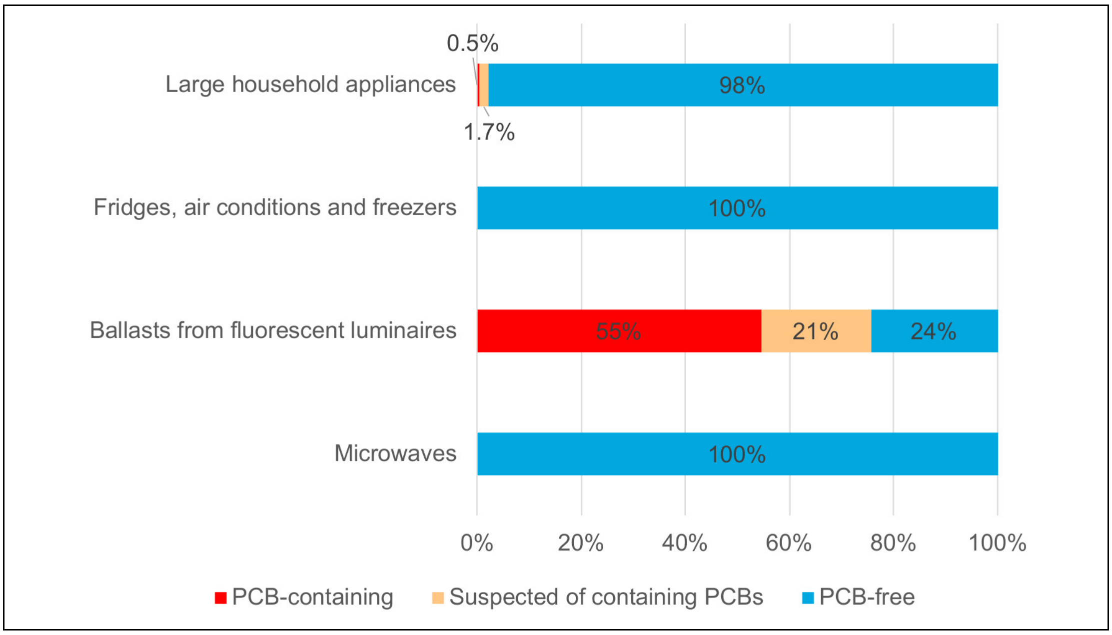


Figure 22: Share of PCB-containing capacitors within appliance categories in units

The question of what share of capacitors contains PCBs only relates to household appliances, refrigerators, ballasts from luminaires and tools. These are the field of application of non-polarised cylindrical capacitors, which are filled with PCBs as a dielectric. Figure 22 shows an overview of the results; the results are discussed per appliance category below. The orange columns show the proportions of capacitors suspected of containing PCBs. These are the capacitors which could not be classified as PCB-free or containing PCBs. They are capacitors which could contain PCBs due to their age but are not listed in the capacitor list (Arnet et al., 2011) and their PCB content was not determined in a laboratory analysis. The reported share of PCB-free capacitors should be seen as minimum values. In a best-case scenario – whereby all capacitors classified as being suspected of containing PCBs are actually PCB-free – the share of PCB-free capacitors would be 99.5 per cent for large household appliances and 45 per cent for fluorescent luminaires. The annual loads of capacitors containing or suspected of containing PCBs are estimated in chapter 7.7.2 based on these figures.

7.4.1.2 Large household appliances

Very few large household appliances still contain capacitors which can be unambiguously classified as containing PCBs via the capacitor list (Arnet et al., 2011). There were many models in the sample that could contain PCBs due to their age, but are not listed in the capacitor list. Some of these capacitors were analysed in the laboratory to check their PCB content. All of the analysed capacitors have been free of PCB. This leaves 1.7 per cent of capacitors which must be classified as suspected of containing PCBs due to their age.

7.4.1.3 Refrigerators, air conditioners and freezers

All classified or analysed capacitors in refrigerators, air conditioners and freezers are free of PCBs. After the classification with the aid of the capacitor list, we analysed the PCB content of all of the capacitors suspected to contain PCBs. All of them have been free of PCB.

7.4.1.4 Ballasts from fluorescent luminaires

Ballast capacitors still often contain PCBs. This is undoubtedly due the old age of fluorescent luminaires when they are sent to be recycled. The representativeness of the sample is low because most of the evaluated capacitors come from a recycler that has obtained these through very few deliveries. A second commissioned recycler was not technically able to remove the capacitors which are completely surrounded by the metal housing from the ballasts. The models of these capacitors could thus not be determined.

The result is consistent with the earlier evaluation by the first author of this study (Gasser, 2009). Despite the lack of sample representativeness, it becomes clear that the proportion of ballasts containing capacitors with PCBs is still significant. It is important for disposal that all capacitors are removed from ballasts prior to mechanical crushing, and that these are disposed of as hazardous waste.

7.4.1.5 SENS small appliances

Among the capacitors collected were models typically used in ballasts. It could not be clarified whether these really came from SENS small appliances and not, for example, from mobile lamps. The share of PCB-containing capacitors in the sampling category of “Other small household appliances” of 26 per cent appears to be implausibly high. Even the significantly higher value of 5 per cent in the “Small household appliances with motors” compared to the value for large household appliances is not very plausible. Due to the lack of cooperation of a recycler who mainly processes this equipment category, the collection for this appliance category could not be carried out in a disassembly facility with a high delivery rate of SENS small appliances. Instead, it was carried out at a facility that does not typically disassemble these appliances. For a reliable statement about the share of PCB-containing capacitors in SENS small appliances, the collection would have to be repeated by a facility that can ensure a correct selection of the appliances.

7.5 Average masses

7.5.1 Non-polarised cylindrical capacitors

The average masses of the capacitors were calculated by weighing the capacitors during the classification of the models and the simultaneous quantity determination. All results are listed in Table 53. For large household appliances, the mean masses of the subcategories and the capacitor average from large household appliances as a total are shown.

Table 53: Average masses of non-polarised cylindrical capacitors by appliance category

Appliance category	Average mass of non-polarised cylindrical capacitors > 2.5 cm
Dishwashers	53.8 g
Washing machines	102.6 g
Other large household appliances	73.3 g
Large household appliances	**79.0 g**
Refrigerators	**70.7 g**
Luminaires	**112.8 g**

7.5.2 Electrolytic capacitors

The average masses of the electrolytic capacitors according to Table 54 were acquired from the data of the quantity and mass evaluation. The quantities and masses were determined for electrolytic capacitors with a dimension larger than 2.5 cm and for those with all dimensions smaller than 2.5 cm. The lines in bold show the mean values of the appliance categories set in regular font style above.

Table 54: Average masses of electrolytic capacitors by appliance category

Appliance category	Average masses e-caps > 2.5 cm	Average masses e-caps < 2.5 cm
Small household appliances with motors	33.8 g	–
Other small household appliances	26.7 g	–
SENS small appliances	**30.2 g**	–
PC flat screens	11.7 g	0.8 g
TV flat screens	12.8 g	1.1 g
CRT TV	13.9 g	0.7 g
Office/IT – screens	**13.1 g**	**0.9 g**
Desktop PCs	7.5 g	0.8 g
Laptop power supply units	11.5 g	1.4 g
Office/IT – PCs and laptop power supply units	**8.8 g**	**0.9 g**
Photocopiers	11.2 g	1.5 g
Multifunctional printers	15.7 g	0.9 g
Office/IT – photocopiers and printers	**13.2 g**	**1.0 g**
Audio devices	15.8 g	0.5 g
Loudspeakers	8.7 g	1.6 g
Video	8.7 g	0.4 g
Consumer electronics	**11.0 g**	**0.5 g**

7.5.3 Microwave capacitors

The average masses of the microwave capacitors have been determined by weighing the capacitors and are shown in Table 55.

Table 55: Average masses of microwave capacitors by appliance category

Appliance category	Average mass of microwave capacitors
Microwave	118.1 g

7.5.4 Appliances

The average masses of the appliances could be determined for the Swico appliances from the test data. These are listed in Table 56. The quantities were very low for the appliance categories “Large-scale photocopiers” and “Amplifiers, radios, compact systems”. A meaningful average mass therefore cannot be specified for these appliance categories. Thus these categories are not included in Table 56.

Table 56: Number and mass of appliances from which the capacitors were removed

No.	Appliance category systems	Collection category	Number of disassembled appliances [units]	Average mass of appliances [kg]
21a	Office electronics, computing, communications/Swico 01	PC flat screens	15	6.9
22a	Office electronics, computing, communications/Swico 08	TV flat screens	29	18.9
22b		TV CRT screens	17	20.5
23a	Office electronics, computing, communications/Swico 03	Desktop computers including power supply units	133	6.0
23c		External laptop power supply units	219	0.286
24b	Office electronics, computing, communications/Swico 06	Multifunctional printers	17	9.5
25b	Consumer electronics and cameras/Swico 10	Loudspeaker boxes with at least 2 loudspeakers	26	6.6
25c		Video players (VHS)	11	2.5

7.6 Mass evaluation of electrolytic capacitors in appliances

7.6.1 Introduction

The mass of all included aluminium electrolytic capacitors was determined for IT and CE appliances. Together with the masses of the appliances, the mass fraction of electrolytic capacitors in relation to the appliances can be determined. However, the appliance numbers in certain categories were very low. The mass evaluations are limited to collection categories with more than 10 disassembled appliances. For smaller appliance numbers, the evaluation would be too dependent on the individual appliances and could no longer be interpreted as a general statement about the mass fractions. The appliance category of the loudspeakers is also excluded from the evaluations since according to the authors' guidelines, only loudspeakers with several boxes were disassembled which contained capacitors > 2.5 cm. Determining the mass fraction in the appliances or the ratio between large and small capacitors is therefore generally not useful for the group of loudspeakers with the data available.

7.6.2 Mass fractions of electrolytic capacitors of the appliance mass

The mass fractions of the capacitors are found through the mass of the collected capacitors of an appliance category divided by the mass of all appliances of that category. The results are outlined in Table 57. The results show that the proportion of aluminium e-caps for most appliance categories lies between 0.6 and 1.1 per cent. The capacitor mass was a larger proportion of 7 per cent only in laptop supply units. For video players, the proportion of 1.5 per cent is only marginally higher than in the majority of appliance categories. The mass fractions of the aluminium electrolytic capacitors with a length of over 2.5 cm in at least one dimension are shown in the last column. This is a subset of the information in the penultimate column.

Table 57: Mass fractions of electrolytic capacitors in the appliance mass

Appliance category	Mass fraction of e-cap of all sizes in appliances	Mass fraction of e-cap > 2.5 cm in appliances
PC flat screens	0.6%	0.3%
TV flat screens	0.8%	0.5%
CRT TV	0.7%	0.4%
Desktop PCs	1.1%	0.5%
Laptop power supply units	7.0%	5.0%
Multifunctional printers	0.6%	0.4%
Video	1.5%	0.5%

7.6.3 Ratio between large and small electrolytic capacitors in the appliances

For aluminium electrolytic capacitors, the mass fractions in the appliances can be determined between capacitors larger than 2.5 cm in one dimension and those smaller than 2.5 cm in all dimensions. This evaluation is shown in Figure 23. It is apparent that e-caps larger than 2.5 cm make up around half of the total mass of the included capacitors. Their mass fraction in laptop power supply units is significantly greater than 50 per cent. Large electrolytic capacitors contribute significantly less than 50 per cent of the total mass only in video players.

The size criterion was introduced to sort out the relevant proportion of capacitors in appliances at an economically justifiable expense. If all capacitors were removed, this would likely lead to a much greater expense in the disassembly of the appliances. The ratio between large and small electrolytic capacitors is therefore evaluated in Figure 24 with reference to the unit quantities. The evaluation by unit quantities shows that the aluminium e-caps < 2.5 cm make up 80 per cent or more of all capacitors. It is only in laptop power supply units that the large aluminium e-caps make up little more than 20 per cent of the total figure. Current technical regulations in Switzerland (SENS et al., 2012) require all aluminium e-caps with a dimension larger than 2.5 cm to be removed. With a removal of around 20 per cent of the total number, this achieves a removal of about 50 per cent of the total mass of the aluminium e-caps and thus the pollutants contained within them.

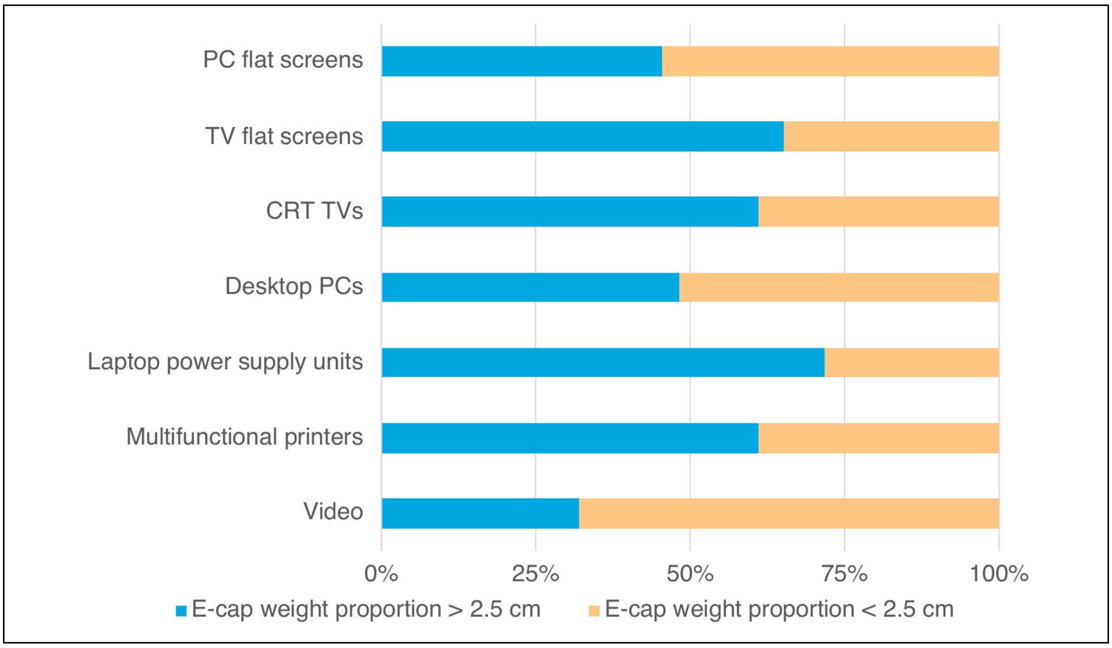


Figure 23: Mass fractions of electrolytic capacitors in the appliances

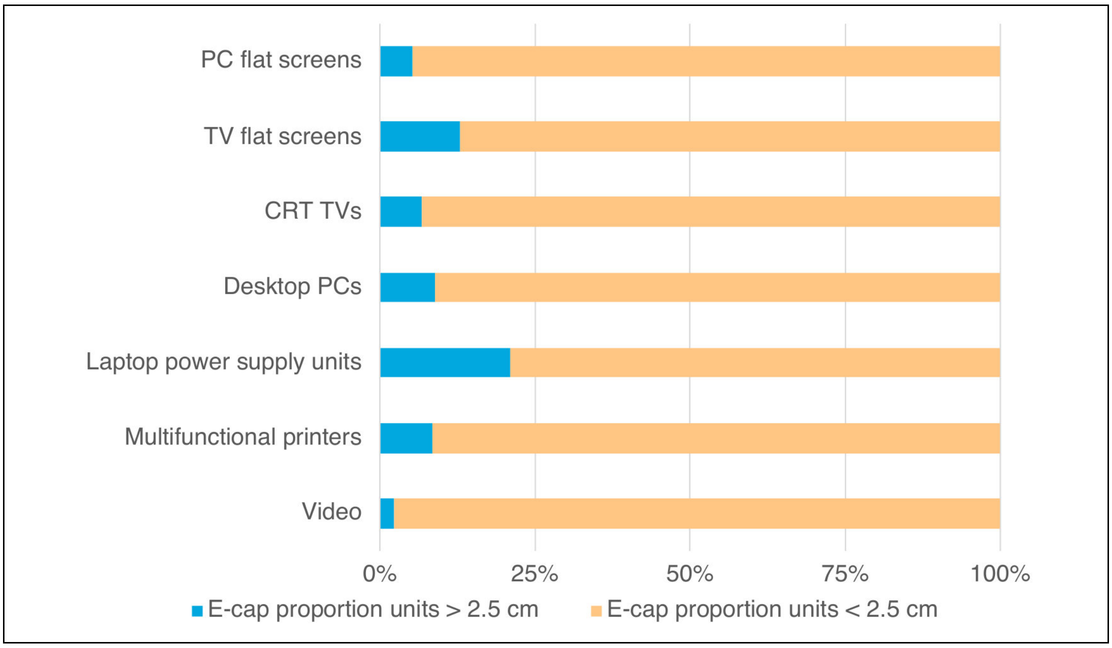


Figure 24: Share of electrolytic capacitors in the appliances by units

It should be noted that these numbers do not apply to non-polarised cylindrical capacitors. These are almost always larger than 2.5 cm in one dimension. Smaller non-polarised capacitors are almost exclusively ceramic or film capacitors without liquid substances. It should also be mentioned that the mass fraction regarding the removal of capacitors containing PCBs would be about 100 %. This is because PCB was foremost if not solely used in capacitors bigger than 2.5 cm in one dimension.

7.7 Extrapolations to the annual amount of WEEE

7.7.1 Quantity of dry capacitors and capacitors with liquids

From the test data on the proportions of dry capacitors, as presented in chapter 6.4.1, it is possible to estimate how many of the annually removed capacitors are dry and how many contain liquids. Some assumptions have to be made for the extrapolation to fill gaps in knowledge. The total amount of annually removed capacitors in Switzerland of around 200 t is known from the material flow analysis by SENS and Swico (SENS et al., 2018). The processed appliance quantities can be determined from the same source. The processed large household appliances, refrigerators, air conditioners and freezers, as well as Swico appliances are used for the calculation. The amount of microwaves cannot be determined from the recorded material flow data. For all Swico appliances, it is assumed that the removed capacitors are electrolytic capacitors which always contain liquids. In addition, we assume that the proportion of capacitors in the total mass is the same for all appliance categories, with the exception of the luminaires. For fluorescent luminaires, we use the figure from the luminaires study (Gasser, 2009) of a 4.6 per cent average mass fraction of the capacitors in fluorescent luminaires. This gives us the extrapolation for dry and liquid-filled capacitors according to Table 58.

Table 58: Estimation of the dry and liquid-filled capacitors in the total annual quantity in Switzerland

Appliance category systems	Proportion of dry capacitors in the collection	Processed appliance quantity in Switzerland in 2017 [t per year]	Capacitors produced in 2017 [t per year]	Calculation of total quantity of dry capacitors in Switzerland [t per year]	Calculation of total quantity of capacitors with liquids in Switzerland [t per year]
Large household appliances	42%	29 071		28	38
Refrigerators, air conditioners and freezers	31%	19 426		14	30
Luminaires	0%	21			1
Swico appliances	0%	45 982			104
All appliance categories		94 500	214	41	173

7.7.2 Annual load of capacitors containing and suspected of containing PCBs

An annual load of PCB-containing capacitors can be estimated from the proportions of PCB-containing capacitors and the annual loads of capacitors with liquids. For this estimation, we multiply the calculated annual quantities of liquid capacitors by the share of PCB-containing capacitors. This approach provides results according to Table 59.

Table 59: Estimation of the annual load of PCB-containing capacitors

Appliance category systems	Total quantity of capacitors with liquids [kg per year]	Total quantity of capacitors containing or suspected of containing PCBs [kg per year]
Large household appliances	38 000	818
Luminaires	960	722

It is apparent that the PCB-containing capacitors from fluorescent luminaires account for a similarly large annual flow as the capacitors from large household appliances.

7.7.3 Annual load of substances of concern in WEEE

For the substances of concern determined through analysis, we know the approximate mass fractions from the laboratory analyses. The highest mass fraction found in the mixed sample was used for a flow estimate. We multiplied this by the annual amount of non-polarised capacitors with liquids or electrolytic capacitors, as we indicate in Table 58.

Table 60: Substances of concern found through analysis with estimation of the annual load

Chemical designation	CAS No.	Capacitor type occurrence	Highest determined mass fraction [mg/kg liquid]	Estimation of the annual load of substances of concern [kg per year]
1-Methylnaphthalene	90-12-0	Non-polarised cylindrical	5 000	34
1-Methoxy-2-nitrobenzene/2-nitroanisole	91-23-6	E-cap	600	6
2-Methylnaphthalene	91-57-6	Non-polarised cylindrical	8 000	54
2,2',5,5'-Tetramethylbiphenyl	3075-84-1	Microwave	800 000	544
Benzyltoluenes	27776-01-8	Non-polarised cylindrical, microwave	46 000	313
Di-p-tolyl-methane	4957-14-6	Microwave	5 000	34
Phenol	108-95-2	E-cap	300	3
Total				989 ±50% or more

To forecast the annual loads of substances from microwave capacitors, we assume an annual quantity for the microwave capacitors of 10 per cent of the non-polarised capacitors, since measurement data to this amount is missing. For the liquid proportion in the capacitors, we assume a general 10 per cent of the capacitor mass. This is based on the results of the complete disassembly of an electrolytic capacitor (see Table 44). The mass fractions of the substances from electrolytic capacitors were multiplied by a factor of six with respect to the analysis result to obtain a mass fraction in the liquid. This calculation results in an annual load in Switzerland of substances of concern of approximately 500 to 1 000 kg per year. The calculation is shown in Table 60. Half of the calculated load comes from a single substance from microwave capacitors. This number is unreliable due to the unknown amount of microwave capacitors. Overall, the calculated load cannot be more accurate than the mass fraction determination in the laboratory analysis with probably significant errors. The load calculated here can thus deviate significantly from the real load.

When compared with the annual load of PCB-containing capacitors, it must be noted that Table 60 shows the mass of substances whereas Table 59 shows the mass of capacitors.

7.8 Additional interpretation of the analysis results

7.8.1 PCB contents in the mixed samples of PCB-free capacitors

As expected, the mixed samples were PCB-free with the exception of the mixed sample from the SENS small appliances. The PCB content of this sample was determined to be 38 mg/kg. An analysis error was ruled out following a consultation with the laboratory manager (Maier, 2018). The accuracy of the result this close to the determination limit is ±30 per cent as estimated by the laboratory manager. The mixed sample of SENS small appliance capacitors was obtained from 13 capacitors. Assuming that one capacitor in the sample contained PCBs, the PCB mass fraction in the liquid of this capacitor would be about 500 mg/kg. It is known from the literature (Arnet et al., 2011) that some manufacturers used PCB-contaminated oils while transitioning to PCB-free capacitors, but still declared these capacitors as PCB-free. The measured PCB content in the mixed sample of 38 mg/kg could be explained by one capacitor containing a PCB-contaminated oil.

7.8.2 Elemental analyses for tungsten and boron

The elemental analyses for tungsten and boron show that boron is present in the capacitors. The mass fraction was determined in the water-soluble phase. Metals from the matrix of capacitor coils dissolving due to the water extraction has been eliminated as a possibility. It is likely that boron is present as a dissolved element in electrolytic capacitors. Unfortunately, a comprehensive analysis of the LCMS data, including boron as a target element, did not lead to any findings about possible boron-containing substances.

7.8.3 Comparison with microwave samples

A comparison of the analysis results for the capacitors of the manufacturer BiCai with the capacitors of other manufacturers shows some similarities and some deviations in the analysed substances. See Table 61 for comparison. The substances are sorted by the highest mass fraction in one of the two samples. It is apparent that the tetramethylbiphenyls are the main components in the mixtures of all manufacturers. These are biaryls with two methyl groups per ring. However, the diarylalkanes, which are sometimes declared on the microwave capacitors, occur in smaller mass fractions. It can be assumed that the manufacturers do not distinguish between biarylalkanes and diarylalkanes in the declaration.

Table 61: Comparative presentation of analysis results for microwave capacitors

Substance	CAS No.	Mass fraction MW BiCai [mg/kg]	Mass fraction MW various manufacturers [mg/kg]
2,2',5,5'-Tetramethylbiphenyl or similar compound	3075-84-1	800 000	800 000
1,3,5-Cycloheptatriene, 6-methyl-1-(6-methyl-1,3,5-cycloheptatrien-1-yl)- or similar compound	N/A		200 000
Benzyltoluenes (p-, m-, o-)	713-36-0		46 000
1,2,3-Trimethyl-4-(1E)-1-propenyl-naphthalene or isomer	26137-53-1	6 000	30 000
5-Ethyl-2-methyl-4,4-diphenyl-3,4-dihydro-2H-pyrrole (EMDP) or similar compound	102177-18-4	5 000	30 000
1,5,6,7-Tetramethyl-3-phenylbicyclo[3.2.0]hepta-2,6-dien or similar compound	126584-00-7	20 000	
1,1'-(1-Methylethylidene)bis(4-methylbenzene) or similar compound	N/A	15 000	
Ethyl(1-phenylethyl)benzene	18908-70-8	10 000	10 000
1,1-Diphenylethane	612-00-0		7 000
Di-p-tolyl-methane or isomer	4957-14-6	5 000	
2,3,4,4a-Tetrahydro-1α,4aβ-dimethyl-9(1H)-phenantron or similar compound	94571-08-1		4 000

8 Findings

8.1 New findings from this study

As far as we are aware, we are presenting the most comprehensive study to date on the liquids in PCB-free capacitors from the return of waste electrical and electronic equipment. This study combines literature references with our own laboratory analyses to obtain the most comprehensive picture possible of common liquids. The sampling for this study was exceptionally extensive. A total of nearly 5 000 capacitors from all appliance categories of WEEE in the take-back systems in Switzerland were collected and classified.

To the best of our knowledge, the mass of all aluminium electrolytic capacitors in WEEE from the sectors of IT and consumer electronics was recorded for the first time. We also recorded the appliance mass of the collected appliances. With this information, we were able to determine the proportion of electrolytic capacitors in the total mass of the appliances.

8.2 Accuracy and representativeness of the results

The sampling for our study can be considered as representative of the returns for the categories of large household appliances, refrigerators, screens, desktop computers and external power supply units in Switzerland. The proportion of PCB-containing capacitors in large household appliances could be determined with a deviation of less than half a per cent. The collected electrolytic capacitors from flat screens, desktop computers and external laptop power supply units provide a comprehensive and representative sample of existing capacitor models. The mass distribution of large and small electrolytic capacitors and the mass fraction of electrolytic capacitors in the collected appliances could be determined reliably.

For the appliance category of fluorescent luminaires, the share of PCB-containing capacitors was determined with a statistical accuracy of 5 per cent, with non-representative sampling giving the result an additional error margin of an unknown extent. The collection process was not optimal for SENS small appliances. The result regarding the PCB content of the included capacitors cannot be considered representative. For Swico appliances, the collection quantities for audio devices, video players and large-scale photocopiers were too low for a representative sampling.

No confidence intervals can be indicated for the determination of substances in PCB-free capacitors. From the extensive collection, eight mixed samples were analysed in the laboratory. This modest volume is a consequence of the available budget and scientifically regrettable. Only a few trace substances could be identified. The main components of the mixed samples remained unknown. Despite the relatively few findings from the chemical analysis, assertions could be made regarding the substances of concern present in all types of capacitors when this knowledge was combined with findings from the literature research.

8.3 Differentiation of capacitors by origin is difficult to implement in practice

The difficulties encountered during sampling for the study clearly demonstrated that a separate collection of capacitors of varying origins is difficult to implement. Even relatively few, well-instructed disassembly facilities and recyclers were not always able to reliably collect the capacitors from different appliance categories separately. The collection ran smoothly for large household appliances and refrigerators, where the removal of the capacitors is part of daily practice. For electrolytic capacitors from Swico appliances, the collection was exemplary thanks to a disassembly facility with exceptionally well-trained staff. The facility carries out the continuous market basket analysis for Swico and is very well organised when it comes to disassembling appliances with component determination. However, this experience cannot be generalised to the average disassembly facility. Microwave capacitors were collected relatively well thanks to their characteristic design. However, some incorrectly sorted microwave capacitors had to be resorted by the authors of this report. The result of the collection of capacitors from SENS small appliances has to be considered very critically. The desired evaluations were largely unreliable or impossible, as there are considerable doubts regarding whether all the capacitors actually came from small appliances, and the amount collected remained very low. The collection of capacitors from fluorescent luminaires was also unsatisfactory in one of two participating facilities. Although it could sort out the desired ballasts, it was unable to remove the capacitors from them.

With that in mind, the authors believe that technical provisions for the removal of capacitors should not distinguish between the types of appliances from which the capacitors originate.

8.4 Chemical analysis results

The chemical-analytical determination of the main components was successful for the microwave capacitors. Mixed samples were analysed for both non-polarised cylindrical and aluminium electrolytic capacitors for financial reasons. The analysis results for the non-polarised cylindrical capacitors were thus masked by a hydrocarbon mixture. This made determining the peaks difficult. It remains largely unclear whether the determined substances in the peaks also originate from technical mineral oil mixtures or if they represent the main components from liquids without a mineral oil base. All determined mass fractions in the mixed samples lie below 2 per cent.

For the electrolytic capacitors, the analysis results refer to the mass of the capacitor coil. Based on the total disassembly of an electrolytic capacitor, it can be estimated that the liquid accounts for about one sixth of the coil mass. A rough conversion of the mass fractions by a factor of six shows that the mass fractions of the determined substances in the liquid of the mixed samples are consistently below 2 per cent for aluminium e-caps.

The number of capacitors in the mixed samples lied between 14 and 33 units (Table 12). A main component of a single model would account for one to a few per cent of the mixed sample. It is therefore possible that the largest determined peaks are main components of one to a few capacitors. However, no single substance could constitute the main component in several of the capacitors in the mixed sample.

Ultimately, only further analyses of individual samples instead of the previously determined mixed samples could provide indications as to whether the mixtures differ between the different capacitor models and which are the main components in the respective mixtures.

8.5 Annual load of substances of concern

All liquids in the analysed capacitor categories contain substances of concern as outlined in the established definition. The concentrations found were consistently low. An estimation of the annual load of substances of concern results in a range of 500 to 1 000 kg per year for Switzerland. This estimate is highly tentative. Nonetheless, it can be ascertained that the total flow is likely to be greater than the annual flow of PCBs from PCB-containing capacitors. However, PCBs are estimated to be significantly more stable in the environment than the now found substances of concern.

8.6 Share and annual flow of capacitors containing PCBs

Large household appliances and refrigerators are traditionally the most important appliance categories for the load of PCB-containing capacitors. For large household appliances, a share of PCB-containing capacitors of 0.5 per cent could be determined. In addition, large household appliances have a share of 1.7 per cent of capacitors suspected of containing PCBs. A laboratory analysis of the PCB content in all models suspected of containing PCBs would allow all capacitors to be classified as PCB-free or containing PCBs. However, this approach is not feasible due to the excessive costs. All collected capacitors from refrigerators were PCB-free. This result was found by combining the classification and the analysis of all capacitors suspected of containing PCBs in the laboratory.

Fluorescent luminaires are increasingly becoming the biggest source of PCBs in the recycling of electric and electronic equipment. There was a high shaer of PCB-containing capacitors in the range of 55 per cent of all disassembled capacitors. With regard to the annual load of PCB-containing capacitors, this category has become as significant as large household appliances. In recycling, the main focus must be to ensure that the capacitors from luminaires are properly removed and disposed of as PCB-containing capacitors.

The high share of PCB-containing capacitors in the examination of capacitors from SENS small appliances is not plausible. This result should not be cited. Rather, the share of PCB-containing capacitors in SENS small appliances should be more accurately determined through a follow-up study.

8.7 Mass determinations of capacitors in appliances

The examination allows the determination of the mass fraction of electrolytic capacitors in the total appliance mass for the sectors of information technology and consumer electronics. The mass fraction of the capacitors was between 0.6 and 1.1 per cent for screens, PCs and multifunction printers. The proportion in power supply units for laptops is significantly higher at 7 per cent.

The mass ratio between electrolytic capacitors smaller than 2.5 cm and larger ones was also determined. It is around 50 : 50, with deviations between the appliance categories of around ±10 per cent. The same ratio in pieces is 80 : 20, whereby 80 per cent of the electrolytic capacitors were smaller than 2.5 cm. It should be noted that these numbers do not apply to non-polarised cylindrical capacitors. These are almost always larger than 2.5 cm in one dimension. Smaller non-polarised capacitors are almost exclusively ceramic or film capacitors without liquid substances.

9 Recommendations

9.1 Definition of substances of concern

The term substances of concern originates from the WEEE Directive (European Parliament, 2012) but is not defined there or in EU legislation. This study defines the term using the H-statements for substances in accordance with the CLP Regulation (European Parliament, 2008). We recommend a list of H-statements which should qualify a substance as a substance of concern in accordance with the WEEE Directive. This list comprises the H-statements according to Table 62. If a liquid is declared with one of the listed H-statements, it must be considered a substance of concern. For the derivation of the list, refer to chapter 7.1. Regardless of the classification with H-statements, substances which are classified as substances of high concern in accordance with the REACH Regulation (European Parliament, 2006), are mentioned in Annex III of the Rotterdam Convention (UNEP/FAO, 2017), which are prohibited in capacitors or banned or severely restricted for general use by law should always be classified as substances of concern in recycling.

Table 62: List of H-statements which qualify a substance as a substance of concern

H-statement	Hazard
H300	Fatal if swallowed
H310	Fatal in contact with skin
H330	Fatal if inhaled
H340	May cause genetic defects
H341	Suspected of causing genetic defects
H350	May cause cancer
H351	Suspected of causing cancer
H360D	May damage the unborn child
H360FD	May damage fertility May damage the unborn child
H360Df	May damage the unborn child Suspected of damaging fertility
H361	Suspected of damaging fertility or the unborn child
H361d	Suspected of damaging the unborn child
H370	Causes damage to organs
H372	Causes damage to organs through prolonged or repeated exposure
H400	Very toxic to aquatic life
H410	Very toxic to aquatic life with long-lasting effects
H411	Toxic to aquatic life with long-lasting effects

9.2 Further examinations for the release and distribution of substance of concern in recycling

The analysis of liquid substances in PCB-free capacitors and the literature research show that substances of concern as per the definition developed in this study are present in PCB-free capacitors. The substances found are described in detail in chapter 7.2. Substances of concern were found in all examined capacitor categories, including in non-polarised cylindrical capacitors, electrolytic capacitors and microwave capacitors.

Removing the capacitors into a distinguishable stream is also necessary for PCB-free capacitors with substances of concern in accordance with the standard EN50625. In order to define which processing technologies could sort the substances of concern into a distinguishable stream in this manner, investigations must be carried out into the release and distribution behaviour of the substances of concern found in the recycling process. The following questions arise and should be clarified:

- Are the substances of concern released from capacitors during mechanical processing?
- Do the substances of concern remain unchanged when released or are they destroyed, for example by thermal impact?
- How do released substances of concern distribute to fractions and the ambient air?
- What measures ensure that the substances of concern are separated into a distinguishable and controlled stream?

9.3 Clarification of the stability of the substances of concern

Irrespective of the results of the other recommended follow-up investigations, the question arises as to which disposal processes can reliably destroy the found substances of concern. A question also arises as to how stable the substances of concern found are in the environment.

The thermal stability of the substances of concern should be clarified in depth for this purpose. In addition, the environmental behaviour of the substances should be assessed in depth.

9.4 Removal of all capacitors with liquids

Irrespective of the results of the other investigations into the release and distribution of the determined substances of concern in recycling, there is a loophole which must be closed when it comes to PCB-free capacitors in the removal requirement from the CENELEC standard EN 50625-1, Annex VII of the WEEE Directive (European Parliament, 2012) and the technical regulations of Swico and SENS (SENS et al., 2012). Only electrolytic capacitors containing substances of concern above a minimum size are included. The restriction to electrolytic capacitors is not justified according to the results of this study. Instead, the removal requirement should apply to all capacitors containing liquid substances of concern.

A look at the European context shows that the WEEELABEX organisation has a similar regulation for the removal of capacitors. According to the WEEELABEX standard (WEEElabex, 2013), the following capacitors must be removed from waste electrical and electronic equipment:

- Capacitors containing polychlorinated biphenyls (PCBs)
- Capacitors containing mineral or synthetic oils
- Electrolytic capacitors containing substances of concern (height > 25 mm; diameter > 25 mm or proportionately similar volume)

The authors of this study believe that this regulation can be simplified by requiring the removal of all capacitors containing liquids.

We therefore recommend to reformulate the removal requirement as follows:

"Capacitors must be removed from waste electrical and electronic equipment if at least one of the following criteria is met:

- The capacitors contain liquid substances of concern (height > 25 mm; diameter > 25 mm or similar volume).
- The capacitors contain polychlorinated biphenyls (PCB)."

We can assume for non-polarized cylindrical capacitors that almost 100 per cent of the liquids are removed with the capacitors above the minimum size. However, for e-caps, only about 50 per cent of the mass is removed with the capacitors above the minimum size. We recommend the consideration of all liquids from capacitors and the retention of the size criterion for the time being.

9.5 Ad hoc regulation pending further findings

Until the questions about the release and distribution of substances of concern in recycling have been clarified, a transitional regulation must be found for handling PCB-free capacitors. In recycling practice, capacitors containing substances of concern will not be distinguishable from those without substances of concern. We therefore recommend the regulation that for the time being, all PCB-free capacitors be removed from electrical appliances if they are bigger than the current size criterion of 2.5 cm in one dimension.

9.6 Assessment of PCB flow from electrical appliances

For large household appliances and fluorescent luminaires, it is recommended to perform a flow estimate for the entire PCB flow from capacitors in recycling. This flow estimate allows an overall view of the importance of the PCB problem from large household appliances and refrigerators. The flow of capacitors should be compared to current flows from other sources such as construction or background concentration. In cooperation with the involved authorities, the question should be clarified as to how a limit flow for PCBs from capacitors could be defined, which could be considered a PCB-free capacitor mix. Flow estimates should also be used to assess whether it is necessary to maintain the requirement for separate processing of electrical appliances without the addition of scrap metal (SENS et al., 2012; Swico, 2016).

9.7 Chemical analysis of individual samples

The main components could not be determined for all mixed samples except those from microwave capacitors. This could be because only mixed samples were analysed, which naturally leads to a mixture of the substances from many capacitors. The chemical-analytical examination of individual samples would show whether all liquids in non-polarised cylindrical capacitors are based on mineral oil. The individual analysis could also enable the evaluation of more peaks in the GCMS. This offers the opportunity to also determine the main components. Since the success of such an analysis campaign is uncertain, we propose a gradual approach. The five models from SENS large household appliances which were most common in the sample should be examined first. Based on the results of the laboratory analysis, it can then be decided whether further laboratory analyses would be useful.

10 Literature

R. S. Alwitt. (1977, June 21). Electrolyte Capacitors.

R. Arnet, E. Kuhn & U. Näf. (2011). *Kondensatoren-Verzeichnis*. chemsuisse, Kantonale Fachstellen für Chemikalien.

A.-C. Chappot & M. Eugster. (2007). *PCB in Kleinkondensatoren aus elektrischen und elektronischen Geräten*. Zürich: Technische Kontrollstellen SENS und SWICO.

T. Ebel. (2002, August 8). Betriebselektrolyt für einen Aluminium-Elektrolyt-Kondensator, Kondensator mit dem Betriebselektrolyt und Verwendung des Kondensators.

ECHA (Ed.). (2013, March 20). Justification for the selection of a candidate CoRAP substance - Biphenyl. Portuguese Environment Agency, PT.

ECHA. (2016a). *C&L Inventory*. Retrieved from http://www.echa.europa.eu

ECHA (Ed.). (2016b). Registration Dossier - Diisobutyl phthalate. European chemicals agency. Retrieved from https://echa.europa.eu/registration-dossier/-/registered-dossier/1354/1

ECHA (Ed.). (2017a). Registration Dossier - 1-Dodecen. European Chemicals Agency, Brussels. Retrieved from https://www.echa.europa.eu/web/guest/registration-dossier/-/registered-dossier/15280

ECHA (Ed.). (2017b). Registration Dossier - Biphenyl. European Chemicals Agency, Brussels. Retrieved from https://www.echa.europa.eu/web/guest/registration-dossier/-/registered-dossier/14948

eco-systèmes (Ed.). (2012, June). Study on the analysis of PCB and other potentially hazardous substances found in capacitors. Eco-systèmes, 12, place de la Défense - 92400 Courbevoie. Retrieved from www.eco-systemes.fr

EU (Ed.). (2016). EUR-Lex Advanced Search. European Union. Retrieved from http://eur-lex.europa.eu

M. Eugster. (2007, October 10). Substances catalogue Eugster extended to microwave capacitors. not published.

M. Eugster, A.-C. Chappot & U. Kasser. (2008). *PCB's in Small Capacitors from Waste Electrical and Electronic Equipments* (No. September). Zürich: SENS, SWICO, SLRS.

European Parliament. Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC (Text with EEA relevance), 1907/2006 (2006).

European Parliament. Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealingDirectives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006, 1272/2008 (2008).

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

J. W. Eustance. (1970, June 5). Elektrischer Kondensator.

D. Gasser. (2009). *Pilotzerlegung Fluoreszenz-Leuchten*. Zürich: SENS.

R. Gloor. (2007). *Untersuchungsbericht Kleinkondensatoren aus Mikrowellengeräten, Zusatzbericht zur Quantifizierung der Hauptkomponenten*. Schlieren: Bachema AG, Analytische Laboratorien.

B. A. F. in ’t Groen. (2013). *Polychloorbifenyls (PCBs) in the Dutch e-waste stream* (No. 74101765- CES/IPT 12-3248). Arnhem: KEMA Nederland B.V.

A. Güntner & O. Baur. (1991, January 10). Elektrolyt für Elektrolytkondensatoren.

J. E. Hand. (1970, March 24). Electrolytic capacitor and novel electrolyte.

E. Hering, K. Bressler & J. Gutekunst. (2014). *Elektronik für Ingenieure und Naturwissenschafter* (6th ed.). Berlin Heidelberg: Springer.

IFA (Ed.). (2016). GESTIS-Stoffdatenbank. Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung. Retrieved from gestis.itrust.de

P. Jay & G. Schwachhofer. (1979, April 26). Liquid Dielecric.

H. Kuchling. (1996). *Taschenbuch der Physik* (16. Auflage.). Leipzig: Fachbuchverlag.

U. Maier. Personal communication (2018). Bachema, Schlieren.

D. M. Mauro & M. S. Young. (1999). *Non-PCB Capacitor Fluids Used in the Power Industry: Chemical Composition and Dissolution Characteristics*. Electric Power Research Institute EPRI, Palo Alto, CA, and Bonneville Power Administration.

Mundorf. (2016). Über die Vorteile der MLytic-Technologie. Retrieved from http://www.mundorf.com/de/?category=hifi&menu=caps_power&content=mlytic

NIH. (2018). *Pubchem open chemistry database*. U.S. National Library of Medicine National Center for Biotechnology Information.

R Development Core Team. (2018). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

D. Rasch, J. Pilz, R. Verdooren & A. Gebhardt. (2011). *Optimal Experimental Design with R*. Boca Raton: CRC Press, Taylor & Francis Group.

S. Ruckstuhl & U. Maier. Personal communication (2018).

A. Sato, I. Shimizu & E. Matsuzaka. (1979, November 20). Electrical Insulating oil compositions.

D. Savi. (2018). *PCB-analysis of capacitors smaller than 2.5 cm* (not published). Zürich: Büro für Umweltchemie.

J. G. D. Schulz, A. Onopchenko & W. A. Kofke. (1980, October 14). Paraffinic insulating oils containing a diarylalkane.

SENS & Swico Recycling (Eds.). (2012). Technische Vorschriften zur Entsorgung von Elektro- und Elektronikaltgeräten. SENS & Swico Recycling, Zürich.

SENS, Swico Recycling & SLRS (Eds.). (2018). Technical Report 2018. SENS, Swico, SLRS, Zurich and Berne.

V. Shedigian. (1985, August 20). Non-toxic impregnant for electrical capacitors.

V. Shedigian. (1987, October 2). Dielectric fluid for a capacitor.

Swico (Ed.). (2016, May 24). Ergänzende Anforderungen an die Behandlung von Elektro- und Elektronikaltgeräten in der Schweiz. Swico Recycling, Zürich.

Swiss Federal Council. Chemical Risk Reduction Ordinance ORRChem, 814.81 (2005).

Swiss Federal Council. Ordinance on the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Chemicals in International Trade ChemPICO, 814.82 (2005).

TDK (Ed.). (2014, August). Material Data Sheet - several electrolytic capacitors. EPCOS AG.

UN. (2011). *Globally Harmonized System of Classification and Labelling of Chemicals (GHS)* (No. Fourth Revised Edition).

UNEP/FAO. (2017). Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade. Rotterdam Convention Secretariat, Food and Agriculture Organization of the United Nations (FAO), Viale delle Terme di Caracalla, 00153 Rome, Italy.

US EPA. (2012). *EPI Suite*. United States Environmental Protection Agency.

US EPA. (2016). *ECOTOX Knowledgebase*. Retrieved 23 August 2016, from https://cfpub.epa.gov/ecotox/quick_query.cfm

WEEELabex. (2013). WEEELabex normative document on Treatment V 10.0. WEEELABEX Organisation, U Habrovky 11/247, 14000 Praha 4.

E. Werner. (2016, October 6). Re: Inquiry regarding liquid dielectrics.

Wikipedia. (2016). *Tantal-Elektrolytkondensator*. Retrieved 6 November 2016, from https://de.wikipedia.org/wiki/Tantal-Elektrolytkondensator

A Characterisation of substances of concern

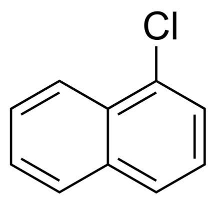
A.1 Introduction

The substances identified as substances of concern in recycling based on the H-statements are more accurately described in the following sub-chapters. The list includes the substances for which further clarifications were necessary, in particular with regard to water solubility. Substances of concern with CMR potential may therefore be missing from the list due to the H-statements. The series of substances is the same as in Table 49 to Table 52. The available data on water solubility, biodegradability and bioconcentration factor were researched in particular. With this information, it can be estimated whether a substance could accumulate in the food chain, making special measures necessary to prevent the substance from entering the environment. Acute toxicity to aquatic life also indicates substances that are so acutely toxic that their release must be prevented.

No classifications could be found in the GHS inventory for two substances. The search for safety data sheets from manufacturers also proved unsuccessful. For these substances, we researched more detailed information on environmental behaviour. Unfortunately, no measurement data was found for the two substances. The environmentally toxic properties of the PCBs are listed as the last substance group.

A.2 Substances of concern in recycling

A.2.1 1-Chloronaphthalene



CAS number: 90-13-1

Synonyms: α-chloronaphthalene

Molecular formula: $C_{10}H_7Cl$

Substance group: aromatic halocarbons

Water solubility, 25°C: 17.4 mg/l

Octanol/water partition coefficient log Kow: 4.24

Bioconcentration factor BCF (estimate based on log Kow): 229 l/kg wet mass

Easily biodegradable (model estimation): no

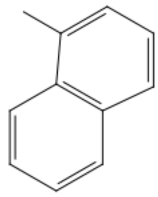
Ecotoxicological data:

LC50 fish, 96 h: 2.3 mg/l

LC50 crustaceans, 48 h: 1.6 mg/l

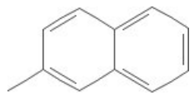
Data sources: (IFA, 2016), water solubility, BCF and biodegradability from (US EPA, 2012)

A.2.2 1-Methylnaphthalene



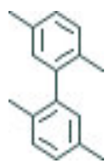
CAS number: 90-12-0
Synonyms: α-methylnaphthalene
Molecular formula: $C_{11}H_{10}$
Substance group: aromatic hydrocarbons
Water solubility, 25°C: 28 mg/l
Octanol/water partition coefficient log Kow: 3.87
Bioconcentration factor BCF (estimate based on log Kow): 166 l/kg wet mass
Easily biodegradable (model estimation): no
Ecotoxicological data:
LC50 fish, 96 h: 9 mg/l
LC50 crustaceans, 48 h: 8.2 mg/l
Data sources: (IFA, 2016), BCF and biodegradability from (US EPA, 2012)

A.2.3 2-Methylnaphthalene



CAS number: 91-57-6
Molecular formula: $C_{11}H_{10}$
Substance group: aromatic hydrocarbons
Water solubility, 25°C: 24.6 mg/l
Octanol/water partition coefficient log Kow: 3.86
Bioconcentration factor BCF (estimate based on log Kow): 164 l/kg wet mass
Easily biodegradable (model estimation): no
Data sources: (US EPA, 2012)

A.2.4 2,2',5,5'-Tetramethylbiphenyl



CAS number: 3075-84-1
Synonyms: 2-(2,5-dimethylphenyl)-1,4-dimethylbenzene
Molecular formula: $C_{16}H_{18}$
Substance group: biaryls
Water solubility, 25°C:
Octanol/water partition coefficient log Kow, estimate: 5.95
Bioconcentration factor BCF (estimate based on log Kow): 3,893 l/kg wet mass
Easily biodegradable (model estimation): no
Data sources: (NIH, 2018), (US EPA, 2012)

A.2.5 2,6-Diisopropylnaphthalene

CAS number: 24157-81-1

Technical mixture: diisopropylnaphthalene (DIPN)

Molecular formula: $C_{16}H_{20}$

Substance group: aromatic hydrocarbons

Water solubility, 25°C: 0.11 mg/l

Octanol/water partition coefficient log Kow, estimate: 6.08

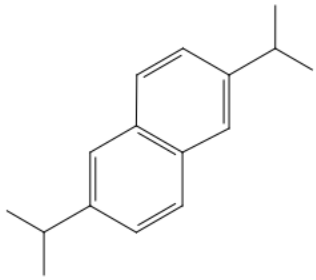
Bioconcentration factor BCF (estimate based on log Kow): 4,778 l/kg wet mass

Easily biodegradable (model estimation): no

Ecotoxicological data:

- *LC50 fish, 96 h:* unknown
- *LC50 crustaceans, 48 h:* unknown

Data sources: Wikipedia, log Kow, BCF and biodegradability from (US EPA, 2012)



A.2.6 Benzyltoluenes

CAS number: 27776-01-8, p-benzyltoluene: 620-83-7, m-benzyltoluene: 620-47-3, o-benzyltoluene: 713-36-0

Synonyms: methyldiphenylmethane

Molecular formula: $C_{14}H_{14}$

Substance group: aromatic hydrocarbons

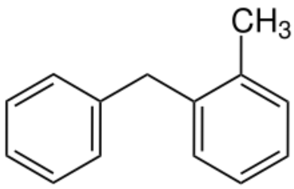
Water solubility, 25°C: 3 mg/l

Octanol/water partition coefficient log Kow: 4.3

Bioconcentration factor BCF (estimate based on log Kow): 476 l/kg wet mass

Easily biodegradable (model estimation): no

Data sources: (IFA, 2016), BCF and biodegradability from (US EPA, 2012)



A.2.7 Biphenyl

CAS number: 92-52-4

Synonyms: diphenyl, phenylbenzene, 1,1'-biphenyl

Molecular formula: $C_{12}H_{10}$

Substance group: aromatic hydrocarbons

Water solubility, 25°C: 4.45 mg/l

Octanol/water partition coefficient log Kow: 3.98

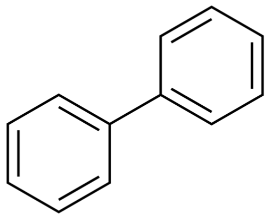
Bioconcentration factor BCF (estimate based on log Kow): 206 l/kg wet mass

Easily biodegradable (model estimation): no

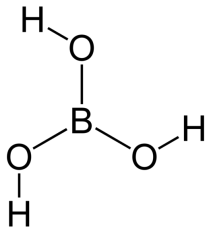
Ecotoxicological data:

- *LC50 fish, 96 h, median:* 3.5 mg/l
- *LC50 crustaceans, 48 h, median:* 1.16 mg/l

Data sources: (IFA, 2016), BCF and biodegradability from (US EPA, 2012)



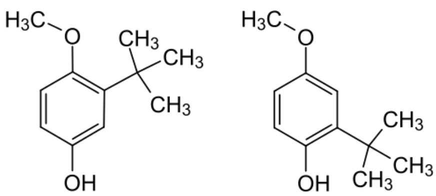
A.2.8 Boric acid



CAS number: 11113-50-1
Synonyms: orthoboric acid
Molecular formula: H_3BO_3
Substance group: inorganic acids
Water solubility, 25°C:
Octanol/water partition coefficient log Kow: 0.757
Easily biodegradable: no
Ecotoxicological data:
- *LC50 fish, 96 h, median:* 487 mg/l
- *LC50 crustaceans, 48 h, median:* 180 mg/l

Data sources: (IFA, 2016)

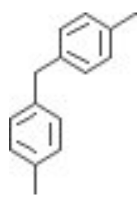
A.2.9 Butylated hydroxyanisole



CAS number: 25013-16-5
Synonyms: tert-butyl-4-methoxyphenol, isomers, (1,1-dimethylethyl)-4-methoxyphenol, tert-butyl-4-hydroxyanisole
Molecular formula: $C_{11}H_{16}O_2$
Substance group: substituted phenols
Water solubility, 25°C: 213 mg/l
Octanol/water partition coefficient log Kow (estimate): 3.5
Bioconcentration factor BCF (estimate based on log Kow): 57.07 l/kg wet mass
Easily biodegradable (model estimation): no
Ecotoxicological data:
- *LC50 fish, 48 h, median:* 1 mg/l
- *LC50 crustaceans, 48 h:* unknown

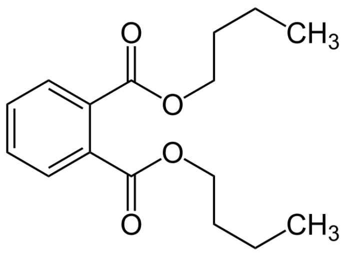
Data sources: (IFA, 2016), BCF and biodegradability from (US EPA, 2012), LC50 fish from (US EPA, 2016)

A.2.10 Di-p-tolyl-methane



CAS number: 4957-14-6
Synonyms: 4,4'-dimethyldiphenylmethane, bis-p-tolylmethane
Molecular formula: $C_{15}H_{16}$
Substance group: diarylalkanes
Water solubility, 25°C: unknown
Octanol/water partition coefficient log Kow (model estimate): 5.11
Bioconcentration factor BCF (estimate based on log Kow): 1,093 l/kg wet mass
Easily biodegradable (model estimation): No
Data sources: (US EPA, 2012)

A.2.11 Dibutyl phthalate



CAS number: 84-74-2

Synonyms: dibutyl ester of phthalic acid, DBP

Molecular formula: $C_{16}H_{22}O_4$

Substance group: carboxylate ester

Water solubility, 25°C: 11.2 mg/l

Octanol/water partition coefficient log Kow: 4.5

Bioconcentration factor BCF (estimate based on log Kow): 433 l/kg wet mass

Easily biodegradable (model estimation): yes

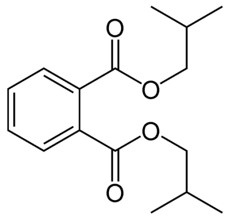
Ecotoxicological data:

LC50 fish, 96 h, median: 1.51 mg/l

LC50 crustaceans, 48 h, median: 3.7 mg/l

Data sources: (IFA, 2016), log Kow, BCF and biodegradability from (US EPA, 2012)

A.2.12 Diisobutyl phthalate



CAS number: 84-69-5

Synonyms: diisobutyl ester of phthalic acid

Molecular formula: $C_{16}H_{22}O_4$

Substance group: carboxylate ester

Water solubility 20°C: 20 mg/l

Octanol/water partition coefficient log Kow: 4.11

Bioconcentration factor BCF (estimate based on log Kow): 239.2 l/kg wet mass

Easily biodegradable: yes

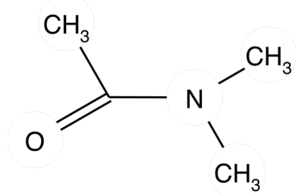
Ecotoxicological data:

LC50 fish, 48 h, median: 0.9 mg/l

LC50 crustaceans, 48 h: unknown

Data sources: (IFA, 2016), BCF and biodegradability from (US EPA, 2012), degradability from (ECHA, 2016b)

A.2.13 Dimethylacetamide



CAS number: 127-19-5

Synonyms: N,N-dimethylacetamide, N,N-dimethylmethanamide, acetic acid-dimethylamide, acetyldimethylamine

Molecular formula: C_4H_9NO

Substance group: carboxamides

Water solubility: mixable

Octanol/water partition coefficient log Kow: –0.77

Bioconcentration factor BCF (estimate based on log Kow): 3 l/kg wet mass

Easily biodegradable (model estimation): yes

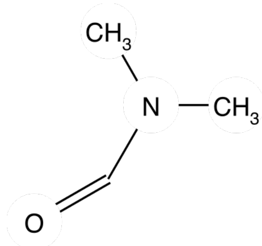
Ecotoxicological data:

LC50 fish, 24 h: 1 000 mg/l

LC50 crustaceans, 48 h: unknown

Data sources: (IFA, 2016), BCF and biodegradability from (US EPA, 2012), LC50 fish from (US EPA, 2016)

A.2.14 Dimethylformamide



CAS number: 68-12-2

Synonyms: N,N-dimethylformamide, N,N-dimethylmethanamide, formic acid dimethylamide, formyl dimethylamine

Molecular formula: C_3H_7NO

Substance group: carboxamides

Water solubility, 25°C: fully mixable

Octanol/water partition coefficient log Kow: –1.01

Bioconcentration factor BCF (estimate based on log Kow): 3 l/kg wet mass

Easily biodegradable (model estimation): yes

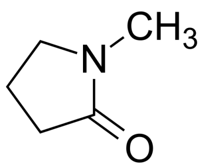
Ecotoxicological data:

LC50 fish, 96 h, median: 10,500 mg/l

LC50 crustaceans, 48 h, median: 14,400 mg/l

Data sources: (IFA, 2016), BCF and biodegradability from (US EPA, 2012)

A.2.15 N-Methylpyrrolidone



CAS number: 872-50-4

Molecular formula: C_5H_9NO

Substance group: lactams

Water solubility, 25°C: mixable

Octanol/water partition coefficient log Kow: –0.38

Bioconcentration factor BCF (estimate based on log Kow): 3.162 l/kg wet mass

Easily biodegradable (model estimation): yes

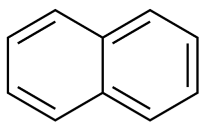
Ecotoxicological data:

LC50 fish, 96 h: 832 mg/l

LC50 crustaceans, 48 h: 1.23 mg/l

Data sources: (IFA, 2016), log Kow, BCF and biodegradability from (US EPA, 2012), LC50 fish from (US EPA, 2016)

A.2.16 Naphthalene



CAS number: 91-20-3

Synonyms: naphthalin

Molecular formula: $C_{10}H_8$

Substance group: polycyclic aromatic hydrocarbons

Water solubility, 25°C: 32 mg/l

Octanol/water partition coefficient log Kow: 3.35

Bioconcentration factor BCF (estimate based on log Kow): 69.9 l/kg wet mass

Easily biodegradable (model estimation): no

Ecotoxicological data:

LC50 fish, 96 h, median: 1.99 mg/l

LC50 crustaceans, 48 h, median: 11.8 mg/l

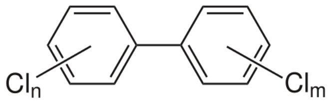
Data sources: (IFA, 2016), BCF and biodegradability from (US EPA, 2012)

A.2.17 Polychlorinated biphenyls

CAS number: 1336-36-3

Molecular formula: $C_{12}H_{(10n)}Cl_n$, n>2

Substance group: chlorinated aromatic hydrocarbons



Water solubility, 25°C: < 0.4 mg/l

Octanol/water partition coefficient log Kow: 6.3

Bioconcentration factor BCF (estimate based on log Kow): 25,300 l/kg wet mass

Easily biodegradable (model estimation): no

Ecotoxicological data:

LC50 fish, 96 h: unknown

LC50 crustaceans, 48 h: unknown

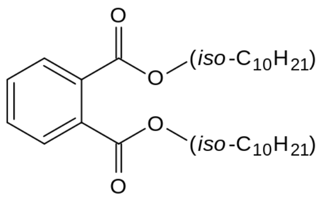
Data sources: (IFA, 2016), log Kow, BCF and biodegradability from (US EPA, 2012)

A.3 Possibly concerning substances in recycling

A.3.1 Diisodecyl phthalate

CAS number: 26761-40-0

Synonyms: diisodecyl ester of phthalic acid



Molecular formula: $C_{28}H_{46}O_4$

Substance group: carboxylate ester

Water solubility, 24°C: 0.28 mg/l

Octanol/water partition coefficient log Kow (estimate): 10.4

Bioconcentration factor BCF (estimate based on log Kow): 76 l/kg wet mass

Easily biodegradable (model estimation): no

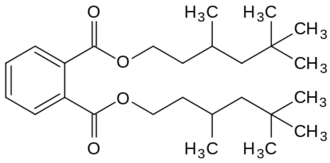
Ecotoxicological data:

LC50 fish, 96 h, median: 1 mg/l

LC50 crustaceans, 48 h, median: unknown

Data sources: (IFA, 2016), log Kow, BCF and biodegradability from (US EPA, 2012), LC50 fish from (US EPA, 2016)

A.3.2 Diisononyl phthalate

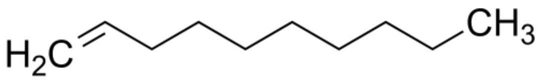


CAS number: 68515-48-0
Molecular formula: $C_{28}H_{46}O_4$
Substance group: carboxylate ester
Water solubility, 25°C: unknown
Octanol/water partition coefficient log Kow (estimate): 9.5
Bioconcentration factor BCF (estimate based on log Kow): 196 l/kg wet mass
Easily biodegradable (model estimation): yes
Ecotoxicological data:
- *LC50 fish, 96 h, median:* unknown
- *LC50 crustaceans, 48 h, median:* unknown

Data sources: log Kow, BCF and biodegradability from (US EPA, 2012)

A.4 Non-hazardous substances in recycling

A.4.1 1-Decene



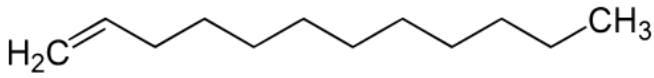
CAS number: 872-05-9
Molecular formula: $C_{10}H_{20}$
Substance group: unsaturated aliphatic hydrocarbons
Water solubility, 25°C: 0.57 mg/l
Octanol/water partition coefficient log Kow: 5.7
Bioconcentration factor BCF (estimate based on log Kow): 113 l/kg wet mass
Easily biodegradable (model estimation): yes
Ecotoxicological data:
- *LC50 fish, 96 h:* unknown
- *LC50 crustaceans, 48 h:* unknown

Data sources: (IFA, 2016), water solubility, log Kow, BCF and biodegradability from (US EPA, 2012)

A.4.2 1-Dodecene

CAS number: 112-41-4

Molecular formula: $C_{12}H_{24}$



Substance group: unsaturated aliphatic hydrocarbons

Water solubility, 25°C: practically insoluble

Octanol/water partition coefficient log Kow (estimate): 6.1

Bioconcentration factor BCF (estimate based on log Kow): 207 l/kg wet mass

Easily biodegradable (model estimation): yes

Ecotoxicological data:

LC50 fish, 96 h: unknown

LC50 crustaceans, 48 h: unknown

Data sources: (IFA, 2016), log Kow, BCF and biodegradability from (US EPA, 2012)

A.4.3 1-Tetradecene

CAS number: 1120-36-1

Molecular formula: $C_{14}H_{28}$

Substance group: unsaturated aliphatic hydrocarbons

Water solubility, 25°C: practically insoluble

Octanol/water partition coefficient log Kow (estimate): 7.08

Bioconcentration factor BCF (estimate based on log Kow): 3,077 l/kg wet mass

Easily biodegradable (model estimation): yes

Ecotoxicological data:

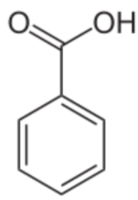
LC50 fish, 96 h: unknown

LC50 crustaceans, 48 h: unknown

Data sources: log Kow, BCF and biodegradability from (US EPA, 2012)

A.4.4 Benzoic acid

CAS number: 65-85-0



Molecular formula: $C_7H_6O_2$

Substance group: carboxylic acids

Water solubility 20°C: 3,400 mg/l

Octanol/water partition coefficient log Kow: 1.87

Bioconcentration factor BCF (estimate based on log Kow): 3 l/kg wet mass

Easily biodegradable (model estimation): yes

Data sources: log Kow, BCF and biodegradability from (US EPA, 2012)

B Substance lists for the laboratory analysis

B.1 Explanations on the substance lists for the analysis

The tables in this chapter list all substances that should be analysed by the commissioned laboratory. All the substances that could possibly be found in capacitors according to the results of the literature review are listed. There are some cases where substance groups are known that could not be analysed in the laboratory. The tables list all substances that have been found in the literature in connection with capacitors, even those whose presence in capacitors is not guaranteed. For the tables with the substances which are proven to be present in capacitors, please refer to the results and in particular chapter 6.1.

The allocation of the substances to the capacitor types corresponds to the knowledge gained through the literature search. Considering the variety of materials, some substances may also be used in capacitor types other than those listed here.

B.2 Non-polarised cylindrical capacitors

Non-polarised cylindrical capacitors are the historical field of application of polychlorinated biphenyls (PCBs). All substances that may be present in them are listed in Table 63.

Table 63: Substances which may be present in non-polarised cylindrical capacitors according to literature

Chemical designation	Abbre-viation	CAS No.	Concerning in recycling
1-Chloronaphthalene (chlorinated naphthalenes)		90-13-1	Yes
1-Methylnaphthalene		90-12-0	Yes
1,2,4-Trimethylbenzene, pseudocumene		95-63-6	Yes
1,2,5-Trimethylbenzene, mesitylene		108-67-8	Yes
2-Methylnaphthalene		91-57-6	Yes
3-Methylcholanthrene		56-49-5	Yes
Acenaphthene		83-32-9	Yes
Benzyltoluene	BT	27776-01-8	Yes
Biphenyl		92-52-4	Yes
Boric acid		11113-50-1	Yes
Butylated hydroxyanisole	BHA, E320	25013-16-5	Yes
Dibutyl phthalate	DBP	84-74-2	Yes
Diisobutyl phthalate	DIBP	84-69-5	Yes
Diphenylmethane		101-81-5	Yes
Fluorene		86-73-7	Yes
Isopropylbiphenyl		25640-78-2	Yes

Chemical designation	Abbre-viation	CAS No.	Concerning in recycling
Naphthalene		91-20-3	Yes
Phenanthrene		85-01-8	Yes
Phenyl xylyl ethane, 4-(1-phenylethyl)-o-xylol	PXE	6196-95-8	Yes
Polychlorinated biphenyls	PCB	1336-36-3	Yes
Anthracene		120-12-7	Suspected
Dibenzyltoluene	DBT	26898-17-9	Suspected
1-Decene		872-05-9	No
1-Dodecene		112-41-4	No
1-Tetradecene		1120-36-1	No
Dioctyl phthalate		117-84-0	No
Castor oil		8001-79-4	No
Soybean oil		None	No
Triacetin		102-76-1	No
Dioctyl phthalate		117-84-0	No

B.3 Electrolytic capacitors

All substances which could be present in aluminium e-caps according to literature research are listed in Table 64.

Table 64: Substances which may be present in aluminium e-caps according to literature

Chemical designation	Abbreviation	CAS No.	Concerning in recycling
Boric acid		11113-50-1	Yes
Dimethylacetamide	DMA, DMAc	127-19-5	Yes
Dimethylformamide	DMF	68-12-2	Yes
N-Methylpyrrolidone	NMP	872-50-4	Yes
Ammonium pentaborate		12007-89-5	Suspected
2,3,5-Trihydroxybenzoic acid		33580-60-8	Assessment not possible
2,3,6-Trihydroxybenzoic acid		16534-78-4	Assessment not possible
2,4,5-Trihydroxybenzoic acid		610-90-2	Assessment not possible
1,2-Benzenedicarboxylic acid		88-99-3	No
1,3-Benzenedicarboxylic acid		121-91-5	No
1,4-Benzenedicarboxylic acid	TPA	100-21-0	No
2-Hydroxybenzoic acid, salicylic acid		69-72-7	No
2,3,4-Trihydroxybenzoic acid		610-02-6	No
2,4,6-Trihydroxybenzoic acid		83-30-7	No
3,4,5-Trihydroxybenzoic acid		149-91-7	No
2,4-Dihydroxybenzoic acid		89-86-1	No
2-Toluic acid		118-90-1	No
3-Toluic acid		99-04-7	No

Chemical designation	Abbreviation	CAS No.	Concerning in recycling
4-Toluic acid		99-94-5	No
Acetophenone		98-86-2	No
γ-Butyrolactone	GBL	96-48-0	No
Ethylene glycol, ethane-1,2-diol	MEG	107-21-1	No
Molybdenum tungstic acid		12027-12-2	No
Phosphotungstic acid		1343-93-7	No
Polyethylene glycol	PEG	25322-68-3	No
Silicotungstic acid		12027-38-2	No
Triethylamine		121-44-8	No

B.4 Microwave capacitors

All substances used in microwave capacitors according to literature research are listed in Table 65.

Table 65: Substances which may be present in microwave capacitors according to literature

Chemical designation	Abbreviation	CAS No.	Concerning in recycling
2,6-Diisopropylnaphthalene		24157-81-1	Yes
Diisodecyl phthalate	DIDP	26761-40-0	Suspected
Trioctyl trimellitate		3319-31-1	Suspected
1,1-Bis(4-methylphenyl)ethane		530-45-0	No, observe
4-Isopropylbiphenyl	IB	7116-95-2	No, observe
1,1-Diphenylethane, diarylethene		612-00-0	Assessment not possible
1,2-Dimethyl-4-(phenylmethyl)benzene		13540-56-2	Assessment not possible
Other alkylated biphenyls		–	Assessment not possible
Diarylethene, 1,1-diphenylethane		612-00-0	Assessment not possible
1-Methyl-4-(phenylmethyl)benzene		620-83-7	No
1,1-Bis(3,4-dimethylphenyl)ethane		1742-14-9	No
2,2'-Dimethylbiphenyl		605-39-0	No
3,4-Epoxy cyclohexane carboxylic acid-(3,4-epoxycyclohexyl methyl ester)		2386-87-0	No
Bis(7-methyloctyl)phthalate		20548-62-3	No
Diisononyl phthalate	DINP	68515-48-0	No

B.5 Unknown capacitor type

For a number of substances, references were found in the literature to the usage of capacitors whereby the specific capacitor type was not specified. All these substances are listed in Table 66. The quality of the literature references is somewhat difficult to estimate in this group. They originate in part from poorly differentiated lists with an unclear research background or are references in literature sources that cannot be clearly assigned to any capacitor type. In order to limit the selection to relevant substances, two criteria are used for the inclusion of substances in Table 66:

1. The source material is good with regard to the use of the substance in small capacitors.
2. The substance is concerning in recycling according to the established classification.

It is sufficient if a substance meets one of the two criteria.

Table 66: Substances which may be found in unspecified capacitors

Chemical designation	Abbre-viation	CAS No.	Concerning in recycling
Butyl phosphate (tributyl phosphate)		126-73-8	Yes
Chlorinated naphthalenes		25586-43-0	No
Diethylhexyl phthalate	DOP, DEHP	117-81-7	Yes
Ditolyl ether		28299-41-4	Yes
Hexabromobenzene		87-82-1	Yes
Short chain chlorinated paraffins		85535-84-8	Yes
N-Methylacetamide		79-16-3	Yes
N-Methylformamide		123-39-7	Yes
Triphenyl phosphate		115-86-6	Yes
Medium chain chlorinated paraffins		85535-85-9	No, observe
2-Chloronaphthalene (chlorinated naphthalenes)		91-58-7	No
Acetonitrile		75-05-8	No
Adipic acid		124-04-9	No
Malic acid		617-48-1	No
Succinic acid (butanedioic acid)		110-15-6	No
Diethylamine	DEA	109-89-7	No
Diethyl phthalate		84-66-2	No
Dimethyl phthalate		131-11-3	No
Ethanolamine		141-43-5	No
Mineral oil		–	No
Tributylamine		102-82-9	No

C Lab reports for analysis

C.1 Sample designations, PCB and elemental analysis results

Bachema AG
Analytische Laboratorien

Schlieren, 09. Juli 2018
EA

Büro für Umweltchemie
Schaffhauserstrasse 21
8006 Zürich

Untersuchungsbericht

(inkl. Daten von früheren Aufträgen)

Objekt: Kondensatoren-Analyse

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser,Boden, Abfall, Recyclingmaterial)
Akkreditiert nach ISO 17025
STS-Nr. 0064

Auftrags-Nr. Bachema	201805939
Proben-Nr. Bachema	25044, 25048-25050, 25054-25055
Tag der Probenahme	
Eingang Bachema	19. Juni 2018 - 27. Juni 2018
Probenahmeort	
Entnommen durch	Büro für Umweltchemie

Auftraggeber	Büro für Umweltchemie, Schaffhauserstrasse 21, 8006 Zürich
Rechnungsadresse	Büro für Umweltchemie, Schaffhauserstrasse 21, 8006 Zürich
Rechnung zur Visierung	Büro für Umweltchemie, Schaffhauserstrasse 21, 8006 Zürich
Bericht an	Büro für Umweltchemie, D. Savi, Schaffhauserstrasse 21, 8006 Zürich
Bericht per e-mail an	Büro für Umweltchemie, D. Savi, d.savi@umweltchemie.ch

Freundliche Grüsse
BACHEMA AG

O. Haag

Olaf Haag
Dipl. Natw. ETH

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201805939

Probenübersicht

Bachema-Nr.		Auftrags-Nr. Bachema	Probenbezeichnung	Probenahme / Eingang Labor
15907	F	201803937	**1 KG**	/ 24.04.18
15908	F	201803937	**2 LCD**	/ 24.04.18
15909	F	201803937	**2 LCD (Rückstellprobe)**	/ 24.04.18
20919	F	201803937	**3.1 MW**	/ 24.05.18
20920	F	201803937	**3.2 MW**	/ 24.05.18
20921	F	201803937	**5.1 HKG**	/ 24.05.18
22933	F	201803937	**6 HHG**	/ 05.06.18
25044	F	201805939	**5.2a HKG**	/ 19.06.18
25048	F	201805939	**5.2b HKG (Rückstellprobe)**	/ 19.06.18
25050	F	201805939	**7a Netz**	/ 19.06.18
25054	F	201805939	**7b Netz (Rückstellprobe)**	/ 19.06.18
15910	W	201803937	**Eluat aus 2 LCD**	/ 24.04.18
25049	W	201805939	**Eluat aus 5.2b HKG**	/ 27.06.18
25055	W	201805939	**Eluat aus 7b Netz**	/ 27.06.18

W	Wasserprobe
F	Feststoffprobe
TS	Trockensubstanz
<	Bei den Messresultaten ist der Wert nach dem Zeichen < (kleiner als) die Bestimmungsgrenze der entsprechenden Methode.
*	Die mit * bezeichneten Analysen fallen nicht in den akkreditierten Bereich der Bachema AG oder sind Fremdmessungen.

Akkreditierung

SWISS ACCREDITATION sas.admin.ch STS 0064 / SWISS TESTING LABS	Auszugsweise Vervielfältigung der Analysenresultate sind nur mit Genehmigung der Bachema AG gestattet. Detailinformationen zu Messmethode, Messunsicherheiten und Prüfdaten sind auf Anfrage erhältlich (s. auch Dienstleistungsverzeichnis oder www.bachema.ch).

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser,Boden, Abfall, Recyclingmaterial) Akkreditiert nach ISO 17025 STS-Nr. 0064

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201805939

Probenbezeichnung		1 KG	2 LCD	3.1 MW	3.2 MW		
Proben-Nr. Bachema		15907	15908	20919	20920		
Tag der Probenahme							
PCB							
PCB 28	mg/kg	**<0.5**		**<0.5**	**<0.5**		
PCB 52	mg/kg	**<0.5**		**<0.5**	**<0.5**		
PCB 101	mg/kg	**<0.5**		**<0.5**	**<0.5**		
PCB 118	mg/kg	**<0.5**		**<0.5**	**<0.5**		
PCB 138	mg/kg	**<0.5**		**<0.5**	**<0.5**		
PCB 153	mg/kg	**<0.5**		**<0.5**	**<0.5**		
PCB 180	mg/kg	**<0.5**		**<0.5**	**<0.5**		
PCB Summe (gemäss ChemRRV)	mg/kg	**<20**		**<20**	**<20**		
PCB Typisierung		**kein PCB-Nachweis**		**kein PCB-Nachweis**	**kein PCB-Nachweis**		
Organische Non-Target-Analytik							
GC-MS Identifikation (nach Extraktion mit Cyclohexan/Ethylacetat)		**s. Anhang**	**s. Anhang**	**s. Anhang**	**s. Anhang**		

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser,Boden, Abfall, Recyclingmaterial) Akkreditiert nach ISO 17025 STS-Nr. 0064

Probenbezeichnung		5.1 HKG	5.2a HKG	6 HHG	7a Netz		
Proben-Nr. Bachema		20921	25044	22933	25050		
Tag der Probenahme							
PCB							
PCB 28	mg/kg	**3.2**		**<0.5**			
PCB 52	mg/kg	**1.2**		**<0.5**			
PCB 101	mg/kg	**<0.5**		**<0.5**			
PCB 118	mg/kg	**<0.5**		**<0.5**			
PCB 138	mg/kg	**<0.5**		**<0.5**			
PCB 153	mg/kg	**<0.5**		**<0.5**			
PCB 180	mg/kg	**<0.5**		**<0.5**			
PCB Summe (gemäss ChemRRV)	mg/kg	**38**		**<20**			
PCB Typisierung		**Aroclor 1242 oder Clophen A 30**		**kein PCB-Nachweis**			
Organische Non-Target-Analytik							
GC-MS Identifikation (nach Extraktion mit Cyclohexan/Ethylacetat)		**s. Anhang**	**s. Anhang**	**s. Anhang**	**s. Anhang**		

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Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201805939

Probenbezeichnung			**Eluat aus 2 LCD**	**Eluat aus 5.2b HKG**	**Eluat aus 7b Netz**			
Proben-Nr. Bachema			15910	25049	25055			
Tag der Probenahme								
Allgemeine und anorganische Parameter								
Wolfram (gelöst)	mg/L	W	**<0.005**	**0.00095**	**0.00057**			
Elemente und Schwermetalle								
Bor (gelöst) ICP-OES	mg/L	B	**98.3**	**262**	**59.8**			
Organische Non-Target-Analytik								
LC-MS-Screening *			**s. Anhang**	**s. Anhang**	**s. Anhang**			

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

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C.2 Sample preparation description

Bachema AG
Analytische Laboratorien

Objekt: **Kondensatoren-Analyse**

Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201803937

Beurteilung

Kommentar zur Probe "2 LCD":

Wir erhielten die Probe "2 LCD" aufgeteilt in zwei Honiggläser.
Die beiden Gläser wurden durch uns wie folgt verwendet:

a) Bachema Nr. 15908, Probe "2 LCD":
Die gesamte Probe wurde mit organischem Lösungsmittel extrahiert.
Der Extrakt wurde für die GCMS-Analyse mit Identifikation verwendet.
Die Ergebnisse beziehen sich auf diese Gesamtprobe.

b) Bachema Nr. 15909, Probe "2 LCD":
Die gesamte Probe wurde zur Herstellung eines Eluats verbraucht.
Eluat siehe Probe Nr. 15910.

c) Bachema Nr. 15910, Eluat aus 15909:
Die gesamte Probe wurde mit Wasser im Verhältnis von 1:10 eluiert.
Das Eluat wurde für die Bestimmung von Bor und Wolfram sowie für das LCMS-Screening verwendet.
Die Ergebnisse beziehen sich auf dieses Eluat.
Bezogen auf die originale Gesamtprobe müssen die Resultate mit einem Faktor von 10 multipliziert werden.
Da es sich hier um ein wässriges Eluat handelt, wurden in dieser Probe nur die wasserlöslichen Anteile erfasst!

Schlieren, 11. Juni 2018

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser,Boden, Abfall, Recyclingmaterial)
Akkreditiert nach ISO 17025
STS-Nr. 0064

Bachema AG
Analytische Laboratorien

201805939

Analyse von Kondensatoren

Setting:

Setting identisch mit Auftrag 201803937, Probe «2 LCD»:

Siehe File Beschrieb.docx im Auftrag 201803937.

Proben:

Proben 5a und 5b (also 25044 und 25048) sind identisches Material.
Proben 7a und 7b (also 25050 und 25054) sind ebenfalls identisches Material.
Wie im letzten Auftrag werden die a-Proben für den organischen Auszug und die b-Proben für das Eluat verwendet.

Vorgehen:

Praktisch identisch mit Auftrag 201803937. Siehe dort.

25044: Gemäss Auftrag 201803937 Beschrieb.docx.
Einwaage: 289.9g in 400 ml CH/EEE, entspricht 0.72 g / ml.
Extrakt ist klar und braun.
Laden auf GCMS 1:50 in CH-ISTD, entspricht 0.0145 g, File 1825044D.

25050: Einwaage: 98.21g in 200 ml CH/EEE, entspricht 0.49 g / ml
Extrakt ist klar und hellbraun.
Laden auf GCMS 1:5 in CH-ISTD, entspricht 0.0982 g, File 1825050C.

25048 und 25054: Mit Beisszange identisch zerlegen wie 25044 und 25080.
Daraus werden die Eluate 25049 und 25055 hergestellt. Siehe dazu 201803937.

25049: Gemäss Auftrag 201803937 Beschrieb.docx.
Einwaage: 279.5 g in 2.0 Liter Wasser, entspricht nicht 1:10.
Muss noch verdünnt werden. 700ml Extrakt + 278 ml Wasser,
ergeben ein Eluat 1:10, also 0.10 g / ml.
Extrakt ist bräunlichgelb, trübe. pH = 7-8.

25055: Einwaage: 92.35 g in 0.923 Liter Wasser, entspricht 1:10, entspricht 0.100 g / ml.
Extrakt ist gelb und flockig. pH = 5-6.

Nach 17 Std. sind die einzelnen Schichten relativ gut zerfallen. Die Probe wird kurz geschüttelt und aufgeteilt in 100ml PET (Anorg.), GC-100 (LCMS), und GC-500 (Rückstell).

27.06.2018 / U. Maier

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser, Boden, Abfall, Recyclingmaterial)
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C.3 Mixed sample analysis results

C.3.1 Refrigerators, air conditioners and freezers

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser, Boden, Abfall, Recyclingmaterial)
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Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201803937

Anhang GC-MS Identifikation (nach Extraktion mit Cyclohexan/Ethylacetat)

Proben-Nr. Bachema: 15907
Probenbezeichnung: 1 KG

Prüfmethode
Extraktion: Schüttelextraktion mit Cyclohexan / Ethylacetat.
GC: Teknokroma Sapiens-X5MS, 30m x 0.25mm, Film 0.25µm
MS: 70eV, m/z 40 - 550

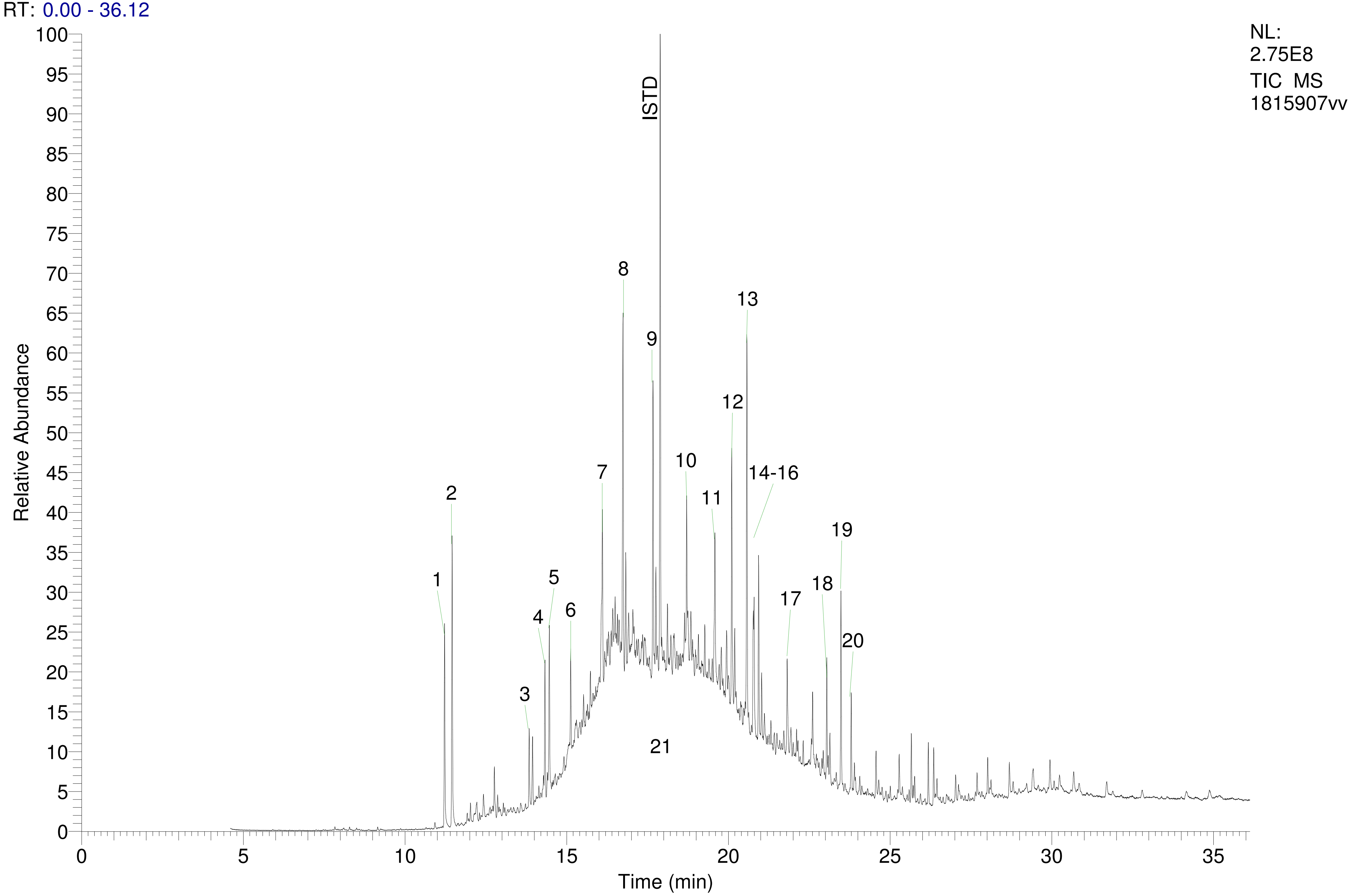
Resultate

Peak Nr.	CAS Nr.	Substanz	Fit (%)	Kommentar	Konz. [mg/kg]
1	90-12-0	**1-Methylnaphthalin**	94	oder Isomer	5000
2	91-57-6	**2-Methylnaphthalin**	93	oder Isomer	8000
3	29956-99-8	**Di-tert-octyl Disulfide**	74	unsicher	2000
4	620-83-7	**p-Benzyltoluol**	91	oder Isomer	3000
5	620-47-3	**m-Benzyltoluol**	92	oder Isomer	4000
6		**unbekannte Verbindung**			2000
7	25360-09-2	**tert-Hexadecanethiol**	75	unsicher	4000
8		**unbekannte Verbindung**			9000
9		**unbekannte Verbindung**			5000
ISTD	16696-65-4	(1,11-Dibromoundecane)		interner Standard	15000
10		**unbekannte Verbindung**			4000
11	NA	**Cyclohexylmethyl tridecyl ester Sulfurous acid (schweflige Säure)**	75	unsicher	4000
12		**unbekannte Verbindung**			7000
13	2386-87-0	**3,4-Epoxycyclohexylmethyl 3,4-epoxycyclohexanecarboxylate**	84	oder Isomer	10000
14	2386-87-0	**3,4-Epoxycyclohexylmethyl 3,4-epoxycyclohexanecarboxylate**	79	oder Isomer	3000
15	2386-87-0	**3,4-Epoxycyclohexylmethyl 3,4-epoxycyclohexanecarboxylate**	79	oder Isomer	3000
16	55255-73-7	**2,2,4,10,12,12-hexamethyl-7-(3,5,5-trimethylhexyl)-6-Tridecene**	75	oder ähnliche Verbindung	4000
17		**unbekannte Verbindung**			3000
18		**unbekannte Verbindung**			3000
19	94-28-0	**Triethylene glycol bis(2-ethylhexanoate)**	80		5000
20		**unbekannte Verbindung**			2000
21		**Kohlenwasserstoffgemisch**		RT 12-24 min	n/q

Fit: Gibt an, wie genau das Spektrum der Probensubstanz mit einem Referenzspektrum übereinstimmt.
99 = identisch
>90 = sehr gute Übereinstimmung
>70 = mässige Übereinstimmung
n/q = nicht quantifizierbar

Konz.: Bei den Konzentrationsangaben handelt es sich um Werte, welche anhand der Konzentration des internen Standards 1,11-Dibromundekan geschätzt wurden. Da sich die einzelnen Verbindungen bei Extraktion, Chromatografie und Detektion unterschiedlich verhalten, kann der wahre Wert um Grössenordnungen vom angegebenen Schätzwert abweichen.

C:\Xcalibur\...\Identifikation\1815907vv 04/25/18 14:59:43



C.3.2 PC and TV flat screens

Bachema AG
Analytische Laboratorien

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201803937

Anhang GC-MS Identifikation (nach Extraktion mit Cyclohexan/Ethylacetat)

Proben-Nr. Bachema: 15908
Probenbezeichnung: 2 LCD

Prüfmethode Extraktion: Schüttelextraktion mit Cyclohexan / Ethylacetat.
GC: Teknokroma Sapiens-X5MS, 30m x 0.25mm, Film 0.25µm
MS: 70eV, m/z 40 - 550

Resultate

Peak Nr.	CAS Nr.	Substanz	Fit (%)	Kommentar	Konz. [mg/kg]
1	111-46-6	Diethylenglycol	95		20
2	108-95-2	Phenol	93		20
3	104-76-7	2-Ethylhexanol	92		7
4	617-94-7	α,α-Dimethyl-benzylalkohol	89		10
5	65-85-0	Benzoesäure	92		30
6	112-34-5	Diethylenglycol-butylether	94		1000
7		unbekannte Verbindung			6
8	91-23-6	1-Methoxy-2-nitrobenzol	96	oder Isomer	100
9	99-03-6	3-Aminoacetophenone	89	oder Isomer	6
10	94-33-7	2-Hydroxyethylbenzoat	93		40
11	121-89-1	3-Nitroacetophenon	94		20
12	619-73-8	4-Nitro-benzylalkohol	93		70
ISTD	16696-65-4	1,11-Dibromoundekan	93	interner Standard	300
13		unbekannte Verbindung			50
14		unbekannte Verbindung			80
15		unbekannte Verbindung			50
16		unbekannte Verbindung			30

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser, Boden, Abfall, Recyclingmaterial)
Akkreditiert nach ISO 17025
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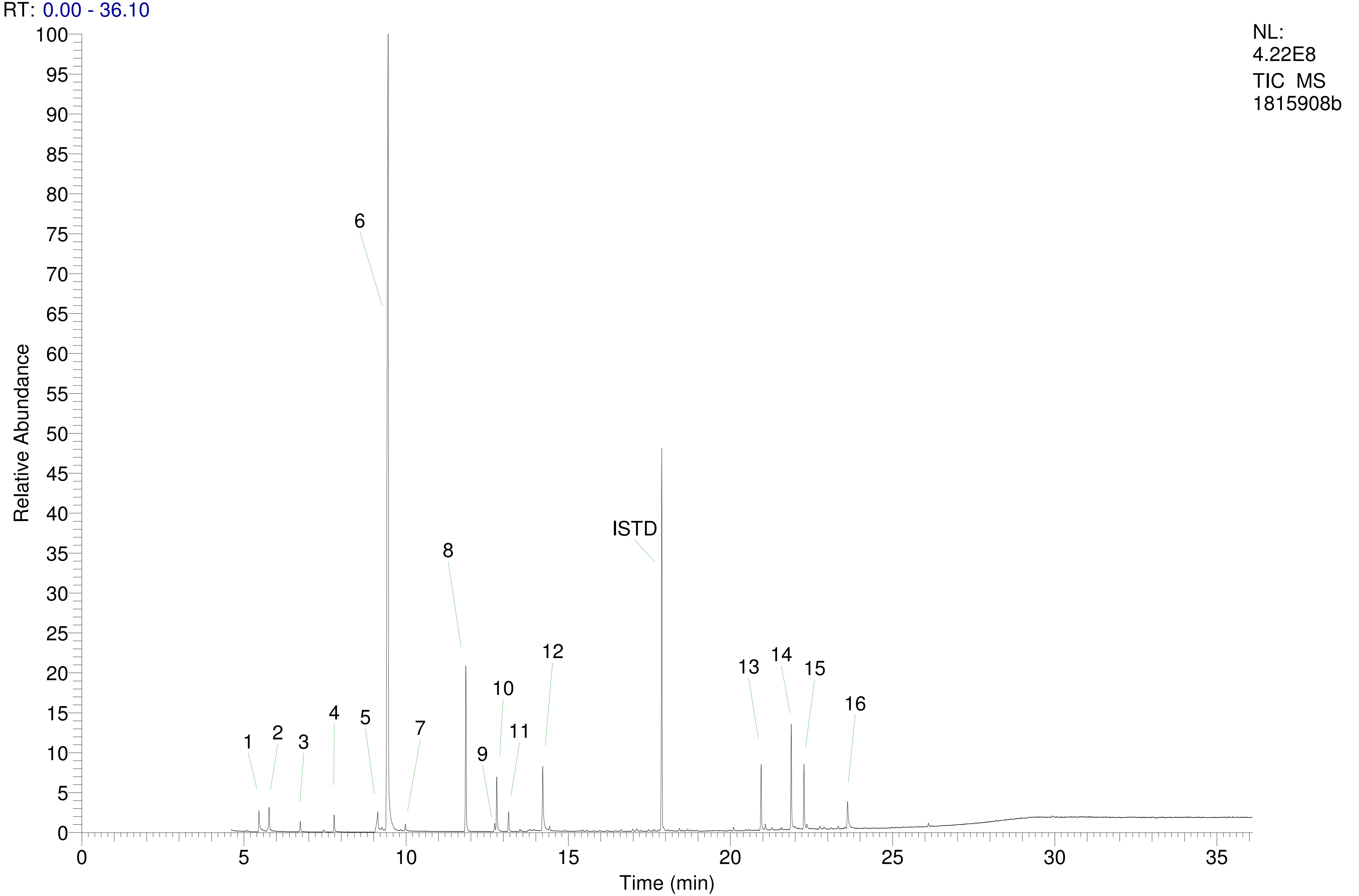
Fit — Gibt an, wie genau das Spektrum der Probensubstanz mit einem Referenzspektrum übereinstimmt.
99 = identisch
>90 = sehr gute Übereinstimmung
>70 = mässige Übereinstimmung

Konz. — Bei den Konzentrationsangaben handelt es sich um Werte, welche anhand der Konzentration des internen Standards 1,11-Dibromundekan geschätzt wurden. Da sich die einzelnen Verbindungen bei Extraktion, Chromatografie und Detektion unterschiedlich verhalten, kann der wahre Wert um Grössenordnungen vom angegebenen Schätzwert abweichen.

c:\xcalibur\data\identifikation\1815908b 04/25/18 19:11:28



Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201803937

Anhang LCMS Screening - Ergebnisse des Non-Target-Screenings

Proben-Nr. Bachema: 15910
Probenbezeichnung: Eluat aus 15909 ("2LCD")

Prüfmethode:
LC: Waters Atlantis dc18 RP-Säule, Eluenten H2O & MeOH (jeweils mit 0.1% Ameisensäure), Direktinjektion von 100µL Pr
MS: TripleTOF 6600 (QTOF von ABSciex), positive und negative Ionisierung mit Elektrospray-Ionisation, Messzyklus: 1 HR-
Auswertung: Automatisierte Non-Target Peaksuche mit Threshold 2000 in "Masterview" - Kontrollprobe: Elutionsblank
Retentionszeitenbereich: 1.5-20 min; automatisierte Summenformelvorhersage mit maximal C50 H100 N10 O10 S5 P5

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

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Positiver Ionisationsmodus - grösste 10 Peaks von insgesamt 370 gefundenen Peaks

Nr. (N/P = negative/ positive Ionisierung)	Name	gemessene Masse	RT [min]	Intensität	automatisierte Summenformel-vorhersage	Güte der Summenformel-vorhersage 0 (gering) bis 100 (hoch)	Kommentar
P001	215.1281 / 9.19	215.1281	9.19	1942223	C11H18O4	83	Gruppe aus 4 Peaks mit gleicher RT
P002	229.1436 / 10.38	229.1436	10.38	1842718	C12H20O4	81	
P003	297.1676 / 12.85	297.1676	12.86	1345319	C12H20N6O3	90	Gruppe aus 7 Peaks mit gleicher RT
P004	273.1698 / 10.32	273.1698	10.32	823143	C14H24O5	77	Gruppe aus 2 Peaks mit gleicher RT
P005	259.1546 / 9.19	259.1547	9.19	758706	C13H22O5	77	Gruppe aus 4 Peaks mit gleicher RT
P006	313.1624 / 10.32	313.1624	10.32	723332	C12H20N6O4	76	Gruppe aus 2 Peaks mit gleicher RT
P007	269.1361 / 10.39	269.1361	10.39	712040	C10H16N6O3	80	ist evtl mit P002 verknüpft
P008	185.1149 / 8.65	185.1149	8.65	648383	C6H12N6O	45	
P009	257.1747 / 12.86	257.1747	12.86	611238	C14H24O4	80	Gruppe aus 7 Peaks mit gleicher RT
P010	299.1465 / 9.19	299.1465	9.19	609502	C11H18N6O4	78	Gruppe aus 4 Peaks mit gleicher RT

Negativer Ionisationsmodus - grösste 3 Peaks von insgesamt 70 gefundenen Peaks

Nr. (N/P = negative/ positive Ionisierung)	Name	gemessene Masse	RT [min]	Intensität	automatisierte Summenformel-vorhersage	Güte der Summenformel-vorhersage 0 (gering) bis 100 (hoch)	Kommentar
N001	229.1434 / 12.98	229.143	12.98	1226340	C12H22O4	92	
N002	273.1703 / 12.80	273.170	12.80	1049252	C14H26O5	85	
N003	245.1384 / 10.34	245.138	10.34	926539	C12H22O5	88	

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser, Boden, Abfall, Recyclingmaterial)
Akkreditiert nach ISO 17025
STS-Nr. 0064

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201803937

Anhang LCMS Screening - Ergebnisse des Suspect-Screenings

Proben-Nr. Bachema: 15910
Probenbezeichnung: Eluat aus 15909 ("2LCD")

Prüfmethode:
LC: Waters Atlantis dc18 RP-Säule, Eluenten H2O & MeOH (jeweils mit 0.1% Ameisensäure), Direktinjektion von 100µL Probe
MS: TripleTOF 6600 (QTOF von ABSciex), positive und negative Ionisierung mit Elektrospray-Ionisation, Messzyklus: 1 HR-FullScan + 10 HR-MSMS (datenabhängig)
Auswertung: Peaksuche der Substanzen aus untenstehender Liste im positiven Ionisationsmodus mittels $[M+H]^+$ und im negativen Ionisationsmodus mittels $[M-H]^-$
Abgleich der MSMS-Spektren mit verschiedenen MSMS-Datenbanken, wenn Spektrum vorhanden
Abgleich mit Referenzstandard (Diethylamin)

Resultate

					LCMS Suspect-Screening (erfasst mittel- bis hochpolare organische Verbindungen)				
Trivialname	**CAS-Nummer**	**Chemische verwandte Gruppe**	**Verwendet in (Literaturhinweise)**	**Bedenkliche Substanz?**	**Summenformel**	**wurde gefunden mit**	**Retentionszeit [min]**	**Intensität**	**Bemerkung**
Dimethylformamid	68-12-2	Amide	Al-Elko	Ja	C_3H_7NO	nicht gefunden			
Dimethylacetamid	127-19-5	Amide	Al-Elko	Ja	C_4H_9NO	nicht gefunden			
N-Methylacetamid	79-16-3	Amide		Ja	C_3H_7NO	nicht gefunden			
N-Methylformamid	123-39-7	Amide		Ja	C_2H_5NO	nicht gefunden			
Triethylamin	121-44-8	Amine	Al-Elko	Nein	$C_6H_{15}N$	$[M+H]^+$	5.1	2573	in Spuren, Identität nicht bestätigt
Diethylamin	109-89-7	Amine		Nein	$C_4H_{11}N$	$[M+H]^+$	2.1 (Totzeit)	433974	grosser Peak bei 2min, durch Standard bestätigt als Diethylamin, Konzentration in der 1:1000-er Verdünnung des Eluats deutlich grösser als 10 µg/L
Ethanolamin	141-43-5	Amine		Nein	C_2H_7NO	nicht gefunden			
2,3,5-Trihydroxybenzoesäure	33580-60-8	Organische Säuren	Al-Elko	Einstufung nicht möglich	$C_7H_6O_5$	nicht gefunden			
2,3,6-Trihydroxybenzoesäure	16534-78-4	Organische Säuren	Al-Elko	Einstufung nicht möglich	$C_7H_6O_5$	nicht gefunden			
2,4,5-Trihydroxybenzoesäure	610-90-2	Organische Säuren	Al-Elko	Einstufung nicht möglich	$C_7H_6O_5$	nicht gefunden			
1,2-Benzoldicarbonsäure	88-99-3	Organische Säuren	Al-Elko	Nein	$C_8H_6O_4$	nicht gefunden			
1,3-Benzoldicarbonsäure	121-91-5	Organische Säuren	Al-Elko	Nein	$C_8H_6O_4$	nicht gefunden			
1,4-Benzoldicarbonsäure	100-21-0	Organische Säuren	Al-Elko	Nein	$C_8H_6O_4$	nicht gefunden			
2-Hydroxybenzoesäure, Salicylsäure	69-72-7	Organische Säuren	Al-Elko	Nein	$C_7H_6O_3$	nicht gefunden			
2,3,4-Trihydroxybenzoesäure	610-02-6	Organische Säuren	Al-Elko	Nein	$C_7H_6O_5$	nicht gefunden			
2,4,6-Trihydroxybenzoesäure	83-30-7	Organische Säuren	Al-Elko	Nein	$C_7H_6O_5$	nicht gefunden			
3,4,5-Trihydroxybenzoesäure	149-91-7	Organische Säuren	Al-Elko	Nein	$C_7H_6O_5$	nicht gefunden			
2,4-Dihydroxybenzoesäure	89-86-1	Organische Säuren	Al-Elko	Nein	$C_7H_6O_4$	$[M-H]^-$	5.9	1168	in Spuren, Identität nicht bestätigt
Polyethylenglycol	25322-68-3	Glycole	Al-Elko	Nein	C_2H_4O (Monomer)	$[M+H]^+$	8.7	231095	wahrscheinlich Quellenfragment eines grösseren Moleküls
Polyethylenglycol-2					$C_4H_{10}O_3$	$[M+H]^+$	8.7	359270	wahrscheinlich Quellenfragment eines grösseren Moleküls
Polyethylenglycol-3					$C_6H_{14}O_4$	$[M+H]^+$	5.2	1534	
Polyethylenglycol-4					$C_8H_{18}O_5$	$[M+H]^+$	6.0	13196	
Polyethylenglycol-5					$C_{10}H_{22}O_6$	$[M+H]^+$	6.5	81890	
Polyethylenglycol-6					$C_{12}H_{26}O_7$	$[M+H]^+$	6.8	142243	
Polyethylenglycol-7					$C_{14}H_{30}O_8$	$[M+H]^+$	7.1	217672	
Polyethylenglycol-8					$C_{16}H_{34}O_9$	$[M+H]^+$	7.3	202481	
Polyethylenglycol-9					$C_{18}H_{38}O_{10}$	$[M+H]^+$	7.5	201982	
Polyethylenglycol-10					$C_{20}H_{42}O_{11}$	$[M+H]^+$	7.7	186892	
Polyethylenglycol-11					$C_{22}H_{46}O_{12}$	$[M+H]^+$	7.9	190260	
Polyethylenglycol-12					$C_{24}H_{50}O_{13}$	$[M+H]^+$	8.1	197265	
Polyethylenglycol-13					$C_{26}H_{54}O_{14}$	$[M+H]^+$	8.2	221065	
Polyethylenglycol-14					$C_{28}H_{58}O_{15}$	$[M+H]^+$	8.4	231100	
Polyethylenglycol-15					$C_{30}H_{62}O_{16}$	$[M+H]^+$	8.5	212306	
Polyethylenglycol-16					$C_{32}H_{66}O_{17}$	$[M+H]^+$	8.7	164684	
Polyethylenglycol-17					$C_{34}H_{70}O_{18}$	$[M+H]^+$	8.9	160690	
Polyethylenglycol-18					$C_{36}H_{74}O_{19}$	$[M+H]^+$	9.0	96634	
Polyethylenglycol-19					$C_{38}H_{78}O_{20}$	$[M+H]^+$	9.2	55988	
Polyethylenglycol-20					$C_{40}H_{82}O_{21}$	$[M+H]^+$	9.3	40309	
Polyethylenglycol-21					$C_{42}H_{86}O_{22}$	$[M+H]^+$	9.5	24537	
Polyethylenglycol-22					$C_{44}H_{90}O_{23}$	$[M+H]^+$	9.7	17489	

C.3.3 BiCai microwaves

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201803937

Anhang GC-MS Identifikation (nach Extraktion mit Cyclohexan/Ethylacetat)

Proben-Nr. Bachema: 20919
Probenbezeichnung: 3.1 MW

Prüfmethode Extraktion: Schüttelextraktion mit Cyclohexan / Ethylacetat.
GC: Teknokroma Sapiens-X5MS, 30m x 0.25mm, Film 0.25µm
MS: 70eV, m/z 40 - 550

Resultate

Peak Nr.	CAS Nr.	Substanz	Fit (%)	Kommentar	Konz. [mg/kg]
1	4957-14-6	Di-p-tolyl-methan	87	oder Isomer	5000
2	18908-70-8	Ethyl(1-phenylethyl)benzol	88		10000
3	26137-53-1	1,2,3-trimethyl-4-(1E)-1-propenyl-naphthalin	80	oder Isomer	6000
4	3075-84-1	2,2',5,5'-Tetramethylbiphenyl	85	oder ähnliche Verbindung	100000
5	3075-84-1	2,2',5,5'-Tetramethylbiphenyl	86	oder ähnliche Verbindung	200000
6	3075-84-1	2,2',5,5'-Tetramethylbiphenyl	80	oder ähnliche Verbindung	200000
7	102177-18-4	5-Ethyl-2-methyl-4,4-diphenyl-3,4-dihydro-2H-pyrrol (EMDP)	86	oder ähnliche Verbindung	5000
8	3075-84-1	2,2',5,5'-Tetramethylbiphenyl	87	oder ähnliche Verbindung	300000
9	NA	1,1'-(1-Methylethylidene)bis[4-methyl-benzol	79	oder ähnliche Verbindung	10000
10	NA	1,1'-(1-Methylethylidene)bis[4-methyl-benzol	81	oder ähnliche Verbindung	5000
11	126584-00-7	1,5,6,7-Tetramethyl-3-phenylbicyclo[3.2.0]hepta-2,6-dien	80	oder ähnliche Verbindung	20000
ISTD	16696-65-4	(1,11-Dibromoundecane)		interner Standard	100000
12		unbekannte Verbindung		vermutlich eine mehrfach aromatische Verbindung	10000
13		unbekannte Verbindung		vermutlich eine mehrfach aromatische Verbindung	8000

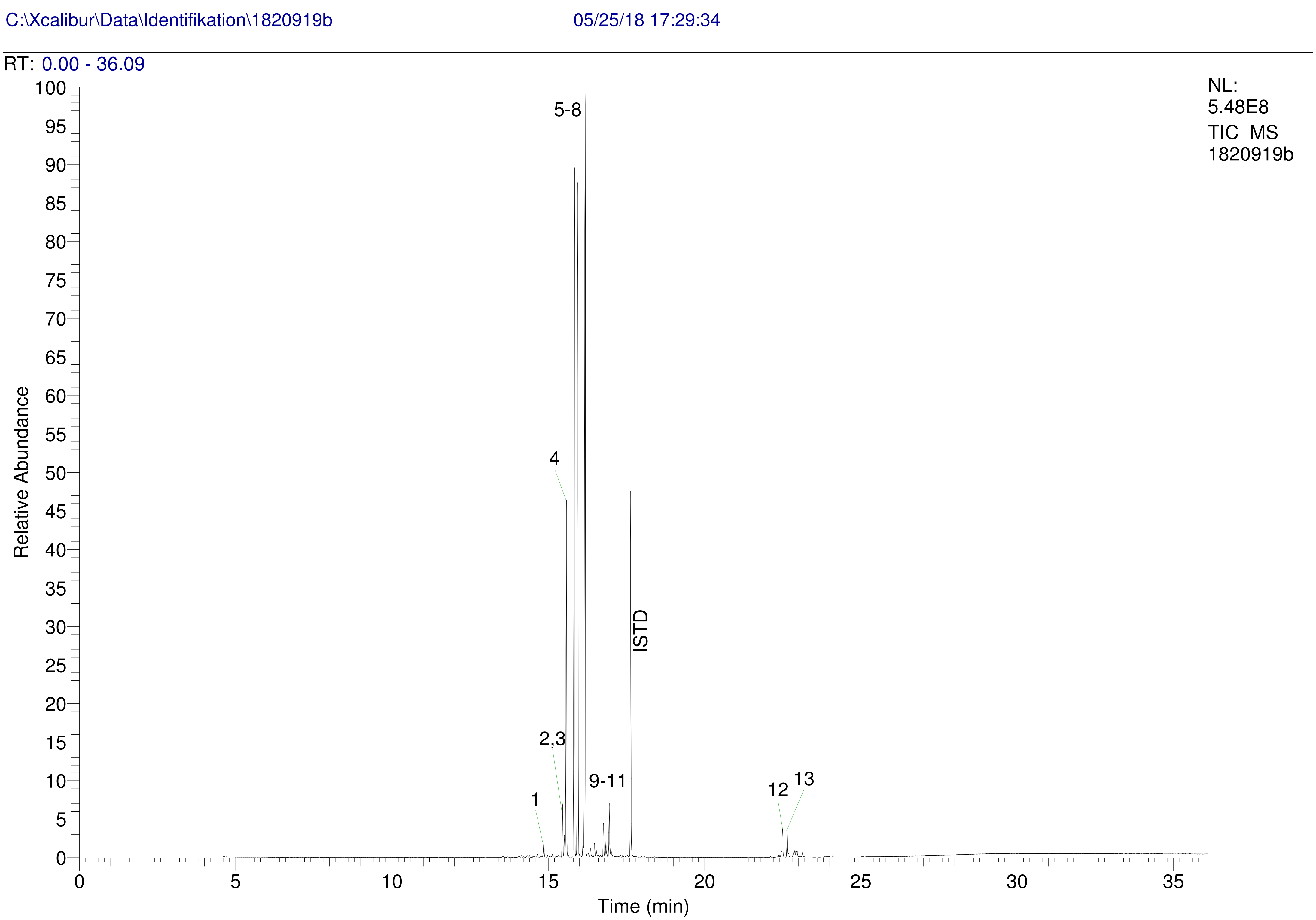
Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser, Boden, Abfall, Recyclingmaterial)
Akkreditiert nach ISO 17025
STS-Nr. 0064

Fit — Gibt an, wie genau das Spektrum der Probensubstanz mit einem Referenzspektrum übereinstimmt.
99 = identisch
>90 = sehr gute Übereinstimmung
>70 = mässige Übereinstimmung

Konz. — Bei den Konzentrationsangaben handelt es sich um Werte, welche anhand der Konzentration des internen Standards 1,11-Dibromundekan geschätzt wurden. Da sich die einzelnen Verbindungen bei Extraktion, Chromatografie und Detektion unterschiedlich verhalten, kann der wahre Wert um Grössenordnungen vom angegebenen Schätzwert abweichen.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Relative Abundance
Time (min)
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2,3
4
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9-11
ISTD
12
13
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5
10
15
20
25
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35
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50
55
60
65
70
75
80
85
90
95
100

C.3.4 Microwaves of other manufacturers

Bachema AG
Analytische Laboratorien

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201803937

Anhang GC-MS Identifikation (nach Extraktion mit Cyclohexan/Ethylacetat)

Proben-Nr. Bachema: 20920
Probenbezeichnung: 3.2 MW

Prüfmethode
Extraktion: Schüttelextraktion mit Cyclohexan / Ethylacetat.
GC: Teknokroma Sapiens-X5MS, 30m x 0.25mm, Film 0.25µm
MS: 70eV, m/z 40 - 550

Resultate

Peak Nr.	CAS Nr.	Substanz	Fit (%)	Kommentar	Konz. [mg/kg]
1	612-00-0	1,1-Diphenylethan	91		7000
2	620-83-7	1-Methyl-4-(phenylmethyl)-benzol	91	p-Benzyltoluol oder Isomer	6000
3	713-36-0	1-Methyl-2-(phenylmethyl)-benzol	91	o-Benzyltoluol oder Isomer	20000
4	620-47-3	1-Methyl-3-(phenylmethyl)-benzol	91	oder Isomer	20000
5	18908-70-8	Ethyl(1-phenylethyl)benzol	90		10000
6	26137-53-1	1,2,3-trimethyl-4-(1E)-1-propenyl-naphthalin	80	oder ähnliche Verbindung	30000
7	3075-84-1	2,2',5,5'-Tetramethylbiphenyl	97	oder ähnliche Verbindung	200000
8	3075-84-1	2,2',5,5'-Tetramethylbiphenyl	88	oder ähnliche Verbindung	300000
9	NA	1,3,5-Cycloheptatriene, 6-methyl-1-(6-methyl-1,3,5-cycloheptatrien-1-yl)-	79	oder ähnliche Verbindung	200000
10	102177-18-4	5-Ethyl-2-methyl-4,4-diphenyl-3,4-dihydro-2H-pyrrol (EMDP)	88	oder ähnliche Verbindung	30000
11	3075-84-1	2,2',5,5'-Tetramethylbiphenyl	87	oder ähnliche Verbindung	300000
ISTD	16696-65-4	(1,11-Dibromoundecane)		interner Standard	100000
12	94571-08-1	2,3,4,4a-Tetrahydro-1α,4aβ-dimethyl-9(1H)-phenanthron	79	oder ähnliche Verbindung	4000

Fit: Gibt an, wie genau das Spektrum der Probensubstanz mit einem Referenzspektrum übereinstimmt.
Konz.: Bei den Konzentrationsangaben handelt es sich um Werte, welche anhand der Konzentration des internen Standards 1,11-Dibromundekan geschätzt wurden. Da sich die einzelnen Verbindungen bei Extraktion, Chromatografie und Detektion unterschiedlich verhalten, kann der wahre Wert um Grössenordnungen vom angegebenen Schätzwert abweichen.

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser, Boden, Abfall, Recyclingmaterial)
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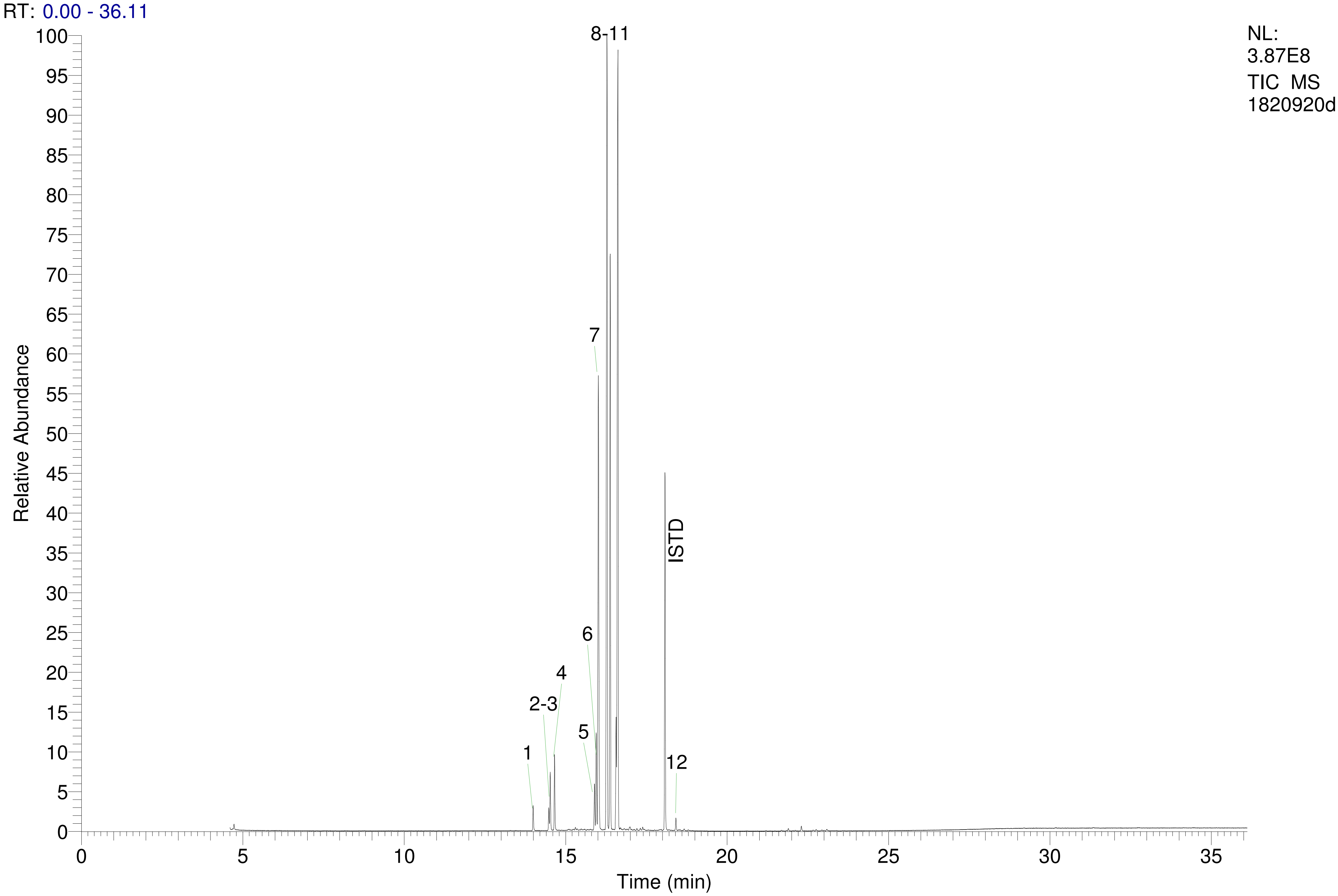

C.3.5 SENS small appliances, non-polarised cylindrical capacitors

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201803937

Anhang GC-MS Identifikation (nach Extraktion mit Cyclohexan/Ethylacetat)

Proben-Nr. Bachema: 20921
Probenbezeichnung: 5.1 HKG

Prüfmethode Extraktion: Schüttelextraktion mit Cyclohexan / Ethylacetat.
GC: Teknokroma Sapiens-X5MS, 30m x 0.25mm, Film 0.25µm
MS: 70eV, m/z 40 - 550

Resultate

Peak Nr.	CAS Nr.	Substanz	Fit (%)	Kommentar	Konz. [mg/kg]
1	91-57-6	2-Methyl-naphthalin	93	oder Isomer	900
2	90-12-0	1-Methyl-naphthalin	94	oder Isomer	4000
3	NA	Butyl cyclohexylmethyl ester Sulfurous acid (schweflige Säure)	77	oder Isomer	1000
4		unbekannte Verbindung		vermutlich ein verzeweigtes Alkan	2000
5		unbekannte Verbindung		vermutlich ein verzeweigtes Alkan	1000
ISTD	16696-65-4	(1,11-Dibromoundecane)		interner Standard	5000
6	27519-02-4	Cyclohexylmethyl undecyl ester Sulfurous acid (schweflige Säure)	76	oder ähnliche Verbindung	1000
7	NA	Cyclohexylmethyl tetradecyl ester Sulfurous acid (schweflige Säure)	78	oder ähnliche Verbindung	2000
8		unbekannte Verbindung		vermutlich ein verzeweigtes Alkan	2000
9		unbekannte Verbindung		vermutlich ein verzeweigtes Alkan	2000
10	NA	Cyclohexylmethyl undecyl ester Sulfurous acid (schweflige Säure)	74	oder ähnliche Verbindung	1000
11	NA	Cyclohexylmethyl tetradecyl ester Sulfurous acid (schweflige Säure)	76	oder ähnliche Verbindung	1000
12		unbekannte Verbindung			1000
13	84-76-4	Dinonyl phthalat	91	oder ähnliches Phthalat	2000
14		Kohlenwasserstoffgemisch		RT 11-28	n/q

Fit — Gibt an, wie genau das Spektrum der Probensubstanz mit einem Referenzspektrum übereinstimmt.
Konz. — Bei den Konzentrationsangaben handelt es sich um Werte, welche anhand der Konzentration des internen Standards 1,11-Dibromundekan geschätzt wurden. Da sich die einzelnen Verbindungen bei Extraktion, Chromatografie und Detektion unterschiedlich verhalten, kann der wahre Wert um Grössenordnungen vom angegebenen Schätzwert abweichen.

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

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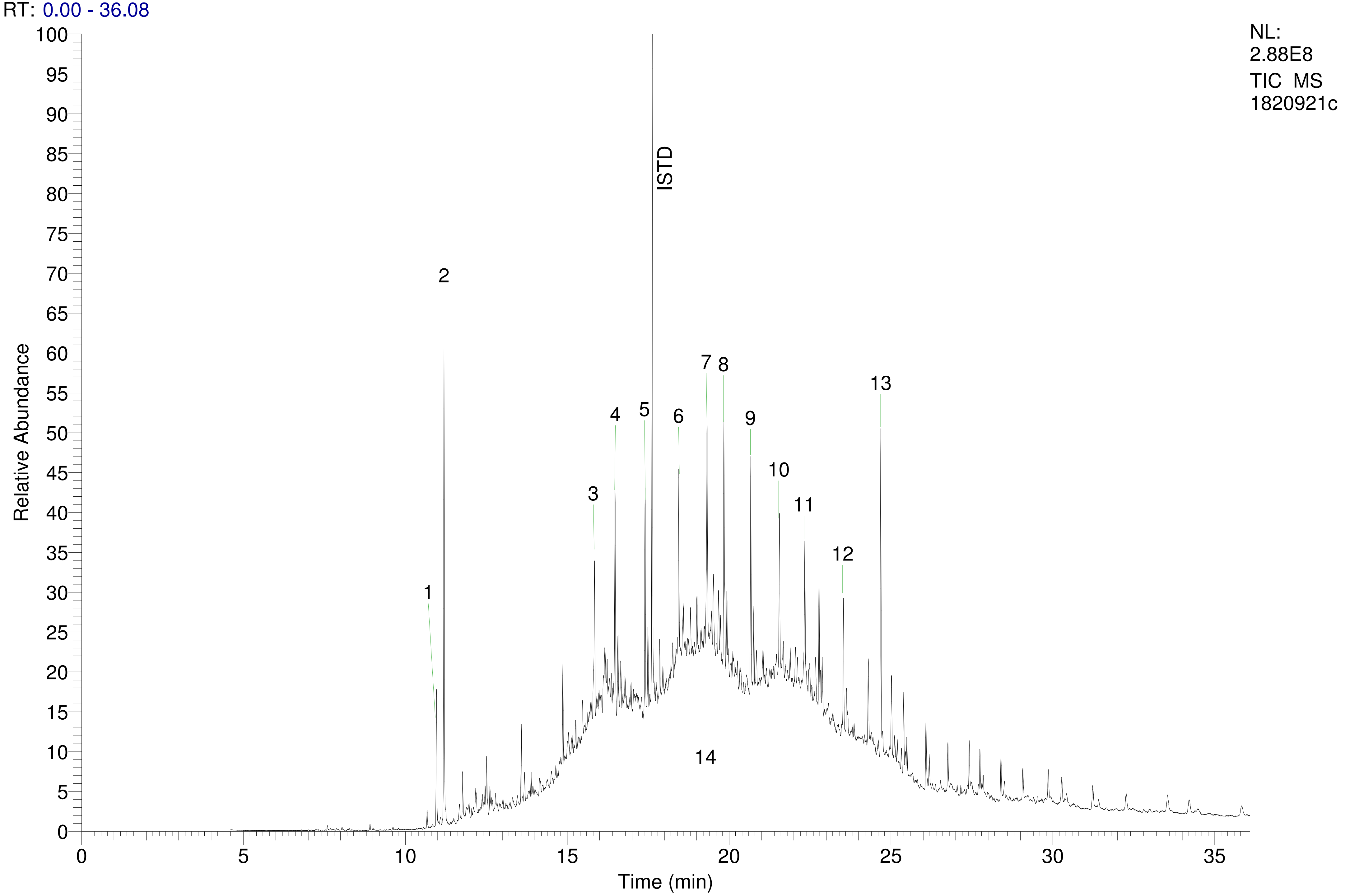

C.3.6 Large household appliances

Bachema AG
Analytische Laboratorien

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201803937

Anhang GC-MS Identifikation (nach Extraktion mit Cyclohexan/Ethylacetat)

Proben-Nr. Bachema: 22933
Probenbezeichnung: 6 HHG

Prüfmethode Extraktion: Schüttelextraktion mit Cyclohexan / Ethylacetat.
GC: Teknokroma Sapiens-X5MS, 30m x 0.25mm, Film 0.25µm
MS: 70eV, m/z 40 - 550

Resultate

Peak Nr.	CAS Nr.	Substanz	Fit (%)	Kommentar	Konz. [mg/kg]
1	91-57-6	2-Methylnaphthalin	93	oder Isomer	1000
2	90-12-0	1-Methylnaphthalin	93	oder Isomer	2000
3	NA	Cyclohexylmethyl hexyl ester Sulfurous acid (schweflige Säure)	81	oder ähnliche Verbindung	1000
4	NA	Cyclohexylmethyl hexadecyl ester Sulfurous acid (schweflige Säure)	80	oder ähnliche Verbindung	2000
5		unbekannte Verbindung		vermutlich ein verweigtes Alkan	4000
6	53960-44-4	2,2-Dimethyl-'4-octen-3-ol	75	oder ähnliche Verbindung	1000
7	5171-85-7	2,2,4,4,5,5,7,7-Octamethyloctan	74	oder ähnliche Verbindung	2000
ISTD	16696-65-4	(1,11-Dibromoundecane)		interner Standard	9000
8	27458-90-8	Di-tert-dodecyl disulfid	78	unsichere Verbindung	1000
9	NA	Cyclohexylmethyl hexyl ester Sulfurous acid (schweflige Säure)	77	oder ähnliche Verbindung	2000
10	NA	Cyclohexylmethyl hexadecyl ester Sulfurous acid (schweflige Säure)	78	oder ähnliche Verbindung	3000
11		unbekannte Verbindung		vermutlich ein sauerstoffhaltiges, verzweigtes Alkan	4000
12		unbekannte Verbindung		vermutlich ein verzweigtes Alkan	1000
13		unbekannte Verbindung		vermutlich ein verzweigtes Alkan	2000
14	NA	Cyclohexylmethyl hexadecyl ester Sulfurous acid (schweflige Säure)	76	oder ähnliche Verbindung	2000
15	NA	Cyclohexylmethyl tetradecyl ester Sulfurous acid (schweflige Säure)	76	oder ähnliche Verbindung	1000
16		unbekannte Verbindung		vermutlich ein sauerstoffhaltiges, verzweigtes Alkan	3000
17		unbekannte Verbindung		vermutlich ein verzweigtes Alkan	1000
18	NA	Cyclohexylmethyl hexyl ester Sulfurous acid (schweflige Säure)	77	oder ähnliche Verbindung	1000
19		unbekannte Verbindung		vermutlich ein sauerstoffhaltiges Alkan	1000
20		Kohlenwasserstoffgemisch		RT 12-30	n/q

Fit Gibt an, wie genau das Spektrum der Probensubstanz mit einem Referenzspektrum übereinstimmt.
99 = identisch
>90 = sehr gute Übereinstimmung
>70 = mässige Übereinstimmung

Konz. Bei den Konzentrationsangaben handelt es sich um Werte, welche anhand der Konzentration des internen Standards 1,11-Dibromundekan geschätzt wurden. Da sich die einzelnen Verbindungen bei Extraktion, Chromatografie und Detektion unterschiedlich verhalten, kann der wahre Wert um Grössenordnungen vom angegebenen Schätzwert abweichen.

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser, Boden, Abfall, Recyclingmaterial)
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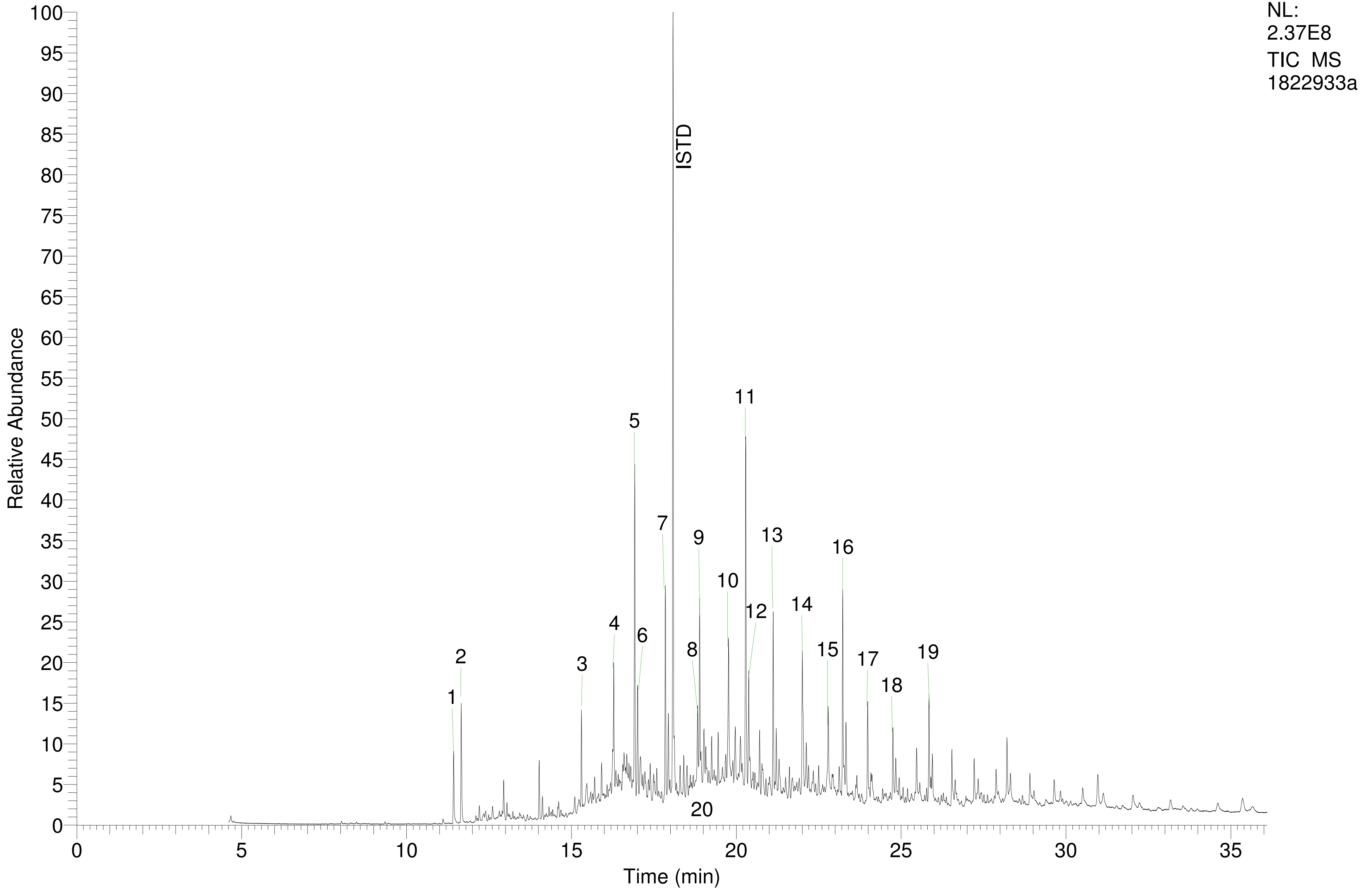

C.3.7 SENS small appliances, electrolytic capacitors

Bachema AG
Analytische Laboratorien

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201805939

Anhang GC-MS Identifikation (nach Extraktion mit Cyclohexan/Ethylacetat)

Proben-Nr. Bachema: 25044
Probenbezeichnung: 5.2a HKG

Prüfmethode Extraktion: Schüttelextraktion mit Cyclohexan / Ethylacetat.
GC: Teknokroma Sapiens-X5MS, 30m x 0.25mm, Film 0.25µm
MS: 70eV, m/z 40 - 550

Resultate

Peak Nr.	CAS Nr.	Substanz	Fit (%)	Kommentar	Konz. [mg/kg]
1	617-84-5	N,N-Diethylformamid	90		20
2	111-46-6	Diethylenglycol	95		200
3	108-95-2	Phenol	94		30
4	104-76-7	2-Ethylhexanol	93	oder ähnliche Verbindung	10
5	100-51-6	Benzylalkohol	96		2000
6	65-85-0	Benzoesäure	84		20
7	112-34-5	Diethylenglycol monobutylether	95	oder Isomer	3000
8	91-23-6	1-Methoxy-2-nitro-benzol	92		20
9	121-89-1	m-Nitroacetophenon	81		10
10	100-02-7	4-Nitrophenol	72	oder ähnliche Verbindung	10
ISTD	16696-65-4	(1,11-Dibromoundecane)		interner Standard	700
11	NA	(3-Iodo-1-methoxy-1-methylpropyl)-benzol	78	unsicher	10
12	NA	(3-Iodo-1-methoxy-1-methylpropyl)-benzol	78	unsicher	50
13	NA	(3-Iodo-1-methoxy-1-methylpropyl)-benzol	74	unsicher	10

Fit: Gibt an, wie genau das Spektrum der Probensubstanz mit einem Referenzspektrum übereinstimmt.
99 = identisch
>90 = sehr gute Übereinstimmung
>70 = mässige Übereinstimmung

Konz.: Bei den Konzentrationsangaben handelt es sich um Werte, welche anhand der Konzentration des internen Standards 1,11-Dibromundekan geschätzt wurden. Da sich die einzelnen Verbindungen bei Extraktion, Chromatografie und Detektion unterschiedlich verhalten, kann der wahre Wert um Grössenordnungen vom angegebenen Schätzwert abweichen.

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser, Boden, Abfall, Recyclingmaterial)
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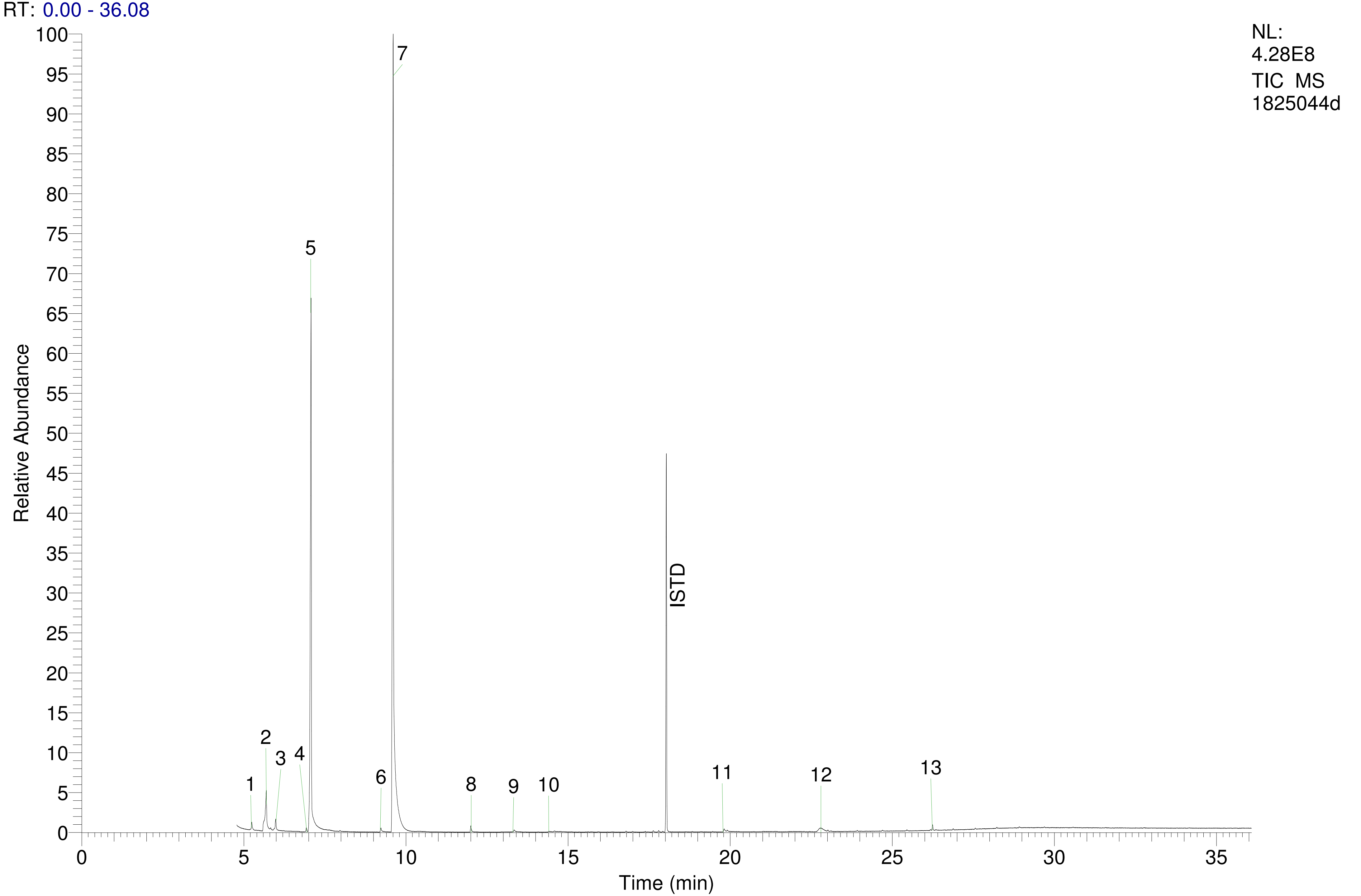

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201805939

Anhang LCMS Screening - Ergebnisse des Non-Target-Screenings

Proben-Nr. Bachema: 25049
Probenbezeichnung: Eluat aus 25048 ("5.2b HKG")

Prüfmethode:
LC: Waters Atlantis dc18 RP-Säule, Eluenten H2O & MeOH (jeweils mit 0.1% Ameisensäure), Direktinjektion von 100µL Probe
MS: TripleTOF 6600 (QTOF von ABSciex), positive und negative Ionisierung mit Elektrospray-Ionisation, Messzyklus: 1 HR-FullScan + 10 HR-MSMS (datenabhängig)
Auswertung: Automatisierte Non-Target Peaksuche mit Threshold 2000 in "Masterview" - Kontrollprobe: Elutionsblank
Retentionszeitenbereich: 1.5-20 min; automatisierte Summenformelvorhersage mit maximal C50 H100 N10 O10 S5 P5 Cl5 Br5

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

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Positiver Ionisationsmodus - grösste 10 Peaks von insgesamt 454 gefundenen Peaks

Nr. (N/P = negative/ positive Ionisierung)	Name	gemessene Masse	RT [min]	Intensität	automatisierte Summenformel-vorhersage	Güte der Summenformel-vorhersage 0 (gering) bis 100 (hoch)	Kommentar
P001	88.0756 / 5.56	88.076	5.56	2468671	C4H9NO	46	Wahrscheinlich Dimethylacetamid (siehe Suspectscreening)
P002	229.1433 / 10.28	229.143	10.28	2205605	C12H20O4	59	Gruppe aus 3 Peaks mit gleicher RT
P003	215.1279 / 9.14	215.128	9.14	1094760	C11H18O4	57	
P004	273.1697 / 10.20	273.170	10.20	997374	C14H24O5	67	Gruppe aus 3 Peaks mit gleicher RT
P005	273.1696 / 10.76	273.170	10.76	986242	C14H24O5	89	Gruppe aus 4 Peaks mit gleicher RT
P006	357.1882 / 10.63	357.188	10.63	724294	C14H36N2P4	40	Gruppe aus 3 Peaks mit gleicher RT
P007	313.1622 / 10.20	313.162	10.20	640152	C10H25N4O5P	63	Gruppe aus 3 Peaks mit gleicher RT
P008	297.1665 / 12.69	297.166	12.69	634099	C12H20N6O3	61	Gruppe aus 6 Peaks mit gleicher RT
P009	74.0602 / 4.24	74.060	4.24	560618	C3H7NO	60	Wahrscheinlich Dimethylformamid (siehe Suspectscreening)
P010	257.1735 / 12.81	257.173	12.81	547152	C14H24O4	50	Gruppe aus 2 Peaks mit gleicher RT

Negativer Ionisationsmodus - grösste 3 Peaks von insgesamt 111 gefundenen Peaks

Nr. (N/P = negative/ positive Ionisierung)	Name	gemessene Masse	RT [min]	Intensität	automatisierte Summenformel-vorhersage	Güte der Summenformel-vorhersage 0 (gering) bis 100 (hoch)	Kommentar
N001	227.9912 / 9.52	227.991	9.52	2991620	C6H3N3O7	44	
N002	229.1462 / 12.85	229.146	12.85	1749124	C12H22O4	65	Gruppe aus 2 Peaks mit gleicher RT
N003	273.1733 / 12.64	273.173	12.64	1010618	C14H26O5	76	Gruppe aus 3 Peaks mit gleicher RT

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Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201805939

Anhang LCMS Screening - Ergebnisse des Suspect-Screenings

Proben-Nr. Bachema: 25049
Probenbezeichnung: Eluat aus 25048 ("5.2b HKG")

Prüfmethode:
LC: Waters Atlantis dc18 RP-Säule, Eluenten H2O & MeOH (jeweils mit 0.1% Ameisensäure), Direktinjektion von 100µL Probe
MS: TripleTOF 6600 (QTOF von ABSciex), positive und negative Ionisierung mit Elektrospray-Ionisation, Messzyklus: 1 HR-FullScan + 10 HR-MSMS (datenabhängig)
Auswertung: Peaksuche der Substanzen aus untenstehender Liste im positiven Ionisationsmodus mittels $[M+H]^+$ und im negativen Ionisationsmodus mittels $[M-H]^-$
Abgleich der MSMS-Spektren mit verschiedenen MSMS-Datenbanken, wenn Spektrum vorhanden
Abgleich mit Referenzstandard, wenn Standard bei Bachema vorhanden

Resultate

Trivialname	CAS-Nummer	Chemische verwandte Gruppe	Verwendet in (Literaturhinweise)	Bedenkliche Substanz?	**LCMS Suspect-Screening** (erfasst mittel- bis hochpolare organische Verbindungen)				
					Summenformel	wurde gefunden mit	wurde gefunden bei Retentionszeit [min]	wurde gefunden mit Intensität	Bemerkung
Dimethylformamid	68-12-2	Amide	Al-Elko	Ja	C3H7NO	$[M+H]^+$	4.5	559475	isobar zu N-Methylacetamid, Identität über MSMS-Fragmente mit hoher Wahrscheinlichkeit bestätigt
Dimethylacetamid	127-19-5	Amide	Al-Elko	Ja	C4H9NO	$[M+H]^+$	5.6	2471983	Identität nicht bestätigt, aber aufgrund ähnlicher MSMS-Fragmente wie Dimethylformamid wahrscheinlich
N-Methylacetamid	79-16-3	Amide		Ja	C3H7NO	$[M+H]^+$	4.5	559475	isobar zu Dimethylformamid, Identität nicht bestätigt, Peak ist eher Dimethylformamid
N-Methylformamid	123-39-7	Amide		Ja	C2H5NO	nicht gefunden			
Triethylamin	121-44-8	Amine	Al-Elko	Nein	C6H15N	$[M+H]^+$	5	289843	Identität nicht bestätigt, aber wahrscheinlich
Diethylamin	109-89-7	Amine		Nein	C4H11N	$[M+H]^+$	1.9 (Totzeit)	379711	grosser Peak bei 2min, durch Standard bestätigt als Diethylamin, Konzentration in der 1:1000-er Verdünnung des Eluats deutlich grösser als 10 µg/L
Ethanolamin	141-43-5	Amine		Nein	C2H7NO	nicht gefunden			
2,3,5-Trihydroxybenzoesäure	33580-60-8	Organische Säuren	Al-Elko	Einstufung nicht möglich	C7H6O5	nicht gefunden			
2,3,6-Trihydroxybenzoesäure	16534-78-4	Organische Säuren	Al-Elko	Einstufung nicht möglich	C7H6O5	nicht gefunden			
2,4,5-Trihydroxybenzoesäure	610-90-2	Organische Säuren	Al-Elko	Einstufung nicht möglich	C7H6O5	nicht gefunden			
1,2-Benzoldicarbonsäure	88-99-3	Organische Säuren	Al-Elko	Nein	C8H6O4	nicht gefunden			
1,3-Benzoldicarbonsäure	121-91-5	Organische Säuren	Al-Elko	Nein	C8H6O4	nicht gefunden			
1,4-Benzoldicarbonsäure	100-21-0	Organische Säuren	Al-Elko	Nein	C8H6O4	nicht gefunden			
2-Hydroxybenzoesäure, Salicylsäure	69-72-7	Organische Säuren	Al-Elko	Nein	C7H6O3	$[M+H]^+$ & [M-H]-	8.9	24604 / 358763	Identität nicht bestätigt
2,3,4-Trihydroxybenzoesäure	610-02-6	Organische Säuren	Al-Elko	Nein	C7H6O5	nicht gefunden			
2,4,6-Trihydroxybenzoesäure	83-30-7	Organische Säuren	Al-Elko	Nein	C7H6O5	nicht gefunden			
3,4,5-Trihydroxybenzoesäure	149-91-7	Organische Säuren	Al-Elko	Nein	C7H6O5	nicht gefunden			
2,4-Dihydroxybenzoesäure	89-86-1	Organische Säuren	Al-Elko	Nein	C7H6O4	$[M-H]^-$	5.9 + 7.1	835	in Spuren, Identität nicht bestätigt
Polyethylenglycol	25322-68-3	Glycole	Al-Elko	Nein	C2H4O (Monomer)	$[M+H]^+$	8.6	65314	wahrscheinlich Quellenfragment eines grösseren Moleküls
Polyethylenglycol-2					C4H10O3	$[M+H]^+$	8.6	103876	wahrscheinlich Quellenfragment eines grösseren Moleküls
Polyethylenglycol-3					C6H14O4	$[M+H]^+$	6.4	1745	
Polyethylenglycol-4					C8H18O5	$[M+H]^+$	6.0	40047	
Polyethylenglycol-5					C10H22O6	$[M+H]^+$	6.4	298228	
Polyethylenglycol-6					C12H26O7	$[M+H]^+$	6.8	223925	
Polyethylenglycol-7					C14H30O8	$[M+H]^+$	7.0	97324	
Polyethylenglycol-8					C16H34O9	$[M+H]^+$	7.3 + 8.7	22495	Intensität von grösserem Peak (RT 7.3)
Polyethylenglycol-9					C18H38O10	$[M+H]^+$	7.5 + 9.0	12467	Intensität von grösserem Peak (RT 7.5)
Polyethylenglycol-10					C20H42O11	$[M+H]^+$	7.7 + 9.3	16890	Intensität von grösserem Peak (RT 9.3)
Polyethylenglycol-11					C22H46O12	$[M+H]^+$	7.8 + 9.6	17552	Intensität von grösserem Peak (RT 9.6)
Polyethylenglycol-12					C24H50O13	$[M+H]^+$	8.0 + 9.9	15112	Intensität von grösserem Peak (RT 9.9)
Polyethylenglycol-13					C26H54O14	$[M+H]^+$	8.2 + 10.2	12187	Intensität von grösserem Peak (RT 10.2)
Polyethylenglycol-14					C28H58O15	$[M+H]^+$	8.4 + 10.5	6150	Intensität von grösserem Peak (RT 10.5)
Polyethylenglycol-15					C30H62O16	$[M+H]^+$	8.5	4133	
Polyethylenglycol-16					C32H66O17	$[M+H]^+$	8.7	3592	
Polyethylenglycol-17					C34H70O18	$[M+H]^+$	8.8	2360	
Polyethylenglycol-18					C36H74O19	$[M+H]^+$	9.0	1823	
Polyethylenglycol-19					C38H78O20	$[M+H]^+$	9.2	1512	
Polyethylenglycol-20					C40H82O21	$[M+H]^+$	9.3	757	
Polyethylenglycol-21					C42H86O22	$[M+H]^+$	9.5	466	
Polyethylenglycol-22					C44H90O23	$[M+H]^+$	9.6	308	

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser, Boden, Abfall, Recyclingmaterial)
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C.3.8 Laptop power supply units and desktop computers

Bachema AG
Analytische Laboratorien

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201805939

Anhang GC-MS Identifikation (nach Extraktion mit Cyclohexan/Ethylacetat)

Proben-Nr. Bachema: 25050
Probenbezeichnung: 7a Netz

Prüfmethode Extraktion: Schüttelextraktion mit Cyclohexan / Ethylacetat.
GC: Teknokroma Sapiens-X5MS, 30m x 0.25mm, Film 0.25µm
MS: 70eV, m/z 40 - 550

Resultate

Peak Nr.	CAS Nr.	Substanz	Fit (%)	Kommentar	Konz. [mg/kg]
1	591-81-1	4-Hydroxybutansäure	97	GHB oder Butyrolacton	40
2	111-46-6	Diethylenglycol	97		100
3	111-46-6	Diethylenglycol	95		100
4	108-95-2	Phenol	93		50
5	617-94-7	2-Phenyl-2-propanol	88	oder ähnliche Verbindung	10
6	65-85-0	Benzoesäure	94		200
7	91-23-6	1-Methoxy-2-nitro-benzol	94		10
8	94-33-7	Ethylenglycol monobenzoat	90		30
9	121-89-1	m-Nitroacetophenon	96		80
10	100-02-7	4-Nitrophenol	92		30
11	619-73-8	4-Nitrobenzyl Alkohol	91	oder Isomer	50
12	505-95-3	12-Hydroxydodecansäure	78	unsicher	10
13	111-20-6	Decandisäure	75	Sebacinsäure oder ähnliche Säure	20
ISTD	16696-65-4	(1,11-Dibromoundecane)		interner Standard	80
14	1593-55-1	Azelainsäure monoethylester	72	oder ähnliche Verbindung	50
15	5578-82-5	Ethylen sebacat	76	oder ähnliche Verbindung	200
16		unbekannte Verbindung			20
17		unbekannte Verbindung		vermutlich eine Carbonsäure	300
18	13145-56-7	1,4-Di-p-tolylbutane-1,4-dione	72		10
19		unbekannte Verbindung		vermutlich eine sauerstoffhaltige, aromatische Verbindung	10

Fit: Gibt an, wie genau das Spektrum der Probensubstanz mit einem Referenzspektrum übereinstimmt.
99 = identisch
>90 = sehr gute Übereinstimmung
>70 = mässige Übereinstimmung

Konz.: Bei den Konzentrationsangaben handelt es sich um Werte, welche anhand der Konzentration des internen Standards 1,11-Dibromundekan geschätzt wurden. Da sich die einzelnen Verbindungen bei Extraktion, Chromatografie und Detektion unterschiedlich verhalten, kann der wahre Wert um Grössenordnungen vom angegebenen Schätzwert abweichen.

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser, Boden, Abfall, Recyclingmaterial)
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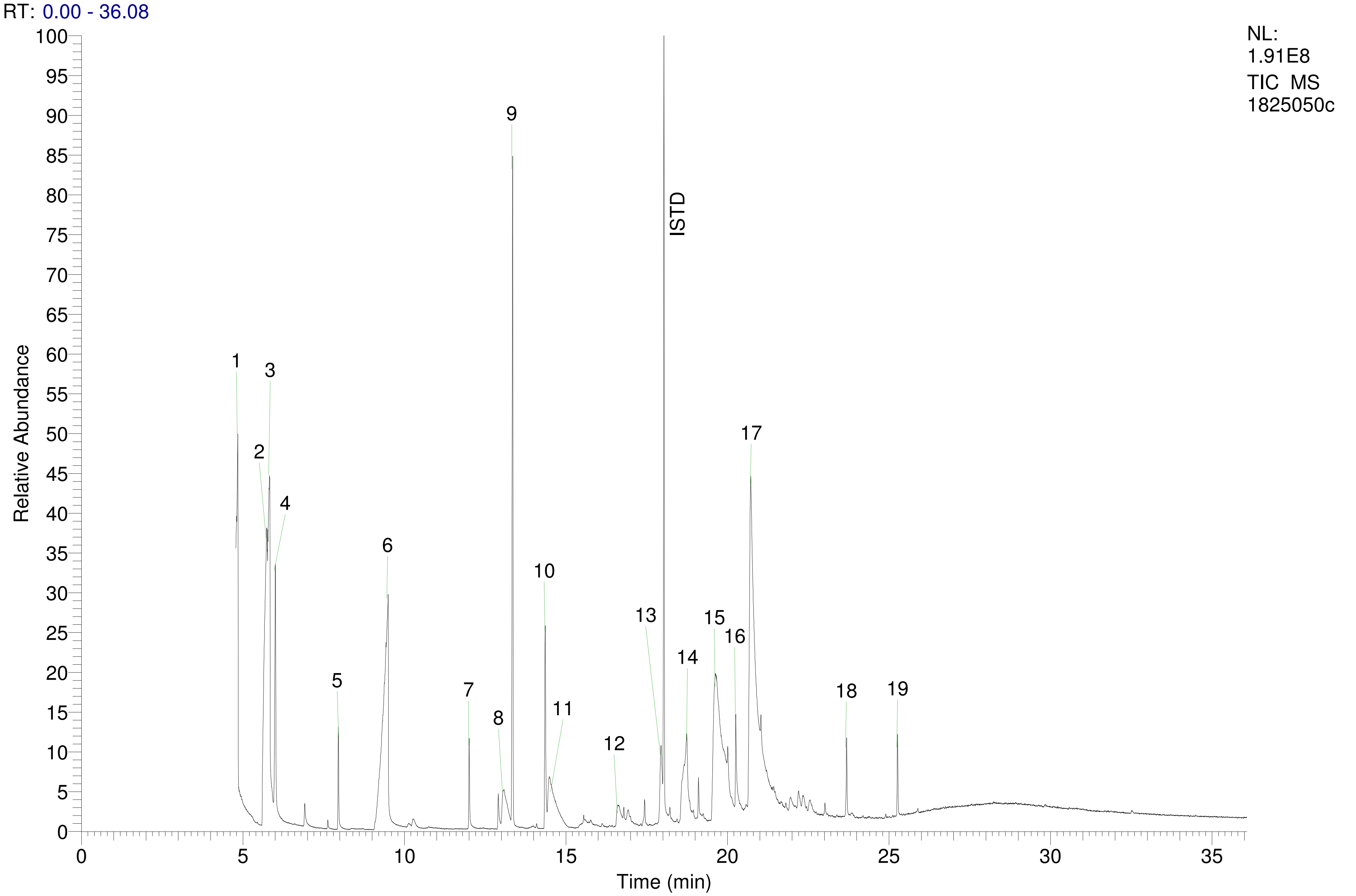

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201805939

Anhang LCMS Screening - Ergebnisse des Non-Target-Screenings

Proben-Nr. Bachema: 25055
Probenbezeichnung: Eluat aus 25054 ("7b Netz")

Prüfmethode:
LC: Waters Atlantis dc18 RP-Säule, Eluenten H2O & MeOH (jeweils mit 0.1% Ameisensäure), Direktinjektion von 100µL Probe
MS: TripleTOF 6600 (QTOF von ABSciex), positive und negative Ionisierung mit Elektrospray-Ionisation, Messzyklus: 1 HR-FullScan + 10 HR-MSMS (datenabhängig)
Auswertung: Automatisierte Non-Target Peaksuche mit Threshold 2000 in "Masterview" - Kontrollprobe: Elutionsblank
Retentionszeitenbereich: 1.5-20 min; automatisierte Summenformelvorhersage mit maximal C50 H100 N10 O10 S5 P5 Cl5 Br5

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

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Positiver Ionisationsmodus - grösste 10 Peaks von insgesamt 388 gefundenen Peaks

Nr. (N/P = negative/ positive Ionisierung)	Name	gemessene Masse	RT [min]	Intensität	automatisierte Summenformel-vorhersage	Güte der Summenformel-vorhersage 0 (gering) bis 100 (hoch)	Kommentar
P001	229.1433 / 10.28	229.143	10.28	3505146	C12H20O4	64	
P002	215.1279 / 9.14	215.128	9.14	1466284	C11H18O4	60	Gruppe aus mehreren Peaks mit gleicher RT
P003	273.1697 / 10.20	273.170	10.20	1093421	C14H24O5	73	Gruppe aus 2 Peaks mit gleicher RT
P004	257.1735 / 12.81	257.173	12.81	797370	C14H24O4	52	Gruppe aus 2 Peaks mit gleicher RT
P005	297.1665 / 12.69	297.166	12.69	756104	C12H20N6O3	70	Gruppe aus 4 Peaks mit gleicher RT
P006	127.1227 / 5.93	127.123	5.93	698862	C7H14N2	41	
P007	313.1622 / 10.20	313.162	10.20	673406	C12H20N6O4	89	Gruppe aus 2 Peaks mit gleicher RT
P008	269.1360 / 10.37	269.136	10.37	620540	C10H16N6O3	57	
P009	255.1201 / 9.08	255.120	9.08	461140	C9H14N6O3	67	Gruppe aus 3 Peaks mit gleicher RT
P010	341.1915 / 12.48	341.192	12.48	356637	C15H35O2P3	86	Gruppe aus 2 Peaks mit gleicher RT

Negativer Ionisationsmodus - grösste 3 Peaks von insgesamt 92 gefundenen Peaks

Nr. (N/P = negative/ positive Ionisierung)	Name	gemessene Masse	RT [min]	Intensität	automatisierte Summenformel-vorhersage	Güte der Summenformel-vorhersage 0 (gering) bis 100 (hoch)	Kommentar
N001	229.1462 / 12.85	229.146	12.85	2407692	C12H22O4	66	Gruppe aus 2 Peaks mit gleicher RT
N002	273.1733 / 12.64	273.173	12.64	1335386	C14H26O5	69	Gruppe aus 3 Peaks mit gleicher RT
N003	201.1151 / 10.35	201.115	10.35	988260	C11H14N4	66	Gruppe aus 2 Peaks mit gleicher RT

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser, Boden, Abfall, Recyclingmaterial)
Akkreditiert nach ISO 17025
STS-Nr. 0064

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201805939

Anhang LCMS Screening - Ergebnisse des Suspect-Screenings

Proben-Nr. Bachema: 25055
Probenbezeichnung: Eluat aus 25054 ("7b Netz")

Prüfmethode:
LC: Waters Atlantis dc18 RP-Säule, Eluenten H_2O & MeOH (jeweils mit 0.1% Ameisensäure), Direktinjektion von 100µL Probe
MS: TripleTOF 6600 (QTOF von ABSciex), positive und negative Ionisierung mit Elektrospray-Ionisation, Messzyklus: 1 HR-FullScan + 10 HR-MSMS (datenabhängig)
Auswertung: Peaksuche der Substanzen aus untenstehender Liste im positiven Ionisationsmodus mittels $[M+H]^+$ und im negativen Ionisationsmodus mittels $[M-H]^-$
Abgleich der MSMS-Spektren mit verschiedenen MSMS-Datenbanken, wenn Spektrum vorhanden
Abgleich mit Referenzstandard, wenn Standard bei Bachema vorhanden

Resultate

					LCMS Suspect-Screening (erfasst mittel- bis hochpolare organische Verbindungen)				
Trivialname	**CAS-Nummer**	**Chemische verwandte Gruppe**	**Verwendet in (Literaturhinweise)**	**Bedenkliche Substanz?**	**Summenformel**	**wurde gefunden mit**	**wurde gefunden bei Retentionszeit [min]**	**wurde gefunden mit Intensität**	**Bemerkung**
Dimethylformamid	68-12-2	Amide	Al-Elko	Ja	C_3H_7NO	nicht gefunden			
Dimethylacetamid	127-19-5	Amide	Al-Elko	Ja	C_4H_9NO	nicht gefunden			
N-Methylacetamid	79-16-3	Amide		Ja	C_3H_7NO	nicht gefunden			
N-Methylformamid	123-39-7	Amide		Ja	C_2H_5NO	nicht gefunden			
Triethylamin	121-44-8	Amine	Al-Elko	Nein	$C_6H_{15}N$	$[M+H]^+$	5.1	1407	Identität nicht bestätigt
Diethylamin	109-89-7	Amine		Nein	$C_4H_{11}N$	$[M+H]^+$	1.9 (Totzeit)	294494	grosser Peak bei 2min, durch Standard bestätigt als Diethylamin, Konzentration in der 1:1000-er Verdünnung des Eluats deutlich grösser als 10 µg/L
Ethanolamin	141-43-5	Amine		Nein	C_2H_7NO	nicht gefunden			
2,3,5-Trihydroxybenzoesäure	33580-60-8	Organische Säuren	Al-Elko	Einstufung nicht möglich	$C_7H_6O_5$	nicht gefunden			
2,3,6-Trihydroxybenzoesäure	16534-78-4	Organische Säuren	Al-Elko	Einstufung nicht möglich	$C_7H_6O_5$	nicht gefunden			
2,4,5-Trihydroxybenzoesäure	610-90-2	Organische Säuren	Al-Elko	Einstufung nicht möglich	$C_7H_6O_5$	nicht gefunden			
1,2-Benzoldicarbonsäure	88-99-3	Organische Säuren	Al-Elko	Nein	$C_8H_6O_4$	$[M-H]^-$	7.1	21665	Identität nicht bestätigt
1,3-Benzoldicarbonsäure	121-91-5	Organische Säuren	Al-Elko	Nein	$C_8H_6O_4$	$[M-H]^-$	7.1	21665	Identität nicht bestätigt
1,4-Benzoldicarbonsäure	100-21-0	Organische Säuren	Al-Elko	Nein	$C_8H_6O_4$	$[M-H]^-$	7.1	21665	Identität nicht bestätigt
2-Hydroxybenzoesäure, Salicylsäure	69-72-7	Organische Säuren	Al-Elko	Nein	$C_7H_6O_3$	[M-H]-	8.9	3225	Identität nicht bestätigt
2,3,4-Trihydroxybenzoesäure	610-02-6	Organische Säuren	Al-Elko	Nein	$C_7H_6O_5$	nicht gefunden			
2,4,6-Trihydroxybenzoesäure	83-30-7	Organische Säuren	Al-Elko	Nein	$C_7H_6O_5$	nicht gefunden			
3,4,5-Trihydroxybenzoesäure	149-91-7	Organische Säuren	Al-Elko	Nein	$C_7H_6O_5$	nicht gefunden			
2,4-Dihydroxybenzoesäure	89-86-1	Organische Säuren	Al-Elko	Nein	$C_7H_6O_4$	nicht gefunden			
Polyethylenglycol	25322-68-3	Glycole	Al-Elko	Nein	C_2H_4O (Monomer)	$[M+H]^+$	2.0 & 2.7	14271	wahrscheinlich Quellenfragment eines grösseren Moleküls
Polyethylenglycol-2					$C_4H_{10}O_3$	nicht gefunden			
Polyethylenglycol-3					$C_6H_{14}O_4$	nicht gefunden			
Polyethylenglycol-4					$C_8H_{18}O_5$	nicht gefunden			
Polyethylenglycol-5					$C_{10}H_{22}O_6$	nicht gefunden			
Polyethylenglycol-6					$C_{12}H_{26}O_7$	$[M+H]^+$	6.8	11279	
Polyethylenglycol-7					$C_{14}H_{30}O_8$	$[M+H]^+$	7.0	12135	
Polyethylenglycol-8					$C_{16}H_{34}O_9$	$[M+H]^+$	7.3	7898	
Polyethylenglycol-9					$C_{18}H_{38}O_{10}$	$[M+H]^+$	7.5	7583	
Polyethylenglycol-10					$C_{20}H_{42}O_{11}$	$[M+H]^+$	7.7	7893	
Polyethylenglycol-11					$C_{22}H_{46}O_{12}$	$[M+H]^+$	7.8	8025	
Polyethylenglycol-12					$C_{24}H_{50}O_{13}$	$[M+H]^+$	8.0	6765	
Polyethylenglycol-13					$C_{26}H_{54}O_{14}$	$[M+H]^+$	8.2	4799	
Polyethylenglycol-14					$C_{28}H_{58}O_{15}$	$[M+H]^+$	8.4	3588	
Polyethylenglycol-15					$C_{30}H_{62}O_{16}$	$[M+H]^+$	8.5	2889	
Polyethylenglycol-16					$C_{32}H_{66}O_{17}$	$[M+H]^+$	8.7	2880	
Polyethylenglycol-17					$C_{34}H_{70}O_{18}$	$[M+H]^+$	8.8	2386	
Polyethylenglycol-18					$C_{36}H_{74}O_{19}$	$[M+H]^+$	9.0	1904	
Polyethylenglycol-19					$C_{38}H_{78}O_{20}$	$[M+H]^+$	9.2	883	
Polyethylenglycol-20					$C_{40}H_{82}O_{21}$	$[M+H]^+$	9.3	521	
Polyethylenglycol-21					$C_{42}H_{86}O_{22}$	$[M+H]^+$	9.5	569	
Polyethylenglycol-22					$C_{44}H_{90}O_{23}$	$[M+H]^+$	9.6	476	

C.3.9 LCMS evaluation including boron

Bachema AG
Analytische Laboratorien

Objekt: Kondensatoren-Analyse

Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201805939

Nachträgliche Auswertung von LC-MS-Screening-Daten nach Borverbindungen mit besonderem Augenmerk auf Borsäure und Ammoniumpentaborat.

Wir haben zusätzliche Auswertungen vorgenommen und uns dabei auf die Probe 25049 "Eluat aus 5.2b HKG" konzentriert, da diese mit 262 mg/l am meisten Bor enthält.

Zusammenfassend gesagt konnten wir in den LC-MS-Screening-Daten keine Hinweise auf borhaltige Verbindungen finden, die mit dieser Methode erfassbar wären. Das bedeutet nicht, dass keine borhaltigen organischen Verbindungen in der Probe vorhanden sind, sondern nur, dass wir mit unserer Methode keine solchen Verbindungen nachweisen konnten. Wie im nächsten Punkt erläutert, sind manche borhaltigen Verbindungen mit unserer Methode nicht erfassbar.

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser,Boden, Abfall, Recyclingmaterial)
Akkreditiert nach ISO 17025
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Im Einzelnen haben wir folgendes gemacht:

1) Borsäure haben wir im Haus, daher haben wir diese mit unserer Methode in relativ hohen Konzentrationen eingespritzt und gemessen. Wir haben leider kein Signal für die Borsäure erhalten, was darauf schliessen lässt, dass sie nicht mittels LC-MS erfassbar ist.

2) Wir haben nach den exakten Massen von Borsäure und Pentaborat in den Fullscan-Massenspektren aller drei gemessenen Proben gesucht. Wir haben keine signifikanten Signale (Peaks) für diese Massen gefunden. Erschwerend hinzu kam, dass man bei eingehender Internetrecherche keine eindeutige Strukturformel für das Ammoniumpentaborat erhält. Wir haben unserer Suche dann die uns am wahrscheinlichsten erscheinende Strukturformel zugrunde gelegt. Abgesehen davon ist es unwahrscheinlich, dass wir für Pentaborat ein Signal bekommen, wenn die Borsäure kein Signal ergibt. Somit konnten wir beide Verdachtssubstanzen nicht detektieren.

3) In den Ergebnissen des Non-Target-Screenings haben wir nochmals eine Summenformelvorhersage laufen lassen und dazu bis zu drei Bor-Atome erlaubt. Innerhalb der 50 grössten Peaks für Probe 25049 wurde allerdings keine plausible Summenformel mit Bor vorhergesagt, so dass auch diese Suche erfolglos blieb.

4) Die Fullscan-Massenspektren können nach spezifischen Isotopenmustern durchsucht werden. Da Bor in zwei Isotopen auftritt (B-10: 20% und B-11: 80%), kann man nach diesem Muster suchen. Auch diese Suche ergab für Probe 25049 keine signifikanten Peaks.

Somit kann das LC-MS-Screening keine Hinweise auf borhaltige organische Verbindungen geben, was aber nicht bedeutet, dass keine solchen Substanzen in der Probe vorhanden sind.

Schlieren, 26. Juli 2018

C.4 Analysis results of the PCB analyses

The analysis reports for the capacitors checked for PCBs from the laboratory are attached in the following pages. Table 67 shows the association between the sample numbers in the laboratory report and the capacitor models from which the samples were taken. It also states whether we analysed an extracted oil or the extracted coil.

Table 67: Samples for PCB analysis

Sample number	Manufacturer	Model	Sample
3	BHC Aerovox	117U 5015	Coil
4	BHC Aerovox	117U 5017	Coil
5	BHC	117U5014	Coil
6	BHC	117U5015	Coil
7	BHC	117U5017	Coil
53	Arcotronics	C.87.1WF3 3µF	Oil
54	Arcotronics	C.87.1WF2 3µF	Oil
56	Arcotronics	C.87.1WF1 2,5µF	Oil
58	Arcotronics	C.87.1WF3 6µF	Oil
59	Arcotronics	C.87.1WF1 4µF	Oil
78	Arcotronics	C.87.1WF2 5 µF	Oil
79	Arcotronics	C.87.8FF2	Oil
81	Arcotronics	C.87.1WF2 4 µF	Oil
264	Cond. Fribourg	HPFNT 72722	Oil
276	ERO	F 1762-0545-226	Coil
289	Arcotronics	C.87.OEF2	Oil
41 (KKGPCB1)	Hydra	13503	Oil
55 (KKGPCB2)	Arcotronics	C.87.8FF2 4µF	Oil
57 (KKGPCB3)	Arcotronics	C.87.1WF1 2,5µF C/D	Oil
52a (KKGPCB4)	ICAR	MLR25M50 603583/I-MK	Oil
18e (KKGPCB5)	M	475007 (P1)	Oil

Bachema AG
Analytische Laboratorien

Schlieren, 11. Oktober 2018
SIS

Büro für Umweltchemie GmbH
Schaffhauserstrasse 21
8006 Zürich

Untersuchungsbericht

Objekt: Kondensatoren-Analyse

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser,Boden, Abfall, Recyclingmaterial)
Akkreditiert nach ISO 17025
STS-Nr. 0064

Auftrags-Nr. Bachema	201809903
Proben-Nr. Bachema	43356-43371
Tag der Probenahme	05. Oktober 2018
Eingang Bachema	05. Oktober 2018
Probenahmeort	
Entnommen durch	D. Savi, Büro für Umweltchemie GmbH

Auftraggeber	Büro für Umweltchemie GmbH, Schaffhauserstrasse 21, 8006 Zürich
Rechnungsadresse	Büro für Umweltchemie GmbH, Schaffhauserstrasse 21, 8006 Zürich
Bericht an	Büro für Umweltchemie GmbH, D. Savi, Schaffhauserstrasse 21, 8006 Zürich
Bericht per e-mail an	Büro für Umweltchemie GmbH, D. Savi, d.savi@umweltchemie.ch

Freundliche Grüsse
BACHEMA AG

A. Rust

Annette Rust
Dr. sc. nat. / Dipl. Umwelt-Natw. ETH

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie GmbH
Auftrags-Nr. Bachema: 201809903

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und
mikrobiologisches
Labor für die Prüfung
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(Wasser,Boden, Abfall,
Recyclingmaterial)
Akkreditiert nach
ISO 17025
STS-Nr. 0064

Probenübersicht

Bachema-Nr.		Probenbezeichnung	Probenahme / Eingang Labor
43356	F	**3**	05.10.18 / 05.10.18
43357	F	**4**	05.10.18 / 05.10.18
43358	F	**5**	05.10.18 / 05.10.18
43359	F	**6**	05.10.18 / 05.10.18
43360	F	**7**	05.10.18 / 05.10.18
43361	F	**53**	05.10.18 / 05.10.18
43362	F	**54**	05.10.18 / 05.10.18
43363	F	**56**	05.10.18 / 05.10.18
43364	F	**58**	05.10.18 / 05.10.18
43365	F	**59**	05.10.18 / 05.10.18
43366	F	**78**	05.10.18 / 05.10.18
43367	F	**79**	05.10.18 / 05.10.18
43368	F	**81**	05.10.18 / 05.10.18
43369	F	**264**	05.10.18 / 05.10.18
43370	F	**276**	05.10.18 / 05.10.18
43371	F	**289**	05.10.18 / 05.10.18

Legende zu den Referenzwerten

Toleranzwert für Transformatorenöl	Toleranzwert für Kondensatoren und Transformatoren gemäss Verordnung zur Reduktion von Risiken beim Umgang mit bestimmten besonders gefährlichen Stoffen, Zubereitungen und Gegenständen (ChemRRV), Anhang 2.14.

Abkürzungen

W	Wasserprobe
F	Feststoffprobe
TS	Trockensubstanz
<	Bei den Messresultaten ist der Wert nach dem Zeichen < (kleiner als) die Bestimmungsgrenze der entsprechenden Methode.
*	Die mit * bezeichneten Analysen fallen nicht in den akkreditierten Bereich der Bachema AG oder sind Fremdmessungen.

Akkreditierung

SWISS ACCREDITATION sas.admin.ch STS 0064 / SWISS TESTING LABS	Auszugsweise Vervielfältigung der Analysenresultate sind nur mit Genehmigung der Bachema AG gestattet. Detailinformationen zu Messmethode, Messunsicherheiten und Prüfdaten sind auf Anfrage erhältlich (s. auch Dienstleistungsverzeichnis oder www.bachema.ch).

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie GmbH
Auftrags-Nr. Bachema: 201809903

Probenbezeichnung		3	4	5	6	Referenzwert	
Proben-Nr. Bachema		43356	43357	43358	43359		
Tag der Probenahme		05.10.18	05.10.18	05.10.18	05.10.18		
PCB							
PCB 28 (TS)	mg/kg TS	**<0.2**	**<0.2**	**<0.2**	**<0.2**		
PCB 52 (TS)	mg/kg TS	**<0.2**	**<0.2**	**<0.2**	**<0.2**		
PCB 101 (TS)	mg/kg TS	**<0.2**	**<0.2**	**<0.2**	**<0.2**		
PCB 118 (TS)	mg/kg TS	**<0.2**	**<0.2**	**<0.2**	**<0.2**		
PCB 138 (TS)	mg/kg TS	**<0.2**	**<0.2**	**<0.2**	**<0.2**		
PCB 153 (TS)	mg/kg TS	**<0.2**	**<0.2**	**<0.2**	**<0.2**		
PCB 180 (TS)	mg/kg TS	**<0.2**	**<0.2**	**<0.2**	**<0.2**		
PCB Summe n. VVEA / AltlV	mg/kg TS	**<5**	**<5**	**<5**	**<5**		
PCB Summe (LAGA)	mg/kg TS	**<5**	**<5**	**<5**	**<5**		

Probenbezeichnung		276				Referenzwert	
Proben-Nr. Bachema		43370					
Tag der Probenahme		05.10.18					
PCB							
PCB 28 (TS)	mg/kg TS	**<0.2**					
PCB 52 (TS)	mg/kg TS	**<0.2**					
PCB 101 (TS)	mg/kg TS	**<0.2**					
PCB 118 (TS)	mg/kg TS	**<0.2**					
PCB 138 (TS)	mg/kg TS	**<0.2**					
PCB 153 (TS)	mg/kg TS	**<0.2**					
PCB 180 (TS)	mg/kg TS	**<0.2**					
PCB Summe n. VVEA / AltlV	mg/kg TS	**<5**					
PCB Summe (LAGA)	mg/kg TS	**<5**					

Probenbezeichnung		7	53	54	56	Referenzwert: *Toleranzwert für Transformatorenöl*	
Proben-Nr. Bachema		43360	43361	43362	43363		
Tag der Probenahme		05.10.18	05.10.18	05.10.18	05.10.18		
PCB							
PCB 28	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 52	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 101	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 118	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 138	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 153	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 180	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB Summe (gemäss ChemRRV)	mg/kg	**<20**	**<20**	**<20**	**<20**	*50*	
PCB Typisierung		**kein PCB-Nachweis**	**kein PCB-Nachweis**	**kein PCB-Nachweis**	**kein PCB-Nachweis**		

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser,Boden, Abfall, Recyclingmaterial)
Akkreditiert nach ISO 17025
STS-Nr. 0064

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie GmbH
Auftrags-Nr. Bachema: 201809903

						Referenzwert	
Probenbezeichnung		**58**				*Toleranzwert für Transformatorenöl*	
Proben-Nr. Bachema		43364					
Tag der Probenahme		05.10.18					
PCB							
PCB 28	mg/kg	**<0.5**					
PCB 52	mg/kg	**<0.5**					
PCB 101	mg/kg	**<0.5**					
PCB 118	mg/kg	**<0.5**					
PCB 138	mg/kg	**<0.5**					
PCB 153	mg/kg	**<0.5**					
PCB 180	mg/kg	**<0.5**					
PCB Summe (gemäss ChemRRV)	mg/kg	**<20**				*50*	
PCB Typisierung		**kein PCB-Nachweis**					

						Referenzwert	
Probenbezeichnung		**59**	**78**	**79**	**81**	*Toleranzwert für Transformatorenöl*	
Proben-Nr. Bachema		43365	43366	43367	43368		
Tag der Probenahme		05.10.18	05.10.18	05.10.18	05.10.18		
PCB							
PCB 28	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 52	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 101	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 118	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 138	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 153	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 180	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB Summe (gemäss ChemRRV)	mg/kg	**<20**	**<20**	**<20**	**<20**	*50*	
PCB Typisierung		**kein PCB-Nachweis**	**kein PCB-Nachweis**	**kein PCB-Nachweis**	**kein PCB-Nachweis**		

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser,Boden, Abfall, Recyclingmaterial) Akkreditiert nach ISO 17025 STS-Nr. 0064

Bachema AG
Analytische Laboratorien

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie GmbH
Auftrags-Nr. Bachema: 201809903

						Referenzwert	
Probenbezeichnung		**264**	**289**			*Toleranz-wert für Transfor-matorenöl*	
Proben-Nr. Bachema		43369	43371				
Tag der Probenahme		05.10.18	05.10.18				
PCB							
PCB 28	mg/kg	**<0.5**	**<0.5**				
PCB 52	mg/kg	**<0.5**	**<0.5**				
PCB 101	mg/kg	**<0.5**	**<0.5**				
PCB 118	mg/kg	**<0.5**	**<0.5**				
PCB 138	mg/kg	**<0.5**	**<0.5**				
PCB 153	mg/kg	**<0.5**	**<0.5**				
PCB 180	mg/kg	**<0.5**	**<0.5**				
PCB Summe (gemäss ChemRRV)	mg/kg	**<20**	**<20**			*50*	
PCB Typisierung		**kein PCB-Nachweis**	**kein PCB-Nachweis**				

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser,Boden, Abfall, Recyclingmaterial) Akkreditiert nach ISO 17025 STS-Nr. 0064

Bachema AG
Analytische Laboratorien

Schlieren, 12. Februar 2019
LW

Büro für Umweltchemie GmbH
Schaffhauserstrasse 21
8006 Zürich

Untersuchungsbericht

Objekt: PCB-verdächtige Kondensatoren

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser,Boden, Abfall, Recyclingmaterial) Akkreditiert nach ISO 17025
STS-Nr. 0064

Auftrags-Nr. Bachema	201901138
Proben-Nr. Bachema	4804-4808
Tag der Probenahme	11. Februar 2019
Eingang Bachema	11. Februar 2019
Probenahmeort	
Entnommen durch	D. Savi, Büro für Umweltchemie GmbH

Auftraggeber	Büro für Umweltchemie GmbH, Schaffhauserstrasse 21, 8006 Zürich
Rechnungsadresse	Büro für Umweltchemie GmbH, Schaffhauserstrasse 21, 8006 Zürich
Bericht an	Büro für Umweltchemie GmbH, D. Savi, Schaffhauserstrasse 21, 8006 Zürich
Bericht per e-mail an	Büro für Umweltchemie GmbH, D. Savi, d.savi@umweltchemie.ch

Freundliche Grüsse
BACHEMA AG

Olaf Haag
Dipl. Natw. ETH

Objekt: **PCB-verdächtige Kondensatoren**
Auftraggeber: Büro für Umweltchemie GmbH
Auftrags-Nr. Bachema: 201901138

Probenübersicht

Bachema-Nr.		Probenbezeichnung	Probenahme / Eingang Labor
4804	F	**KKGPCB1**	11.02.19 / 11.02.19
4805	F	**KKGPCB2**	11.02.19 / 11.02.19
4806	F	**KKGPCB3**	11.02.19 / 11.02.19
4807	F	**KKGPCB4**	11.02.19 / 11.02.19
4808	F	**KKGPCB6**	11.02.19 / 11.02.19

Legende zu den Referenzwerten

Toleranzwert für Transformatorenöl	Toleranzwert für Kondensatoren und Transformatoren gemäss Verordnung zur Reduktion von Risiken beim Umgang mit bestimmten besonders gefährlichen Stoffen, Zubereitungen und Gegenständen (ChemRRV), Anhang 2.14.

Abkürzungen

W	Wasserprobe
F	Feststoffprobe
TS	Trockensubstanz
<	Bei den Messresultaten ist der Wert nach dem Zeichen < (kleiner als) die Bestimmungsgrenze der entsprechenden Methode.
{1}	Die Analysenmethode liegt zurzeit nicht im akkreditierten Bereich der Bachema AG.
{2}	Externe Analyse von Unterauftragnehmer / Fremdlabor.
{3}	Feldmessung von Kunde erhoben.

Akkreditierung

Die Resultate der Untersuchungen beziehen sich auf die im Prüfbericht aufgeführten Proben und auf den Zustand der Proben bei der Entgegennahme durch die Bachema AG.
Der vollständige Prüfbericht steht dem Kunden zur freien Verfügung. Die Verwendung von Auszügen (einzelne Seiten) oder Ausschnitten (Teile einzelner Seiten) des Prüfberichts sowie Hinweise auf den Prüfbericht (z.B. zu Werbezwecken oder bei Präsentationen) sind nur mit Genehmigung der Bachema AG gestattet.
Detailinformationen zu Messmethode, Messunsicherheiten und Prüfdaten sind auf Anfrage erhältlich (s. auch Dienstleistungsverzeichnis oder www.bachema.ch)

Bachema AG
Rütistrasse 22
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und mikrobiologisches Labor für die Prüfung von Umweltproben (Wasser,Boden, Abfall, Recyclingmaterial)
Akkreditiert nach ISO 17025
STS-Nr. 0064

Objekt: **PCB-verdächtige Kondensatoren**
Auftraggeber: Büro für Umweltchemie GmbH
Auftrags-Nr. Bachema: 201901138

Probenbezeichnung		KKGPCB1	KKGPCB2	KKGPCB3	KKGPCB4	*Referenzwert* *Toleranz-wert für Transfor-matorenöl*	
Proben-Nr. Bachema		4804	4805	4806	4807		
Tag der Probenahme		11.02.19	11.02.19	11.02.19	11.02.19		
PCB							
PCB 28	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 52	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 101	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 118	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 138	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 153	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB 180	mg/kg	**<0.5**	**<0.5**	**<0.5**	**<0.5**		
PCB Summe (gemäss ChemRRV)	mg/kg	**<20**	**<20**	**<20**	**<20**	*50*	
PCB Typisierung		**kein PCB-Nachweis**	**kein PCB-Nachweis**	**kein PCB-Nachweis**	**kein PCB-Nachweis**		

Probenbezeichnung		KKGPCB6				*Referenzwert* *Toleranz-wert für Transfor-matorenöl*	
Proben-Nr. Bachema		4808					
Tag der Probenahme		11.02.19					
PCB							
PCB 28	mg/kg	**<0.5**					
PCB 52	mg/kg	**<0.5**					
PCB 101	mg/kg	**<0.5**					
PCB 118	mg/kg	**<0.5**					
PCB 138	mg/kg	**<0.5**					
PCB 153	mg/kg	**<0.5**					
PCB 180	mg/kg	**<0.5**					
PCB Summe (gemäss ChemRRV)	mg/kg	**<20**				*50*	
PCB Typisierung		**kein PCB-Nachweis**					

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