Liquids in capacitors

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

Updated final report

SENS eRecycling

SWICO

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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 waste electrical and electronic equipment 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. Questions about the behaviour in recycling and the environment were clarified for the substances of concern in capacitors. In addition, we propose guidelines as to how these capacitors should be handled in recycling.

1.2 Literature research

While researching literature at the beginning of the study, we evaluated accessible knowledge about liquid substances in capacitors. We used 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 basic works 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. Furthermore, five individual models were selected from the non-polarised cylindrical capacitors. Liquid samples were prepared from these for each model. The 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). The 20 largest peaks from the chromatograms of the GCMS analyses were evaluated.

The mass proportion of the capacitor liquids was determined for electrolytic capacitors, non-polarised cylindrical capacitors and microwave capacitors.

Based on the results of the analyses, mass flows were estimated for PCB loads and loads of substances of concern in Switzerland. In addition, the mass flow of liquids in recycling was modelled using a sample process, and critical pathways for the release of substances of concern were identified.

1.4 Results and discussion

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 utilise 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. Capacitors from luminaires still often contain PCBs. In our study, 55 per cent of the capacitors contained PCBs and another 21 per cent were suspected of containing PCBs. The capacitors containing PCBs still account for a significant PCB load of 300 to 350 kg a year in Switzerland.

The results for small SENS appliances (these consist of mainly small household appliances, electrical tools and sports appliances) were not plausible and cannot be considered to be representative of returned small SENS appliances. We speculate that the high proportion of PCB-containing capacitors arose because capacitors from fluorescent household luminaires were included in the collection by mistake.

The mass fraction of liquids in capacitors is about 15 per cent for non-polarised cylindrical and electrolytic capacitors, and about 10 per cent for microwave capacitors.

Further evaluations were made based on the data material. 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

A definition of substances of concern was developed within the scope of this study, the use of which we recommend. The stability and environmental behaviour of the identified substances of concern was further clarified with the help of literature data. It was concluded that the substances of concern should be destroyed in high temperature processes, if they adhere to combustible materials.

All liquids in the analysed capacitor categories could contain substances of concern according to the established definition. The concentrations of substances of concern found were low, except in microwave capacitors. Based on the data, the annual load of substances of concern in PCB-free capacitors was estimated to be between 0.5 and 5 t a year.

The removal requirement stipulated in the CENELEC standard 50625 and the WEEE Directive should be revised to include all capacitors which contain liquids. The size criterion for electrolytic capacitors should be reconsidered as half of the liquids are in capacitors smaller than 2.5 cm. The authors were unable to reach consensus on this issue. Capacitors containing PCBs, which are still found in large household appliances and luminaires, must still be removed from waste electrical and electronic equipment prior to mechanical processing. PCB-free capacitors shall be removed as an identifiable stream during treatment as stipulated by the CENELEC standard 50625.

The removal into an identifiable stream after mechanical processing poses the problem that capacitors can be destroyed in the shredder. We describe this behaviour with a breakage rate and use the processing of small household appliances to show which breakage rates can lead to critical flows of substances of concern in subsequent treatment. Further studies are needed to clarify the distribution of the liquids in treatment fractions and permissible processing technologies.

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List of abbreviations

BCF	Bioconcentration factor
CAS	Chemical Abstracts Service
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)
ECHA	European Chemicals Agency
e-cap	Electrolytic capacitor
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
REACH	Regulation (EC) No. 1907/2006 of the European Parliament and of the Council, stands for: registration, evaluation, authorisation and restriction of chemicals.
SDS	Safety data sheet
WEEE	Waste electrical and electronic equipment

Number format

2,000.5	Two thousand point five
,	Thousands separator
.	Decimal point

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 ban on PCBs in 1986. The question has arisen regarding the proportion of PCB-containing capacitors in the current stream of waste electrical and electronic equipment. 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.

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?
- What is the mass fraction of the liquids in the 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?
- How stable are the substances of concern from capacitors in the disposal processes?
- What are the environmental hazards of the substances of concern?
- How is the liquid from capacitors distributed in the recycling process?
- Does this lead to new recommendations for the removal of hazardous substances?

The important question of how the substances of concern behave in the recycling process could only be addressed theoretically. A possible distribution of the liquid was modelled based on a typical mass flow for the recycling of waste electrical and electronic equipment. Empirical studies on this topic could not be conducted within the framework of the present study.

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 and the WEEE Directive (European Parliament, 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 electrolytic (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 in this case. 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 sample acquired in this manner was 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 addition, the liquids from five models of non-polarised cylindrical capacitors were analysed individually. 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.

2.4.7 Clarification of the chemical-toxic properties of the substances of concern

The chemical and environmentally toxic properties of the substances of concern were investigated through literature-based research. These clarifications included information on thermal stability, parameters on the distribution of substances in the environment, toxicity to mammals, fish, crustaceans and algae, as well as degradability and accumulation in the environment.

3 Terms

3.1 Non-polarised cylindrical capacitors

Non-polarised capacitors form a large group of different construction types. See also Table 1. 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. All the non-polarised cylindrical capacitors we encountered in WEEE were larger than 2.5 cm in at least one dimension. 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 FK metal and dielectric film with liquid impregnation.

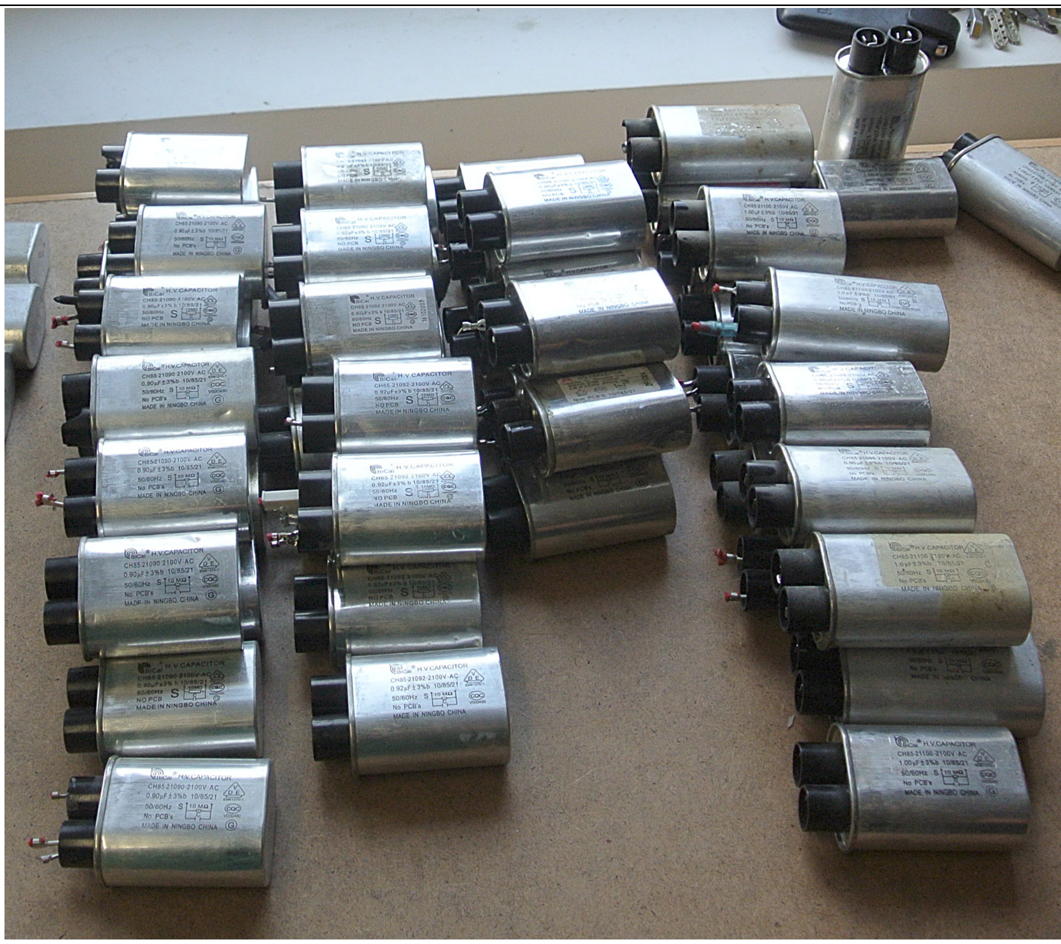

Figure 3: Microwave capacitors from decommissioned microwaves

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.

As shown by the study, the abbreviations used are not always clear. Manufacturer names may differ from this diagram.

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 characteristic liquid and design which differ 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:* KC: polycarbonate, KI: polyphenylene sulphide, KP: polypropylene, KS: polystyrene, KT: PET, LEI-KO: 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:* MKC: polycarbonate, MKI: polyphenylene sulphide, MKP: polypropylene, MKS: polystyrene, MKT: PET, MKU: cellulose acetate (historically)	Plastic film, metal layer evaporated, no intermediate film Hard wax or *oil impregnation* possible	
Electrolytic	Aluminium		*With liquid electrolytes*: lotting paper impregnated with salt solution between aluminium film Generally polarised component, also non-polarised for special applications (audio)	Electrolytic
	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
Electrolytic/ 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 NDK: low, class 2 HDK: 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	MIS: 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 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/TDK 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 was only 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 "αdodecene-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). The use of castor oil is indicated on capacitors. In addition, mineral oils can also be suitable. A patent describes a mixture of aliphatic and aromatic hydrocarbons especially for plastic capacitors (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 assumption, see chapter 6.2.5.

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 WEEE. 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) 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. However, the term substances of concern is not used in the ORRChem. In addition, the Swiss Ordinance on the Rotterdam Convention on the Prior Informed Consent (PIC) (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 6.1.

4.3.2 Classification of substances according to the GHS

The identified substances according to the discussion in chapter 7.1 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, 2016) 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
(Z)-4-decenal	21662-09-9	Mostly no classification, 23 out of about 200: H315, H319, H335, 13 out of about 200: H412
1-Chloronaphthalene (chlorinated naphthalenes)	90-13-1 25586-43-0	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 tract), H411
1-Tetradecene	1120-36-1	H304, H315, (H411)
1,1-Bis(3,4-dimethylphenyl)ethane	1742-14-9	No classification
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
1,2-Benzenedicarboxylic acid	88-99-3	H315, H319, H335
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
1,3-Benzenedicarboxylic acid	121-91-5	No classification
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
13-Hexyloxacyclotridec-10-en-2-one	127062-51-5	No information
2-Ethylhexanol	104-76-7	H315, H319, H332, H335
2-Hydroxybenzoic acid, salicylic acid	69-72-7	H302, H312, H315, H318, H319, H335
2-Hydroxyethyl benzoate	94-33-7	No information
2-Methylnaphthalene	91-57-6	H302, H400, H410
2-Nitroanisole/1-Methoxy-2-nitrobenzene	91-23-6	H302, H350
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
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
Other alkylated biphenyls	–	–

Chemical designation	CAS No.	GHS labelling according to ECHA
Benzoic acid	65-85-0	H315, H318, H372
Benzyl alcohol	100-51-6	H302, H332
Benzyltoluenes (p- and m-)	27776-01-8	H304, H315, (p-,o-: H319), H332, (p-,o-: H335), H400, H410
Biphenyl	92-52-4	H315, H319, H335, H400, H410
Bis(2-ethylhexyl) adipate	103-23-1	No classification in the vast majority of REACH dossiers
Bis(7-methyloctyl)phthalate	20548-62-3	No classification (SDS Sigma-Aldrich)
Boric acid	11113-50-1 10043-35-3	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
Diethylene glycol	111-46-6	H302, H373 (kidney) (oral)
“Diethylhexyl phthalate” Bis(2-ethylhexyl)phthalate	117-81-7	H360FD (H400, H410)
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
Dimethylbenzyl alcohol	617-94-7	H302, H315, H319
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, mo-noethylene 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 definitive 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 electrolytic 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 units 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 7.7.2. 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 luminaires 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. The abbreviations IT and CE stand for information technology and consumer electronics. In 2006, the disassembly of ballasts from luminaires resulted in proportions 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: Proportion of capacitors containing PCB – data from 2009 luminaires study

Appliance category	Proportion of PCB capacitors [proportion units]	
	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 proportion 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]	Proportion 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 proportions 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 (Eugster et al., 2008). 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.

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

Formula 1: Calculation of the sample size for the proportion 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 proportion 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 tolerated,

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

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 (total 1,500 capacitors)	Washing machines	1,000
11b		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 luminaires 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 left-most 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.

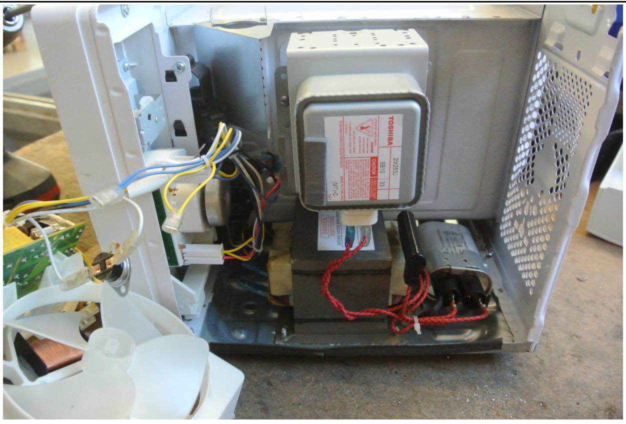

Figure 5: Microwave with typical capacitor in the bottom right of the picture

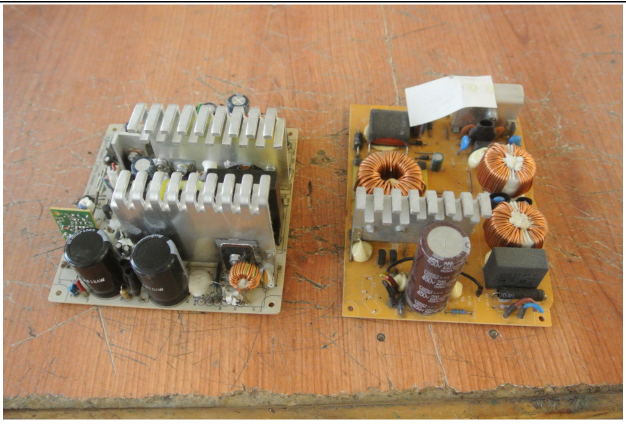

Figure 6: Internal power supply units from electrical or electronic appliances

Figure 7: External power supply unit to operate a laptop

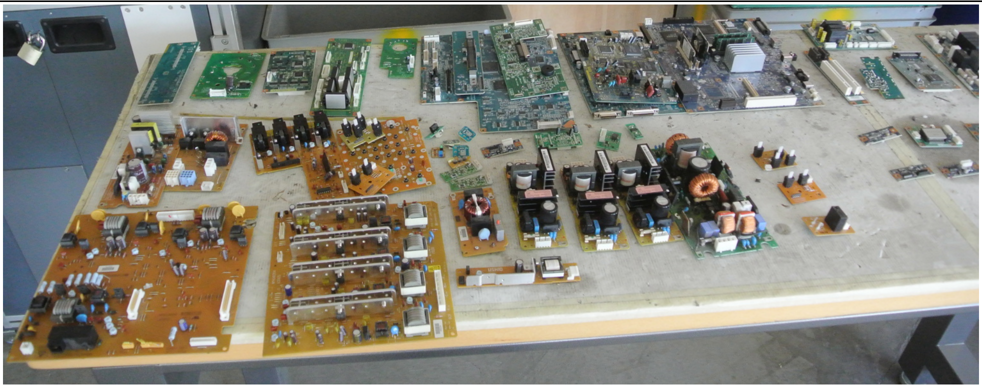

Figure 8: Circuit boards of a large-scale photocopier

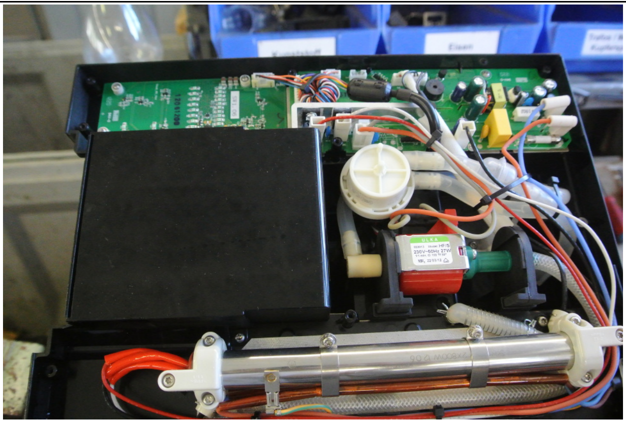

Figure 9: Interior of a steam iron station

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 were drained from the capacitors to prepare the samples 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.

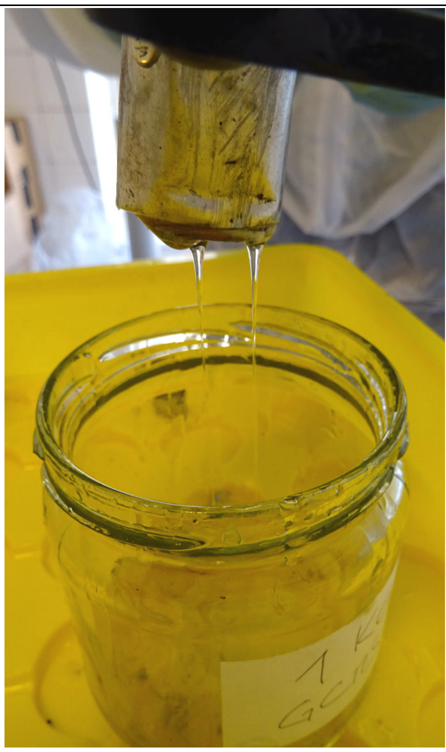

Figure 11: Liquid flowing from a non-polarised cylindrical capacitor after cutting

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 e-caps 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 (with BiCai and other manufacturers separated), SENS small appliances, flat screens, as well as desktop computers and external laptop power supply units. In addition, five samples of individual models of large household appliances were prepared, which were analysed like the mixed sample of large household appliances. 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, Al 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 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.

In addition, in a second analysis campaign, individual models of large household appliances were examined, as described in 5.2.6.

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 6.6.1, 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 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 Analysis of substances of individual capacitor models of non-polarised cylindrical capacitors

5.2.6.1 Approach

The analysis of individual models was to allow a better understanding of how the results of the mixed samples were obtained. Non-polarised cylindrical capacitors from large household appliances were selected. In contrast to the previous investigation, only capacitors of the same model were used for each sample. Models were selected that were already included in the mixed sample for large household appliances. Several criteria were considered in the selection of the five models:

– Largest number of units in the collection
– Individual samples of models from different manufacturers
– Different types of liquids

Five models from four different manufacturers were chosen, as shown in Table 13.

5.2.6.2 Laboratory analysis concept

The liquid samples were analysed by GCMS, and the PCB content of the samples was also checked. The analysis was carried out according to the same specifications as for the capacitors from large household appliances.

5.2.6.3 Preparation of the samples from individual models

The samples were prepared from the liquids of several capacitors of the same model. Three to six capacitors were cut open to obtain a liquid sample. The number depended on how much liquid could be obtained per capacitor. Table 13 lists the five samples obtained with their key figures. The pictures in Annex D show the capacitor models from which the five samples were made.

Table 13: Samples created for individual models of non-polarised cylindrical capacitors

Capaci-tor No.	Capacitor model	Capacitor manufacturer	Description of laboratory sample	Number of capacitors
311	NIL F 158405000020 X1Y2 0.47 µF	BK	HHGG 1	3
109	MAB 5/500	Hydra	HHGG 2	4
126	MAB 5/400	Hydra	HHGG 3	3
90	E12.C58-30104F 10µF	Electronicon	HHGG 4	6
95	C.87.8BF2 4 µF	AV	HHGG 5	6

5.2.7 Evaluation of the GCMS and LCMS analyses

The aim was to search for the main components in the 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. No liquids from individual capacitors were detected in the mixed samples tested. Instead, the analysis provides a picture of the common substances in all capacitors of a mixed sample. The analyses show the substances per capacitor model for the samples of the individual models of non-polarised cylindrical capacitors. The GCMS analysis also allowed an approximate quantification of the mass fraction of the substance by comparing the peak areas with those of the laboratory standard of known mass fraction.

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 (MS). 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, 2020). 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) and the German Federal/state waste working group (LAGA).

5.4 Mass fraction of liquids in capacitors

5.4.1 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 naturally 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 6.7.1.

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

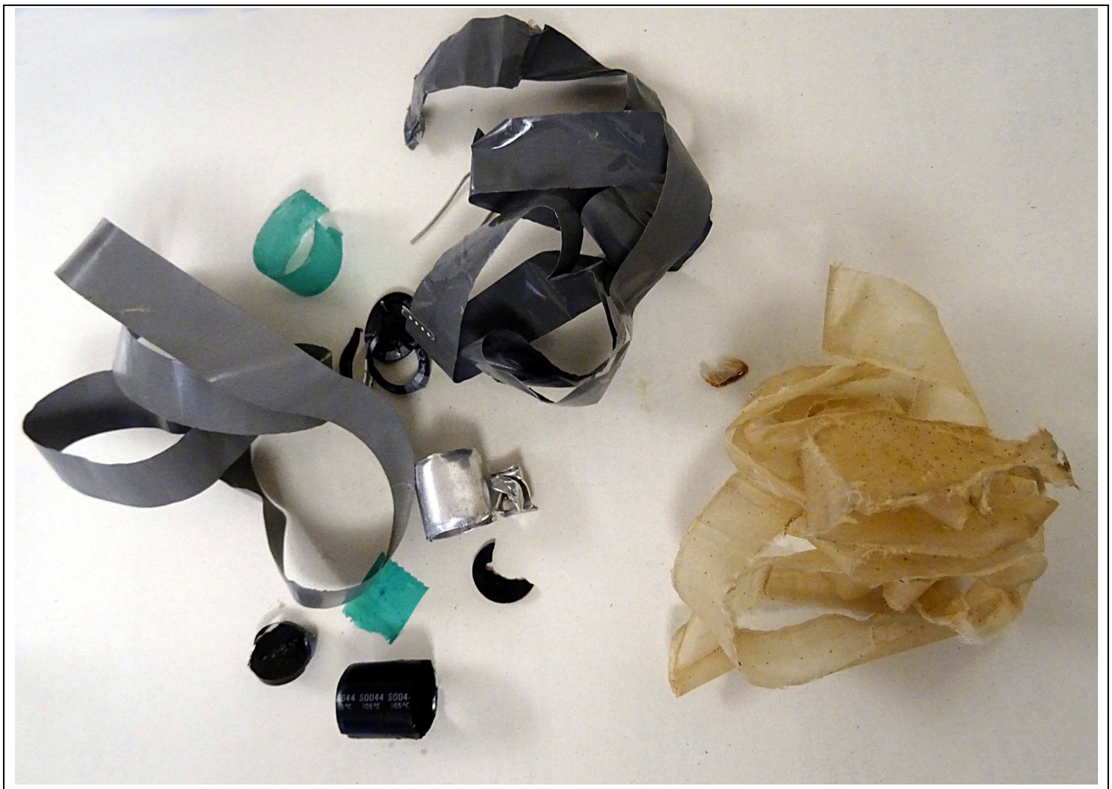

Figure 14: Components of the disassembled aluminium electrolytic capacitor

5.4.2 Mass fraction of liquids in non-polarised cylindrical capacitors

The same capacitors were used to determine the mass fraction of the liquid in non-polarised cylindrical capacitors as for the analysis of the contents of individual capacitor models. The models and number of capacitors can be seen in Table 13. A large part of the liquid was measured by the weight of the laboratory samples. The solids were placed in closed vessels to allow the remaining liquid to drip off. After a draining period of four months, the solids and the drained liquid were separated, as is shown in Figure 15. The masses of the solids and liquids were then measured separately.

Figure 15: Separated sample of capacitor model No. 109

5.4.3 Mass fraction of liquids in microwave capacitors

The microwave capacitors could only be tapped with a hammer and chisel. The outflowing liquid was collected. Residual oil was allowed to drip from the capacitors for about an hour.

5.5 Mass flow of liquids from capacitors in the recycling process

An exemplary model for the processing of small electrical or electronic household appliances was created to enable an assessment of how problematic the liquids from capacitors are in the recycling process. This category is defined in the SENS take-back system as “small household appliances”. It includes appliances such as vacuum cleaners, toasters, drills, electric toys or exercise bikes. The exemplary recycling process was created using data from batch processes at recycling partners. Data about the produced fractions in the recycling of electrical or electronic appliances and how they are further processed and disposed of has been collected during these batch processes. The treatment of the appliances was divided into process steps for the mass flow analysis. The process steps generate fractions, which are sent for final treatment. All final treatment steps were divided into the four categories “plastics recycling”, “metal smelting”, “high-temperature incineration” and “waste incineration”. All sorted fractions which, according to this list, lead to the same final treatment step were combined. After the analysis of the mass flows, the model was simplified and those process steps that are not critical with regard to the substances of concern in capacitors were combined into one process step.

The batch processing data were normalised to 1 t of input material. The proportion of capacitors in the input was determined from the batch data, and the mass fraction of liquid in the capacitors was set to 15 per cent. The determination of the mass fraction of liquids in capacitors is described in chapter 5.4.2 and in the results in 6.7.

First, capacitors are manually removed from the appliances in the recycling process. These capacitors, together with the liquid they contain, enter a high-temperature incinerator. The other capacitors remain in the appliances that undergo mechanical processing. Some of the capacitors are destroyed in the mechanical process. These lose at least some of the liquid they contain. The loss of liquid is always complete in the exemplary model. We refer to the proportion of capacitors that are destroyed during mechanical processing as the breakage rate. In chapter 6.9, we present the results for three breakage rates: 15, 30 and 40 per cent.

The remaining capacitors – which were not already sorted out before the mechanical processing – are sorted out after the mechanical processing. A portion of them of 100 per cent minus the breakage rate still contains the capacitor liquid. Together with the capacitors which have been sorted out in the first step, they are taken to a high-temperature incinerator. The liquid from the broken capacitors is distributed to all other fractions resulting from the mechanical processing. This released liquid was distributed among the fractions in the model according to the mass fraction of each fraction in all fractions produced. The liquid discharged from the fractions then enters the same process for final recycling as the carrier fraction. For all fractions except plastics for recycling, this involves either incineration (waste incineration or high-temperature incineration) or metal smelting. The plastics go to the plastics recycler, which we represent as a separate process.

The plastics recycler separates the plastics mixture from the WEEE recycler process into three fractions:

– plastics for incineration (referred to as “RESH/dust to waste incineration plant” in Figure 23);
– metals for metal recycling; and
– plastics for material recycling.

The first two of these fractions are subjected to thermal processes. The plastics for material recycling are separated according to type and granulated. The granules are then used in the production of secondary plastics. According to the current knowledge and understanding of the authors, this form of recycling does not involve a process with high temperatures that destroy the substances of concern. It is therefore the critical path for assessing the behaviour of substances of concern in the recycling of waste electrical and electronic waste.

When the model was created, it was assumed that all capacitors would be sorted and none would remain in other fractions. This is an idealisation; in reality, there will be capacitors with liquids that are not sorted out in either process. However, the amount is unknown and cannot be deduced from other known data. This percentage is of secondary importance as far as the research is concerned, since the critical path passes through the liquid leaked on plastics to material recycling. The plastics fraction must be relatively pure and cannot contain large proportions of unsorted capacitors, if only for reasons of processability.

5.6 Research on the stability and risks of the substances of concern

The substance properties of the substances of concern were investigated to assess their stability in recycling processes. On the one hand, the following chemical-physical properties were determined:

- molar mass;
- density;
- melting point;
- boiling point;
- vapour pressure;
- ignition temperature; and
- flash point.

On the other hand, information on the following environmental properties of the substances was collected:

- water solubility;
- octanol/water partition coefficient; and
- bioconcentration factor.

Information on toxicity for rats, fish, crustaceans and algae was also collected. The researched information is provided in Annex A.

The stability in the disposal processes was assessed for mechanical separation in a shredder and for incineration in a waste incineration plant. The evaluation of incineration in a waste incineration plant was carried out in cooperation with KEZO Hinwil (Böni, 2020).

The environmental behaviour was examined from several points of view. For chemical substances, REACH dossiers indicate whether a substance is rapidly biodegradable. Unfortunately, such REACH dossiers could only be found for 11 substances of concern.

The REACH Regulation defines half-lives for substances in the environment, beyond which they are described as “persistent” or “very persistent”. These half-lives can be found in Table 14 (Environment Agency Austria, 2019).

Table 14: Limit values for half-life in days per environmental compartment for the classifications as persistent or very persistent according to the EU REACH Regulation

Classification	In sea-water	In fresh-water	In marine sediment	In freshwater sediment	In the soil
Persistent	60	40	180	120	120
Very persistent	60	60	180	180	180

We do not know of any reliable public data collection for the half-lives that would identify them for the substances of concern in capacitors. For the evaluation, one has to rely on dossiers of substance tests under the REACH Regulation. Unfortunately, this substance testing has not been completed for any of the substances on the list of substances of concern in recycling.

According to the REACH Regulation, a substance is considered “bioaccumulative” if its BCF is greater than 2,000 l/kg. If the BCF is greater than 5,000 l/kg, the substance is considered “very bioaccumulative” (Environment Agency Austria, 2019; European Parliament, 2006). The measure of the BCF refers to litres of water per kilogram body weight of a fish. This quantity is calculated from the concentration of a substance in the fish tissue divided by the concentration in the water surrounding the fish. Calculating this factor is very complex, as test organisms have to be kept at a constant concentration of the test substance for a long period. Test results are only available for very few sustances. Most BCF values are model values estimated from the octanol/water partition coefficient of a substance.

For the substances of concern, it was also investigated whether they are priority substances in terms of water protection at the European level according to Annex X of the EU Water Framework Directive (European Parliament, 2000). The Water Framework Directive defines “priority substances” as those that pose a significant risk to the aquatic environment. Substances which pose a risk to humans through the aquatic environment are also considered as “priority substances”.

The Eawag Biocatalysis/Biodegradation database was consulted to assess the degradation pathways of substances of concern in the environment (Eawag, 2019).

6 Results

6.1 Definition of substances of concern

Electronic components consistently contain toxic substances, such as copper in cables, arsenic in semiconductors or flame retardants in plastics. Since the definition of substances of concern is used in connection with the removal of capacitors, care should be taken to ensure that the definition of substances of concern in capacitors covers only those substances which require special 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 also considered substances of concern in recycling. All substances listed in Annex III of the Rotterdam Convention 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 in laboratory analyses. The results of this research have been recorded in Table 2. Table 15 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 non-hazardous substances 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 15: 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.

6.2 Analysis results of the liquid substances

6.2.1 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. A fit of more than 90 is considered high grade. 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 was not present in the laboratory library and a substance with a similar mass spectrum was obtained as a result. Low-grade results are uncertain and should not be considered as evidence of the substance being found.

In the following, those substances are listed that could be verified with a very good match. Compounds measured at a concentration below 100 mg/kg are not included. Such trace substances are not relevant to this study. Some substances of hormonal origin have not been included in the table of results, as they are likely to result from impurities during sampling. These are squalene, α-Sitosterol, ß-Sitosterol and γ-Sitosterol.

However, those substances which were analysed with a moderate match were included if they appear plausible based on 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.

Several peaks with the same substance from the library were identified in numerous GCMS analyses. These are probably structural isomers. For the analysis, these were each combined and the identified quantities of substances in the sample were added up. This is not chemically correct. These are each different substances which were not able to be classified more precisely. To answer the question of whether problematic substances are present in capacitors, however, there is no other way than to work with the substance identified by the library search. This approach is therefore justifiable with regard to the study.

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 boron. This analysis did not yield any usable hits either.

The elemental analysis for tungsten and boron which was additionally carried out 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. The laboratory reports of the PCB analyses are included in Annex C.

6.2.2 Non-polarised cylindrical capacitors

6.2.2.1 Mixed samples

The analysis results relate to the extracted liquid in 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 16). The mineral oils contained are visible as peak 21; these are designated as hydrocarbon mixture in the result table.

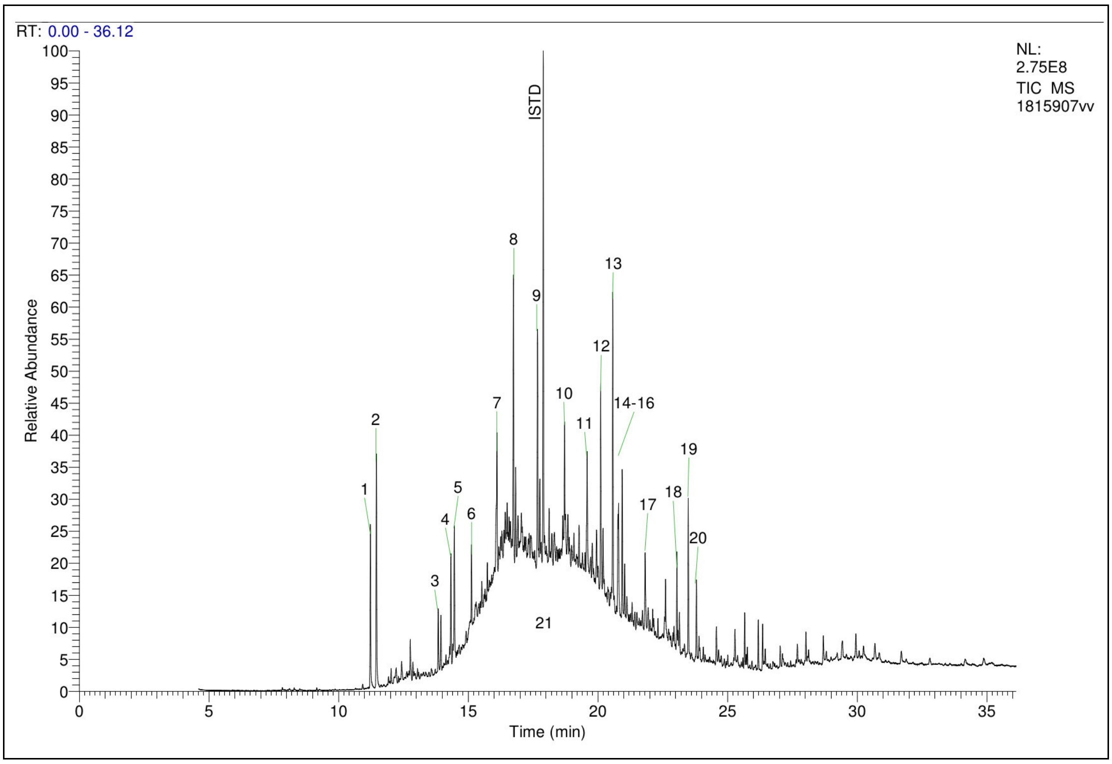

Figure 16: Chromatogram of the mixed sample from refrigerator capacitors

The results of the GCMS analysis of capacitors from large household appliances are listed in Table 16. 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 16: 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 17. The full laboratory reports can be found in Annex C.3.1.

Table 17: 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 18. For the complete results, please refer to Annex C.3.5.

Table 18: 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 19 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 19: 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 17: Some of the collected capacitors from SENS small appliances

6.2.3 Analysis of the individual samples

Colour and consistency of the liquids were qualitatively recorded during sampling and are reproduced in Table 20.

Table 20: Qualitative classification of sample colour and consistency

Capacitor No.	Description of the liquid
311	Clear, viscous
109	Green, quite fluid
126	Slightly yellowish, viscous
90	Yellow, very viscous
95	Brown to white, not transparent, almost solid

The results of the GCMS analyses of capacitors from large household appliances are listed in the following tables. Each table shows the results from the analysis of a capacitor model. The analysed capacitor model can be determined from the specified capacitor number using Table 13.

No compounds were found to a high grade in the analysis of the liquid from capacitor 311. Therefore, only the sum of the unknown compounds is listed in Table 16. In addition, a hydrocarbon mixture was present which is visible in the chromatogram as a continuous “elevation” (No. 27) in Figure 18. It can be concluded from the image of the analysis that it is oil of mineral origin.

Table 21: GCMS analysis results for capacitor 311 (sample No. HHGG1)

Chemical designation	CAS No.	Mass fraction [mg/kg]	Conformity
Sum of unknown compounds		31,300	
Hydrocarbon mixture		Not quantified	

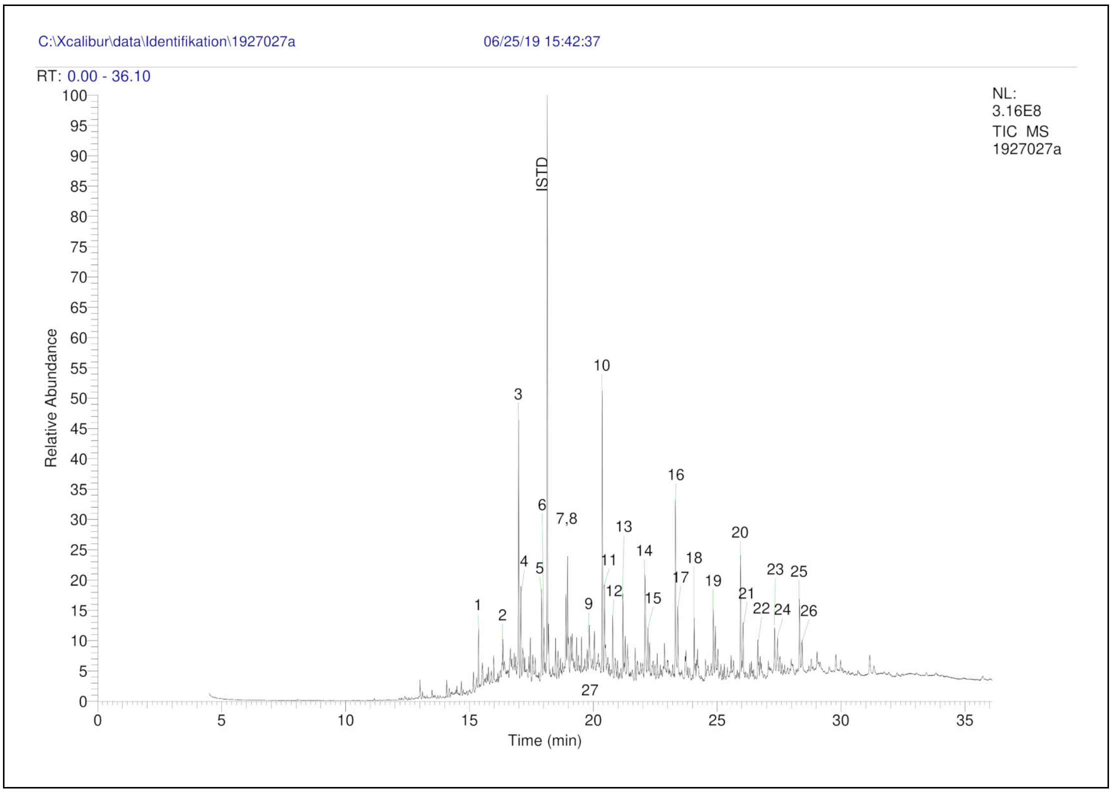

Figure 18: Chromatogram of the GCMS analysis of capacitor 311

On capacitor 109, “vegetable oil” is indicated by the manufacturer. The analysis found stigmasterol, which is a phytosterol and occurs mainly in vegetable oils (Falbe et al., 1992). The hydrocarbon mixture found (No. 21 in Figure 19) only occurred during the analysis with long retention times over 25 minutes.

Table 22: GCMS analysis results for capacitor 109 (sample No. HHGG2)

Chemical designation	CAS No.	Mass fraction [mg/kg]	Conformity
(Z)-4-decenal	21662-09-9	150	Moderate
13-Hexyloxacyclotridec-10-en-2-one	127062-51-5	100	Moderate
3,4-Epoxy cyclohexane carboxylic acid-(3,4-epoxycyclohexyl methyl ester)	2386-87-0	10,000	Moderate
Stigmasterol	83-48-7	200	Moderate
Sum of unknown compounds		1,140	
Hydrocarbon mixture		Not quantified	

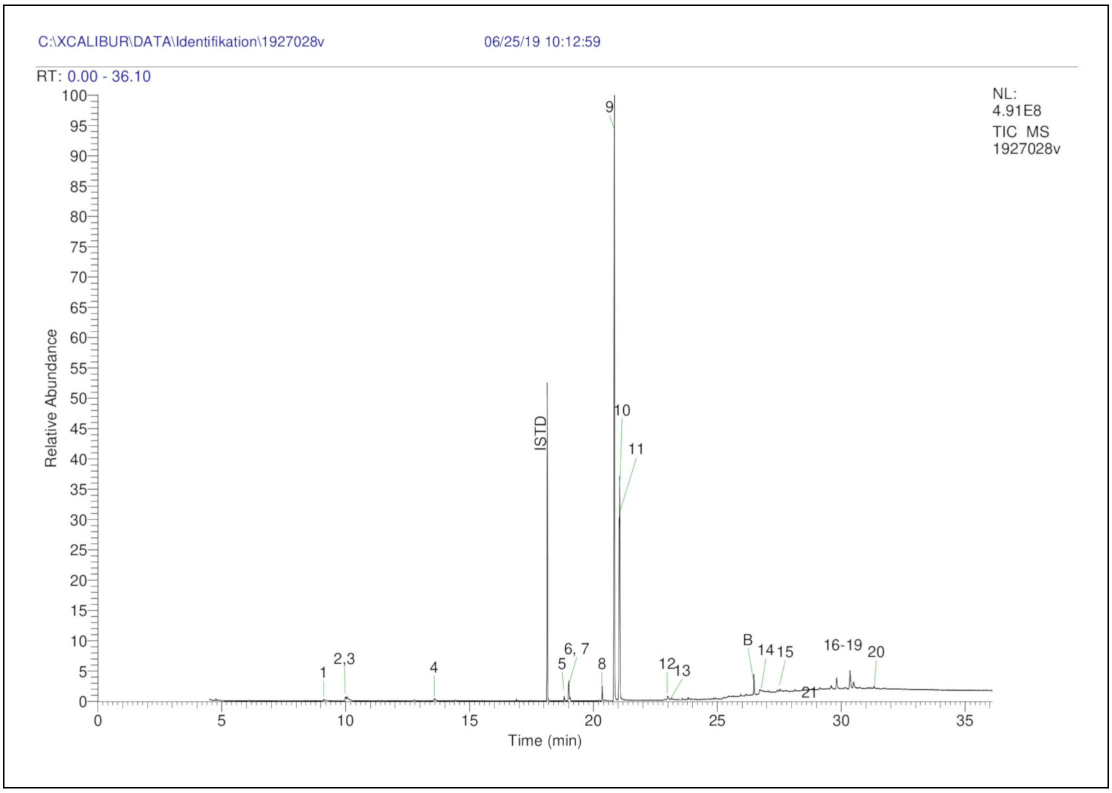

Figure 19: Chromatogram of the GCMS analysis of capacitor 109

The GCMS analysis of the liquid from capacitor 126 suggests a mineral oil base. The substances according to Table 23 were determined to a high or moderate grade. The analysed carboxylic acid without a CAS No. could not be studied further, because no research on substance properties is possible without a CAS No. The mixture of hydrocarbons detected extends over the entire retention time (chromatogram figure in Annex C.4.3).

Table 23: GCMS analysis results for capacitor 126 (sample No. HHGG3)

Chemical designation	CAS No.	Mass fraction [mg/kg]	Conformity
1-Methylnaphthalene	90-12-0	10,000	Very good
Di-tert-dodecyl disulfide	27458-90-8	1,000	Moderate
Carboxylic acid, eicosyl vinyl ester	N/A	1,000	Moderate
(E)-3-Eicosene	74685-33-9	1,000	Moderate
2-Hexyldecan-1-ol	2425-77-6	3,000	Moderate
Sum of unknown compounds		57,000	
Hydrocarbon mixture		Not quantified	

The detected concentrations of the analysed substances were still significantly lower for capacitor 90 than for the other individual samples. These are all trace substances. Table 24 shows that the sum of all detected substances is only 3,500 mg/kg.

Table 24: GCMS analysis results for capacitor 90 (sample No. HHGG4)

Chemical designation	CAS No.	Mass fraction [mg/kg]	Conformity
3,4-Epoxy cyclohexane carboxylic acid-(3,4-epoxycyclohexyl methyl ester) or isomer	2386-87-0	1,700	Moderate
13-Hexyloxacyclotridec-10-en-2-one	127062-51-5	200	Very good
Bis(2-ethylhexyl) adipate	103-23-1	300	Very good
Sum of unknown compounds		1,330	

The δ-Tocopherol found in sample 95 is a form of vitamin E and is produced in plant cells. The analysis detected m- and p-benzyltoluene with the CAS Nos 620-47-3 and 620-83-7. These two substances were summed up in Table 25 as benzyltoluenes with the CAS No. for the mixture of isomers. The H-statements are also only available for the mixture, so that a distinction is useless for answering the question at the centre of the study. A hydrocarbon mixture could not be detected in this sample (chromatogram in Annex C.4.5).

Table 25: GCMS analysis results for capacitor 95 (sample No. HHGG5)

Chemical designation	CAS No.	Mass fraction [mg/kg]	Conformity
13-Hexyloxacyclotridec-10-en-2-one	127062-51-5	500	Very good
δ-Tocopherol	119-13-1	300	Moderate
Benzyltoluenes	27776-01-8	950	Very good
Diethylhexyl phthalate	117-81-7	6,000	Very good
Sum of unknown compounds		4,710	

6.2.3.1 Proportion of the identified substances in the capacitor liquid

If all mass fractions which are reported in the laboratory results are added up, the result is Table 26. The concentrations determined are very uncertain due to the method and can also deviate considerably from the real value. Nevertheless, the analysis shows that the main components could not be determined for any of the analysed capacitor models.

Table 26: Sum and proportions of the identified substances in the capacitor liquid

Capacitor No.	Sum of identified substances [mg/kg]	Concentration of identified substances
311	31,300	3.1%
109	11,890	1.2%
126	74,000	7.4%
90	3,530	0.4%
95	12,460	1.2%

6.2.3.2 Comparison of the individual samples with the HHGG mixed sample

All sampled capacitors for the analysis of the liquids from individual models were also part of the mixed sample of the large household appliance capacitors. In comparison with the mixed sample, the following findings emerge:

- The individual analyses revealed further substances which could not be detected in the mixed sample. These were all substances with low concentrations in the liquids of individual models. These were probably further diluted in the mixed sample and thus fell outside the range of the analysed peaks.

- Two types of results emerged in the individual analyses: those with a hydrocarbon mixture over the entire retention time (capacitor Nos 311 and 126) and those with a hydrocarbon mixture only at high retention times (capacitor Nos 109 and 90). One sample showed practically no such "mixing peak" (capacitor No. 95). We assume that the liquids with a hydrocarbon mixture over the entire retention range are of mineral origin. In contrast, the liquids without such mixture or only with high retention times are based on vegetable oil.
- The elements detected in the capacitors with sample Nos 109 and 95 indicate that they could be vegetable oils or mixtures based on vegetable oil.
- Although the interfering hydrocarbon mixture was not present in three samples, the main components could not be determined for these either.
- Of the five substances determined in the mixed sample, two were found again in the sample from capacitor 126. When differentiating between 1-Methylnaphthalene and 2-Methylnaphthalene, however, it must be said that these cannot be clearly distinguished in the GCMS analysis. Thus, the statement that three out of five substances were found again would also be correct. Two other substances determined with a fit of around 75 per cent in the mixed sample could not be confirmed. It is possible that the substances originate from capacitor models which were present in the mixed sample but were not analysed individually.

6.2.4 Electrolytic capacitors

The analysis results refer to the mass of the extracted coils. The shown mass fractions thus relate to the substances for 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.

Table 27: 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

The analysis results of the mixed sample from flat screens are shown in Table 27 and Table 28. 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 28: 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 29 and Table 30. For the complete laboratory report, please refer to Annex C.3.8.

Table 29: 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
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 30: 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 31, the detailed information can be found in Annex C.3.7.

Table 31: 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 32: 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 probably correct
Diethylamine	109-89-7	> 100 mg/kg entire sample	Yes
2,4-Dihydroxybenzoic acid	89-86-1	In traces	No

Chemical designation	CAS No.	Qualitative mass fraction	Identity confirmed?
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 probably correct

The results of the elemental analyses for tungsten and boron are outlined in Table 33. 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 33: 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

6.2.5 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 20). 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.

The analysis results for the mixed samples from the manufacturer BiCai are shown in Table 34. 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 35. 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.

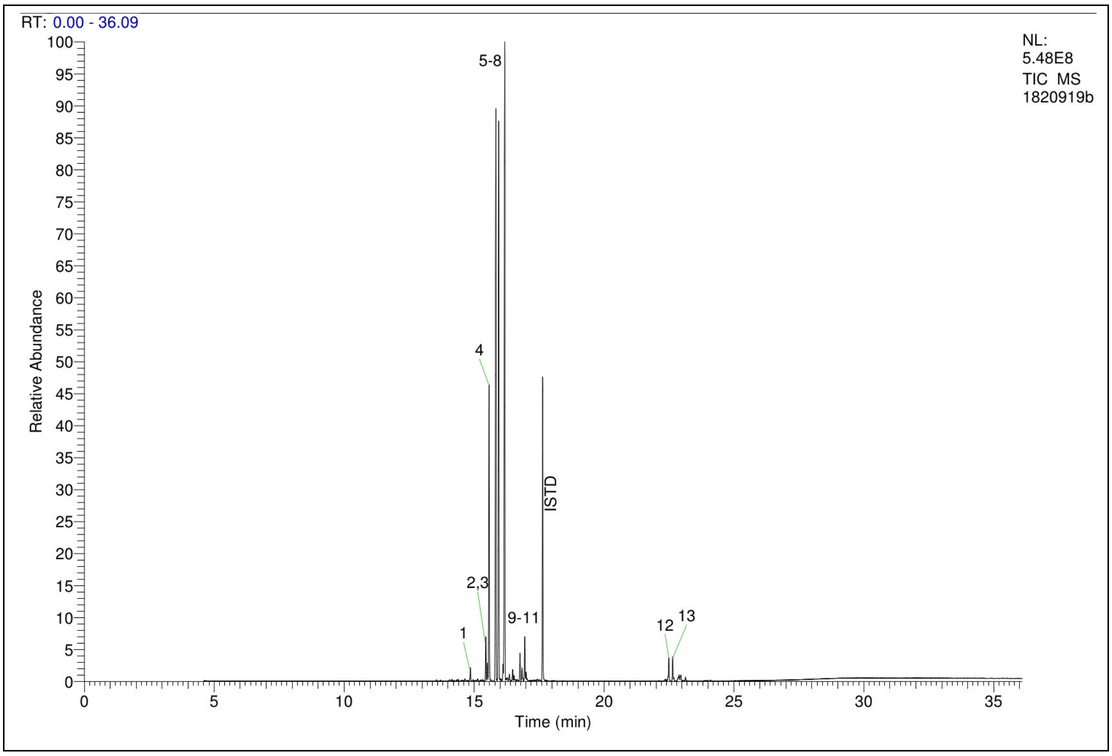

Figure 20: Chromatogram of the mixed sample from capacitors produced by BiCai

Table 34: 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 35: 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

Chemical designation	CAS No.	Mass fraction [mg/kg]	Conformity
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)-phenant-ron 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 36 and Annex C.1).

Table 36: 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

6.2.6 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 37. The sample numbers are specified according to Table 11 or Table 20. 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 37: Analysed capacitor substances unidentified in literature

Chemical designation	CAS No.	Found in capacitor type	Sample No./capacitor No.
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
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
13-Hexyloxacyclotridec-10-en-2-one	127062-51-5	Non-polarised cylindrical	109, 90, 95
2-Ethylhexanol or similar compound	104-76-7	Aluminium e-caps	2 LCD, 7 Netz, 5.2 HKG

Chemical designation	CAS No.	Found in capacitor type	Sample No./capacitor No.
2-Hydroxyethyl benzoate	94-33-7	Aluminium e-caps	2 LCD
2-Nitroanisole/1-methoxy-2-nitrobenzene or isomer	91-23-6	Aluminium e-caps	2 LCD
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
3-Nitroacetophenone	121-89-1	Aluminium e-caps	2 LCD, 7 Netz, 5.2 HKG
4-Nitrobenzyl alcohol or isomer	619-73-8	Aluminium e-caps	2 LCD
4-Nitrophenol or similar compound	100-02-7	Aluminium e-caps	5.2 HKG
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
Benzoic acid	65-85-0	Aluminium e-caps	2 LCD
Bis(2-ethylhexyl) adipate	103-23-1	Non-polarised cylindrical	90
Dinonyl phthalate	84-76-4	Non-polarised cylindrical	5.1 HKG
Di-p-tolyl-methane or isomer	4957-14-6	Microwave capacitors	3.1 MW
Ethyl(1-phenylethyl)benzene	18908-70-8	Microwave capacitors	3.2MW
Phenol	108-95-2	Aluminium e-caps	2 LCD, 7 Netz, 5.2 HKG
(Z)-4-decenal	21662-09-9	Non-polarised cylindrical	109

6.3 Literature references to liquid substances

6.3.1 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.

6.3.2 Non-polarised cylindrical capacitors

For the non-polarised cylindrical capacitors, the literature research leads to the 13 substances in Table 38 whose use we consider assured.

Table 38: 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)

6.3.3 Electrolytic capacitors

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

Table 39: 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-caps 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-caps HKG laboratory analysis, (Chappot et al., 2007)
Boric acid	11113-50-1	(Eco-systèmes, 2012)
Diethylamine	109-89-7	FPD, e-caps HKG and Netz laboratory analysis, (Chappot et al., 2007)
Dimethylacetamide	127-19-5	E-caps HKG laboratory analysis, (Hering et al., 2014), (Eco-systèmes, 2012)
Dimethylbenzyl alcohol	617-94-7	FPD and Netz laboratory analysis, (Chappot et al., 2007)
Dimethylformamide	68-12-2	E-caps 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

Chemical designation	CAS No.	Sources
Polyethylene glycol	25322-68-3	FPD, e-caps HKG and Netz laboratory analysis, Patent WO2002061775
Triethylamine	121-44-8	FPD, e-caps HKG and Netz laboratory analysis, Patent DE3930310C1
γ-Butyrolactone	96-48-0	(Hering et al., 2014), (Güntner et al., 1991), (TDK, 2014), (Mundorf, 2016)

6.3.4 Microwave capacitors

The literature research for substances in microwave capacitors is summarised in Table 40.

Table 40: 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)

6.4 Assessment of the stability and risks of the substances of concern

6.4.1 Chemical-physical properties

The chemical-physical properties of the substances of concern are fully documented in Annex A. In this chapter, we evaluate some key figures for the researched properties for all substances.

A number of properties are interesting for the thermal stability of the materials in recycling processes and their behaviour in incineration, which we list in Table 41. We list the lowest and highest value of each property, as well as the corresponding substances. As the properties could only be obtained for a part of the substances of concern, we list in the last column the number of substances for which the value is available. In total, the substance properties for 24 substances of concern and suspected to be of concern were researched.

Table 41: Substance properties with relevance for the thermal stability of substances of concern

Property	Unit	Minimum	Substance of concern with minimum value	Maximum	Substance of concern with maximum value	Value known for number of substances
Melting point	[°C]	–64	Diisobutyl phthalate	110	Ammonium pentaborate	24/24
Boiling point	[°C]	153	Dimethylformamide	420	Diisodecyl phthalate	22/24
Flash point	[°C]	58	Dimethylformamide	263	Trioctyl trimellitate	20/24
Ignition temperature	[°C]	265	N-Methylpyrrolidone	595	Phenol	18/24

A special case is boric acid with a melting point of 168 °C to 171 °C as boron trioxide melt (IFA, 2016). Boric acid breaks down already at 100 °C to 130 °C. Since it is not pure in capacitors, no boron trioxide melt will develop from it.

A further series of chemical-physical parameters is of interest for assessing the distribution of substances. They are shown in Table 42. As in the previous table, we list the minimum and maximum values to give an overview of the range of substance properties.

Table 42: Substance properties with relevance for distribution of substances in the recycling process

Property	Unit	Minimum	Substance of concern with minimum value	Maximum	Substance of concern with maximum value	Value known for number of substances
Density (20 °C)	[kg/m^3]	690	Butylated hydroxyanisole	1,580	Ammonium pentaborate	22/24
Vapour pressure (20 °C)	[hPa]	Insignificant	8 different	7.2	Naphthalene	22/24
Water solubility (25 °C)	[mg/l]	Not water-soluble	Diethylhexyl phthalate, diisononyl phthalate	Mixable	Dimethylacetamide, dimethylformamide, N-Methylpyrrolidone	22/24
Octanol/water partition coefficient log K_{ow}	Non-dimensional	–1.01	Dimethylformamide	11.59	Trioctyl trimellitate	23/24

6.4.2 Toxic properties

To classify the toxic properties of the substances of concern in capacitors, we have researched the characteristic values from animal experiments. The ranges are indicated in Table 43. There is considerably less data available on toxic properties than on chemical-physical parameters. Lower values mean higher toxicity (the substance is toxic at lower concentrations).

Table 43: Substance properties with relevance for toxicity

Property	Unit	Mini-mum	Substance of concern with minimum value	Maxi-mum	Substance of concern with maximum value	Value known for number of sub-stances
LD_{50} oral, rat	[mg/kg]	317	Phenol	64,000	Diisodecyl phthalate	16/24
LC_{50} fish (96 h)	[mg/l]	0.31	Benzyltoluenes	10,500	Dimethylforma-mide	17/24
LC_{50} crustaceans (48 h)	[mg/l]	1.23	N-Methylpyrroli-done	14,400	Dimethylforma-mide	12/24
EC_{50} crustaceans (48 h)	[mg/l]	0.13	Diethylhexyl phthalate	12,800	Dimethylforma-mide	8/24
EC_{50} algae (72 h)	[mg/l]	0.4	Dibutyl phthalate	>1,000	Dimethylforma-mide	10/24

6.4.3 Biodegradability

Biodegradability was already taken into account for the classification of substances of concern. For that classification, we mostly had to rely on model values. Research in the existing REACH dossiers was carried out in an attempt to better substantiate and clarify this information. REACH dossiers on a dozen substances were available for examination. Eleven of these contained information on biodegradability. All information provided was consistent with the model statements already established as to whether or not the substance was biodegradable. For two substances the situation was not clear:

- Biphenyl (CAS No. 92-52-4) is described as biodegradable in the REACH dossier, but it is also considered a potential PBT substance (persistent, bioaccumulative, toxic), which is inconsistent with the dossier (ECHA, 2020).
- Naphthalene (CAS No. 91-20-3) is not easily biodegradable according to the risk assessment under REACH (European Commission, 2003). In the REACH registration dossier, however, it is described as biodegradable in water.

6.4.4 Bioaccumulation

The BCF of the substances of concern was researched to assess the bioaccumulation potential. The BCFs for all substances are model estimates. They are based on the log K_{ow} and are subject to a high degree of uncertainty. A high value means that the substance accumulates significantly in the fatty tissue of aquatic organisms. Such a substance has a high potential for bioaccumulation.

Table 44: Range of BCFs of the substances of concern

Property	Unit	Mini-mum	Substance of concern with minimum value	Maxi-mum	Substance of concern with maximum value	Value known for number of substances
BCF	[l/kg wet mass]	3	Dimethylacetamide, dimethylformamide	4,778	2,6-Diisopropyl-naphthalene	22/24

None of the substances of concern falls into the category of "very bioaccumulative" substances under the REACH regulation. The two substances in Table 45 meet the classification as "bioaccumulative". It should be noted that both BCFs are based on an estimate using the octanol/water partition coefficients. These, in turn, were estimated from the chemical structure using the EPI Suite software tool from the US authority EPA. The values are therefore extremely uncertain and can only be interpreted as an indication of a possible potential for bioaccumulation of the two substances.

Table 45: Substances of concern in recycling which, according to the model values, are potentially bioaccumulative

Substance designation	CAS No.	BCF [l/kg wet]	REACH classification
2,2',5,5'-Tetramethylbiphenyl	3075-84-1	3,916	Bioaccumulative
2,6-Diisopropylnaphthalene	24157-81-1	4,778	Bioaccumulative

6.4.5 Substances presenting a significant risk to the aquatic environment

The six substances of concern in capacitors, identified as "priority substances" in the Water Framework Directive, are listed in Table 46.

Table 46: Substances of concern which are "priority substances" under the Water Framework Directive

Substance designation	CAS No.
1-Chloronaphthalene (chlorinated naphthalenes)	90-13-1
1-Methylnaphthalene	90-12-0
2-Methylnaphthalene	91-57-6
2,6-Diisopropylnaphthalene	24157-81-1
Diethylhexyl phthalate	117-81-7
Naphthalene	91-20-3

6.4.6 Degradation pathways in the environment

Degradation pathways in the environment were found for five substances in the Eawag database (Eawag, 2019). We list these substances and the degradation products in the first degradation step in Table 47. A further analysis of the degradation products was only possible in isolated cases, as most of the substances do not have a CAS No. or are not identified by one in the database. For this reason, it was not possible to research the substance properties. For the few existing CAS numbers, a substance search on the website of the ECHA produced hits for catechol, 4-hydroxybenzoate and phenyl phosphate. Of these, only catechol – or pyrocatechol – is classified as a substance of concern according to our definition. It is classified with the relevant H-statements H341 "Suspected of causing genetic defects" and H350 "May cause cancer". Phenol itself is not classified as a carcinogen, which means that the degradation product is more harmful than the starting material.

Table 47: Known degradation products of substances of concern from capacitors

Starting material	CAS No.	Degradation products after the first step	CAS No.
2-Methylnaphthalene	91-57-6	Naphthyl-2-methyl-succinate	
		cis-1,2-Dihydroxy-1,2-dihydro-7-methylnaphthalene	
		2-Hydroxy-methylnaphthalene	
Biphenyl	92-52-4	cis-2,3-Dihydro-2,3-dihydroxybiphenyl	34244-66-1
Dibutyl phthalate	84-74-2	Tert-butyl alcohol	
		Monobutyl phthalate	
Dimethylformamide	68-12-2	Dimethylamine	
Naphthalene	91-20-3	cis-1,2-Dihydroxy-1,2-dihydronaphthalene	
		2,3-Dihydroxynaphthalene	
Phenol	108-95-2	Catechol	120-80-9
		4-Hydroxybenzoate	99-96-7
		Phenyl phosphate	701-64-4

6.5 Proportion of capacitors containing PCB

6.5.1 Non-polarised cylindrical capacitors

6.5.1.1 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 49 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 48:Occurrence of capacitors containing PCBs in large household appliances

	Washing machines		Dishwashers		Other		All large household appliances	
Classification	**Units**	**Percentage**	**Units**	**Percentage**	**Units**	**Percentage**	**Units**	**Percentage**
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 proportion 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 49 after the result as ±x per cent.

Table 49: Proportion of PCB-containing capacitors in large household appliances with confidence intervals

Classification	Units	Proportion ± 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	

6.5.1.2 Refrigerators, air conditioners and freezers

After large household appliances, refrigerators, air conditioners and freezers are the second most important source of non-polarised cylindrical capacitors. The proportions of capacitors are shown in Table 50 according to PCB content. No capacitor clearly contained PCBs in the sample. Fifteen of them were suspected of containing PCBs after the classification using the list of capacitors (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 50: Occurrence 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	

6.5.1.3 Ballasts from fluorescent luminaires

The proportions of capacitors containing PCBs, capacitors suspected of containing PCBs and PCB-free capacitors are shown below in Table 51 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 51: Occurrence 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 proportion 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 capacitors from ballasts and are shown in Table 52 after the result as ±x per cent.

Table 52: Proportion of PCB-containing capacitors in ballasts with confidence intervals

Classification	Units	Proportion ± 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.

6.5.1.4 SENS small appliances

As with large household appliances, the results for SENS small appliances are shown for the sampling in Table 52 per collected category, and the total values for SENS small appliances are shown in the last column.

Table 53: Occurrence of capacitors containing PCBs in SENS small appliances[2]

	Small household appliances with motors		Other small household appliances		Total small household appliances	
Classification	**Units**	**Percentage**	**Units**	**Percentage**	**Units**	**Percentage**
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 54 after the results as ±x per cent.

Table 54: Proportion of PCB-containing capacitors in small household appliances with confidence intervals[2]

Classification	Units	Proportion ± 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	

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

The capacitor collection from SENS small appliances is not beyond doubt. It must be assumed that capacitors from mobile luminaires are included in the sample. The result should be interpreted with caution and should not be cited. See also the discussion in chapter 7.5.1.5.

6.5.2 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 expected (Savi, 2018).

6.5.3 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 6.2.5).

6.6 Proportion of capacitors with liquids

6.6.1 Proportion 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 55 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 21. After this finding was confirmed for 19 units, all capacitors of this type were classified as dry and included in the total.

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 55 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. Examples for this housing shape are shown in Figure 22. Technically, these are electrolyte capacitors and not counted as dry capacitors.

Figure 21: Opened plastic capacitors without liquid substances

Table 55: Proportion 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%

Figure 22: Motor start electrolytic capacitors in black plastic housings

6.6.2 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 56.

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 56: Classification of liquid leakage during sampling of non-polarised cylindrical capacitors

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

6.7 Mass fraction of liquids in capacitors

6.7.1 Mass fractions 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 57. 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 57: Masses from the disassembly of an electrolytic capacitor

Weighing	Mass [g]	Proportion [%]
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%

6.7.2 Mass fraction of liquids in non-polarised cylindrical capacitors

Table 58 shows the results of the mass measurement of the liquid and solid components of capacitors. The first mass to be determined was the mass of the liquid which, after opening the capacitors, leaked out within a few minutes and was used for the laboratory sample. Then the drained liquid was weighed after a standing time of about four months. The penultimate column shows the mass of the solids after the drip-off time. The losses are likely to be mainly losses of liquid. These occur during sampling due to deposits on the tools used and afterwards due to evaporation during the drip-off time.

Table 58: Masses from the separation of the capacitors into liquid and solid components

Capacitor No.	Quantity in sample	Mass of liquid in laboratory sample [g]	Mass of drained liquid [g]	Mass of solids [g]	Loss [g]
311	3	23.5	23.1	305	2.9
109	4	21.7	8.1	168.1	1.9
126	3	27.6	8.1	183.5	2.9
90	6	12.5	21.1	301.7	0.3
95	6	12.5	23.6	255.5	8.4
Total	**22**	**97.8**	**84.0**	**1,213.8**	**16.4**

The analysis of the mass fractions produces the result in Table 59. The recovery rate was very good at 99 per cent. It is plausible to interpret the losses primarily as liquid losses. Thus, the losses can be added to the liquid. Since some liquid adhesion to the solids is unavoidable, rounding the results to a 5-per-cent accuracy is appropriate to the uncertainties of the survey method. The following mass distribution for non-polarised cylindrical capacitors can be derived from the data:

– 85 per cent solids
– 15 per cent liquids

Table 59: Distribution of liquids and solids in non-polarised cylindrical capacitors

	Mass [g]	Percentage
Liquids	182	13%
Solids	1,214	86%
Losses	16	1%

In order to get an idea of the variation, the mass fraction of the liquid was calculated separately per model. As the data in Table 60 show, the numbers are similar. For capacitor 90, separation was difficult because the liquid was very viscous (see also Table 20). The lower liquid content could therefore at least partly be due to insufficient separation of solids and liquid.

Table 60: Proportion of liquids, solids and losses per capacitor model

Capacitor No.	Liquid content	Solids content	Proportion of loss
311	13%	86%	1%
109	15%	84%	1%
126	16%	83%	1%
90	10%	90%	0%
95	12%	85%	3%
Massed average	**13%**	**86%**	**1%**

6.7.3 Mass fraction of liquids in microwave capacitors

The data in Table 61 show the masses of the liquids and solids after the separation of the microwave capacitors. Losses of mass are also indicated. The “Collected liquid” line became necessary because, during the outflow, 3.5 g of liquid got into the collecting container standing under the sampling container, which was also taken into account for the total mass. These liquid losses contribute to the loss calculation per capacitor, but not to the loss across all capacitors. Therefore, the loss in the “Total” line does not correspond to the sum of the losses of the individual models.

Table 61: Proportion of liquids, solids and losses per capacitor model

Capacitor No.	Quantity in sample	Mass of whole capacitors [g]	Mass of liq-uid [g]	Mass of solids [g]	Loss [g]
614	1	182.1	7.9	173.7	0.5
624	1	156.8	14.5	141.8	0.5
629	1	143.4	12.8	129.7	0.9
631	1	180.8	22.7	158.6	-0.5
632	1	329.0	29	298.7	1.3
Collected liquid			3.5		
Total	**5**	**992.1**	**90.4**	**902.5**	**-0.8**

The analysis of the mass fractions produces the result in Table 62. The recovery rate was almost perfect at a rounded 100 per cent. Since complete liquid separation could not be achieved with the chosen procedure, rounding the liquid proportion to a 5-per-cent accuracy is appropriate to the uncertainties of the survey method. The following mass distribution for microwave capacitors can be derived from the data:

- 90 per cent solids
- 10 per cent liquids

Table 62: Distribution of liquids and solids in non-polarised cylindrical capacitors

	Mass [g]	Percentage
Liquids	90	9%
Solids	903	91%
Losses	3	0%

The proportion of liquid varied widely across the models, as shown by the data in Table 61. Capacitor 614 had significantly less liquid than the others. No explanation for this could be found. Capacitor 631 had a higher liquid content; a specific reason for this could not be identified.

Table 63: Proportion of liquids, solids and losses per capacitor model

Capacitor No.	Liquid content	Solids content	Proportion of loss
614	4%	95%	0.3%
624	9%	90%	0.3%
629	9%	90%	0.6%
631	13%	87%	-0.3%
632	9%	91%	0.4%
Average	**9%**	**91%**	**-0.1%**

6.8 Calculation of annual loads for capacitors and liquids

6.8.1 Calculation of annual loads for capacitors

From the mass flow data that SENS and Swico collect from the recyclers, the total quantity of capacitors removed from the appliances by the recyclers is known. We require the masses of the removed capacitors per appliance category to estimate the annual flows of substances from capacitors.

From a previous study, the mass fraction of capacitors in luminaires is known (Gasser, 2009). We multiply this key figure of 0.046 by the amount of luminaires processed according to mass flow data of 21 t. This results in just under 1 t of capacitors that come from luminaires. This quantity is first deducted from the reported total quantity of 214 t for 2017. We weight the reduced total quantity with the masses of the appliance categories “SENS large household appliances”, “refrigerators, air conditioners and freezers” and “Swico appliances”. This results in quantities of capacitors for the three appliance categories “SENS large household appliances”, “refrigerators, air conditioners and freezers” and “Swico appliances (capacitors larger than 2.5 cm)” according to Table 64.

A test calculation can be made for the category of “Swico appliances” using the data from chapter 7.7. The mass fraction of all electrolytic capacitors in Swico appliances was determined to be 0.3 to 1.5 per cent. The mass fractions were determined for appliance categories in the Swico mix and cannot be applied directly to “Swico appliances” as an overall category. However, the data show that a value of 0.5 per cent should be realistic. Given a flow of 45,982 t of appliances, this results in a capacitor flow of a rounded 230 t. We also know from the same analysis that about 50 per cent of the electrolytic capacitors in “Swico appliances” are larger than 2.5 cm. In relation to the annual flow, this would be around 115 t. This figure tallies very well with the 104 t calculated from the annual mass flow. This is to be expected, since the recyclers only have to separate the capacitors that are larger than 2.5 cm. This allows us to add the “Swico appliances (capacitors smaller than 2.5 cm)” line to Table 64.

From the test data on the proportions of dry capacitors, as presented in chapter 6.6.1, it is possible to estimate how many of the annually removed capacitors are dry and how many contain liquids. 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 luminaires. This gives us the forecast for dry and liquid-filled capacitors according to Table 64.

Table 64: Annual loads of capacitors by appliance category

Appliance category	Proportion of dry capacitors in the collection	Processed appliance quantity in 2017 [t per year]	Capacitors weighted by category [t per year]	Total quantity of dry capacitors [t per year]	Total quantity of capacitors with liquids [t per year]
Large household appliances	42%	29,071	66	28	37
Refrigerators, air conditioners and freezers	31%	19,426	44	14	30
Luminaires	0%	21	1	0	1

Appliance category	Proportion of dry capacitors in the collection	Processed appliance quantity in 2017 [t per year]	Capacitors weighted by category [t per year]	Total quantity of dry capacitors [t per year]	Total quantity of capacitors with liquids [t per year]
Swico appliances (capacitors larger than 2.5 cm)	0%	45,982	104	0	104
Swico appliances (capacitors smaller than 2.5 cm)	0%		104	0	104
All appliance categories (capacitors larger than 2.5 cm)		94,500	214	42	172
All appliance categories (all capacitors)			318	42	276

6.8.2 Estimate of annual PCB load

Using the known liquid proportion of 15 per cent in non-polarised cylindrical capacitors, the annual PCB load in the SENS take-back system can be calculated. The proportion of PCB-containing capacitors in large household appliances and the annual mass of the capacitors reported are also used for this purpose.

The proportion of capacitors containing or suspected of containing PCBs is multiplied by the annual load of capacitors in accordance with chapter 6.8.1 to obtain the annual load of capacitors containing or suspected of containing PCBs (Table 65). The quantity of capacitors can now be multiplied by 15 per cent to obtain the total load of PCB-containing liquids per year.

A Dutch study (Groen, 2013) determined the PCB content in the liquid of non-polarised cylindrical capacitors. The PCB content in 10 PCB-containing capacitors was between 63 and 94 per cent. Another two capacitors were contaminated with PCBs and contained 76 mg/kg and 271 mg/kg, respectively.

For the calculation of the PCB loads, we assume as a conservative estimate that the capacitors contain pure PCB and equate the PCB load with the load of PCB-containing liquids. The annual PCB load from capacitors in the SENS system can thus be estimated at 300 to 350 kg per year (Table 65).

Table 65: Estimate of annual PCB load

Appliance category systems	Annual load of capacitors according to mass flow data [kg per year]	Annual load of capacitors containing or suspected of containing PCBs [kg per year]	Annual PCB load [kg per year]
Large household appliances	65,000	1,425	214
Luminaires	960	722	108
Refrigerators	44,000	0	0
Swico appliances (capacitors > 2.5 cm)	104,000	0	0
Total	214,000	0	300–350

The authors of the study PCBs in small capacitors from waste electrical and electronic equipment (Eugster et al., 2008) calculated annual PCB loads for Switzerland in 2006. At that time, the PCB load in large household appliances was estimated at 90 to 1,000 kg per year and in luminaires at 300 to 3,000 kg per year.

6.8.3 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 64. 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 extent is missing. We multiply the annual quantity of non-polarised cylindrical capacitors from other appliances accordingly by 90 per cent. As mass fractions for the liquid in capacitors, 15 per cent were used for non-polarised cylindrical capacitors and 10 per cent for microwave capacitors. 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. The results of the calculation are shown in Table 66.

Table 66: 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	46
1-Methoxy-2-nitrobenzene/2-nitroanisole	91-23-6	E-cap	600	19
2-Methylnaphthalene	91-57-6	Non-polarised cylindrical	8,000	49
2,2',5,5'-Tetramethylbiphenyl	3075-84-1	Microwave	800,000	541
Benzyltoluenes	27776-01-8	Non-polarised cylindrical, microwave	46,000	467
Di-p-tolyl-methane	4957-14-6	Microwave	5,000	3
Phenol	108-95-2	E-cap	300	6
Total				500-5,000 kg per year

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. Due to the necessary assumptions for the calculation of the annual flow of microwave capacitors, the liquid proportion in the coils of electrolytic capacitors and the uncertainty of the concentration measurement in laboratory analysis, the flow calculated here is only to be understood as an order of magnitude. This results in an annual load of more than 500 to less than 5,000 kg per year.

6.9 Flow of the capacitor liquid in the recycling process

Modelling the mass flow of the liquids in the recycling process shows by way of example how the liquids are distributed among the fractions. The critical path is plastics recycling, which does not involve a thermal process that destroys the substances of concern. The figures for plastics recycling are shown in red in the two figures in this chapter. The liquid in the capacitors is abbreviated in the figures as “LQ”.

It should be noted that the calculation is based on two conservative assumptions for electrolytic capacitors. On the one hand, the entire liquid from the broken capacitors is distributed among the fractions; on the other hand, the content of substances of concern in the liquid is set rather high at 5 per cent. However, this would not apply if the capacitors were largely microwave capacitors. For these, it is very likely that the liquid will be released completely in case of damage. The laboratory analysis also revealed a proportion of substances of concern of up to 80 per cent.

Figure 23 shows the modelling for an assumed breakage rate of 15 per cent. In this scenario, for every tonne of small household appliances that are processed, around 8 g of capacitor liquid enters the recycled plastics fraction. Based on the laboratory tests, a single-digit percentage of substances of concern can be assumed for the predominantly electrolytic capacitors. Using a conservatively estimated assumption of 5 per cent content of substances of concern in the liquid, less than half a gram of substances of concern per tonne of processed appliances would be transferred to the plastics fraction.

Treatment step	Manual dismantling	→	Mechanical processing WEEE recycling		Plastics recycling
Input LQ in capacitors	477 g		381 g		17 g
Fractions created by treatment steps					
LQ in manually dismantled capacitors	96 g				
LQ in capacitors sorted out after shredder			324 g		
Liquid leaked to fractions from damaged capacitors					
LQ on plastics to plastics recycling			17 g	→	
LQ on cables			0.04 g		
LQ on printed circuit boards			0.03 g		
LQ on RESH/dust to municipal incineration			6 g		9 g
LQ on metals and motors			34 g		0.2 g
LQ on batteries and hazardous waste			0.1 g		
LQ in plastics granulate as secondary material					8 g
Liquid in final treatment					
LQ to high temperature incineration	96 g		324 g		
LQ to municipal incineration			6 g		9 g
LQ to metal smelting			34 g		0.2 g
LQ in plastics granulate as secondary material					**8 g**
Subst. of concern at a mass fraction of max. ca. 5 % (no microwave-cap.)					**0.4 g**

Figure 23: Flow estimation of liquids from PCB-free capacitors in WEEE recycling with a breakage rate of 15 per cent per tonne of input of household WEEE

A second calculation was made for a breakage rate of 30 per cent. The results of this calculation are shown in Figure 24. Now, slightly less than 1 g of substances of concern per tonne of input of electrical and electronic household appliances is transferred to the plastics fraction.

Treatment step	Manual dismantling	→	Mechanical processing WEEE recycling		Plastics recycling
Input LQ in capacitors	477 g		381 g		34 g
Fractions created by treatment steps					
LQ in manually dismantled capacitors	96 g				
LQ in capacitors sorted out after shredder			267 g		
Liquid leaked to fractions from damaged capacitors					
LQ on plastics to plastics recycling			34 g	→	
LQ on cables			0.09 g		
LQ on printed circuit boards			0.06 g		
LQ on RESH/dust to municipal incineration			13 g		17 g
LQ on metals and motors			67 g		0.3 g
LQ on batteries and hazardous waste			0.2 g		
LQ in plastics granulate as secondary material					16 g
Liquid in final treatment					
LQ to high temperature incineration	96 g		267 g		
LQ to municipal incineration			13 g		17 g
LQ to metal smelting			67 g		0.3 g
LQ in plastics granulate as secondary material					**16 g**
Subst. of concern at a mass fraction of max. ca. 5 % (no microwave-cap.)					**0.8 g**

Figure 24: Flow estimation of liquids from PCB-free capacitors in WEEE recycling with a breakage rate of 30 per cent per tonne of input of household WEEE

In Figure 25, we show the results for modelling with a breakage rate of 40 per cent. Now about 20 grams of liquid per tonne input are transferred to the recycled plastics fraction. For the substances of concern, there is a transfer of more than 1 g per tonne of input.

Treatment step	Manual dismantling	→	Mechanical processing WEEE recycling		Plastics recycling
Input LQ in capacitors	477 g		381 g		45 g
Fractions created by treatment steps					
LQ in manually dismantled capacitors	96 g				
LQ in capacitors sorted out after shredder			229 g		
Liquid leaked to fractions from damaged capacitors					
LQ on plastics to plastics recycling			45 g	→	
LQ on cables			0.11 g		
LQ on printed circuit boards			0.08 g		
LQ on RESH/dust to municipal incineration			17 g		23 g
LQ on metals and motors			90 g		0.5 g
LQ on batteries and hazardous waste			0.3 g		
LQ in plastics granulate as secondary material					22 g
Liquid in final treatment					
LQ to high temperature incineration	96 g		229 g		
LQ to municipal incineration			17 g		23 g
LQ to metal smelting			90 g		0.5 g
LQ in plastics granulate as secondary material					**22 g**
Subst. of concern at a mass fraction of max. ca. 5 % (no microwave-cap.)					**1.1 g**

Figure 25: Flow estimation of liquids from PCB-free capacitors in WEEE recycling with a breakage rate of 40 per cent per tonne of input of household WEEE

6.10 Collection result

6.10.1 Capacitors > 2.5 cm in one dimension

Table 67 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 26 shows an overview of the collected units.

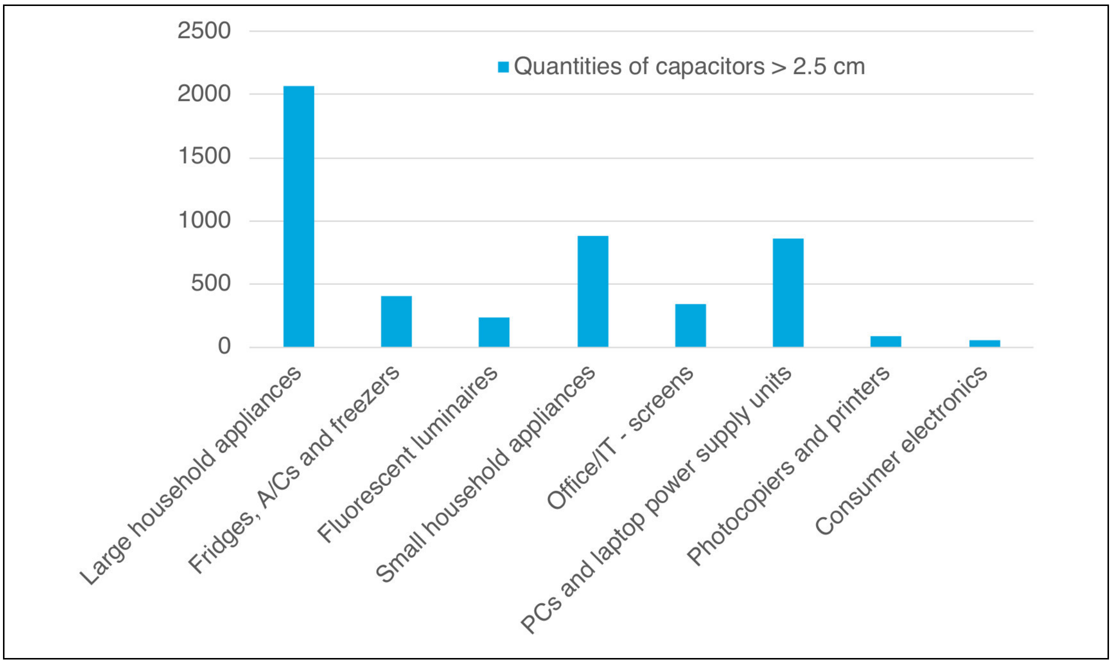

Figure 26: Collected capacitors > 2.5 cm per appliance category

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 from 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 67 also shows the masses of the collected capacitors per appliance category. Capacitors were weighed per appliance category while determining the models.

Table 67: 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

6.10.2 Aluminium electrolytic capacitors smaller than 2.5 cm

All aluminium e-caps 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 68 below.

Table 68: 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

6.10.3 Comparison of capacitor quantities in all size classes

Based on the presented collection numbers, we created the evaluation according to Figure 27. 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.

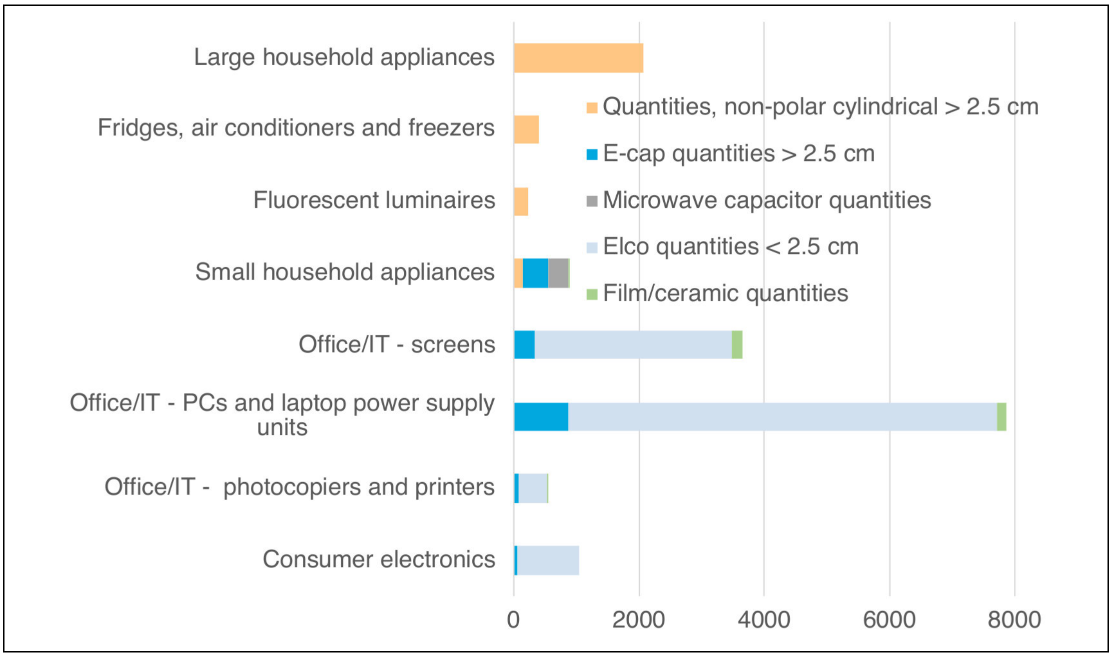

Figure 27: Numbers of collected capacitor classes per appliance category

6.10.4 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 69.

Table 69: 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
25a	Consumer electronics and cameras/Swico 10	Audio devices such as amplifiers, radios, compact systems	6	28

No.	Appliance category systems	Collection category	Number of disassembled appliances [units]	Mass of disassembled appliances [kg]
25b		Loudspeaker boxes with at least 2 loudspeakers	26	171
25c		Video players (VHS)	11	28
Total	(without UPS)		475	2,411

7 Discussion

7.1 Classification of liquids in capacitors

7.1.1 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 70. A new addition compared to the table in the 2019 report is diethylhexyl phthalate. Biphenyl has been reclassified as a potential substance of concern compared to the 2019 report.

Table 70: Substances of concern in capacitor liquids

Chemical designation	CAS No.	Substance of concern based on H-statements?	Easily biodegradable?	CMR?	Substance of concern in recycling	Capacitor type occurrence
1-Chloronaphthalene (chlorinated naphthalenes)	90-13-1	Yes	No	No	Yes	Non-polarised cylindrical
1-Methoxy-2-nitrobenzene/2-nitroanisole	91-23-6	Yes	No	Yes	Yes	E-cap
1-Methylnaphthalene	90-12-0	Yes	No	No	Yes	Non-polarised cylindrical
2-methylnaphthalene	91-57-6	Yes	No	No	Yes	Non-polarised cylindrical
2,2',5,5'-Tetramethylbiphenyl	3075-84-1	Yes	No	No	Yes	Microwave
2,6-Diisopropylnaphthalene	24157-81-1	Yes	No	No	Yes	Microwave
Benzyltoluenes	27776-01-8	Yes	No	No	Yes	Non-polarised cylindrical, microwave
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	Microwave
Dibutyl phthalate	84-74-2	Yes	Yes	Yes	Yes	Non-polarised cylindrical

Chemical designation	CAS No.	Substance of concern based on H-statements?	Easily biodegradable?	CMR?	Substance of concern in recycling	Capacitor type occurrence
Diethylhexyl phthalate	117-81-7	Yes	Yes	Yes	Yes	Non-polarised cylindrical
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

7.1.2 Potentially concerning substances

There are indications for the five substances in Table 71 that they could meet the criteria for substances of concern. The 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 potential substance of concern remains. Compared to the first report, biphenyl is now listed as a potential substance of concern. In-depth research has shown that biphenyl is rapidly degradable in the environment. At the same time, however, it is being examined as a possible PBT substance in the REACH process, with the assessment being postponed (ECHA, 2013). Until new findings are available, biphenyl is therefore classified as a suspect substance in recycling. This means that the available information does not justify classification as a substance of concern in recycling. However, new developments should be followed closely for the assessment of biphenyl.

Table 71: Potentially concerning substances in capacitor liquids

Chemical designation	CAS No.	Substance of concern based on H-statements	Easily biode-gradable?	CMR?	Sub-stance of concern in recy-cling	Capacitor type occur-rence
Ammonium pentaborate	12046-04-7	Suspected	–	Yes	Suspected	E-cap
Biphenyl	92-52-4	Yes	Yes	No	Suspected	Non-polar-ised cylindri-cal
Diisodecyl phthalate	26761-40-0	Suspected	No	No	Suspected	Microwaves
Diisononyl phthalate	28553-12-0	Suspected	Yes	No	Suspected	Microwaves
Trioctyl trimellitate	3319-31-1	Suspected	–	Yes	Suspected	Microwaves

7.1.3 Non-classifiable substances

It was not possible to classify the 13 substances in Table 72 found in capacitor liquids. No classification with H-statements was found for any of the substances listed.

Table 72: Substances in capacitor liquids which could not be classified

Chemical designation	CAS No.	Substance of concern based on H-state-ments	Substance of concern in re-cycling	Capacitor type occur-rence
1,1-Bis(4-methylphenyl)ethane	530-45-0	Assessment not possible	Assessment not possible	Microwaves
1,1-Diphenylethane, dia-rylethene	612-00-0	Assessment not possible	Assessment not possible	Microwaves
1,1'-(1-Methylethyli-dene)bis(4-methylbenzene)	Unknown	Assessment not possible	Assessment not possible	Microwaves
1,2-Dimethyl-4-(phenylme-thyl)benzene	13540-56-2	Assessment not possible	Assessment not possible	Microwaves
1,2,3-Trimethyl-4-(1E)-1-pro-penyl-naphthalene	26137-53-1	Assessment not possible	Assessment not possible	Microwaves
1,3,5-Cycloheptatriene, 6-methyl-1-(6-methyl-1,3,5-cy-cloheptatrien-1-yl)-	Unknown	Assessment not possible	Assessment not possible	Microwaves
1,5,6,7-Tetramethyl-3-phe-nylbicyclo[3.2.0]hepta-2,6-dien	126584-00-7	Assessment not possible	Assessment not possible	Microwaves
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	Microwaves
4-Isopropylbiphenyl	7116-95-2	Assessment not possible	Assessment not possible	Microwaves
5-Ethyl-2-methyl-4,4-diphe-nyl-3,4-dihydro-2H-pyrrole (EMDP)	102177-18-4	Assessment not possible	Assessment not possible	Microwaves

Chemical designation	CAS No.	Substance of concern based on H-statements	Substance of concern in recycling	Capacitor type occurrence
13-Hexyloxacyclotridec-10-en-2-one	127062-51-5	Assessment not possible	Assessment not possible	Non-polarised cylindrical
Ethyl(1-phenylethyl)benzene	18908-70-8	Assessment not possible	Assessment not possible	Microwaves

7.1.4 Substances not of concern

Table 73 shows all liquid substances in capacitors which can be considered nort of concern 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 73: Non-hazardous substances in capacitor liquids

Chemical designation	CAS No.	Substance of concern based on H-statements	Easily biodegradable?	CMR?	Substance of concern in recycling	Capacitor type occurrence
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-(phenylmethyl)benzene	620-83-7	No	–	No	No	Microwave
1-Tetradecene	1120-36-1	Suspected	Yes	No	No	Non-polarised cylindrical
1,1-Bis(3,4-dimethylphenyl)ethane	1742-14-9	No	–	No	No	Microwave
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

Chemical designation	CAS No.	Substance of concern based on H-statements	Easily biodegradable?	CMR?	Substance of concern in recycling	Capacitor type occurrence
2,2'-Dimethylbiphenyl	605-39-0	No	–	No	No	Microwave
2,4-Dihydroxybenzoic acid	89-86-1	No	–	No	No	E-cap
3-Nitroacetophenone	121-89-1	No	–	No	No	E-cap
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(2-ethylhexyl) adipate	103-23-1	No	–	No	No	Non-polarised cylindrical
Bis(7-methyloctyl)phthalate	20548-62-3	No	–	No	No	Microwave
Butyldiglycol	112-34-5	No	–	No	No	E-cap
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	Microwave
Dimethylbenzyl alcohol	617-94-7	No	–	No	No	E-cap
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
(Z)-4-decenal	21662-09-9	No	–	No	No	Non-polarised cylindrical

7.2 Substances of concern with conspicuous ecotoxicity properties

7.2.1 Conspicuous substances

The analysis of the substance properties identified a number of conspicuous substances which we consider to be of most concern in terms of ecotoxicity. The substances are the following:

- N-Methylpyrrolidone: Is fully miscible with water and at the same time the most toxic substance for crustaceans among the substances of concern in recycling. However, it also has the lowest ignition temperature of all substances of concern. This indicates that N-Methylpyrrolidone is easily destroyed in processes at elevated temperatures.
- Phenol: Is the most toxic to rats of all substances of concern. The degradation product catechol is carcinogenic. Phenol has the highest ignition temperature of all substances of concern. However, the boiling point and flash point are relatively low. The substance becomes gaseous at 182 °C and, at 80 °C, an ignitable gas mixture forms over the pure substance. Both these aspects rather suggest good destructibility in thermal processes.
- 2,2',5,5'-Tetramethylbiphenyl: The BCF estimated using modelling software (US EPA, 2012) gives an indication of the bioaccumulative nature of the substance. The concentration in microwave capacitors can be high; in laboratory analysis, it was determined to be 80 per cent. However, the analytical quality of the GCMS analysis was only moderate. It is therefore not entirely clear whether the substance has been determined correctly. In addition, hardly any substance properties are known, which makes it impossible to further assess the environmental behaviour.
- 2,6-Diisopropylnaphthalene: The BCF estimated using modelling software (US EPA, 2012) gives an indication of the bioaccumulative nature of the substance. Very few substance properties are known about the substance. 2,6-Diisopropylnaphthalene is a component in the mixture of isomers of diisopropylnaphthalenes (DIPN). It is technically used on a large scale as a solvent for dyes in carbonless paper (Wikipedia, 2020). This is an open application, which is far more critical than its use in capacitors.
- Benzyltoluenes, this mixture of p-, m- and o-benzyltoluene, are very toxic to aquatic organisms and degrade very slowly in the environment.
- Four substances belong to the group of naphthalenes (Table 74). These are very toxic to fish and are not rapidly biodegradable based on model estimates. Naphthalene (CAS No. 91-20-3) is also suspected of being carcinogenic.

The substances mentioned are described for each type of capacitor in the following chapters.

7.2.2 Non-polarised cylindrical capacitors

Particularly conspicuous in non-polarised cylindrical capacitors are the substances of concern with regard to their environmental impact according to Table 74.

Table 74: Substances of concern in non-polarised cylindrical capacitors with particularly problematic properties

Substance designation	CAS No.	Particularly critical property	Related parameters
Benzyltoluenes	27776-01-8	Toxicity to aquatic organisms	LC_{50} fish = 0.3 mg/l EC_{50} crustaceans = = 0.4 mg/l
		Not biodegradable	DT_{50} > 1 year
Naphthalenes (naphthalene, 1-Chloronaphthalene, 1-Methylnaphthalene, 2-Methylnaphthalene)	 91-20-3 90-13-1 90-12-0 91-57-6	Toxicity to fish	 LC_{50} fish = 2 mg/l LC_{50} fish = 2.3 mg/l LC_{50} fish = 9 mg/l LC_{50} fish = 1.5 mg/l
		Not biodegradable	EPI Suite model
		Naphthalene only: carcinogenic	H351 Suspected of causing cancer

7.2.3 Microwave capacitors

In microwave capacitors, 2,2',5,5'-Tetramethylbiphenyl was identified as the main component. We consider the environmental impact of this substance and two others to be particularly critical (Table 75).

Table 75: Substances of concern in microwave capacitors with particularly problematic properties

Substance designation	CAS No.	Particularly critical property	Related parameters
2,2',5,5'-Tetramethylbiphenyl	3075-84-1	Potentially bioaccumulative	BCF (model estimate) ≈ ≈ 3,900
		Not biodegradable	EPI Suite model
2,6-Diisopropylnaphthalene	24157-81-1	Potentially bioaccumulative	BCF (model estimate) ≈ ≈ 4,800
		Not biodegradable	EPI Suite model
Benzyltoluenes	27776-01-8	Toxicity to aquatic organisms	LC_{50} fish = 0.3 mg/l EC_{50} crustaceans = = 0.4 mg/l
		Not biodegradable	DT_{50} > 1 year

7.2.4 Electrolytic capacitors

Among the substances of concern, the properties of phenol and N-Methylpyrrolidone appear to be more problematic than those of the other substances, as shown in Table 76.

Table 76: Substances of concern in electrolytic capacitors with particularly problematic properties

Substance designation	CAS No.	Particularly critical property	Related parameters
N-Methylpyrrolidone	872-50-4	Toxicity to crustaceans	LC_{50} crustaceans = 1.2 mg/l
Phenol	108-95-2	Toxicity to mammals	LD_{50} oral, rat = 317 mg/kg
		Carcinogenic degradation product	Catechol, CAS No. 120-80-9

7.3 Behaviour of the substances of concern in the recycling process

7.3.1 Behaviour of the substances of concern in mechanical crushing

The significantly increased temperature in the shredder was taken into account for the assessment of the material behaviour in the shredder. However, it cannot be assumed that the workpieces are heated continuously. Metal parts on the belt downstream from the shredder are clearly heated. However, the temperature in the shredder is unlikely to exceed 100 °C by much. All substances of concern have boiling points above 100 °C. The ignition temperatures are well above 200 °C for all substances of concern. It can therefore be assumed that the substances pass through the shredding process essentially unchanged. At best, a partial transition of substances with boiling points below 200 °C into the gas phase is feasible.

7.3.2 Behaviour of the substances of concern in waste incineration plants

Moving grate incineration is the most widely used technology in municipal waste incineration plants. Burning temperatures range from 800 °C to 1,000 °C. All available ignition temperatures of the substances of concern were in the range of 265 °C to 595 °C. It can therefore be estimated that the substances of concern would burn off in the waste incineration plant. However, this does not say anything about whether the resulting gaseous secondary products can also be safely filtered out in a municipal waste incineration plant. The question also arises as to which solid residues would occur and how these should be assessed. We have consulted the municipal waste incineration plant of the upper Zurich region (KEZO) to answer these questions. The investigations established that, according to the current state of knowledge, the substances of concern can be incinerated in a waste incinerator without any problems if the following conditions are met (Böni, 2020):

- The substances of concern occur as impurities on combustible fractions.
- They are present on the contaminated fractions at a low concentration below the percentage range.

KEZO estimates that whole capacitors would not be destroyed in a waste incineration plant, but would be transferred to the slag more or less intact (Böni, 2020). Entire capacitors or fractions containing them cannot therefore be treated of in a waste incineration plant.

7.4 Liquid substances in PCB-free capacitors

7.4.1 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 which were analysed in the GCMS laboratory analysis to a with a very good correspondence to the substance library (also see chapter 6.2.1). 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 6.1.

7.4.2 Non-polarised cylindrical capacitors

The substances in Table 77 were identified in PCB-free non-polarised cylindrical capacitors. Nine out of nineteen are substances of concern.

Table 77: 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
13-Hexyloxacyclotridec-10-en-2-one	127062-51-5	GCMS analysis	No
Benzyltoluenes (p- and m-)	27776-01-8	GCMS analysis	Yes
Biphenyl	92-52-4	Literature	Suspected
Bis(2-ethylhexyl)adipate	103-23-1	GCMS analysis	No
Butylated hydroxyanisole	25013-16-5	Literature	Yes
Dibutyl phthalate	84-74-2	Literature	Yes
Diethylhexyl phthalate	117-81-7	GCMS analysis and 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
(Z)-4-decenal	21662-09-9	GCMS analysis	No

7.4.3 Electrolytic capacitors

In addition to the substances listed in Table 78, 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 78: 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
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

7.4.4 Microwave capacitors

The analysis results of the microwave capacitors show numerous biaryls, diarylalkanes or arylalkanes (Table 79). 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 mass fractions. 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 79: 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
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

7.4.5 Assessment of the results of the analysis

All GCMS and LCMS analyses, with the exception of microwave capacitors, failed to determine the main components. The main components do not show up in gas chromatography. One of the reasons for this could be substances with a high boiling point. The highly viscous liquids obtained during sampling indicate that they contain many low-volatile substances. It is known for vegetable oils that the main components do not appear in the GCMS analysis (Maier, 2018).

7.5 Proportion of capacitors containing PCB

7.5.1.1 Overview

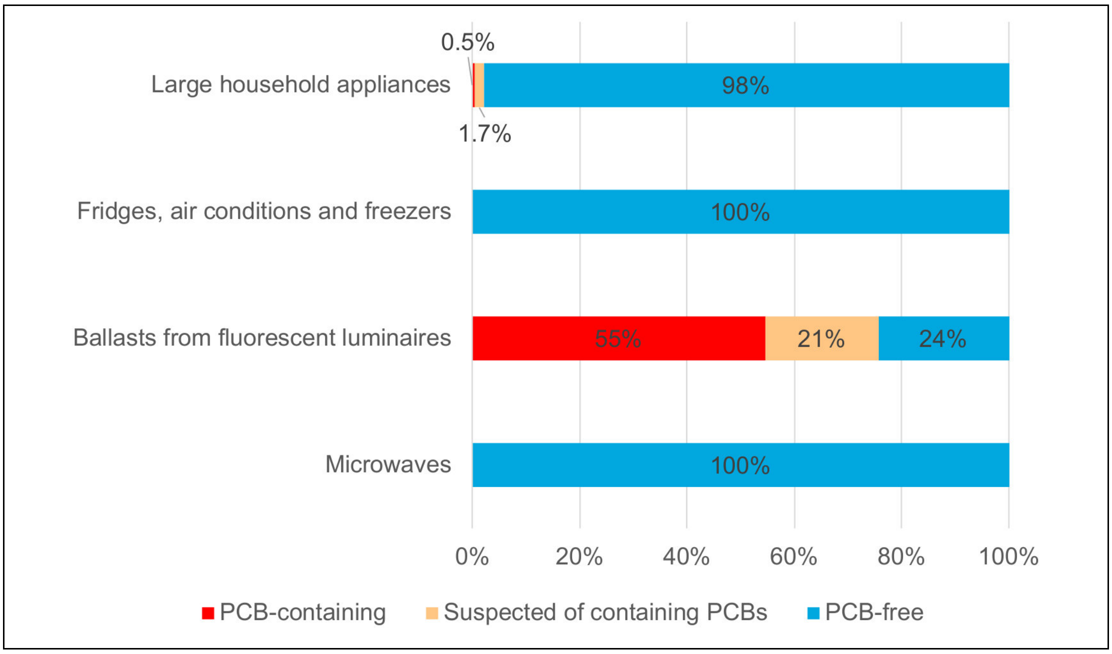

Figure 28: Proportions of PCB-containing capacitors within appliance categories in units

The question of what proportion 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 28 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 proportions 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 proportion of PCB-free capacitors would be 99.5 per cent for large household appliances and 45 per cent for fluorescent luminaires. The annual PCB load for Switzerland resulting from these figures is estimated in chapter 6.8.2.

7.5.1.2 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.

7.5.1.3 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.

7.5.1.4 Ballasts from fluorescent luminaires

Capacitors in ballasts 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 corresponds well with the earlier analysis of capacitors from luminaires in Switzerland (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.

7.5.1.5 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 luminaires. The proportion 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 proportion 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.

7.6 Average masses

7.6.1 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 80. For large household appliances, the mean masses of the subcategories and the capacitor average from large household appliances are shown as a total.

Table 80: Average masses of non-polarised cylindrical capacitors by appliance category

Appliance category	Average masses 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**

7.6.2 Electrolytic capacitors

The average masses of the electrolytic capacitors according to Table 81 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 81: 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**

7.6.3 Microwave capacitors

The average masses of the microwave capacitors were determined by weighing the collected capacitors and are shown in Table 82.

Table 82: Average masses of microwave capacitors by appliance category

Appliance category	Average mass of microwave capacitors
Microwaves	118.1 g

7.6.4 Appliances

The average masses of the appliances could be determined for the Swico appliances from the test data. These are listed in Table 83. 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. These appliance categories are not included in Table 83.

Table 83: 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

7.7 Mass evaluation of electrolytic capacitors in appliances

7.7.1 Introduction

The masses of all included aluminium e-caps were 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.

7.7.2 Mass fractions of electrolytic capacitors in 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 84. 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 e-caps 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 84: Mass fractions of electrolytic capacitors in the appliance mass

Appliance category	Mass fraction of e-caps of all sizes in appliances	Mass fraction of e-caps > 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%

7.7.3 Ratio between large and small electrolytic capacitors in the appliances

For aluminium e-caps, 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 29.

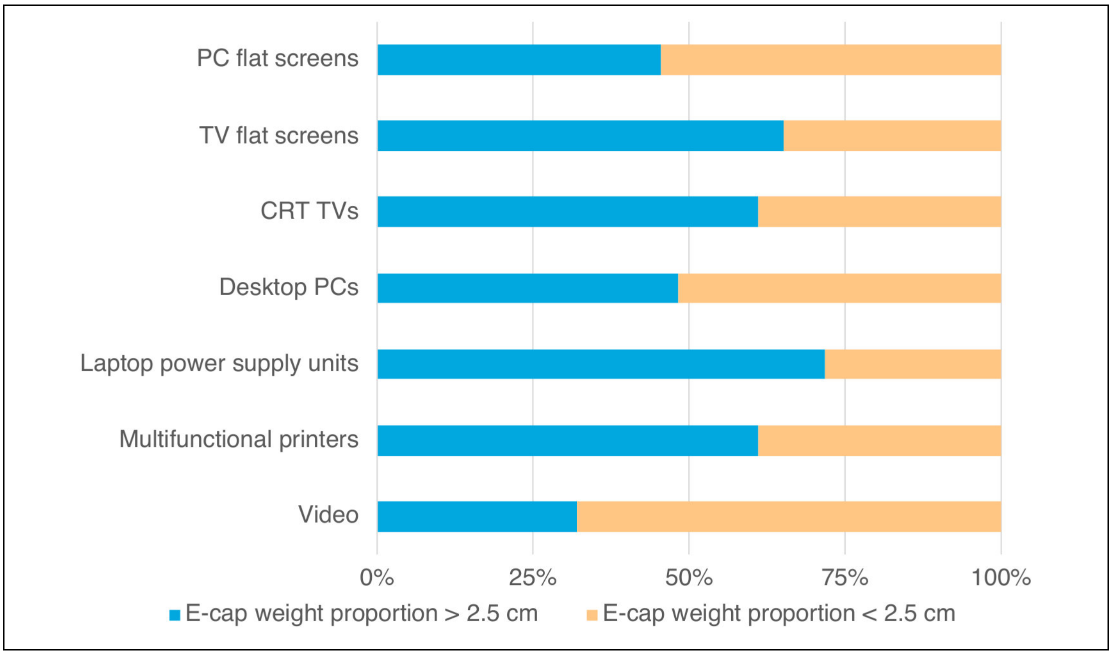

Figure 29: Mass fractions of electrolytic capacitors in the appliances

It is apparent that electrolytic capacitors larger than 2.5 cm make up around half of the total mass of the included capacitors. Their proportion 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 30 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 (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.

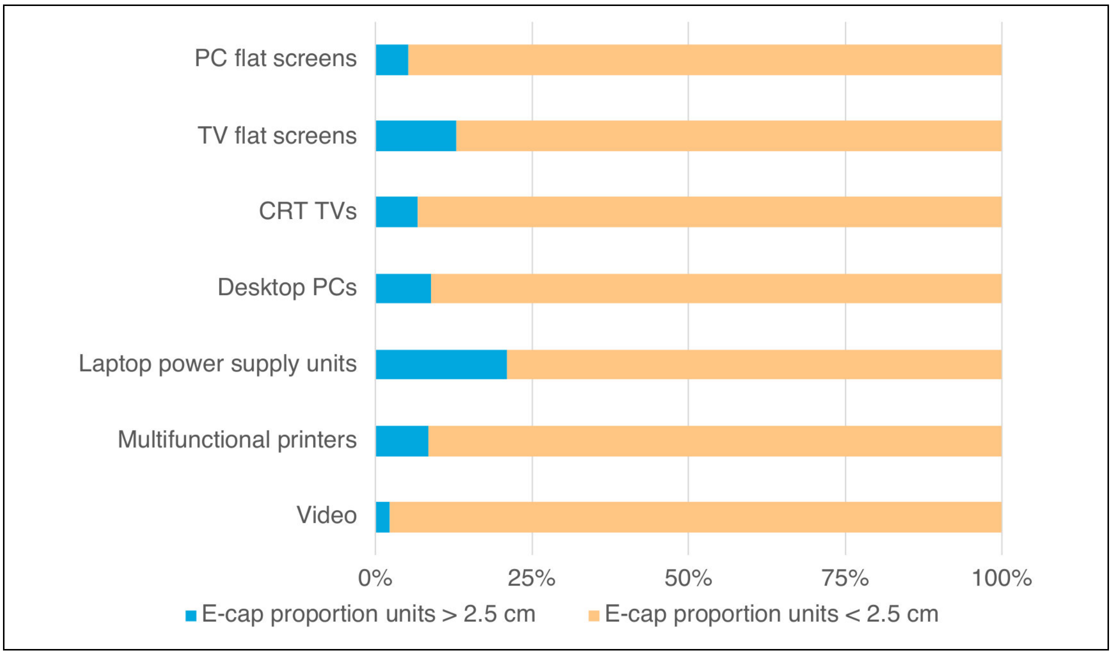

Figure 30: Proportions of electrolytic capacitors in the appliances by units

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 85 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 85: 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 WEEE. 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.

The mass fractions of liquids in capacitors was determined on the basis of small random samples. We also had access to the data from the mass flow analysis at the WEEE recyclers in Switzerland. This made it possible to determine the flows of substances of concern and PCBs in the capacitors of WEEE.

The chemical behaviour, in particular the stability of the substances of concern found, was researched in the literature. Recommendations for the handling of the substances of concern in recycling were derived from this. Further clarifications are necessary to arrive at final statements which can also be used for technical specifications.

8.2 Plastics in recycling as a critical path

Environmentally friendly disposal of the substances of concern from capacitors – with the exception of PCBs – is ensured for all fractions that go into a waste incineration plant with flue gas cleaning if the substances were released from the capacitors in small quantities. A prerequisite for this is the sorting of the undamaged capacitors into a separate fraction in the recycling process. Entire capacitors cannot be incinerated in a waste incineration plant, which also means that the substances of concern would not be destroyed.

Given the similarly high temperatures in metal recycling, the assessment for waste incineration can also be applied to metal recycling. The substances of concern are therefore not a problem even in metal fractions that enter a smelter as long as they are adhesions in low concentrations. This requires a flue gas cleaning system that meets the European standard (European Parliament, 2010).

If fractions are treated in a recycling process at low temperatures, adhering substances of concern can be transferred to the secondary products. For the recycling practice, this means above all that it must be ensured that the substances of concern cannot enter recycled plastics in significant concentrations. To ensure this, microwave capacitors must be removed before mechanical processing, as they can contain substances of concern in very high concentrations of up to 80 per cent. In addition, the liquid from microwave capacitors leaks immediately and practically completely as soon as the casing is damaged in the recycling process.

Concerning electrolytic capacitors, model calculations on liquid distribution using real process data show that significant amounts of substances of concern could be transferred to secondary products under the following conditions:

- Most electrolytic capacitors are not stripped manually prior to mechanical crushing.
- In mechanical processing, very high breakage rates occur with the liquids being released.

The supplementary technical regulations of SENS and Swico regarding EN 50625 (SENS et al., 2019) define limit values in relation to the input fraction for monitoring the removal of hazardous substances. For PCBs, this limit value is 1 g per tonne. If this limit value is applied similarly to the load of substances of concern, the model calculations (see chapter 6.8.2) indicate a permissible breakage rate of around 30 per cent in the shredding process.

According to the findings of this study, the following measures can be taken to ensure that the substances of concern are not discharged in relevant quantities into secondary fractions for small electrical household appliances:

- Capacitors containing or suspected of containing PCBs must be removed before mechanical processing of the appliances.
- Microwave capacitors must be removed before mechanical processing of the appliances.
- Not more than 30 per cent of the capacitors may be destroyed in the mechanical processing of the appliances in such a way that the contained liquid leaks from the capacitors.

8.3 Mass fraction of liquids in capacitors lower than previously thought

Based on expert estimates, the mass fraction of liquid in non-polarised cylindrical capacitors was previously estimated to be significantly higher than the 15 per cent now measured. The mass fraction was found to be 10-15 per cent in electrolytic capacitors and 10 per cent in microwave capacitors. The results are subject to greater uncertainty, since only a few models have been analysed for the measurement of the liquid proportion.

8.4 Annual load of substances of concern

All liquids in the analysed capacitor categories could contain substances of concern as outlined in the established definition. The mass fractions found were consistently low. An estimation of the annual load of substances of concern results in a range of 500 to 5,000 kg per year. 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.

8.5 PCB load from capacitors still significant

Large household appliances and refrigerators are traditionally the most important appliance categories for the load of PCB-containing capacitors. For large household appliances, a proportion of PCB-containing capacitors of 0.5 per cent could be determined. In addition, large household appliances have a proportion 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. We found a high proportion 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 ballasts in luminaires are properly removed and disposed of as PCB-containing capacitors.

The high proportion of PCB-containing capacitors in the examination of capacitors from small household appliances is not plausible. We suspect that ballasts from luminaires were also included by mistake in the collection of small household appliances.

The PCB load from capacitors for Switzerland of approximately 300 to 350 kg per year is still significant when compared with the modelled emissions into the air and with the background concentration in the Rhine near Basel:

– Current modelling of PCB loads (Glüge et al., 2017) estimates Switzerland's PCB emissions into the air in 2020 at around 400 kg per year. Such modelling is dependent on a large number of assumptions. Its accuracy should not be overestimated.
– The Rhine monitoring station is located in Weil near Basel and is operated by the canton of Basel-Stadt. It measures, among many other factors, the water discharge, suspended solids content and the mass fractions of eight PCB congeners (PCB-28, PCB-52, PCB-101, PCB-118, PCB-138, PCB-153, PCB-120, PCB-180) in suspended matter. Based on this information, the PCB load in the Rhine for the year 2016 can be calculated at around 30 kg per year.

It would be irresponsible to dispose of PCBs from capacitors in an uncontrolled manner in the future. For the PCB loads from capacitors to fall into the range of the background concentration, the proportion of PCB-containing capacitors in large household appliances would have to decrease by a further factor of 10. In addition, the proportion of PCB-containing capacitors in luminaires would have to drop to less than 1 per cent.

8.6 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.

8.7 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 IT and CE 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 small household 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 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 generally distinguish between the types of appliances from which the capacitors originate. A distinction by type of appliance would only be conceivable for specialised companies that only process certain types of appliances.

8.8 Chemical analysis results

The chemical-analytical determination of the main components was successful for the microwave capacitors. The analysis results for the mixed samples of non-polarised cylindrical capacitors were masked by a hydrocarbon mixture. The analysis of five individual models showed that some of the non-polarised cylindrical capacitors are filled with mixtures based on mineral oil and others with mixtures based on vegetable oil. In the case of mineral-oil-based capacitors, it remains unclear whether the identified individual substances originate from the mineral oil mixture or were added separately. All identified mass fractions in the liquids from non-polarised cylindrical capacitors are 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 even for aluminium electrolytic capacitors.

8.9 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 proportion of PCB-containing capacitors was determined with a statistical accuracy of 5 per cent, with the non-representative sampling adding 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 representative sampling.

No confidence intervals can be indicated for the determination of substances in PCB-free capacitors. From the extensive collection, eight mixed samples and five individual samples were analysed in the laboratory. Only a few trace substances could be identified. The main components of the mixtures remained unknown with the exception of the microwave capacitors. 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.

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 86. 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 6.1. 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 86: 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 Most conspicuous substances as lead substances for analyses

Cost-effective analyses of critical fractions are of great interest for practical quality monitoring in recycling processes. Four out of the six identified substances or groups of substances of concern with conspicuous properties (chapter 7.2.1) could serve as lead substances. The substances are the following:

- N-Methylpyrrolidone
- Phenol
- Benzyltoluenes (mixtures of p-, m- and o-benzyltoluene)
- Naphthalenes (group of substances)

For example, the concentrations of these lead substances in plastics fractions could be tested regularly in terms of material recovery. For a practical test concept, we recommend clarifying the following questions:

- Which analytical methods are suitable for the listed substances?
- What are the detection limits of the analytical methods?
- What are the costs of these analyses?
- What are the requirements for taking and storing samples?

9.3 Advance removal before mechanical processing necessary for PCB-containing and microwave capacitors

The results of the clarification of substance properties in the environment and in disposal processes, the load analysis of PCBs in capacitors, and the mass flow of liquids from capacitors in the recycling process show that PCB-containing capacitors and microwave capacitors must be removed from appliances before mechanical processing.

Since it is not possible in recycling practice to distinguish between PCB-containing and PCB-free capacitors of the same shape, this regulation means that all non-polarised cylindrical capacitors with a height greater than 25 mm or a diameter greater than 25 mm or a proportionally similar volume must be removed from large household appliances and luminaires before mechanical processing.

Electrolytic capacitors from small household appliances can be separated into their own stream after mechanical processing, provided that the capacitors are for the most part not destroyed. On the basis of the model calculations, a breakage rate of a maximum of 30 per cent appears to be unproblematic with regard to possible emissions into the environment and any transfer of the substances to secondary products. This requirement should be substantiated more thoroughly by further model calculations before it is implemented in a technical regulation.

9.4 Rule for removing 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 and Annex VII of the WEEE Directive(European Parliament, 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. The WEEELABEX standard (WEEELabex, 2013) extends the removal requirement to “capacitors containing mineral or synthetic oils”. 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 WEEE 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).”

If all capacitors above the minimum size are removed from the appliances, it can be assumed that almost 100 per cent of the liquids are removed from the appliances in the case of non-polarised cylindrical capacitors, because small non-polarised capacitors are dry types. In the case of electrolytic capacitors, however, only about 50 per cent of the liquids are removed when the capacitors above the minimum size are removed (see Figure 29). The authors could not reach a consensus on whether the size criterion should also be abandoned in order to cover all liquids of the electrolytic capacitors.

9.5 Further model calculations on liquid flow in recycling for large household, IT and CE appliances

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.

Model calculations were made in this study for the distribution of liquid from capacitors under the assumption of different breakage rates for the recycling of small household appliances. Such model calculations ought also to be made for the recycling of large household, IT and CE appliances. The permissible breakage rate could then also be derived for these appliance categories in the same way as it was done for small household appliances in this study. The results could then be used to formulate a robust set of technical regulations.

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

Removing the capacitors into a distinguishable stream is necessary for PCB-free capacitors with substances of concern in accordance with the CENELEC standard. 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?
– How do released substances of concern distribute to fractions and the ambient air?
– What measures ensure that the capacitors are separated into a distinguishable and controlled stream?

9.7 Analysis of substances of concern in plastics for recycling

In the model calculations on the mass flow of liquids from capacitors in the recycling process, the recovery of plastics was identified as a critical path for substances of concern from capacitors. The adhesions of substances of concern on plastics fractions in the recycling process should be analysed in a follow-up study. This should be done for recyclers who today already sort out large proportions of capacitors after shredding and whose processes have relatively high breakage rates. It should also be clarified with plastics recyclers whether and how the identified substances of concern are or could be monitored by plastics recyclers.

10 Literature

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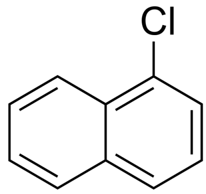
A Chemical-toxic properties of the substances of concern

Common name (CAS No.) 1-Chloronaphthalene (chlorinated naphthalenes) (90-13-1)

Capacitor type occurrence: Non-polarised cylindrical

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	**Easily biodegradable?**	**CMT?**	**Substance of concern in recycling?**
Yes	No	No	Yes

Physical properties

Molar mass [g/mol] (source)	162.62 (1)
Density (20 °C) [g/cm³] (source)	1.19 (1)
Melting point [°C] (source)	–6 (1)
Boiling point [°C] (source)	259 (1)
Vapour pressure (20 °C) [hPa] (source)	0.05 (1)
Ignition temperature [°C] (source)	>500 (1)

Stability in the environment

Biodegradable according to REACH dossier	**Persistence, bioaccumulation, toxicity according to the ECHA?**
No dossier available	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Unknown	

Distribution in the environment

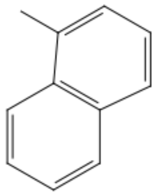
Water solubility 25 °C [mg/l] (source)	**Octanol/water partition coefficient log K_{ow} (source)**	**BCF [l/kg wet mass] (source)**
17.4 (2)	4.24 (1)	291.4 (6 with K_{ow} of 1)

Toxicity

LD_{50} oral, rat [mg/kg] (source)	
LC_{50} fish (96 h) [mg/l] (source)	2.3 (1)
LC_{50} crustaceans (48 h) [mg/l] (source)	1.6 (1)
EC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} algae (72 h) [mg/l] (source)	

Common name (CAS No.) **1-Methylnaphthalene (90-12-0)**

Capacitor type occurrence: Non-polarised cylindrical



Structural formula:

Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	No	No	Yes

Physical properties

Molar mass [g/mol] (source)	142.2 (1)
Density (20 °C) [g/cm^3] (source)	1.02 (1)
Melting point [°C] (source)	–31 (1)
Boiling point [°C] (source)	245 (1)
Vapour pressure (20 °C) [hPa] (source)	2 (1)
Ignition temperature [°C] (source)	485 (1)

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
No information on environmental fate	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Unknown	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
28 (1)	3.87 (1)	166 (6)

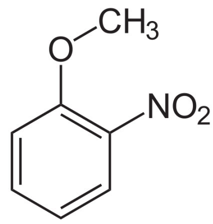
Toxicity

LD_{50} oral, rat [mg/kg] (source)	1,840 (1)
LC_{50} fish (96 h) [mg/l] (source)	9 (1)
LC_{50} crustaceans (48 h) [mg/l] (source)	8.2 (1)
EC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} algae (72 h) [mg/l] (source)	

Common name (CAS No.) (91-23-6) **1-Methoxy-2-nitrobenzene/2-Nitroanisole**

Capacitor type occurrence: E-cap

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	No	Yes	Yes

Physical properties

Molar mass [g/mol] (source)	153.14 (1)
Density (20 °C) [g/cm^3] (source)	1.25 (1)
Melting point [°C] (source)	9 (1)
Boiling point [°C] (source)	273 (1)
Vapour pressure (20 °C) [hPa] (source)	0.06 (1)
Ignition temperature [°C] (source)	464 (1)

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
No dossier available	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Unknown	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
1.69 (1)	1.73 (1)	6.4 (6)

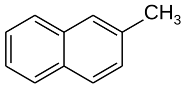
Toxicity

LD_{50} oral, rat [mg/kg] (source)	750 (1)
LC_{50} fish (96 h) [mg/l] (source)	192 (1)
LC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} algae (72 h) [mg/l] (source)	59.5 (1)

Common name (CAS No.) **2-Methylnaphthalene (91-57-6)**

Capacitor type occurrence: Non-polarised cylindrical

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	No	No	Yes

Physical properties

Molar mass [g/mol] (source)	142.2 (1)
Density (20 °C) [g/cm³] (source)	1.006 (1)
Melting point [°C] (source)	34.6 (1)
Boiling point [°C] (source)	241.1 (1)
Vapour pressure (20 °C) [hPa] (source)	0.07 (2)
Ignition temperature [°C] (source)	488 (1)

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
No dossier available	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Naphthyl-2-methyl-succinate cis-1,2-Dihydroxy-1,2-dihydro-7-methylnaphthalene 2-Hydroxy-methylnaphthalene	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
24.6 (1)	3.86 (2)	164 (6)

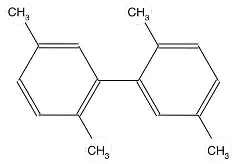
Toxicity

LD_{50} oral, rat [mg/kg] (source)	1,630 (1)
LC_{50} fish (96 h) [mg/l] (source)	1.46 (1)
LC_{50} crustaceans (48 h) [mg/l] (source)	3.2 (1)
EC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} algae (72 h) [mg/l] (source)	

Common name (CAS No.) **2,2',5,5'-Tetramethylbiphenyl (3075-84-1)**

Capacitor type occurrence: Microwaves

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	No	No	Yes

Physical properties

Molar mass [g/mol] (source)	210.32 (7)
Density (20 °C) [g/cm³] (source)	
Melting point [°C] (source)	49.5 (7)
Boiling point [°C] (source)	284 (7)
Vapour pressure (20 °C) [hPa] (source)	
Ignition temperature [°C] (source)	

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
No dossier available	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Unknown	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
	5.95 (4)	3,916 (6)

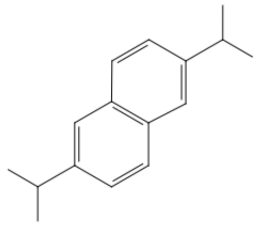
Toxicity

LD_{50} oral, rat [mg/kg] (source)	
LC_{50} fish (96 h) [mg/l] (source)	
LC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} algae (72 h) [mg/l] (source)	

Common name (CAS No.) **2,6-Diisopropylnaphthalene (24157-81-1)**

Capacitor type occurrence: Microwaves

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	No	No	Yes

Physical properties

Molar mass [g/mol] (source)	212.34 (2)
Density (20 °C) [g/cm³] (source)	0.965 (3)
Melting point [°C] (source)	70 (8)
Boiling point [°C] (source)	319 (3)
Vapour pressure (20 °C) [hPa] (source)	<0.1 (6)
Ignition temperature [°C] (source)	

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
No dossier available	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Unknown	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
0.11 (3)	6.08 (2)	4,778 (6)

Toxicity

LD_{50} oral, rat [mg/kg] (source)	>3,900 (3)(3)
LC_{50} fish (96 h) [mg/l] (source)	
LC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} algae (72 h) [mg/l] (source)	

Common name (CAS No.) **Ammonium pentaborate (12046-04-7)**

Capacitor type occurrence: E-cap

Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Suspected	–	Yes	Suspected

Physical properties

Molar mass [g/mol] (source)	272.15 (9)
Density (20 °C) [g/cm^3] (source)	1.58 (7)
Melting point [°C] (source)	110 (7)
Boiling point [°C] (source)	
Vapour pressure (20 °C) [hPa] (source)	
Ignition temperature [°C] (source)	

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
No dossier available	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Unknown	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)

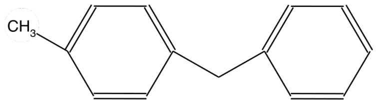
Toxicity

LD_{50} oral, rat [mg/kg] (source)	
LC_{50} fish (96 h) [mg/l] (source)	
LC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} algae (72 h) [mg/l] (source)	

Common name (CAS No.) **Benzyltoluenes (27776-01-8)**

Capacitor type occurrence: Non-polarised cylindrical, microwave

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	No	No	Yes

Physical properties

Molar mass [g/mol] (source)	182.26 (1)
Density (20 °C) [g/cm³] (source)	0.995 (1)
Melting point [°C] (source)	–12 (3)
Boiling point [°C] (source)	285 (1)
Vapour pressure (20 °C) [hPa] (source)	0.0066 (1)
Ignition temperature [°C] (source)	510 (1)

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
No (DT_{50} > 1 year)	Under development
Degradation products, Eawag Biocatalysis/Biodegradation database	
Unknown	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
3 (1)	4.3 (1)	476 (6)

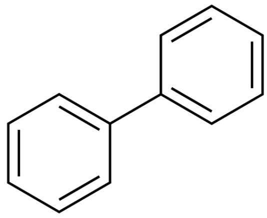
Toxicity

LD_{50} oral, rat [mg/kg] (source)	2,531 (inhalation: 0.001 mg/m³) (10)
LC_{50} fish (96 h) [mg/l] (source)	0.31 (10)
LC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} crustaceans (48 h) [mg/l] (source)	0.4 (10)
EC_{50} algae (72 h) [mg/l] (source)	0.9 (10)

Common name (CAS No.) **Biphenyl (92-52-4)**

Capacitor type occurrence: Non-polarised cylindrical

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	Yes	No	Suspected

Physical properties

Molar mass [g/mol] (source)	154.21 (1)
Density (20 °C) [g/cm^3] (source)	1.04 (1)
Melting point [°C] (source)	69 (1)
Boiling point [°C] (source)	255 (1)
Vapour pressure (20 °C) [hPa] (source)	<0.1 (2)
Ignition temperature [°C] (source)	540 (1)

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
Yes, but being studied because potential for PBT	Under development under SEV
Degradation products, Eawag Biocatalysis/Biodegradation database	
cis-2,3-Dihydro-2,3-dihydroxybiphenyl, CAS No. 34244-66-1	

Distribution in the environment

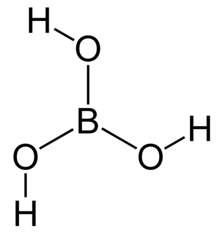
Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
4.45 (1)	3.98 (1)	206 (6)

Toxicity

LD_{50} oral, rat [mg/kg] (source)	2,140 (1)
LC_{50} fish (96 h) [mg/l] (source)	3.5 (1)
LC_{50} crustaceans (48 h) [mg/l] (source)	1.9 (1)
EC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} algae (72 h) [mg/l] (source)	1.16 (1)

Common name (CAS No.)	**Boric acid (11113-50-1, 10043-35-3)**
Capacitor type occurrence:	E-cap

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	**Easily biodegradable?**	**CMT?**	**Substance of concern in recycling?**
Yes	No	Yes	Yes

Physical properties

Molar mass [g/mol] (source)	61.83 (1)
Density (20 °C) [g/cm³] (source)	1.435 (1)
Melting point [°C] (source)	169.5 (1)
Boiling point [°C] (source)	
Vapour pressure (20 °C) [hPa] (source)	0 (10)
Ignition temperature [°C] (source)	

Stability in the environment

Biodegradable according to REACH dossier	**Persistence, bioaccumulation, toxicity according to the ECHA?**
No dossier available	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Decomposition temperature: 100 °C to 130 °C, formation of metaboric acid by dehydration, at 160 °C formation of glassy boron trioxide melt (CAS No. 1303-86-2) (Gestis). Boron trioxide is H360FD, substance of concern	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	**Octanol/water partition coefficient log K_{ow} (source)**	**BCF [l/kg wet mass] (source)**
50,000 (2)	0.757 (1)	3.162 (6)

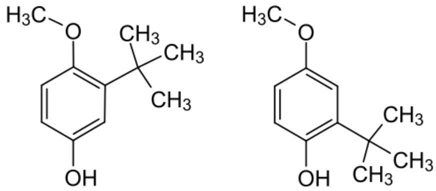
Toxicity

LD_{50} oral, rat [mg/kg] (source)	
LC_{50} fish (96 h) [mg/l] (source)	487 (1)
LC_{50} crustaceans (48 h) [mg/l] (source)	180 (1)
EC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} algae (72 h) [mg/l] (source)	

Common name (CAS No.) **Butylated hydroxyanisole (25013-16-5)**

Capacitor type occurrence: Non-polarised cylindrical

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	Yes	Yes	Yes

Physical properties

Molar mass [g/mol] (source)	180.25 (1)
Density (20 °C) [g/cm³] (source)	0.69 (10)
Melting point [°C] (source)	59 (1)
Boiling point [°C] (source)	268 (1)
Vapour pressure (20 °C) [hPa] (source)	0.00311 (10)
Ignition temperature [°C] (source)	

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
Yes	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Unknown	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
213 (1)	3.5 (1)	57.07 (6)

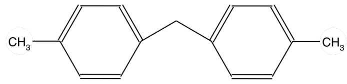
Toxicity

LD_{50} oral, rat [mg/kg] (source)	
LC_{50} fish (96 h) [mg/l] (source)	1 (5)
LC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} algae (72 h) [mg/l] (source)	

Common name (CAS No.) **Di-p-tolyl-methane (4957-14-6)**

Capacitor type occurrence: Microwaves

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	No	No	Yes

Physical properties

Molar mass [g/mol] (source)	169.3 (2)
Density (20 °C) [g/cm³] (source)	
Melting point [°C] (source)	28 (2)
Boiling point [°C] (source)	286 (2)
Vapour pressure (20 °C) [hPa] (source)	<0.1 (6)
Ignition temperature [°C] (source)	

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
No dossier available	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Unknown	

Distribution in the environment

Water solubility 25°C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
2.7 (6)	5.11 (6)	1,093 (6)

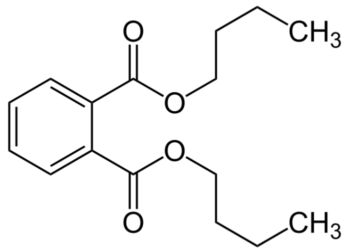
Toxicity

LD_{50} oral, rat [mg/kg] (source)	
LC_{50} fish (96 h) [mg/l] (source)	
LC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} algae (72 h) [mg/l] (source)	

Common name (CAS No.) **Dibutyl phthalate (84-74-2)**

Capacitor type occurrence: Non-polarised cylindrical

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	Yes	Yes	Yes

Physical properties

Molar mass [g/mol] (source)	278.35 (1)
Density (20 °C) [g/cm³] (source)	1.05 (1)
Melting point [°C] (source)	–35 (1)
Boiling point [°C] (source)	340 (1)
Vapour pressure (20 °C) [hPa] (source)	<0.1 (1)
Ignition temperature [°C] (source)	400 (1)

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
Yes	Postponed
Degradation products, Eawag Biocatalysis/Biodegradation database	
Tert-butyl alcohol + monobutyl phthalate	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
11.2 (1)	4.5 (2)	433 (6)

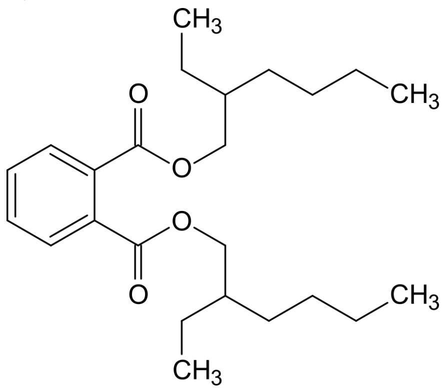
Toxicity

LD_{50} oral, rat [mg/kg] (source)	7,500 (1)
LC_{50} fish (96 h) [mg/l] (source)	1.51 (1)
LC_{50} crustaceans (48 h) [mg/l] (source)	3.7 (1)
EC_{50} crustaceans (48 h) [mg/l] (source)	2.99 (1)
EC_{50} algae (72 h) [mg/l] (source)	0.4 (1)

Common name (CAS No.) **Diethylhexyl phthalate (117-81-7)**

Capacitor type occurrence: Non-polarised cylindrical

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	Yes	Yes	Yes

Physical properties

Molar mass [g/mol] (source)	390.56 (1)
Density (20 °C) [g/cm^3] (source)	0.99 (1)
Melting point [°C] (source)	–52.5 (1)
Boiling point [°C] (source)	385 (1)
Vapour pressure (20 °C) [hPa] (source)	<0.1 (1)
Ignition temperature [°C] (source)	370 (1)

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
Yes	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Unknown	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
<0.1 (1)	7.88 (2)	1,712 (6)

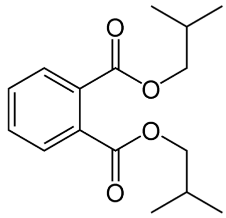
Toxicity

LD_{50} oral, rat [mg/kg] (source)	30,000 (1)
LC_{50} fish (96 h) [mg/l] (source)	1,110 (1)
LC_{50} crustaceans (48 h) [mg/l] (source)	11 (1)
EC_{50} crustaceans (48 h) [mg/l] (source)	0.13 (1)
EC_{50} algae (72 h) [mg/l] (source)	

Common name (CAS No.) **Diisobutyl phthalate (84-69-5)**

Capacitor type occurrence: Non-polarised cylindrical

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	Yes	Yes	Yes

Physical properties

Molar mass [g/mol] (source)	278.35 (1)
Density (20 °C) [g/cm³] (source)	1.039 (1)
Melting point [°C] (source)	–64 (1)
Boiling point [°C] (source)	327 (1)
Vapour pressure (20 °C) [hPa] (source)	0.112 (1)
Ignition temperature [°C] (source)	423 (1)

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
No dossier available	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Unknown	

Distribution in the environment

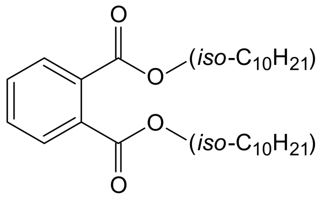
Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
20 (1)	4.11 (2)	239.2 (6)

Toxicity

LD_{50} oral, rat [mg/kg] (source)	15,000 (1)
LC_{50} fish (96 h) [mg/l] (source)	0.9 (2)
LC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} algae (72 h) [mg/l] (source)	

Common name (CAS No.) **Diisodecyl phthalate (26761-40-0)**

Capacitor type occurrence: Microwaves



Structural formula:

Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Suspected	No	No	Suspected

Physical properties

Molar mass [g/mol] (source)	446.67 (1)
Density (20 °C) [g/cm³] (source)	0.96 (1)
Melting point [°C] (source)	–50 (1)
Boiling point [°C] (source)	420 (12)
Vapour pressure (20 °C) [hPa] (source)	<0.1 (1)
Ignition temperature [°C] (source)	380 (1)

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Unknown	

Distribution in the environment

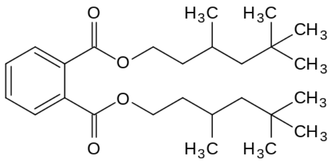
Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
0.28 (1)	10.36 (6)	14.4 (12)

Toxicity

LD_{50} oral, rat [mg/kg] (source)	64,000 (1)
LC_{50} fish (96 h) [mg/l] (source)	
LC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} algae (72 h) [mg/l] (source)	

Common name (CAS No.)	**Diisononyl phthalate (28553-12-0)**
Capacitor type occurrence:	Microwaves

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	**Easily biodegradable?**	**CMT?**	**Substance of concern in recycling?**
Suspected	No	No	Suspected

Physical properties

Molar mass [g/mol] (source)	418.62 (1)
Density (20 °C) [g/cm^3] (source)	0.97 (1)
Melting point [°C] (source)	–48 (1)
Boiling point [°C] (source)	260 (1)
Vapour pressure (20 °C) [hPa] (source)	<0.1 (1)
Ignition temperature [°C] (source)	375 (1)

Stability in the environment

Biodegradable according to REACH dossier	**Persistence, bioaccumulation, toxicity according to the ECHA?**
	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Unknown	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	**Octanol/water partition coefficient log K_{ow} (source)**	**BCF [l/kg wet mass] (source)**
<0.1 (1)	9.37 (6)	231.3 (6)

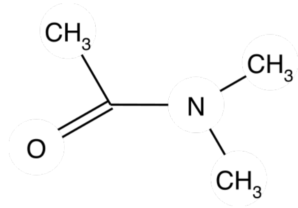
Toxicity

LD_{50} oral, rat [mg/kg] (source)	
LC_{50} fish (96 h) [mg/l] (source)	
LC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} algae (72 h) [mg/l] (source)	

Common name (CAS No.) **Dimethylacetamide (127-19-5)**

Capacitor type occurrence: E-cap

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	Yes	Yes	Yes

Physical properties

Molar mass [g/mol] (source)	87.12 (1)
Density (20 °C) [g/cm³] (source)	0.94 (1)
Melting point [°C] (source)	–20 (1)
Boiling point [°C] (source)	165 (1)
Vapour pressure (20 °C) [hPa] (source)	3.3 (1)
Ignition temperature [°C] (source)	400 (1)

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
Yes	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Unknown	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
Mixable (1)	–0.77 (1)	3 (6)

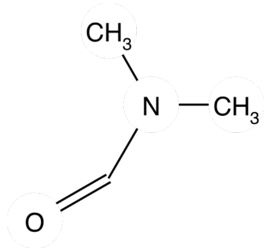
Toxicity

LD_{50} oral, rat [mg/kg] (source)	4,300 (1)
LC_{50} fish (96 h) [mg/l] (source)	1,000 (5)
LC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} crustaceans (48 h) [mg/l] (source)	>1,000 (10)
EC_{50} algae (72 h) [mg/l] (source)	>500 (10)

Common name (CAS No.) **Dimethylformamide (68-12-2)**

Capacitor type occurrence: E-cap

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	Yes	Yes	Yes

Physical properties

Molar mass [g/mol] (source)	73.09 (1)
Density (20 °C) [g/cm^3] (source)	0.95 (1)
Melting point [°C] (source)	–61 (1)
Boiling point [°C] (source)	153 (1)
Vapour pressure (20 °C) [hPa] (source)	3.77 (1)
Ignition temperature [°C] (source)	440 (1)

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
Yes	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Dimethylamine	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
Mixable (1)	–1.01 (1)	3 (6)

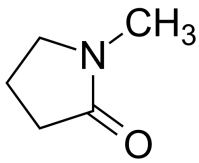
Toxicity

LD_{50} oral, rat [mg/kg] (source)	2,800 (1)
LC_{50} fish (96 h) [mg/l] (source)	10,500 (1)
LC_{50} crustaceans (48 h) [mg/l] (source)	14,400 (1)
EC_{50} crustaceans (48 h) [mg/l] (source)	12,800 (1)
EC_{50} algae (72 h) [mg/l] (source)	>1,000 (10)

Common name (CAS No.) **N-Methylpyrrolidone (872-50-4)**

Capacitor type occurrence: E-cap

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	Yes	Yes	Yes

Physical properties

Molar mass [g/mol] (source)	99.13 (1)
Density (20 °C) [g/cm³] (source)	1.03 (1)
Melting point [°C] (source)	–24 (1)
Boiling point [°C] (source)	203 (1)
Vapour pressure (20 °C) [hPa] (source)	0.32 (1)
Ignition temperature [°C] (source)	265 (1)

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
Yes	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Unknown	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
Mixable (1)	–0.38 (2)	3.162 (6)

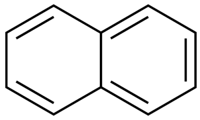
Toxicity

LD_{50} oral, rat [mg/kg] (source)	3,910 (1)
LC_{50} fish (96 h) [mg/l] (source)	832 (5)
LC_{50} crustaceans (48 h) [mg/l] (source)	1.23 (1)
EC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} algae (72 h) [mg/l] (source)	600.5 (10)

Common name (CAS No.) **Naphthalene (91-20-3)**

Capacitor type occurrence: Non-polarised cylindrical

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	No	Yes	Yes

Physical properties

Molar mass [g/mol] (source)	128.17 (1)
Density (20 °C) [g/cm^3] (source)	1.14 (1)
Melting point [°C] (source)	80 (1)
Boiling point [°C] (source)	218 (1)
Vapour pressure (20 °C) [hPa] (source)	7.2 (1)
Ignition temperature [°C] (source)	540 (1)

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
No, according to Risk Assessment (UK 2007), objection by manufacturer in registration dossier	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
cis-1,2-Dihydroxy-1,2-dihydronaphthalene 2,3-Dihydroxynaphthalene	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
31 (1)	3.35 (1)	69.9 (6)

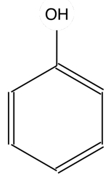
Toxicity

LD_{50} oral, rat [mg/kg] (source)	490 (1)
LC_{50} fish (96 h) [mg/l] (source)	1.99 (1)
LC_{50} crustaceans (48 h) [mg/l] (source)	11.8 (1)
EC_{50} crustaceans (48 h) [mg/l] (source)	3.6 (1)
EC_{50} algae (72 h) [mg/l] (source)	0.4 (10)

Common name (CAS No.) **Phenol (108-95-2)**

Capacitor type occurrence: E-cap

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Yes	Yes	Yes	Yes

Physical properties

Molar mass [g/mol] (source)	94.11 (1)
Density (20 °C) [g/cm^3] (source)	1.07 (1)
Melting point [°C] (source)	41 (1)
Boiling point [°C] (source)	182 (1)
Vapour pressure (20 °C) [hPa] (source)	0.2 (10)
Ignition temperature [°C] (source)	595 (1)

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
Yes	No study available
Degradation products, Eawag Biocatalysis/Biodegradation database	
Catechol, CAS No. 120-80-9 4-Hydroxybenzoates, CAS No. 99-96-7 Phenyl phosphates, CAS No. 701-64-4	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
84 (1)	1.5 (1)	4.269 (6)

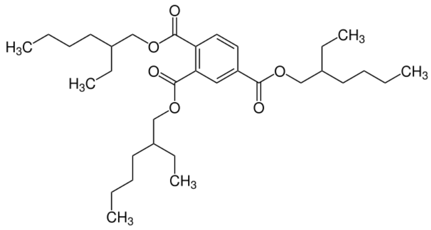
Toxicity

LD_{50} oral, rat [mg/kg] (source)	317 (1)
LC_{50} fish (96 h) [mg/l] (source)	20.5 (1)
LC_{50} crustaceans (48 h) [mg/l] (source)	20 (1)
EC_{50} crustaceans (48 h) [mg/l] (source)	12.6 (1)
EC_{50} algae (72 h) [mg/l] (source)	229 (1)

Common name (CAS No.) **Trioctyl trimellitate (3319-31-1)**

Capacitor type occurrence: Microwaves

Structural formula:



Classification in recycling

Substance of concern based on H-statements?	Easily biodegradable?	CMT?	Substance of concern in recycling?
Suspected		Yes	Suspected

Physical properties

Molar mass [g/mol] (source)	546.78 (1)
Density (20 °C) [g/cm³] (source)	0.988 (1)
Melting point [°C] (source)	–43 (1)
Boiling point [°C] (source)	414 (1)
Vapour pressure (20 °C) [hPa] (source)	<0.1 (1)
Ignition temperature [°C] (source)	410 (1)

Stability in the environment

Biodegradable according to REACH dossier	Persistence, bioaccumulation, toxicity according to the ECHA?
	Under development under SEV
Degradation products, Eawag Biocatalysis/Biodegradation database	
Unknown	

Distribution in the environment

Water solubility 25 °C [mg/l] (source)	Octanol/water partition coefficient log K_{ow} (source)	BCF [l/kg wet mass] (source)
0.1 (1)	11.59 (6)	18.96 (6)

Toxicity

LD_{50} oral, rat [mg/kg] (source)	
LC_{50} fish (96 h) [mg/l] (source)	
LC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} crustaceans (48 h) [mg/l] (source)	
EC_{50} algae (72 h) [mg/l] (source)	

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 6.2.

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 87.

Table 87: Substances which may be present in non-polarised cylindrical capacitors according to literature

Chemical designation	Abbreviation	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	Abbrevi-ation	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 88.

Table 88: Substances which may be present in e-caps according to literature

Chemical designation	Abbre-viation	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

Chemical designation	Abbre-viation	CAS No.	Concerning in recycling
3-Toluic acid		99-04-7	No
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 89.

Table 89: Substances which may be present in microwave capacitors according to literature

Chemical designation	Abbrevi-ation	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 90. 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 90:

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.

A substance must meet both criteria for inclusion in the list of substances of concern.

Table 90: Substances which may be found in unspecified capacitors

Chemical designation	Abbreviation	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 Laboratory reports of analyses

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)

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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
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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).

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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**		

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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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			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**			

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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!

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(Wasser,Boden, Abfall,
Recyclingmaterial)
Akkreditiert nach
ISO 17025
STS-Nr. 0064

Schlieren, 11. Juni 2018

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:

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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

C.3 Laboratory reports of mixed samples

C.3.1 Refrigerators, air conditioners and freezers

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: 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.

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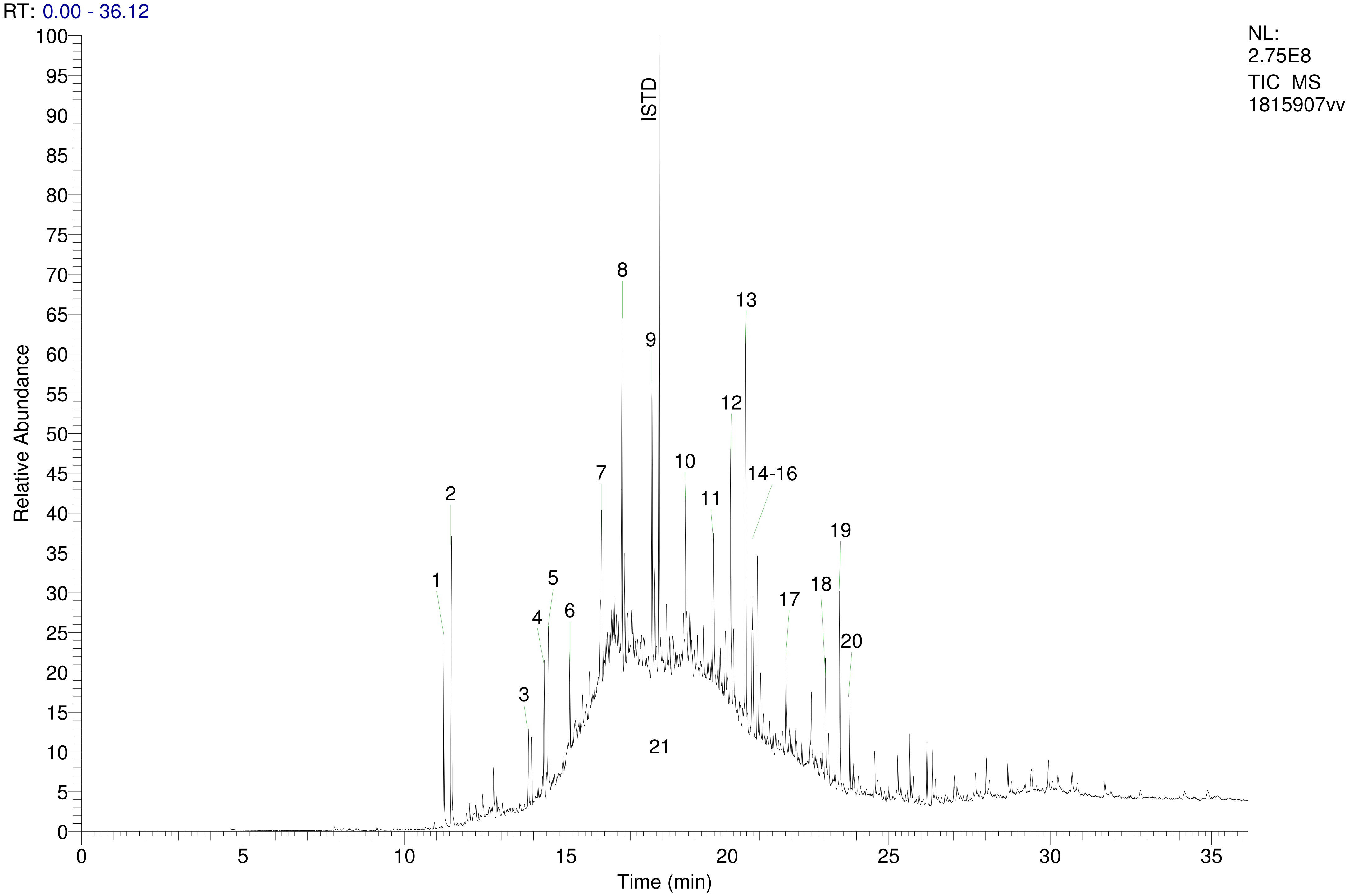
C:\Xcalibur\...\Identifikation\1815907vv 04/25/18 14:59:43



C.3.2 PC and TV flat screens

bachema

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

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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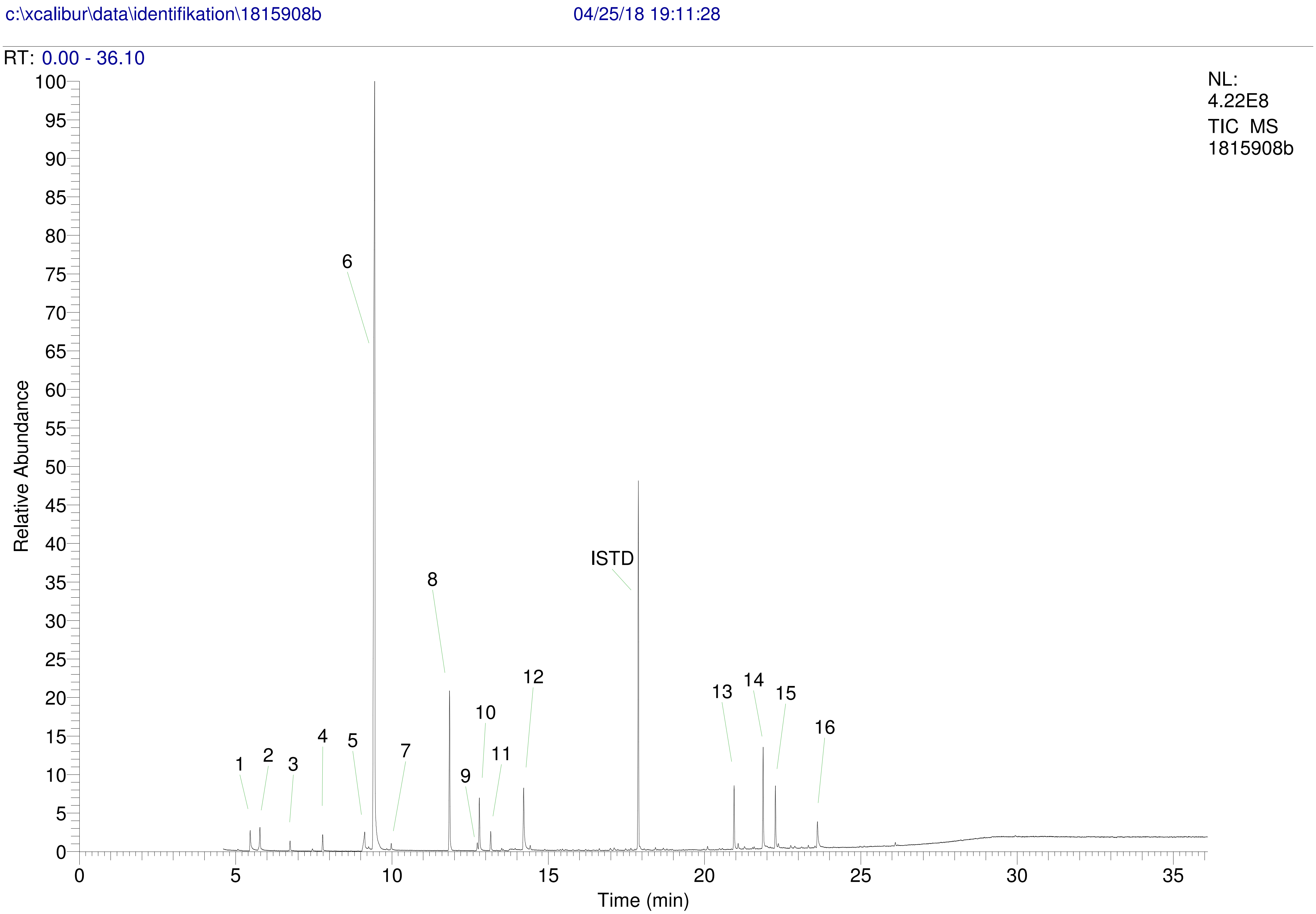

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04/25/18 19:11:28
RT: 0.00 - 36.10
NL:
4.22E8
TIC MS
1815908b
Relative Abundance
Time (min)
1
2
3
4
5
6
7
8
9
10
11
12
ISTD
13
14
15
16

Bachema AG
Analytische Laboratorien

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

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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

Bachema AG
Analytische Laboratorien

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)

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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	C3H7NO	nicht gefunden			
Dimethylacetamid	127-19-5	Amide	Al-Elko	Ja	C4H9NO	nicht gefunden			
N-Methylacetamid	79-16-3	Amide		Ja	C3H7NO	nicht gefunden			
N-Methylformamid	123-39-7	Amide		Ja	C2H5NO	nicht gefunden			
Triethylamin	121-44-8	Amine	Al-Elko	Nein	C6H15N	$[M+H]^+$	5.1	2573	in Spuren, Identität nicht bestätigt
Diethylamin	109-89-7	Amine		Nein	C4H11N	$[M+H]^+$	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	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	nicht gefunden			
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	1168	in Spuren, Identität nicht bestätigt
Polyethylenglycol	25322-68-3	Glycole	Al-Elko	Nein	C2H4O (Monomer)	$[M+H]^+$	8.7	231095	wahrscheinlich Quellenfragment eines grösseren Moleküls
Polyethylenglycol-2					C4H10O3	$[M+H]^+$	8.7	359270	wahrscheinlich Quellenfragment eines grösseren Moleküls
Polyethylenglycol-3					C6H14O4	$[M+H]^+$	5.2	1534	
Polyethylenglycol-4					C8H18O5	$[M+H]^+$	6.0	13196	
Polyethylenglycol-5					C10H22O6	$[M+H]^+$	6.5	81890	
Polyethylenglycol-6					C12H26O7	$[M+H]^+$	6.8	142243	
Polyethylenglycol-7					C14H30O8	$[M+H]^+$	7.1	217672	
Polyethylenglycol-8					C16H34O9	$[M+H]^+$	7.3	202481	
Polyethylenglycol-9					C18H38O10	$[M+H]^+$	7.5	201982	
Polyethylenglycol-10					C20H42O11	$[M+H]^+$	7.7	186892	
Polyethylenglycol-11					C22H46O12	$[M+H]^+$	7.9	190260	
Polyethylenglycol-12					C24H50O13	$[M+H]^+$	8.1	197265	
Polyethylenglycol-13					C26H54O14	$[M+H]^+$	8.2	221065	
Polyethylenglycol-14					C28H58O15	$[M+H]^+$	8.4	231100	
Polyethylenglycol-15					C30H62O16	$[M+H]^+$	8.5	212306	
Polyethylenglycol-16					C32H66O17	$[M+H]^+$	8.7	164684	
Polyethylenglycol-17					C34H70O18	$[M+H]^+$	8.9	160690	
Polyethylenglycol-18					C36H74O19	$[M+H]^+$	9.0	96634	
Polyethylenglycol-19					C38H78O20	$[M+H]^+$	9.2	55988	
Polyethylenglycol-20					C40H82O21	$[M+H]^+$	9.3	40309	
Polyethylenglycol-21					C42H86O22	$[M+H]^+$	9.5	24537	
Polyethylenglycol-22					C44H90O23	$[M+H]^+$	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

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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STS-Nr. 0064

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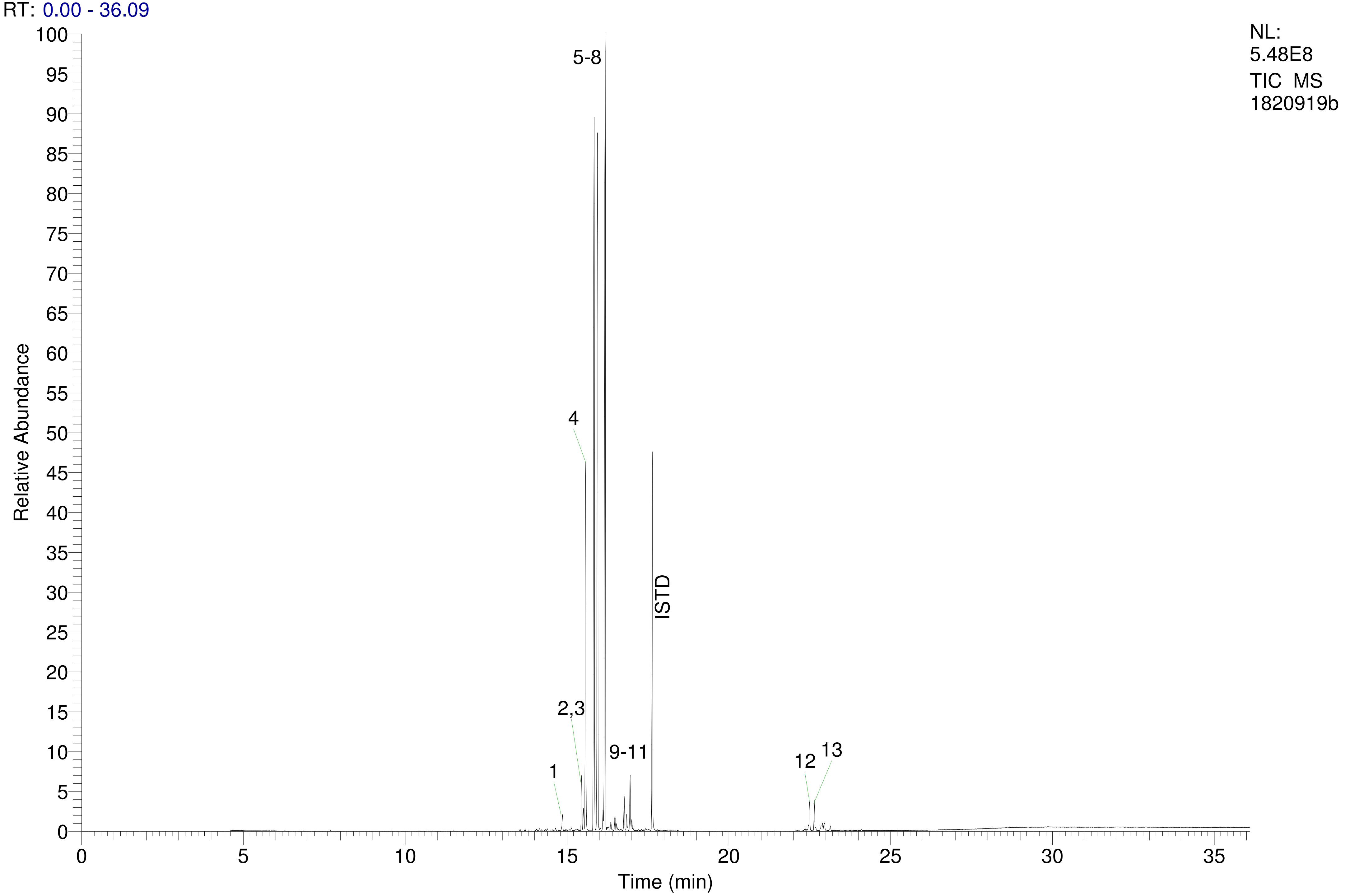

C.3.4 Microwaves of other manufacturers

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.

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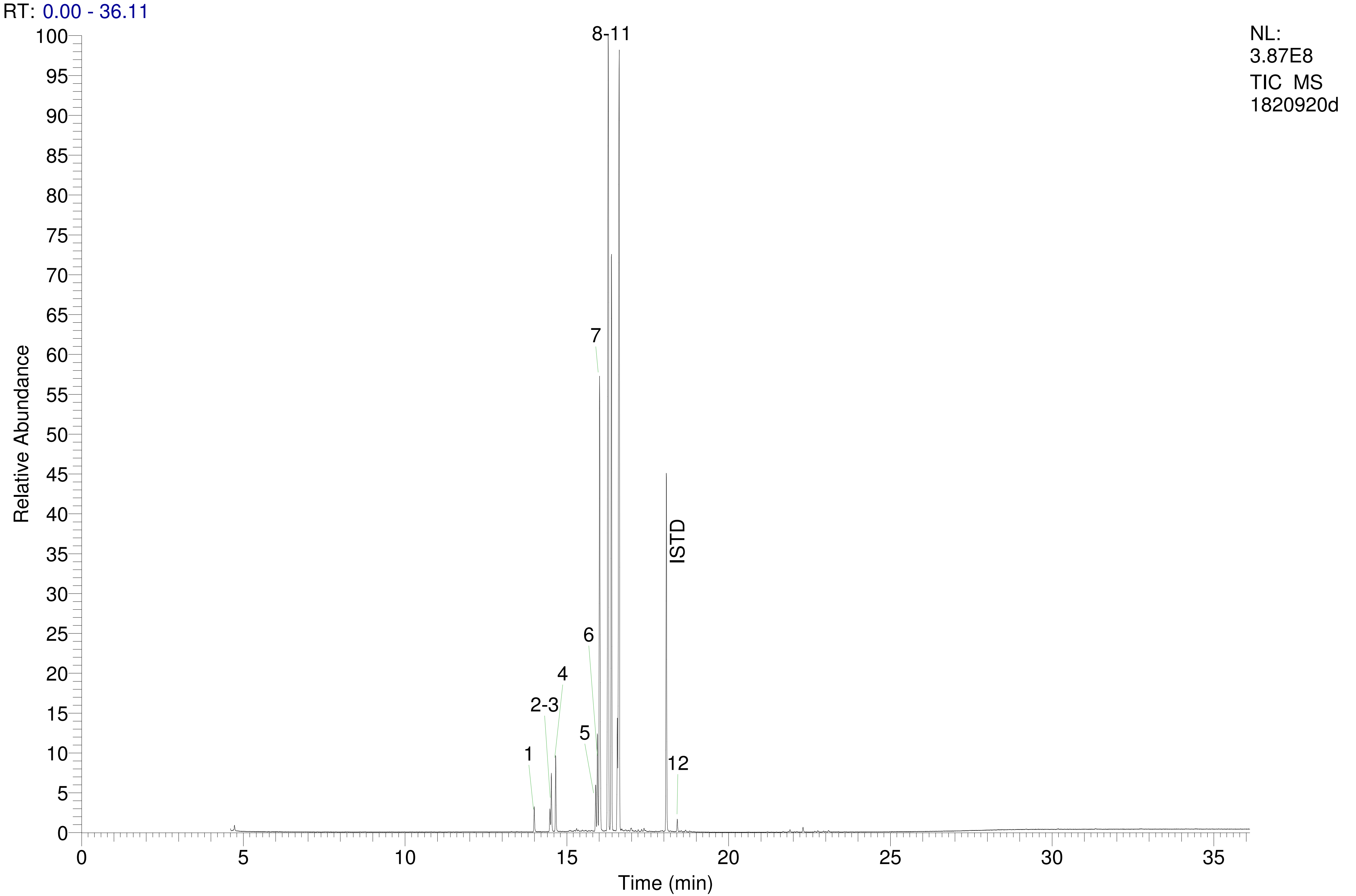

C.3.5 SENS small appliances, non-polarised cylindrical capacitors

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: 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.

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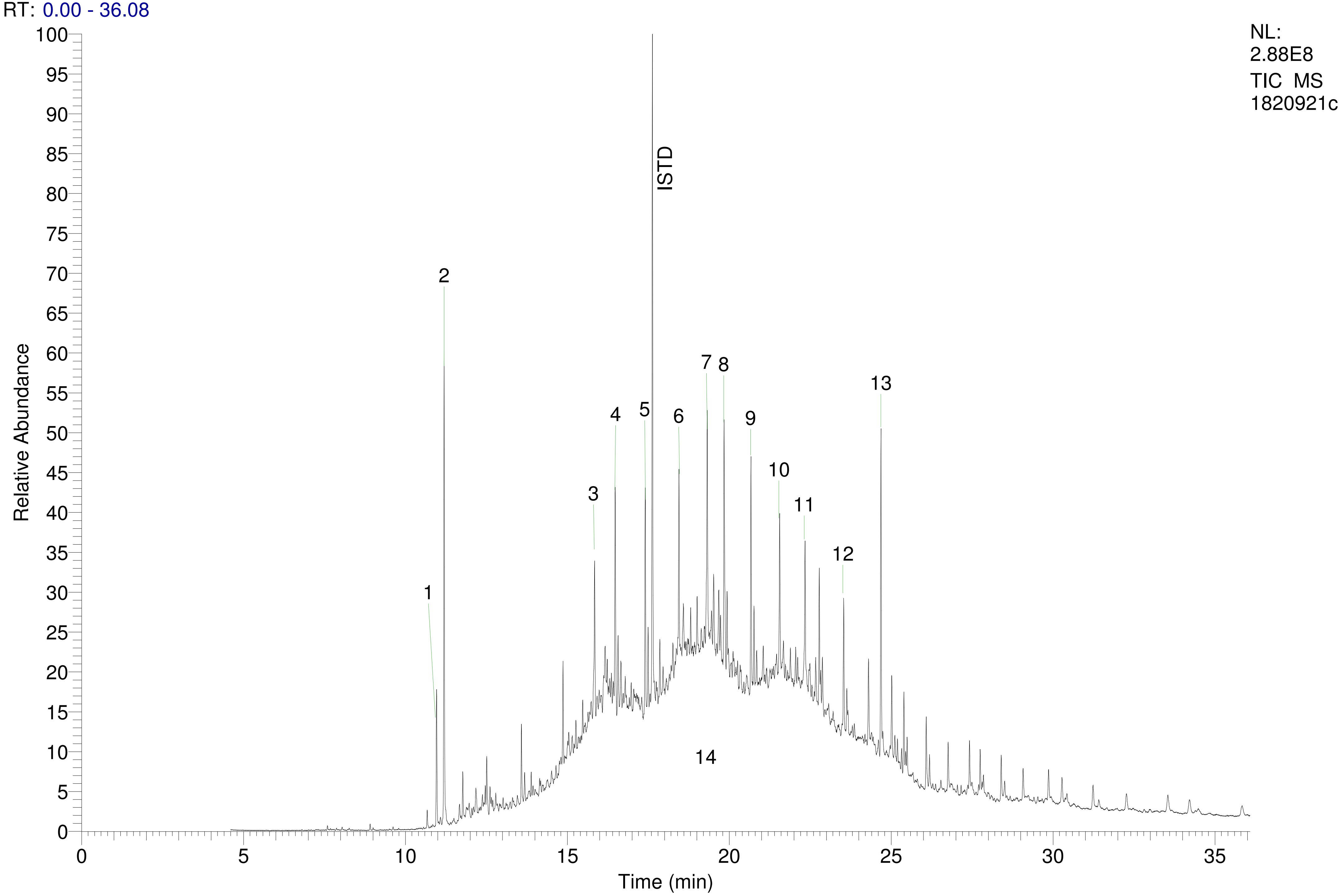

C.3.6 Large household appliances

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.

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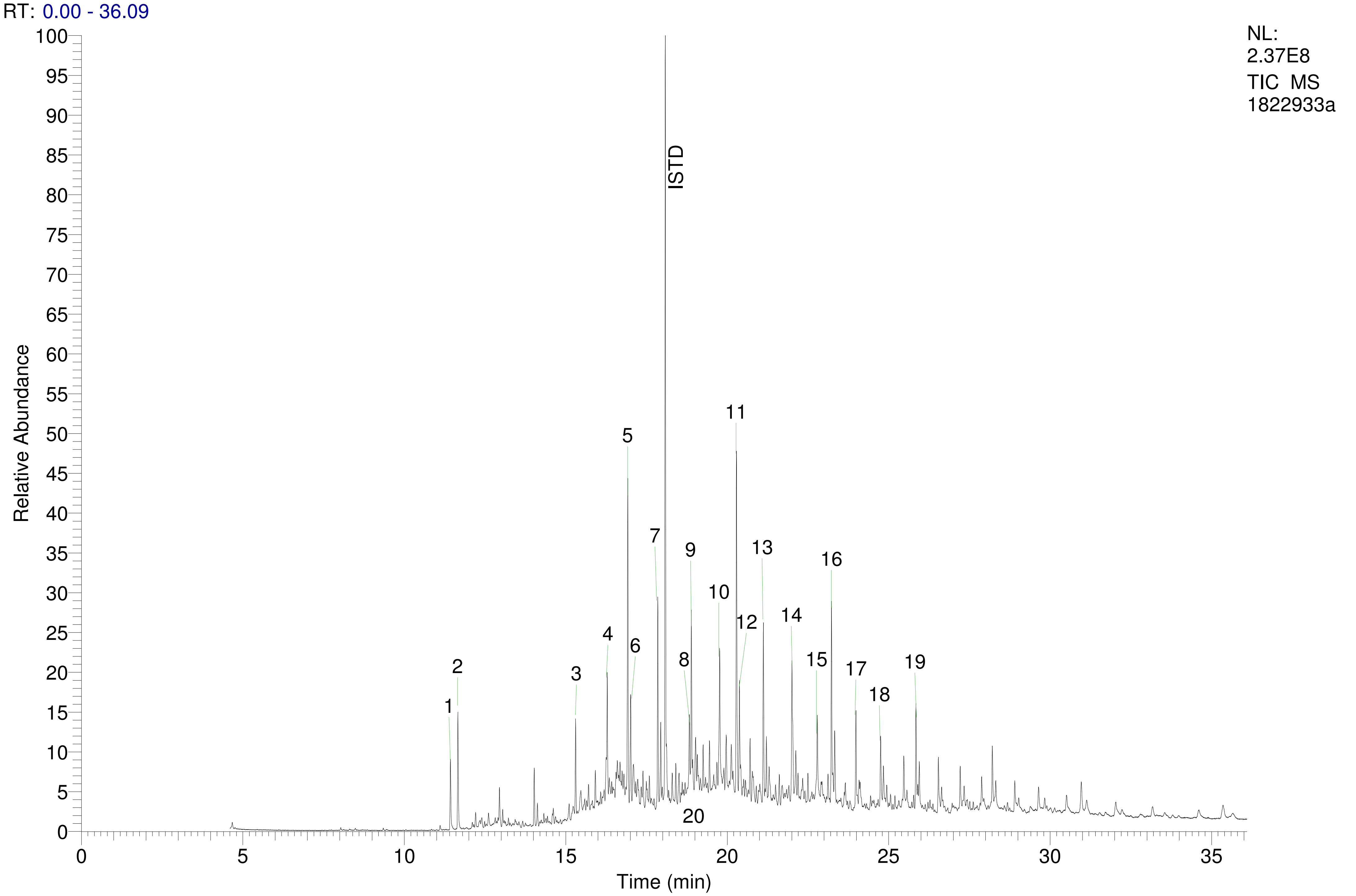

C.3.7 SENS small appliances, electrolytic capacitors

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.

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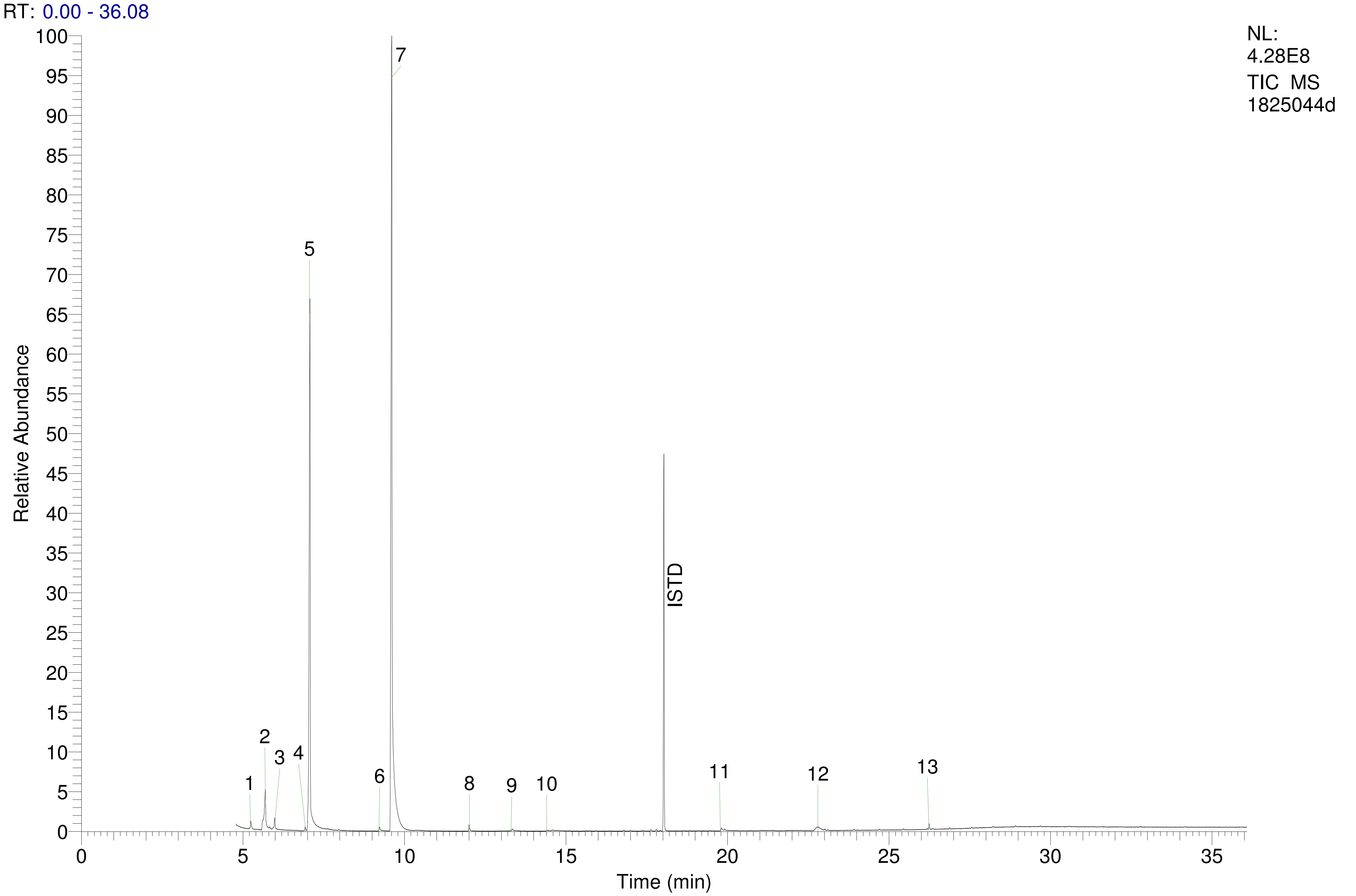

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie
Auftrags-Nr. Bachema: 201805939

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

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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

bachema

Bachema AG
Analytische Laboratorien

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					**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	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	

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

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

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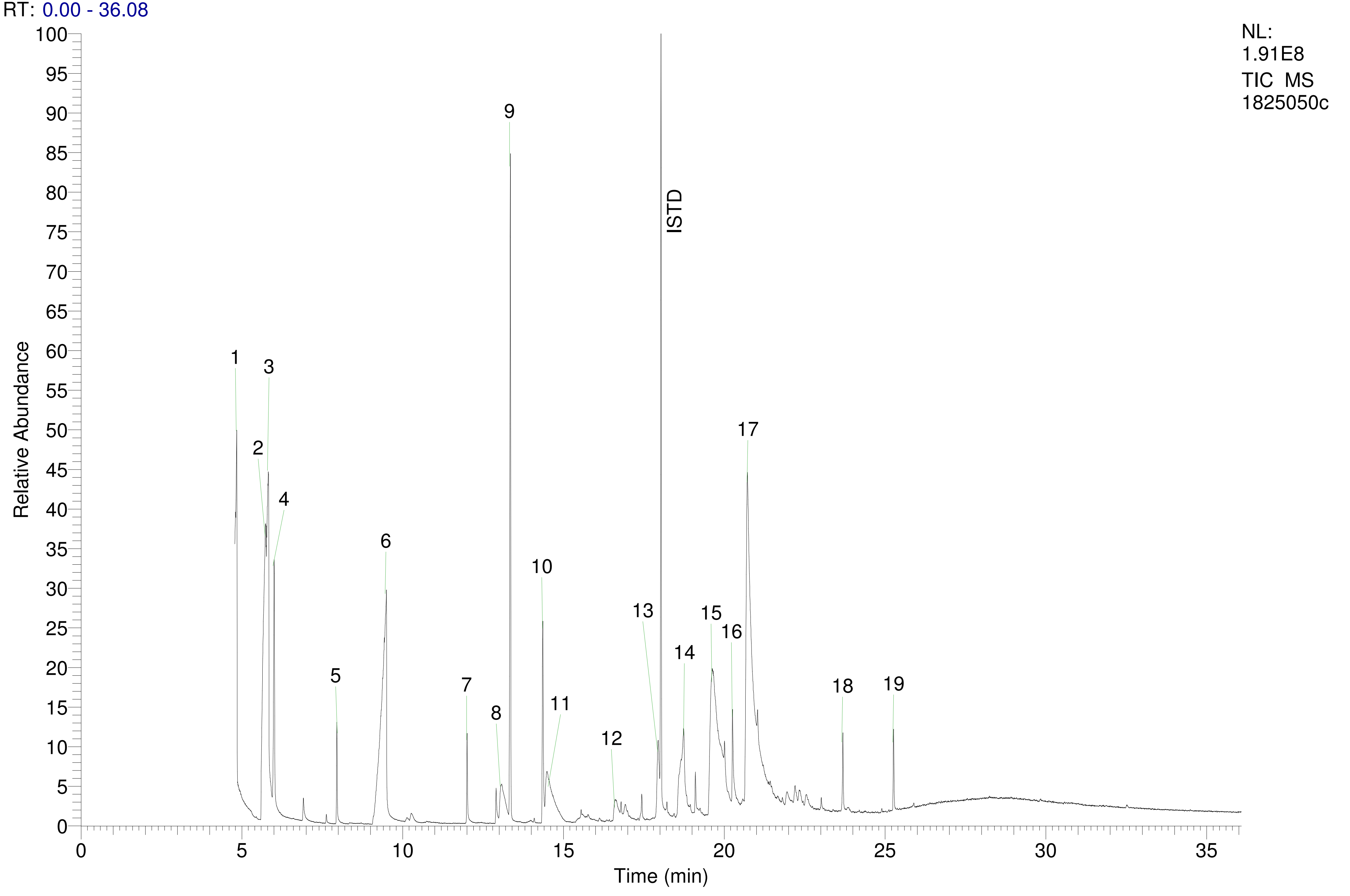
Fit Gibt an, wie genau das Spektrum der Probensubstanz mit einem Referenzspektrum übereinstimmt.
99 = identisch
>90 = sehr gute Übereinstimmung
>70 = mässige Übereinstimmung

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\1825050c 06/22/18 16:29:42



Bachema AG
Analytische Laboratorien

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

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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

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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 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

					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	C3H7NO	nicht gefunden			
Dimethylacetamid	127-19-5	Amide	Al-Elko	Ja	C4H9NO	nicht gefunden			
N-Methylacetamid	79-16-3	Amide		Ja	C3H7NO	nicht gefunden			
N-Methylformamid	123-39-7	Amide		Ja	C2H5NO	nicht gefunden			
Triethylamin	121-44-8	Amine	Al-Elko	Nein	C6H15N	$[M+H]^+$	5.1	1407	Identität nicht bestätigt
Diethylamin	109-89-7	Amine		Nein	C4H11N	$[M+H]^+$	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	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	$[M-H]^-$	7.1	21665	Identität nicht bestätigt
1,3-Benzoldicarbonsäure	121-91-5	Organische Säuren	Al-Elko	Nein	C8H6O4	$[M-H]^-$	7.1	21665	Identität nicht bestätigt
1,4-Benzoldicarbonsäure	100-21-0	Organische Säuren	Al-Elko	Nein	C8H6O4	$[M-H]^-$	7.1	21665	Identität nicht bestätigt
2-Hydroxybenzoesäure, Salicylsäure	69-72-7	Organische Säuren	Al-Elko	Nein	C7H6O3	[M-H]-	8.9	3225	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	nicht gefunden			
Polyethylenglycol	25322-68-3	Glycole	Al-Elko	Nein	C2H4O (Monomer)	$[M+H]^+$	2.0 & 2.7	14271	wahrscheinlich Quellenfragment eines grösseren Moleküls
Polyethylenglycol-2					C4H10O3	nicht gefunden			
Polyethylenglycol-3					C6H14O4	nicht gefunden			
Polyethylenglycol-4					C8H18O5	nicht gefunden			
Polyethylenglycol-5					C10H22O6	nicht gefunden			
Polyethylenglycol-6					C12H26O7	$[M+H]^+$	6.8	11279	
Polyethylenglycol-7					C14H30O8	$[M+H]^+$	7.0	12135	
Polyethylenglycol-8					C16H34O9	$[M+H]^+$	7.3	7898	
Polyethylenglycol-9					C18H38O10	$[M+H]^+$	7.5	7583	
Polyethylenglycol-10					C20H42O11	$[M+H]^+$	7.7	7893	
Polyethylenglycol-11					C22H46O12	$[M+H]^+$	7.8	8025	
Polyethylenglycol-12					C24H50O13	$[M+H]^+$	8.0	6765	
Polyethylenglycol-13					C26H54O14	$[M+H]^+$	8.2	4799	
Polyethylenglycol-14					C28H58O15	$[M+H]^+$	8.4	3588	
Polyethylenglycol-15					C30H62O16	$[M+H]^+$	8.5	2889	
Polyethylenglycol-16					C32H66O17	$[M+H]^+$	8.7	2880	
Polyethylenglycol-17					C34H70O18	$[M+H]^+$	8.8	2386	
Polyethylenglycol-18					C36H74O19	$[M+H]^+$	9.0	1904	
Polyethylenglycol-19					C38H78O20	$[M+H]^+$	9.2	883	
Polyethylenglycol-20					C40H82O21	$[M+H]^+$	9.3	521	
Polyethylenglycol-21					C42H86O22	$[M+H]^+$	9.5	569	
Polyethylenglycol-22					C44H90O23	$[M+H]^+$	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.

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

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Recyclingmaterial)
Akkreditiert nach
ISO 17025
STS-Nr. 0064

C.4 Laboratory reports of individual samples

C.4.1 HHGG1, capacitor No. 311

The laboratory report is inserted on the following pages.

Bachema AG
Analytische Laboratorien

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie GmbH
Auftrags-Nr. Bachema: 201906292

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

Proben-Nr. Bachema: 27027
Probenbezeichnung: HHGG 1 (Kond.-Nr. 311)

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

Resultate Das Chromatogramm hat grosse Ähnlichkeit mit der Probe **6 HHG**, Bachema Nr. 22933 (2018), enthält jedoch keine Methylnaphthaline.

Peak Nr.	CAS Nr.	Substanz	Fit (%)	Kommentar	Konz. [mg/kg]
1	NA	Sulfurous acid, cyclohexylmethyl hexyl ester	79	oder ähnliche Verbindung	600
2	NA	Sulfurous acid, cyclohexylmethyl hexadecyl ester	78	oder ähnliche Verbindung	600
3	55162-61-3	3,5,24-Trimethyltetracontan	72	oder ähnliche Verbindung	3000
4		unbekannte Verbindung			1000
5	55255-73-7	2,2,4,10,12,12-hexamethyl-7-(3,5,5-trimethylhexyl)-6-Tridecene	77	oder ähnliche Verbindung	1000
6	NA	Docosyl octyl ether	78	oder ähnliche Verbindung	900
ISTD	16696-65-4	1,11-Dibromoundecan	93	interner Standard	6000
7	110225-00-8	2-Hexyl-1-Dodecanol	76		1000
8	NA	Sulfurous acid, cyclohexylmethyl undecyl ester	76	oder ähnliche Verbindung	2000
9	55255-73-7	2,2,4,10,12,12-Hexamethyl-7-(3,5,5-trimethylhexyl)-6-tridecene	76	oder ähnliche Verbindung	1000
10		unbekannte Verbindung			3000
11	NA	Heptyl hexacosyl ether	75	oder ähnliche Verbindung	2000
12	NA	Carbonic acid, eicosyl vinyl ester	78	oder ähnliche Verbindung	800
13	NA	Octyl tetracosyl ether	73	oder ähnliche Verbindung	1000
14	NA	Sulfurous acid, cyclohexylmethyl hexadecyl ester	74	oder ähnliche Verbindung	2000
15	5333-42-6	2-Octyl-1-Dodecanol	77	oder ähnliche Verbindung	700
16		Heptyl hexacosyl ether	70	oder ähnliche Verbindung	2000
17		unbekannte Verbindung			1000
18	55255-73-7	2,2,4,10,12,12-hexamethyl-7-(3,5,5-trimethylhexyl)-6-Tridecene	73	oder ähnliche Verbindung	1000
19	NA	Heptyl octacosyl ether	73	oder ähnliche Verbindung	900
20		unbekannte Verbindung			1000
21	NA	Heptyl hexacosyl ether	72	oder ähnliche Verbindung	1000
22		unbekannte Verbindung			600
23		unbekannte Verbindung			700
24		unbekannte Verbindung			1000
25		unbekannte Verbindung			1000
26		unbekannte Verbindung			500
27		Kohlenwassertoffgemisch		RT 14-30 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

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.
n.q. = nicht quantifizierbar

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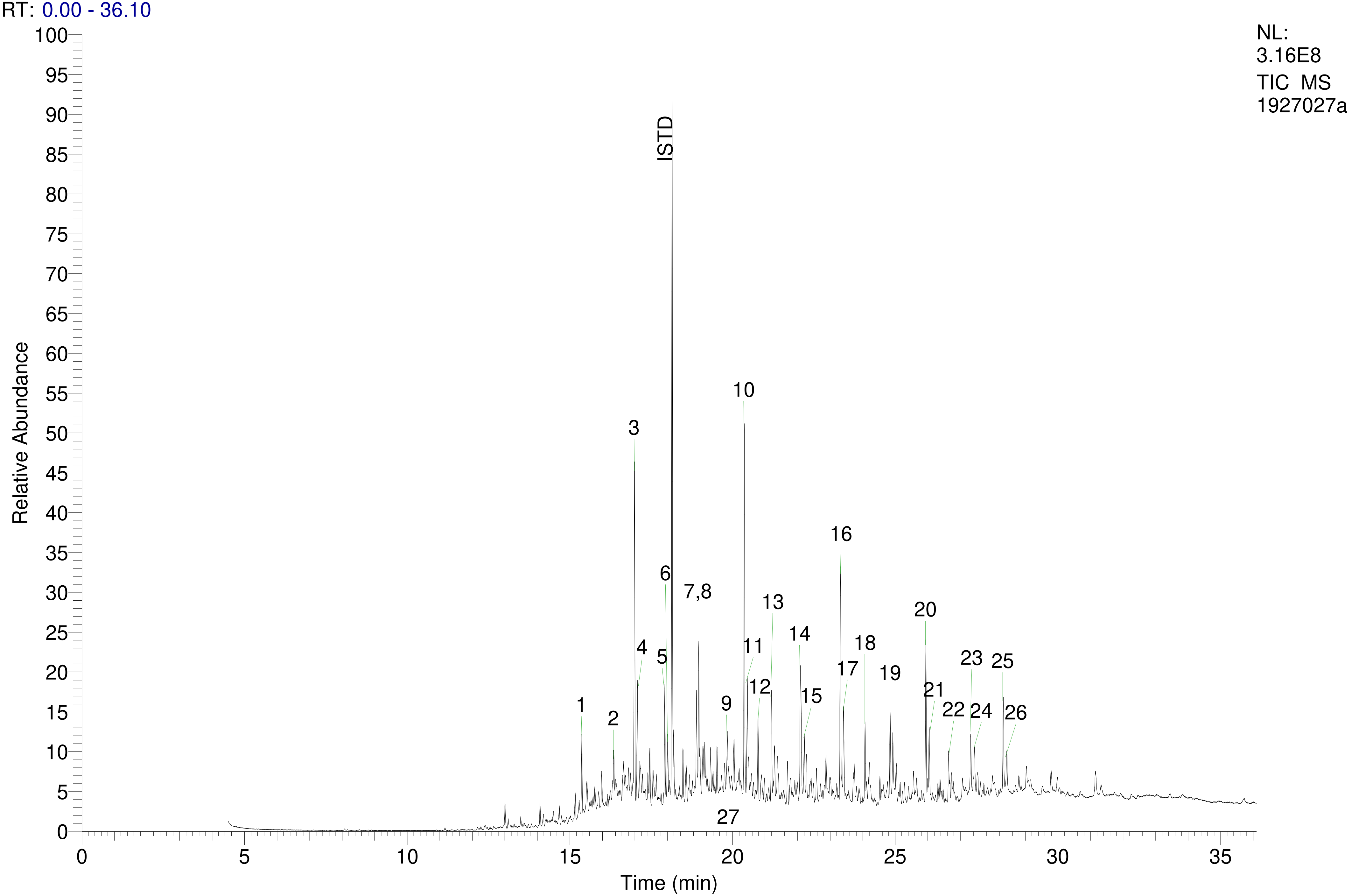

C.4.2 HHGG2, capacitor No. 109

The laboratory report is inserted on the following pages.

Bachema AG
Analytische Laboratorien

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie GmbH
Auftrags-Nr. Bachema: 201906292

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

Proben-Nr. Bachema: 27028
Probenbezeichnung: HHGG 2 (Kond.-Nr. 109)

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]
B				auch im Laborblindwert vorhanden	
1		unbekannte Verbindung			50
2	21662-09-9	Cis-4-decenal	81	oder ähnliche Verbindung	50
3	21662-09-9	Cis-4-decenal	80	oder ähnliche Verbindung	100
4		unbekannte Verbindung			50
ISTD	16696-65-4	(1,11-Dibromoundecane)	94	interner Standard	3000
5	6786-21-6	6,7-Dioxabicyclo[3.2.2]non-8-ene	78	oder ähnliche Verbindung	40
6	1004-24-6	4-Methylenecyclohexanemethanol	75	oder ähnliche Verbindung	300
7	1679-51-2	3-Cyclohexene-1-methanol	75	oder ähnliche Verbindung	40
8	127062-51-5	13-Hexyloxacyclotridec-10-en-2-one	89		100
9	2386-87-0	3,4-Epoxycyclohexylmethyl 3,4-epoxycyclohexanecarboxylate	93	oder Isomer	6000
10	2386-87-0	3,4-Epoxycyclohexylmethyl 3,4-epoxycyclohexanecarboxylate	87	oder Isomer	2000
11	2386-87-0	3,4-Epoxycyclohexylmethyl 3,4-epoxycyclohexanecarboxylate	89	oder Isomer	2000
12		unbekannte Verbindung			90
13		unbekannte Verbindung			40
14		unbekannte Verbindung			300
15		unbekannte Verbindung			40
16	474-62-4	Campesterol	74	oder ähnliches Hormon	60
17	83-48-7	Stigmasterol	87	oder ähnliches Hormon	200
18	83-46-5	α-Sitosterol	86	oder ähnliches Hormon	300
19	56362-45-9	24-Methyl-5-cholestene-3-ol	71	oder ähnliches Hormon	100
20		unbekannte Verbindung		vermutlich ein Hormon	30
21		Kohlenwasserstoffgemisch		RT 23-30 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

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.
n.q. = nicht quantifizierbar

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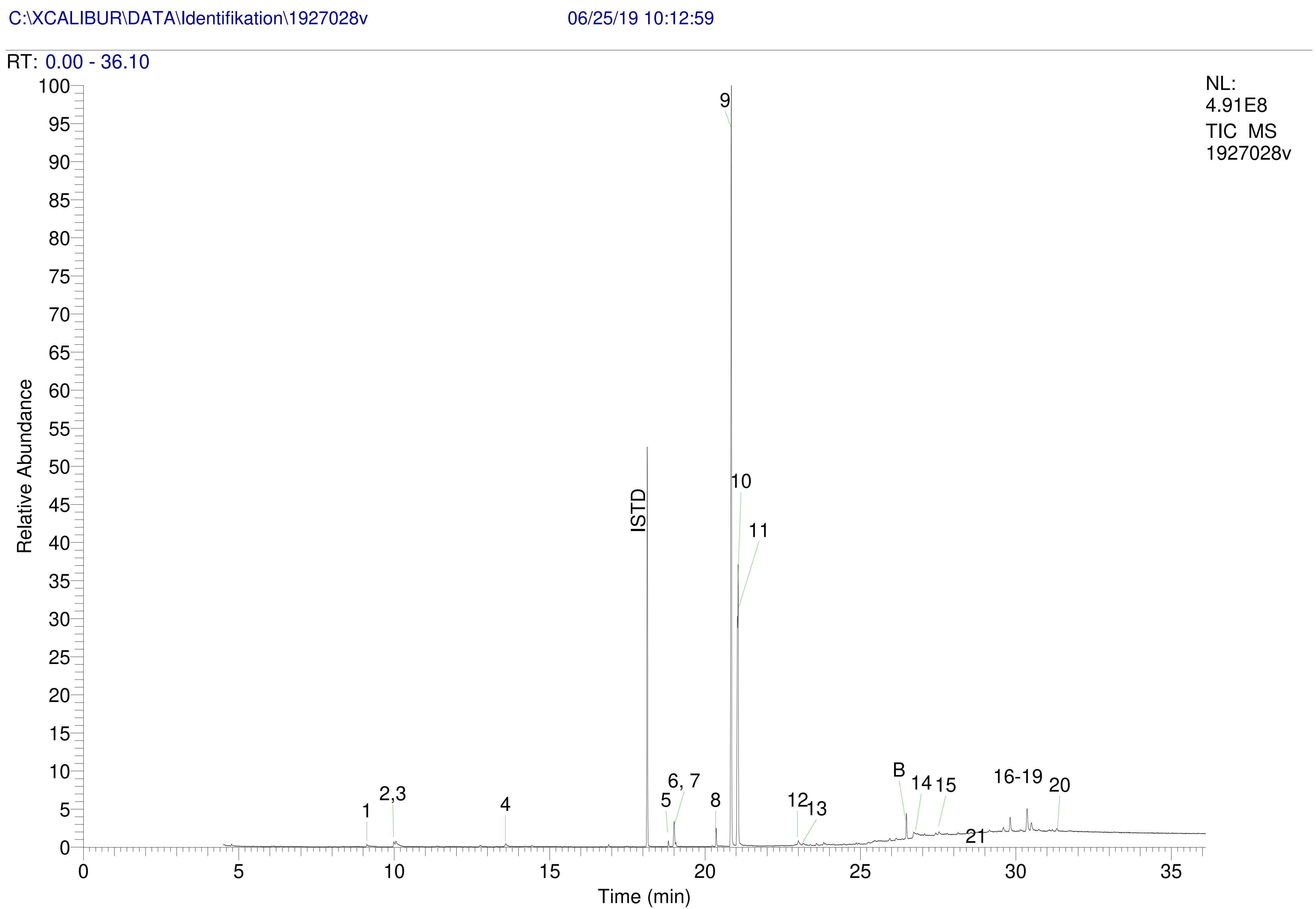
Akkreditiert nach ISO 17025
STS-Nr. 0064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RT: 0.00 - 36.10
NL:
4.91E8
TIC MS
1927028v
Relative Abundance
Time (min)
ISTD
1
2,3
4
5
6, 7
8
9
10
11
12
13
B
14
15
16-19
20
21

C.4.3 HHGG3, capacitor No. 126

The laboratory report is inserted on the following pages.

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie GmbH
Auftrags-Nr. Bachema: 201906292

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

Proben-Nr. Bachema: 27029
Probenbezeichnung: HHGG 3 (Kond.-Nr. 126)

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

Resultate Das Chromatogramm hat grosse Ähnlichkeit mit der Probe **6 HHG**, Bachema Nr. 22933 (2018).

Peak Nr.	CAS Nr.	Substanz	Fit (%)	Kommentar	Konz. [mg/kg]
1	90-12-0	1-Methylnaphthalin	94	oder Isomer	4000
2	90-12-0	1-Methylnaphthalin	93	oder Isomer	6000
3	NA	2,4,4-Triethyl-1-hexen	77	oder ähnliche Verbindung	2000
4	15796-04-0	2,4,4,6,6,8,8-Heptamethyl-1-nonen	77	oder ähnliche Verbindung	1000
5	NA	Sulfurous acid, cyclohexylmethyl hexadecyl ester	79	oder ähnliche Verbindung	2000
6	NA	Sulfurous acid, cyclohexylmethyl hexadecyl ester	79	oder ähnliche Verbindung	3000
7	74685-33-9	(E)-3-Eicosene	82	oder ähnliche Verbindung	1000
8	2425-77-6	2-Hexyl-1-decanol	81	oder ähnliche Verbindung	2000
9		unbekannte Verbindung			7000
10		unbekannte Verbindung			2000
11		unbekannte Verbindung			1000
12	55255-73-7	6-Tridecene, 2,2,4,10,12,12-hexamethyl-7-(3,5,5-trimethylhexyl)-	74	oder ähnlicher Verbindung	4000
ISTD	16696-65-4	(1,11-Dibromoundecane)	94	interner Standard	20000
13	NA	Sulfurous acid, cyclohexylmethyl hexadecyl ester	77	oder ähnliche Verbindung	3000
14	2425-77-6	2-Hexyl-1-decanol	81		1000
15	NA	Sulfurous acid, cyclohexylmethyl hexadecyl ester	76	oder ähnliche Verbindung	4000
16	NA	Carbonic acid, eicosyl vinyl ester	81	oder ähnliche Verbindung	1000
17	27458-90-8	Di-tert-dodecyldisulfid	81	oder ähnliche Verbindung	1000
18	NA	Eicosyl heptyl ether	74	oder ähnliche Verbindung	5000
19		unbekannte Verbindung			2000
20	15796-04-0	2,4,4,6,6,8,8-Heptamethyl-1-nonen	73	oder ähnliche Verbindung	3000
21	NA	Sulfurous acid, cyclohexylmethyl hexadecyl ester	74	oder ähnliche Verbindung	2000
22	NA	Sulfurous acid, cyclohexylmethyl hexadecyl ester	73	oder ähnliche Verbindung	2000
23	NA	Heptyl octacosyl ether	72	oder ähnliche Verbindung	3000
24	NA	Heptyl octacosyl ether	75	oder ähnliche Verbindung	1000
25		unbekannte Verbindung			2000
26	NA	Sulfurous acid, cyclohexylmethyl hexadecyl ester	72	oder ähnliche Verbindung	1000
27	NA	Butyl dotriacontyl ether	74	oder ähnliche Verbindung	1000
28	NA	Heptyl octacosyl ether	71	oder ähnliche Verbindung	2000
29		unbekannte Verbindung			1000
30		unbekannte Verbindung			2000
31		unbekannte Verbindung			1000
32		Kohlenwasserstoffgemisch		RT 11 - 31 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

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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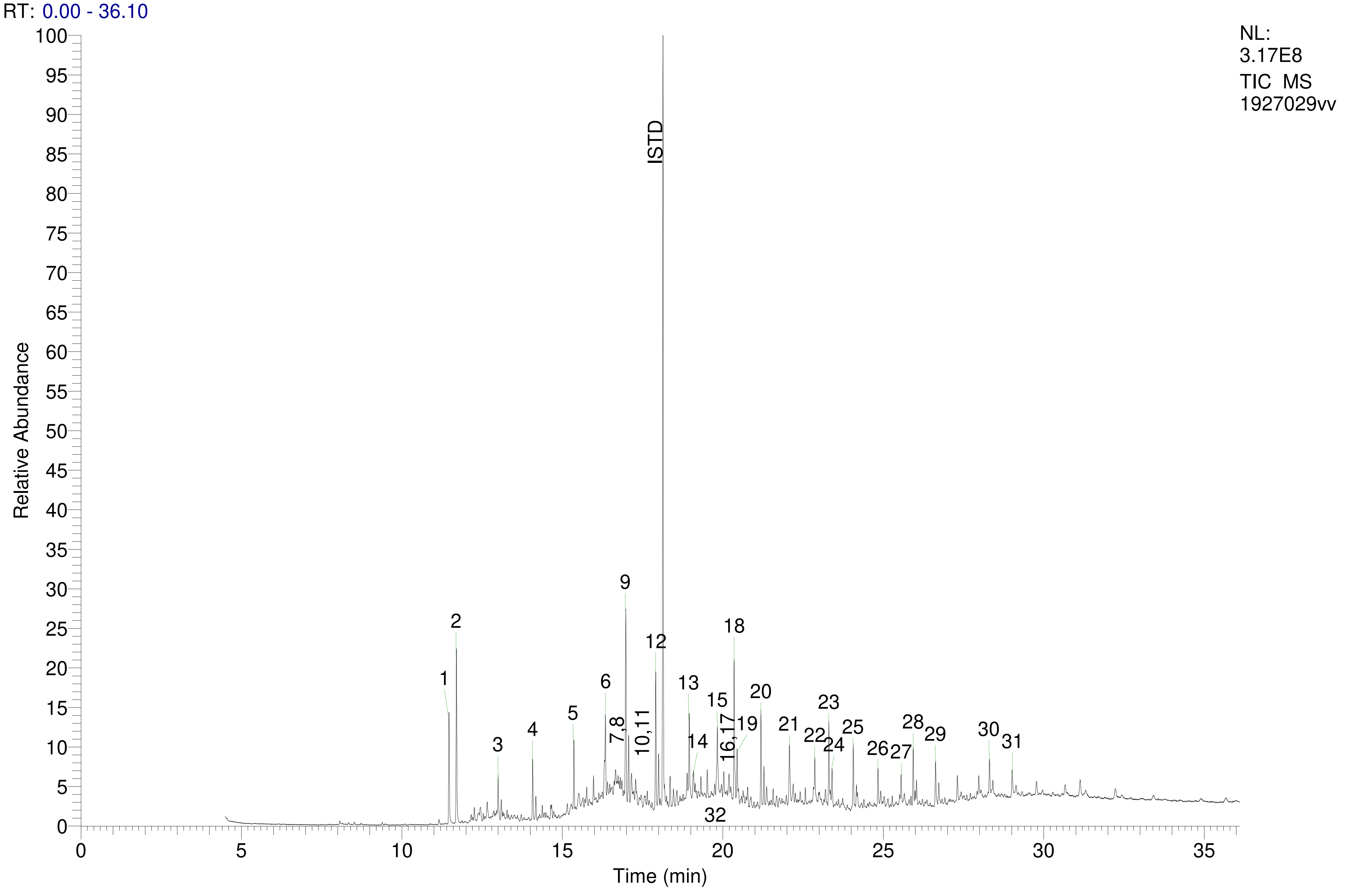

C.4.4 HHGG4, capacitor No. 90

The laboratory report is inserted on the following pages.

Bachema AG
Analytische Laboratorien

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie GmbH
Auftrags-Nr. Bachema: 201906292

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

Proben-Nr. Bachema: 27030
Probenbezeichnung: HHGG 4 (Kond.-Nr. 90)

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]
ISTD	16696-65-4	(1,11-Dibromoundecane)	93	interner Standard	3000
1	1004-24-6	4-Methylenecyclohexanemethanol	75	oder ähnliche Verbindung	70
2	127062-51-5	13-Hexyloxacyclotridec-10-en-2-on	91	oder ähnliche Verbindung	200
3	5493-45-8	1,2-Cyclohexanedicarboxylic acid, bis(oxiranylmethyl) ester	74	oder ähnliche Verbindung	50
4	5493-45-8	1,2-Cyclohexanedicarboxylic acid, bis(oxiranylmethyl) ester	88	oder ähnliche Verbindung	200
5	2386-87-0	3,4-Epoxycyclohexylmethyl 3,4-epoxycyclohexanecarboxylate	91	oder Isomer	1000
6	NA	4-Oxo-3-oxa-8,10-diazatricyclo [7.4.0.0 (2,7)]trideca-1(9),2(7), 5,10,12-pentaene-5-carbonitrile	73	oder ähnliche Verbindung	80
7	2386-87-0	3,4-Epoxycyclohexylmethyl 3,4-epoxycyclohexanecarboxylate	86	oder Isomer	300
8	2386-87-0	3,4-Epoxycyclohexylmethyl 3,4-epoxycyclohexanecarboxylate	88	oder Isomer	400
9	103-23-1	Bis(2-ethylhexyl) adipate	92		300
10	111-02-4	Squalen	83		300
11		unbekannte Verbindung			600
12	119-13-1	δ-Tocopherol	79	oder Isomer	100
13		unbekannte Verbindung			200
14		unbekannte Verbindung		vermutlich ein Tocopherol	30
15	474-62-4	Campesterol	73	oder ähnliches Hormon	70
16	83-48-7	Stigmasterol	83	oder ähnliches Hormon	200
17	83-46-5	β-Sitosterol	75	oder ähnliches Hormon	300
18	481-14-1	(3β,24Z)-Stigmasta-5,24(28)-dien-3-ol	77	oder ähnliches Hormon	100

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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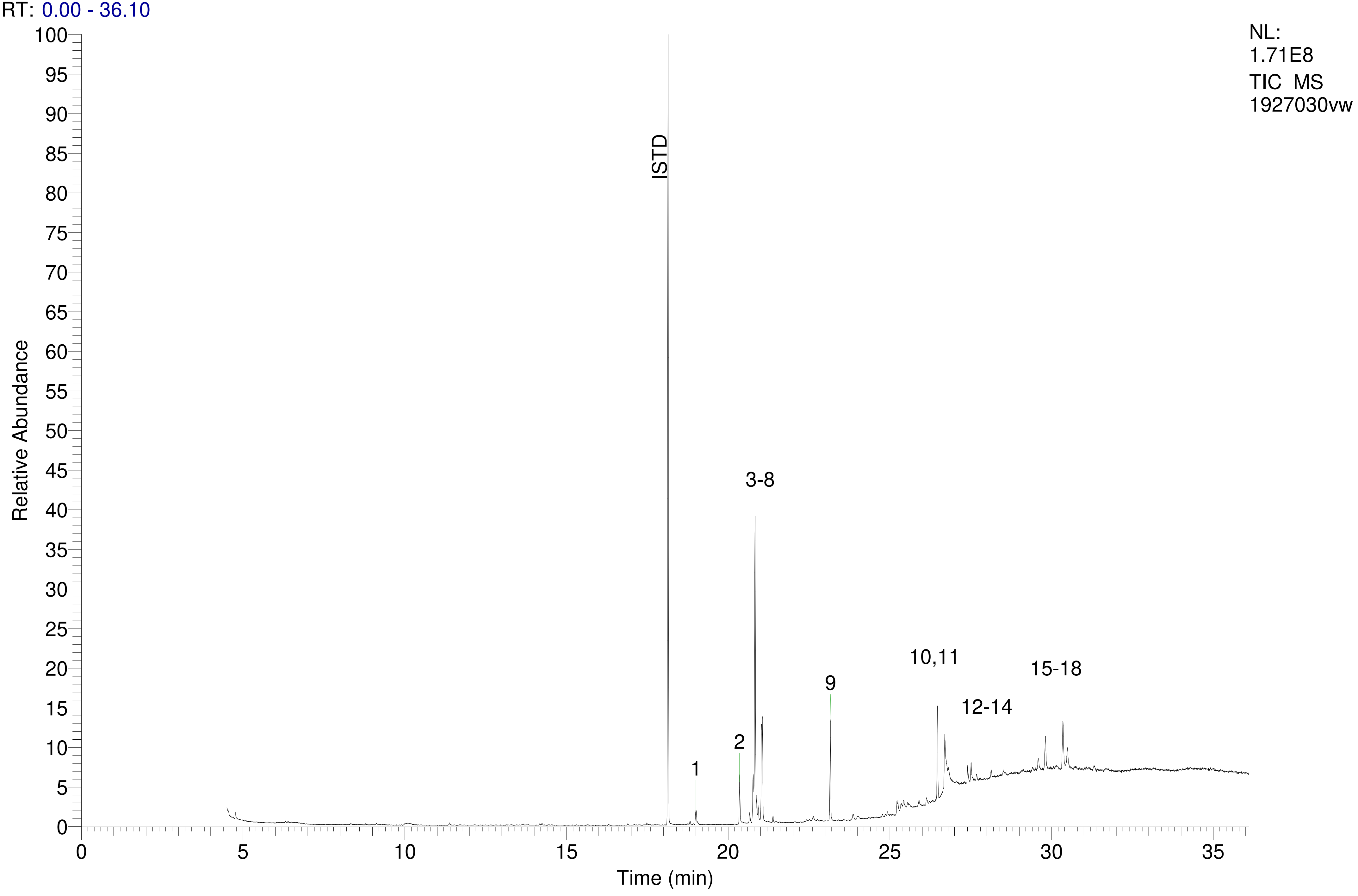

C.4.5 HHGG5, capacitor No. 95

The laboratory report is inserted on the following pages.

Bachema AG
Analytische Laboratorien

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie GmbH
Auftrags-Nr. Bachema: 201906292

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

Proben-Nr. Bachema: 27031
Probenbezeichnung: HHGG 5 (Kond.-Nr. 95)

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. [µg/kg]
1	627-82-7	Diglycerin		nicht quantifizierbar	n.q.
2	78-62-6	Diethoxydimethylsilan	72		500
3		unbekannte Verbindung		vermutlich ein Silan	n.q.
4	104-76-7	2-Ethylhexanol	91		70
5	620-47-3	1-Methyl-3-(phenylmethyl)-benzol	91	oder Isomer	50
6	620-83-7	1-Methyl-4-(phenylmethyl)-benzol	93	oder Isomer	400
7	620-47-3	1-Methyl-3-(phenylmethyl)-benzol	93	oder Isomer	500
ISTD	16696-65-4	(1,11-Dibromoundecan)	94	interner Standard	2000
8	127062-51-5	13-Hexyloxacyclotridec-10-en-2-on	92		500
9		unbekannte Verbindung			60
10	141-24-2	Methyl ricinoleate	81		50
11		unbekannte Verbindung		evtl. 1,9-Diphenyl-1,3,5,7-nona-tetraene	100
12		unbekannte Verbindung		evtl. 1,9-Diphenyl-1,3,5,7-nona-tetraene	40
13		unbekannte Verbindung		vermutlich ein Fettsäureester	100
14		unbekannte Verbindung			90
15	117-81-7	Bis(2-ethylhexyl) phthalat	95		6000
16		unbekannte Verbindung			300
17		unbekannte Verbindung			300
18		unbekannte Verbindung	73	vermutlich ein Fettsäureester	400
19		unbekannte Verbindung			300
20		unbekannte Verbindung	73	vermutlich ein Fettsäureester	500
21	111-02-4	Squalen	83		300
22		unbekannte Verbindung			1000
23	141-22-0	Ricinolsäure	77	oder ähnliche Verbindung	400
24	141-08-2	1-Glyceryl ricinoleate	74	oder ähnliche Verbindung	300
25	119-13-1	δ-Tocopherol	85	oder Isomer	300
26		unbekannte Verbindung			70
27	7616-22-0	γ-Tocopherol	83	oder Isomer	80
28		unbekannte Verbindung			50
29		unbekannte Verbindung		vermutlich ein Hormon	90
30	83-48-7	Stigmasterol	81	oder ähnliches Hormon	100
31	83-47-6	ç-Sitosterol	72	oder ähnliches Hormon	200
32	56362-45-9	(3β)-24-Propyliden-cholest-5-en-3-ol	74	oder ähnliches Hormon	70

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.
n.q. = nicht quantifizierbar

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Akkreditiert nach ISO 17025
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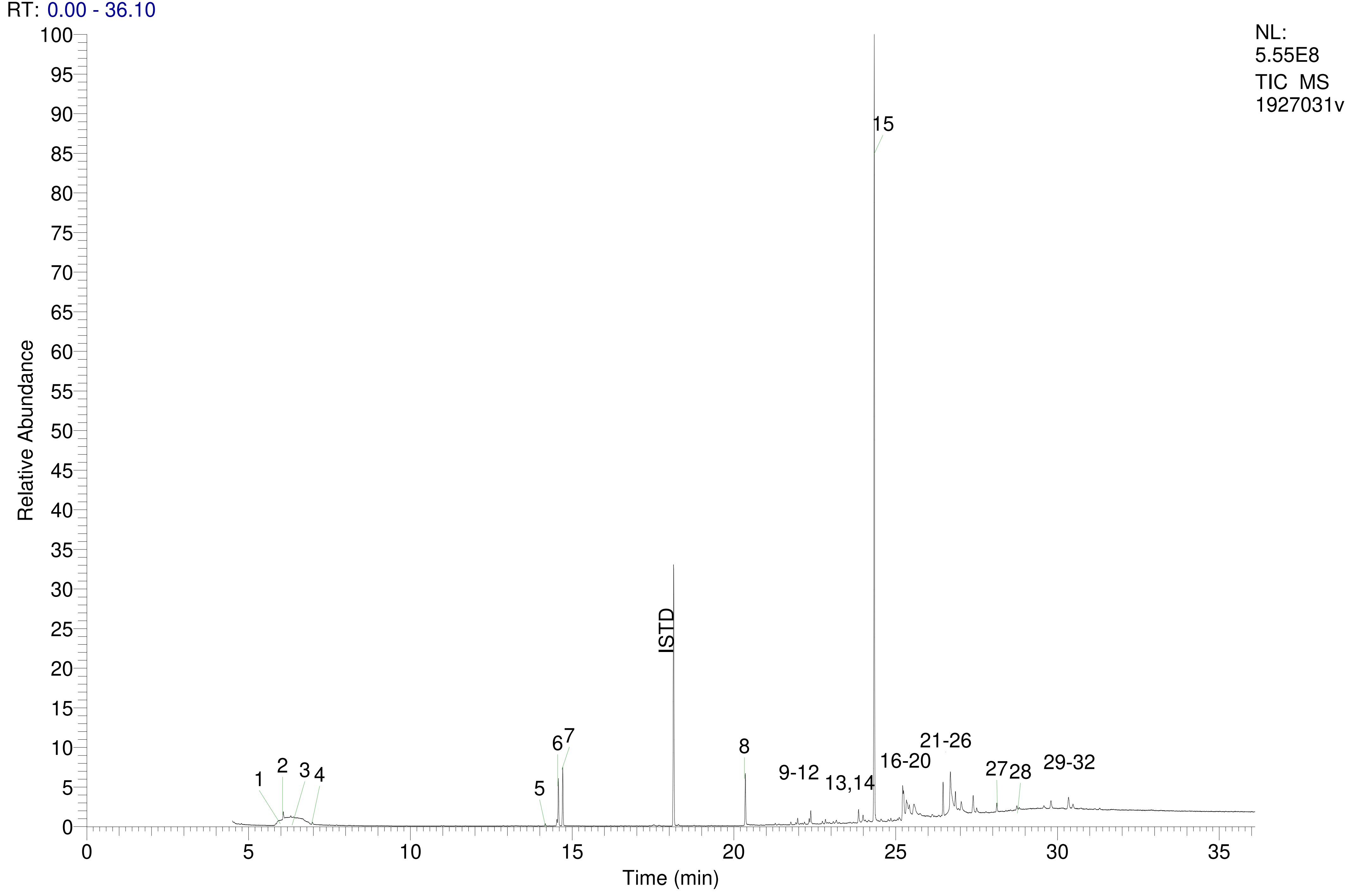
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TIC MS
1927031v
Relative Abundance
Time (min)
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5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ISTD
1
2
3
4
5
6
7
8
9-12
13,14
15
16-20
21-26
27
28
29-32

C.4.6 Laboratory reports of PCB analyses

The laboratory report is inserted on the following page.

Objekt: **Kondensatoren-Analyse**
Auftraggeber: Büro für Umweltchemie GmbH
Auftrags-Nr. Bachema: 201906292

						Referenzwert	
Probenbezeichnung		**HHGG 1 (Kond.-Nr. 311)**	**HHGG 2 (Kond.-Nr. 109)**	**HHGG 3 (Kond.-Nr. 126)**	**HHGG 4 (Kond.-Nr. 90)**		
Proben-Nr. Bachema		27027	27028	27029	27030		
Tag der Probenahme							
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**		
PCB Typisierung		**kein PCB-Nachweis**	**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**		

						Referenzwert	
Probenbezeichnung		**HHGG 5 (Kond.-Nr. 95)**					
Proben-Nr. Bachema		27031					
Tag der Probenahme							
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**					
PCB Typisierung		**kein PCB-Nachweis**					
Organische Non-Target-Analytik							
GC-MS Identifikation (nach Extraktion mit Cyclohexan/Ethylacetat)		**s. Anhang**					

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

C.5 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 91 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 91: 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
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Untersuchungsbericht

Objekt: Kondensatoren-Analyse

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

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

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

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

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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

						Referenzwert	
Probenbezeichnung		**3**	**4**	**5**	**6**		
Proben-Nr. Bachema Tag der Probenahme		43356 05.10.18	43357 05.10.18	43358 05.10.18	43359 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**		

						Referenzwert	
Probenbezeichnung		**276**					
Proben-Nr. Bachema Tag der Probenahme		43370 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**					

						Referenzwert	
Probenbezeichnung		**7**	**53**	**54**	**56**	*Toleranzwert für Transformatorenöl*	
Proben-Nr. Bachema Tag der Probenahme		43360 05.10.18	43361 05.10.18	43362 05.10.18	43363 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**		

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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

Probenbezeichnung		58				Referenzwert: *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**					

Probenbezeichnung		59	78	79	81	Referenzwert: *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**		

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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**				

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Bachema AG
Analytische Laboratorien

Schlieren, 12. Februar 2019
LW

Büro für Umweltchemie GmbH
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Untersuchungsbericht

Objekt: PCB-verdächtige Kondensatoren

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Chemisches und
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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.

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Akkreditiert nach ISO 17025
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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

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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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D Photos of the non-polarised cylindrical capacitors which were analysed individually

The capacitor models shown were used for the analysis of the liquids separated according to individual models as described in 5.2.6.

Figure 31: Model No. 311

Figure 32: Model No. 109

Figure 33: Model No. 126

Figure 34: Model No. 90

Figure 35: Model No. 95

E H-statements for classification as a substance of concern in recycling

Table 92: 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
H300	Fatal if swallowed	No	**Yes**
H310	Fatal in contact with skin	No	**Yes**
H330	Fatal if inhaled	No	**Yes**
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**
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**