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– ways to increase recycling



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Nordic co-operation

Nordic co-operation is one of the world's most extensive forms of regional collaboration, involving Denmark, Finland, Iceland, Norway, Sweden, the Faroe Islands, Greenland, and Åland.

Nordic co-operation has firm traditions in politics, the economy, and culture. It plays an important role in European and international collaboration, and aims at creating a strong Nordic community in a strong Europe.

Nordic co-operation seeks to safeguard Nordic and regional interests and principles in the global community. Shared Nordic values help the region solidify its position as one of the world's most innovative and competitive.

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Introduction and background

Aim and scope of the study

The aim of the project is to create a knowledge base on how plastics recycling can increase without increasing the risk of emitting hazardous substances in the environment.

The task includes:

- Describing the legislation and standards having an influence on hazardous substances in connection with plastics recycling.
- Describing techniques for sorting/ separation of plastics containing hazardous substances.
- Describing the traceability along the value chain.
- Identifying the knowledge gaps when it comes to control of hazardous substances in plastics recycling.

This will lead to:

- Identification of the key plastic wastes which are especially suitable for recycling in the context of resource-efficient and non-toxic cycles, and which deserve further attention.

The findings will be put together in recommendations on actions to be taken in order to increase the amount of plastic waste recycled without increasing the risk of emitting hazardous substances.

Generally, according to the EU and Nordic legislation, for particularly hazardous substances the objective is phasing out of the substances, while the targets for substances with other hazardous properties are safe use and risk reduction. Particularly hazardous substances are according to the Swedish Chemicals Agency substances that

are carcinogenic, toxic for reproduction or mutagenic (CMR 1A / 1B) as well as substances that are persistent, bioaccumulative and toxic or very persistent and very bioaccumulative (PBT or vPvB). According to the Swedish Environmental Objective A Non-Toxic Environment also substances that are endocrine disruptors or highly allergenic should be substances considered particularly hazardous. Mercury, cadmium and lead are not only classified as 1A/1B but also counted as particularly hazardous substances. Hazardous substances are substances that are classified as hazardous (to humans or the environment) under the Classification, Labelling and Packaging (CLP) regulation, and those that meet the regulatory criteria for hazardous substances, but have not yet been classified. The focus-area of this study is the Nordic region, but since the market for products is global, it is inevitable to also touch upon other regions.

It is important to remember that the hazardous substances mentioned in the report in most cases are intentionally added during production of the primary product. In all Nordic countries the most desirable option is the substitution or elimination of particularly hazardous substances, and the safe use and risk reduction of hazardous substances from the very beginning.

Motivation for the project

This project is a part of the Nordic Council of Ministers' initiative "Green growth" and a continuation of the previous three projects on plastics recycling ("Future solutions for Nordic plastic recycling", "Plastic sorting at recycling centres" and "Nordic plastic value chains – case WEEE"). In all these reports the content of hazardous substances was mentioned as an obstacle for increased plastics recycling. The project is also in line with EU's aim for increased plastics recycling and the package on circular economy.

In modern society we use plastic polymers in many different applications. To make the polymers fit our needs, we give them desirable properties by the use of added substances. Therefore, plastic products, like all other products and materials, contain a broad range of substances. The substances, or additives, can for example be flame retardants, pigments, fillers, UV-chemicals, plasticizers and stabilisers that are used to improve the properties of the plastics and reduce costs. The global production of additives is around 13 million tonnes, and the demand is forecasted to increase in the years to come. The global consumption of plasticisers was alone 6.2 million tonnes in 2011 (World Economic Forum, 2016).

Apart from intentionally added additives, substances can also arise unintentionally, including catalyst residues and compounds produced from side-reactions. Some, but far from all, of the substances added intentionally or unintentionally to the plastics, pose a risk to the environment and to human health due to their hazardous properties.

Alongside higher recycling demands and aim for a more circular society and preservation of precious resources it becomes clear that increased recycling can be accompanied with undesired side-effects in terms of introducing hazardous substances back into the loop. In addition, plastic waste containing hazardous substances might affect the possibilities of recycling. Today there is lack of a comprehensive picture of how recycling of plastics can be combined with the aim of non-toxic environment. This potential clash of aims needs to be addressed in a comprehensive manner. There are rules and regulations that influence the possibilities of recycling, both legislation for substances, articles, and for waste. The term article and the term product are sometimes used interchangeably throughout the report. These legal frameworks are to a great extent designed to protect human health and the environment, but sometimes unwanted effects of lower possibilities to recycle arises due to the legislations or the interpretations of the legislations. This report tries to bring light to some of these questions.

In a study conducted by the Swedish Chemicals Agency 2012 (KEMI, 2012) companies manufacturing different product groups were asked about their biggest challenges in using recycled material. It was stated that the ambition in using recycled plastics varied between the different product groups and that the variation could be seen as a consequence of the restriction of content of hazardous substances in the product. For example toy producers were in general more reluctant to use recycled material than producers of clothes or shoes due to the strict restrictions for chemical content in toys. It is not always restrictions set in the legislations but often demands from the producers on the material put into products.

According to interviews conducted with experts at the governmental organizations in Finland the biggest barriers hampering recycling of plastics were the following:

- How to identify hazardous substances in plastic wastes to be recycled. Key hazardous substances: POP substances (brominated flame retardants-BFRs), phthalates (DEHP, DBP, DIBP) and heavy metals).
- How to separate the plastic waste containing the hazardous substances from the plastic waste to be recycled and direct the problematic plastic streams to thermal treatment.

This is also coming back in KEMI (2012) where the main hindrances were identified as the risk of contamination and costs reducing these risks as well as limited availability of the recycled materials. The following was seen to be necessary in order to use recycled material to a greater extent:

- development of cleaner material streams
- development of cleaner separation and cleaning techniques
- development of standards for recycled material.

The recycling industry is required to have knowledge and information about a high number of substances to fulfill the existing legislations and other demands from producers. This makes traceability or improved methods for analyzing the waste the key challenges for the sector. Other challenges are sorting and optimizing the processes to maximize the amounts of plastics to recycling and still keep a profitable business.

Method

The outcome of this project is based on four pillars

1. A literature review. The project group has gone through available literature relevant to the subject, both scientific and grey literature. The focus in the literature search has been Nordic, but also international literature has been taken into consideration, particularly on the EU level.
2. Interviews with stakeholders in Denmark, Finland, Norway and Sweden. The interviewees are both representatives from authorities as well as practitioners such as plastic sorters and recyclers.
3. Workshop with authorities from all Nordic countries. At the workshop the findings from pillar 1 and 2 was presented and discussed among the participants.
4. In the final phase of the project all findings have been compiled in to this report with conclusions and recommendations.

The report considers different types of recycling, but has a main focus in mechanical recycling; see further explanations in chapter 4.

Summary

Hazardous substances in plastics – ways to increase recycling

The aim of the project is to create a knowledge base on how plastics recycling can increase without increasing the risk of emitting hazardous substances in the environment.

The first general conclusion is that to be able to increase recycling in a safe way there are measures that need to be taken at different levels, both upstream and downstream as well as market solutions. The following areas are of interest:

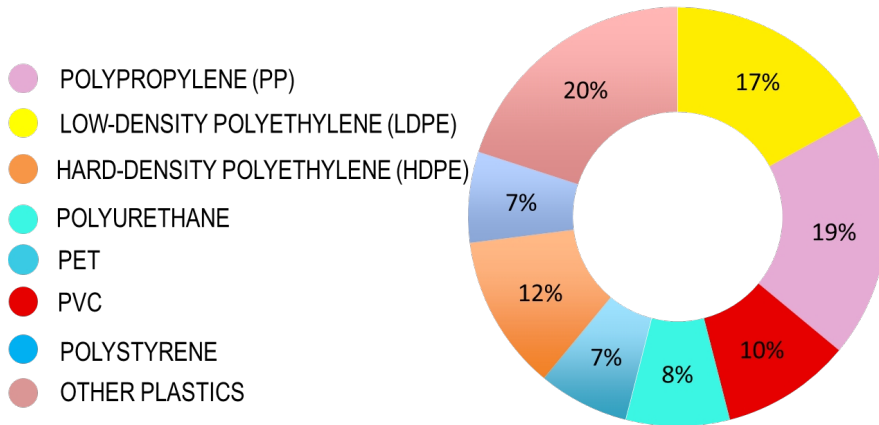
- Legislation: new legislation is not necessary, but harmonisation and clear guidance to the existing one is.
- Market: to create a market safety on content is needed.
 - If substances added had been less hazardous the recycled raw material would be “more safe” to use in new products.
 - There should be higher attention put on the knowledge of the recyclers and their need for more information and guidance.
- Traceability and content: Further work on labelling reaching the recycle part of the value chain needs to be developed. It is also needed to develop a systematic approach towards risk assessments linked to recycling.

1. Collection and recycling of plastic waste in the Nordic countries

Fundamental to recycling of plastics is to have collection and recycling systems in place. Collection systems dedicated for plastic waste can be organised and practically operated in different ways dependent on the country, the legislation behind the collection and recycling, and the actors involved. Plastic waste can also be collected for recycling as part of another waste stream where the target fractions might not necessarily be plastics. This is the case for example end-of-life vehicles (ELVs) and Waste Electrical and Electronic Equipment (WEEE). The opposite is when the waste stream is meant to completely consist of plastics, such as the plastic packaging waste stream.

Even though the life-times of plastic products or products containing plastics vary, the products turn into waste sooner or later. The sector consuming most plastics in the EU is the packaging industry, representing nearly 40% of the total plastics demand. This is an example of an application with a relatively short life time. On the contrary to packaging, the building sector with products of relatively long life times, consumes around 20% of the total plastic demand in the EU. The dominating plastic types used in the EU are polypropylene (PP), and low-density polyethylene (LDPE), common plastic types for packaging. The plastic demand per plastic type in the EU is presented in Figure 1.

Figure 1: Plastic demand per plastic type in the EU 2014 (modified from PlasticsEurope, 2015)



1.1 Amounts and plastic waste groups

We have chosen to divide plastic products generating plastic containing waste into seven categories; consumer products, products for children, construction materials, electronics, furniture, ELV, and packaging. To some extent the product groups also match the waste flows that the products eventually will end up in, but this picture is not entirely true. There are separate collection systems for packaging, ELVs and WEEE in place, whereas the situation for consumer products, products for children, and for furniture is different. These product groups end up in mixed waste fractions to energy recovery or in waste fractions subject to recycling.

This chapter includes estimates of quantities of plastic present in different waste streams and a description of how the plastics in the waste streams are managed. The data presented is not always the most recent, but is regarded accurate enough to give an overall picture of the plastic waste streams in the studied countries and their quantities in relation to each other. A more detailed review of the existing collection and recycling systems for plastic waste in the Nordic countries is found in Fråne *et al.* (2014).

There are two principle waste streams subject to recycling; pre-consumer and post-consumer waste. The pre-consumer plastic waste originates from industrial processing, and has never reached the end-consumer. On the contrary, post-consumer plastic waste is plastic waste coming from end-consumers such as households or businesses. Pre-consumer plastic waste is generally more homogenous than post-consumer plastic waste, and the content in the plastics is known to a higher degree, which facilitates recycling. The focus in this project is post-consumer plastic waste as it represents the biggest challenge for recycling and for knowing the potential content of hazardous substances.

1.1.1 Plastic waste from electronics

Collected WEEE in the countries in focus for the study is primarily treated by four recyclers; Stena Technoworld, Sims Recycling Solutions, Kuusakoski Recycling and Ekokem. In addition to these there is also a number of dismantlers and pre-processors such as DCR, DanWEEE and Averhof in Denmark.

Overall data on the collection and recycling of WEEE is generally more comprehensive than data specific to plastics. Different studies suggest that the plastic waste fraction in WEEE represents around 20% by mass. Mepex (2013) estimated the fraction of plastics in different products groups, see Table 1.

Table 1: Fraction of plastics in different WEEE product groups (Mepex, 2013)

Product group	Fraction of plastics
Large household equipment (WEEE Directive Group 1) 15%	15%
Other household items (Group 2) 20%	20%
IT and Telecommunications Equipment (Group 3) 20%	20%
Consumer / lighting / electrical equipment, medical devices (4, 5, 6, 8) 20%	20%
Toys / leisure / sports, monitoring, dispensers (7, 9, 10) 5%	5%

In Baxter *et al.* (2014) Eurostat data for collected amounts of WEEE in the different Nordic countries together with the fraction of plastics in different WEEE product groups (Table 2) were used to estimate the total amount of plastics in the collected WEEE. The Eurostat data for total WEEE collected is also available on a product-group basis, which was used to estimate the total amount of WEEE plastic waste collected. Please observe

that the estimated quantities refer to WEEE collected, and exclude WEEE that for various reasons end up in other, more mixed waste fractions. The Eurostat data is for WEEE collected in 2010, but is regarded as adequate enough to serve the study's purposes.

Table 2: WEEE plastic waste collected in Denmark, Finland, Norway and Sweden (Baxter *et al.*, 2014)

	WEEE collected, W (tonnes)	Total WEEE plastics collected, P (tonnes)	Fraction of plastics collected in WEEE, P/W
Denmark	82,237	14,528	17.7%
Finland	50,023	8,559	17.1%
Norway	106,834	18,743	17.5%
Sweden	159,471	27,957	17.5%

WEEE plastics consist of a variety of polymer types, for example polystyrene (PS) and acrylonitrile butadiene styrene (ABS), which pose a challenge for WEEE recyclers. Sims Recycling in Sweden acts as example for how WEEE plastics are treated in the Nordic region. Sims start off by identifying and sorting out WEEE items containing restricted substances and hazardous components according to the WEEE directive such as batteries and fluorescent tubes. Appliances such as TV's are scanned with X-ray fluorescence (XRF) analysers to detect plastics that contain bromine. The remaining items are sent to fragmentation to reduce the size of the material. Magnetic and eddy-current separators catch steel and aluminum before the fragmented WEEE is transported on a conveyer belt where air separate different pieces of material according to type of material, such as plastics. The plastic fraction consists of a high number of polymers, is shredded further, and is thereafter shipped to Germany for further processing. The plastic fraction contains around 90% plastics and may include hazardous substances such as BFRs. In Germany the plastic fraction is refined using density separation to remove plastics containing bromine. Around half of the plastic fraction sent to Germany is rejected due to its bromine content, while the other half contains PE, PP and ABS and could be recycled (Karlsson, 2016). Other facilities use the same kind of technique, for example Stena Technoworld in Halmstad (Stena Technoworld, 2016).

The presence of hazardous substances in WEEE plastics is currently a challenge for WEEE plastics recycling. Examples of these problematic substances and heavy metals are cadmium, chromium (VI), lead, phthalates and BFRs. To comply with legislation it is a necessity to dismantle the plastic components from the incoming WEEE. The dismantling makes the recycling of the plastic more costly and time-consuming. WEEE

plastics are in addition heterogeneous in terms of polymer composition, which requires sorting. WEEE plastic recycling also requires technological expertise, practical “know-how” and substantial economical investments (Karlsson, 2016).

1.1.2 Waste from plastic packaging

Finland, Norway and Sweden have implemented producer responsibility obligations for packaging, although differently organised. In Denmark the packaging directive has been implemented without use of a producer responsibility scheme. Different collection models are used to collect plastic packaging waste in the Nordic region, ranging from collection at the kerbside in multi-compartment bins, separate containers, and in transparent plastic bags to public bring systems. Plastic packaging waste both ends up in dedicated collection and recycling systems for plastic packaging waste aimed for recycling, and in waste fractions remaining after various degree of source-separation, often called residual waste. There are no official figures on the generated total amount of plastic packaging waste in the Nordic countries, but it is possible by assuming that the amount of plastic packaging put on the market represents the waste quantity due to the short life time of packaging. This quantity equals 613,500 tonnes, see Table 3.

The amount of plastic packaging put on the market in the studied countries as well as the amount of collected plastic packaging waste for recycling is presented in Table 3. In regards to polymer types, plastic packaging mainly consists of HDPE/LDPE, PP and polyethylene terephthalate (PET) (Plastics Europe, 2015). These are also the plastic types in focus when plastic packaging waste is sorted for recycling after collection.

Table 3: Amounts of plastic packaging put on the market and the amount of collected plastic packaging waste sent to recycling

	Plastic packaging put on the market (tonnes)	Collected plastic packaging waste for recycling (tonnes)
Denmark ¹	155,900	20,000
Finland ¹	117,100	29,700
Norway ²	137,500	54,400
Sweden ²	203,000	87,000
Sum	613,500	191,100

Note: ¹Fråne *et al.* 2014.

²Naturvårdsverket (2016a).

The lion's share of the plastic packaging waste collected in Norway and Sweden take the same route for sorting and cleaning, it is transported to Swerec in Sweden and to three recyclers in Germany; Eing Kunststoffverwertung GmbH, Relux Recycling GmbH and Umweltdienste Kedenburg GmbH (Fråne *et al.*, 2014). The sorting procedure of the plastic packaging waste in Sweden is similar to the procedure Germany, but as an example the handling at Swerec is described. The plastic packaging is first sorted as soft and rigid plastics. The soft plastic (LDPE) is baled and sold to recyclers. The rigid plastics go through manual and/or optical sorting depending on the size of the items. The plastics are sorted according to polymer types adjusted for HDPE, PP and PET. All other polymer types are not identified, and thus sorted out as a reject fraction, which is sent to energy recovery. The optical sorting process has a blow system attached that blows away the plastic of the correct polymer type. The system sometimes misses too heavy packaging, for example if there is food waste left in the packaging that makes the item too heavy for the blow system. The PP and PE fractions are milled and washed whereas the PET fraction is directly sold to PET recyclers (Karlsson, 2016).

In Norway the largest supplier of recycled materials is Norsk Gjenvinning and the largest users of recycled plastics are Folldal Gjenvinning and Norfolier Greentec. Norsk Gjenvinning tries to be involved in the waste stream at an early stage to improve the quality (value). The sources of plastics are mainly packaging from for example shops and packaging films and shrink films from industries. Films from agriculture are also important. The sorted plastics is loaded on trucks and sent directly to recycling customers. Shops and industries are also sources of hard plastics from bottles, cans and trays. This fraction contains different plastic materials as PE, PP, PET and PS.

As the material sources coming to Norwegian recyclers are well defined, one has control of the additives the plastics contain from production. Impurities will come from the use of the plastics. Agricultural films will contain organic waste and require proper cleaning to give the recycled material high value. Big-bags are often used for feedstock and the material may therefore contain fat, which is difficult to remove.

Norfolier Greentec produces waste bags for various markets based on blown polyethylene film. Materials used in production are 100% recycled polyethylene films – both low density and linear low density polyethylene (LDPE and LLDPE) coming from both industry and agriculture. Materials from external sources are all post-consumer materials. Norfolier uses only materials from EuCertPlast certified sources, which guarantees traceability. Their supplier, Folldal Gjenvinning provides datasheets including analyses of chemical content.

Finnish Packaging Recycling RINKI Ltd arranges the bring collection and delivery of consumer plastics packaging that are under the producer responsibility scheme in Finland. Ekokem is currently the only company receiving plastics packages that are collected under the producer responsibility scheme in Finland. In addition, Ekokem also collects plastic films straight from the waste customers, and some actors deliver their plastics wastes to Ekokem themselves. In briefly, the business model of the just opened plastics refinery contains the following steps: sorting, washing, and production of recycled plastic granulates by extrusion and granulation. The refinery will produce the best possible quality recyclates (LDPE, HDPE, and PP) from mixed feedstock material, which are sold mainly to domestic plastics industry customers. The share of plastics that cannot be processed is expected to be little, as Ekokem is able to handle dirty plastic materials. The plastics that cannot be recycled (containing mainly different kinds of rejects) are utilized as part of solid recovered fuel and as last possible alternative diverted to grate incineration.

In Denmark much of the plastic packaging waste is incinerated together with other waste fractions from the households. However, more and more municipalities are introducing collection schemes for household plastic waste. Little of the household source separated plastic waste is recycled in Denmark, most is sent abroad for recycling. The largest municipality, Copenhagen, is during the period 2015-2017 implementing a system for collecting hard plastic waste from households.

1.1.3 PET bottles

PET bottles are collected and recycled through separate deposit return systems in the Nordic region. In Table 4 the amount of PET bottles put on the market and the amount of collected PET bottles sent to recycling is presented.

Table 4: Amounts of PET bottles put on the market and the amount of collected PET bottles sent to recycling

	PET bottles put on the market (tonnes)	Collected PET bottles in deposit refund systems (tonnes)
Denmark ¹	10,600	6000
Finland ¹	13,300	12,500
Norway ¹	8300	4200
Sweden ²	25,000	21,000

Note: ¹Fråne *et al.* 2014.

²Naturvårdsverket (2016a).

Due to the deposit refund systems the collection and recycling of PET bottles ensures an exceptionally homogenous stream including PET bottles only. The majority of the bottles are of transparent PET, and the rest mostly of blue and green PET. The organisation in charge of the deposit refund systems dictates the condition of the material, from how the bottles should be shaped to what label and belonging glue is accepted. The homogenous flow and acceptance control through the deposit refund systems results in minor contamination in comparison to other plastic waste flows, and also very importantly, ensures traceability and allow for closed loop food contact material recycling. In addition, there is hardly any hazardous substances present (Karlsson, 2016).

1.1.4 Plastic waste (non-packaging) from consumer products

This category is broad in the sense that it contains a variety of products with different applications, everything from rain coats and toys to tooth brushes and plastic furniture is part of this category. There are generally no dedicated collection systems for non-packaging plastic waste from households. The plastic products might, for example, end up in the dedicated collection systems targeted on plastic packaging waste as a differentiation between packaging and non-packaging is not always made by the consumer. In that case the plastic products, dependent on the polymer type, are recycled together with the plastic packaging. Collection systems where plastic packaging and non-packaging plastic items are discarded together also exist. In addition, non-packaging plastic products end up in mixed waste (residual waste) to energy recovery. Due to the heterogeneity of non-packaging plastic products there is no compiled statistics on the amount no comprehensive data on the amount generated or recycled annually why we present known quantities of waste streams in which non-packaging consumer products might end up.

Non-packaging plastic waste in mixed residual waste to waste-to-energy

The most likely fate of non-packaging plastic waste that fit into ordinary waste bins and bags, is that they are discarded into mixed residual waste fractions sent to waste-to-energy. Non-packaging plastic waste can be everything from toys to dish brushes. In Fråne *et al.* (2014) the generated amount of non-packaging plastic items discarded in mixed residual waste fractions from municipal sources sent to waste-to-energy was roughly estimated to 180,000 tonnes per year for the studied countries (63,000 tonnes for Denmark, 54,000 tonnes for Finland, 21 000 tonnes for Norway and 42,000 tonnes

for Sweden). The generated amount was estimated based on waste analyses of mixed residual waste. The generated amount of plastic waste in mixed residual waste is likely to be much higher as commercial sources were not included in the study.

Plastic bulky waste

For example garden furniture, buckets or large plastic items for children can also be separately collected for recycling at manned recycling centrals in a fraction commonly called plastic bulky waste. The meaning of plastic bulky waste is large items of plastic waste that do not fit into bins and bags and therefore need different handling. Plastic bulky waste is not subject to any dedicated, nationwide collection and recycling systems in the Nordics, but an increasing trend of collecting plastic bulky waste at municipal recycling centrals is observed in Sweden and in Denmark. In a previous nordic project (Andersen *et al.* 2015) a guideline was developed to facilitate this development in all Nordic countries. The collection is based on initiatives between municipalities and waste management companies. As far as known pilot projects also take place in Norway. There are no compiled statistics on the amounts of plastic bulky waste generated, but in Sweden around 4,000 tonnes from 20 municipalities are collected and sent to the plastic sorting company Swerec every year. Although, 20 municipalities seems like a low number, the collection covers a big portion of Sweden's population since the municipalities involved are those most populated, including Stockholm, Gothenburg and Malmö (Karlsson, 2016). Sample analysis conducted by Swerec showed that 50% of the plastic is made of PP, 30% of PE, 10% of other polymer types and 10% of non-plastics (Jensen *et al.* 2012a).

At Swerec the sorting process of plastic bulky waste is nearly identical to the sorting processes applied on packaging waste. Each transport of plastic bulky waste from a certain municipality is held apart from other incoming waste. Due to the size-difference of the incoming plastic bulky waste large-sized items suitable for recycling need to be manually separated by a material handler, e.g. garden furniture. After the manual handling of the plastic bulky waste, both large-sized (identified by the material handler) and small-sized plastics items are sorted in the same sorting facility as plastic packaging. As the plastic bulky waste is taken care of by the same sorting equipment as the plastic packaging waste accepted by Swerec the same polymer types are identified and sorted out for recycling; high- and low-density polyethylene (HDPE/LDPE), PP and PET (polyethene teraphthalate). This means in practice that other plastic types, for example PVC, are not sent for recycling, but to energy recovery. According to Swerec, the sorted

plastic bulky plastic for recycling is sold for the same purposes, to the same clients and is recycled into the same kind of products as the secondary raw material from plastic packaging waste (Karlsson, 2016).

The total quantity of generated plastic bulky waste in the studied countries is unknown. The potential amount of plastics in bulky waste in Sweden has roughly been estimated to 36,000 tonnes based on the share of plastic waste in the combustible bulky waste fraction collected at manned recycling centrals in Sweden (Jensen *et al.* 2012b).

PVC

PVC is treated a bit different in the Nordics and Denmark has the strictest legislation. As the rules are now, PVC waste has to be segregated in two fractions in Denmark, hard and soft PVC, and while much of the hard PVC can be recycled, soft PVC has to be disposed of at landfills and it is agreed between the authorities and the industry that soft PVC is disposed of directly to landfills without treatment (Miljøstyrelsen 2001 and Miljøstyrelsen 2015b). When incinerated, 1 kg of PVC may generate up to 1–1.4 kg of flue gas cleaning residues (European Commission, 2000). In Finland, Norway and Sweden PVC waste is generally sent to energy recovery, and is not separated at source from other types of plastics.

1.1.5 End-of-life vehicles (ELV)

ELV are collected and dismantled in the Nordic countries according to Directive 2000/53/EG on end-of-life vehicles. The directive only applies for vehicles with a total weight of 3.5 tonnes why this project has focused on passenger ELV. Common practice is to empty the vehicles from fluids, dismantle hazardous waste, and dismantle components for reuse. The dismantler thereafter sends the car bodies to shredding focusing on extracting bulk metals such as iron and steel, copper and aluminum. The plastics present in the ELV primarily ends up in the so-called shredder light fraction, which is either sent to incineration or to landfill. There are on-going initiatives where plastic components are dismantled for recycling as the reuse and recycling shall be at least 85% average weight per vehicle and year by 1st of January 2015. The main challenge to reach the target is to recycle material that is not subject to recycling today, mostly non-metallic materials where plastics represent the highest amount. A higher recycling rate would be possible to achieve by dismantling vehicle components before the car bodies

are shredded (Cullbrand *et al.* 2015). Based on an assumed content of plastics in passenger ELV of 12%, the average kerb weight including driver's weight of 1,424 kg for discarded ELVs in 2010 and the total number of discarded ELVs in 2014 of 186,967 in Sweden, the total amount of plastics present in discarded ELVs is estimated to around 29,000 tonnes of plastics for Sweden. Based on the same assumptions but for Denmark with slightly lower car weight the estimated amount would be 17,000 tonnes.

1.1.6 Plastic waste from construction and demolition

The building sector is the second largest consumer of plastics after the packaging industry in the EU (PlasticsEurope, 2015). Plastics are for example used in pipes, profiles, carpets, and insulation material, product groups that often have a relatively long life time as they are incorporated into the buildings. Construction and demolition waste (C&DW) is heterogeneous in composition and is highly dependent on the type of building or construction project. Waste from construction differs for example from waste from demolition activities. Common practice is to discard plastic waste in a mixed combustible waste fraction, which can be subject to various degrees of sorting. It is not common to sort out plastic waste from C&DW to recycling (Jensen *et al.*, 2012b). Plastic waste data from the construction and demolition sector can be retrieved from Eurostat, but this is likely to be an underestimated amount as only a small share of the total generated plastic waste is source-sorted for recycling and reported as plastic waste.

The total quantity of plastic present in C&D waste, i.e. also in various mixed waste fractions, is difficult to estimate. Jensen *et al.* (2012b) roughly estimated the amount of generated plastic waste from the construction and demolition sector in Sweden to 43,000 tonnes of plastic waste in 2010. A very small share of the total amount of plastic waste available was sent to recycling, in the magnitude of a few hundreds of tonnes. This is in line with figures from Bio by Deloitte (2015a). A general challenge with C&D plastic waste figures is to understand whether the total amount of generated plastic waste is taken into account or only the source-separated plastic waste.

The total estimated quantity of generated plastic waste in the studied countries are summarised in Table 5.

Table 5: Estimated total amount of generated plastic waste in the studied countries

Product type	Estimates of annual amounts of generated plastic waste (tonnes)			
	Denmark	Finland	Norway	Sweden
Consumer products	23,500 tonnes of plastic bulky waste	No specific data available	No specific data available	36,000 tonnes of plastic bulky waste. 42,000 tonnes of non-packaging plastic items in mixed residual MSW waste
Products for children	No specific data available	No specific data available	No specific data available	No specific data available
Construction and demolition materials ¹	7,823 (2012) ²	11,000 (2013)	5,149 (2014) ³	200 (2012) ⁴
Electronics (plastics in collected WEEE)	14,528	No specific data available	18,743	27,957
Furniture	No specific data available	No specific data available	No specific data available	No specific data available
ELV (plastics in collected ELV)	17,000	12,000–15,000	No specific data available	29,000
Packaging (excl. PET bottles)	155,900	117,100	137,500	203,000
PET bottles	10,600	13,300	8,300	25,000

Note: ¹ Primarily source-separated plastic waste and not total generation.

² Bio by Deloitte (2015b).

³ Statistics Norway (2016).

⁴ Bio by Deloitte (2015a).

1.2 Types of recycling

Two main types of recycling can be distinguished, mechanical recycling and chemical recycling (also called feedstock recycling). Mechanical recycling can further be divided into mechanical recycling in closed loops and mechanical recycling in open loops (World Economic Forum *et al.* 2016).

1.2.1 Chemical recycling

Chemical recycling is when a polymer is chemically degraded into its monomers or other basic chemicals. The output may be reused for polymerisation into new plastics for the production of other chemicals or as an alternative fuel. Chemical recycling is not yet applied at large scale, even though a few examples exist e.g. for Nylon 6, PET, and PVC (World Economic Forum *et al.* 2016). Depending on the type of chemical recycling, additives can be separated from the monomers, but it can become costly and energy-intensive.

Chemical recycling is performed to a very limited extent compared to mechanical recycling. Around 50,000 tonnes of plastic waste is chemically recycled within the EU compared to over 5 million tonnes of mechanical recycling (JRC 2013).

Pyrolysis

Under ISO 15270, conversion technologies, such as cracking (pyrolysis), and depolymerisation are recognized as forms of feedstock recycling technologies when the products are used (a) for the production of fuels or raw chemicals or (b) as a reduction agent in the smelting process, rather than for combustion and energy recovery which would be considered a waste-to-energy process. (American Chemistry Council, 2011)

Pyrolysis of plastics or plastic to liquids (PTL) is a thermal decomposition of a material in an oxygen-free environment into liquids or gaseous product/compounds/chemicals. Plastic containing waste streams contain various resins, which degrade to wide range of products from monomers to a mix of waxes, paraffins, and olefins. Depending on the resin mixtures and the operating conditions yields vary widely. As a rule both gaseous and liquid products are mixtures of numerous different compounds. The pyrolysis temperature is the most influential parameter and values between 400 and 800 °C are generally employed depending on the feedstock being processed, and on the target products (Butler *et al.*, 2011).

The latest generation of pyrolysis technologies are designed to accept a wide variety of resin types, can accommodate many forms of contamination and require little pretreatment before being fed into the system. The majority of the pyrolytic systems can accommodate consumer packaging of all types. Majority of systems can accommodate PET and PVC in varying amounts. The threshold levels for PVC, at 10%–15% are generally commensurate with the presence of PVC in the packaging waste stream. Various commercially relevant dechlorination methods are available. The PTL process can treat 100% PVC, but the investment costs are very high (American Chemistry Council, 2011, Butler *et al.* 2011).

There is a vast literature on plastics pyrolysis and halogens. In plastic pyrolysis the dehalogenation can be performed simultaneously or successively (i.e. prior or after pyrolysis). However, there are still some concerns with certain flame retardants which may react differently to heating and some, much more than others, act as direct precursors to the formation of brominated dioxins. These, in turn easily convert into mixed and chlorinated dioxins, by bromine-chlorine exchange. Problem is their distribution over gas, liquid, and residue (Yang *et al.* 2013).

Key challenges in commercialization of the PTL systems include securing the supply of fairly constant quality low-cost feedstock, and unclear legislation related to the PTL processes. One solution is to develop co-processing technology (American Chemistry Council, 2011, Butler *et al.* 2011, Yang 2013).

Econyl process

Nylon 6 (also referred to as polyamide 6) is a built by the polymer caprolactam, and is used in a wide of range of applications from textiles to non-fibre applications as plastic parts in the automotive industry, in electrical appliances, in plastic packaging and fishing gear (World Economic Forum *et al.* 2016).

Chemical recycling of nylon 6 is one of the few examples of chemical recycling on an industrial scale, and has been practiced since the 1990s. By the Econyl process, used by the company Aquafil in Slovenia, Nylon 6 waste is depolymerised into 100% recycled virgin-quality caprolactam which is used to produce new Nylon 6. At least 50% in Aquafil's recycled caprolactam comes from post-consumer Nylon 6 waste (World Economic Forum *et al.* 2016). Cu-impregnated nylon 6 fishing equipment from Norwegian aquaculture, about 3,000 tons a year collected by the company Nofir, is chemically recycled at Aquafil's plant in Slovenia.

Vinyloop-process

VinyLoop is a solvent-based recycling technology that produces recycled PVC compounds. VinyLoop uses selective dissolution and filtration to separate the PVC from other materials such as rubber, other plastics, and textiles. The recycled PVC compound can be extruded, injection moulded or calendered to various applications such as hoses, foils and shoe soles. The company VinyLoop Ferrara S.p.A with its plant in Ferrara, Italy, treats 10 000 tonnes of PVC waste per year and is used as a pilot plant for industrial research (VinyLoop, 2013).

CreaSolve® process

In the Creasolve process, patented by Fraunhofer Institute, proprietary solvents are used to selectively dissolve the target polymer. This reduces besides the hazard also the cost for the equipment. Finally the desired polymer precipitates when a special CreaSolv® Precipitation Formulation is added after the cleaning from impurities. The ingredients of the formulations are commercially available and are not research products (GmbH, 2016).

1.2.2 Mechanical recycling

Mechanical recycling refers to operations where recyclates to be used for plastic product manufacturing are produced by mechanically processing plastic. Only polymers possible to melt, i.e. thermoplastics, can be mechanically recycled and re-processed into products by techniques such as injection moulding and extrusion (European Plastic Recyclers, 2016).

In mechanical recycling, different kinds of mechanical processes, such as shredding, sorting, washing, drying, granulating and compounding, are used to convert wastes into new products.

Mechanical recycling of post-consumer plastic waste often leads recycling into products with a lower quality than the original applications whereas mechanical recycling of pre-consumer waste is more straightforward as the waste stream is more homogenous, and has a known content.

Mechanical recycling can be divided into mechanical recycling in closed loops and mechanical recycling in open loops. Mechanical recycling in closed loops is the most value-preserving form of recycling where the polymers are kept intact and the quality kept at an equal level compared to before recycling as the plastic is recycled into the

same applications. This also allows traceability. In mechanical open-loop recycling the polymers are kept intact, but the recycled plastics suffer from quality loss why the possible applications are products with lower requirements compared to the plastics' original use (World Economic Forum *et al.*, 2016).

1.3 Examples of closed-loop mechanical recycling

In this sub-chapter examples of closed-loop mechanical recycling are presented. By closed-loop mechanical recycling we mean recycling back into the same kind of products that the waste originally derived from. This does not have to happen in the same country or within the same company.

1.3.1 *Recycling of rigid PVC products in Denmark*

Collection for recycling of rigid PVC products has taken place in Denmark at least since the beginning of the 1990's, where the Danish EPA and the Danish plastic association agreed upon a voluntary recycling scheme for used rigid PVC. The recycling scheme is now organised as a private company, WUPPI A/S, owned by manufacturers of rigid PVC products (established in 1997). The rigid PVC has primarily been used for building and construction purposes, and includes items like:

- Pipes and fittings.
- Hoses.
- Gutters.
- Door and window frames, profiles.
- Plates, roof plates.

Heavy metals, like lead and cadmium have earlier been used as stabilisers and colorants in these products. As rigid PVC is often used in products with a relatively long life the collected rigid PVC waste still contains some amounts of heavy metals.

Also for these reasons, in 1999 a tax on new PVC products was introduced in Denmark (Lovbekendtgørelse nr. 954 af 20. December 1999 om afgift af polyvinylklorid og ftalater (PVC-afgift) with the latest adjustment in 2007). In 2000 a statutory order was

issued prohibiting imports and selling of products containing lead, including PVC products (“Bekendtgørelse om forbud mod import og salg af produkter, der indeholder bly” BEK nr 1212 af 13/11/2000 with later adjustments in 2007 and 2009).

WUPPI collects approximately 4,000 tonnes of rigid PVC waste per year, which is about 60% of the total collection in Denmark. Some of this waste contains lead, and cannot be recycled due to the statutory order in Denmark. All the PVC waste is therefore exported to Germany, Holland and France, where it is recycled into products such as pipes. The lead containing materials is encapsulated in inner layers of primarily sewerage pipes (WUPPI, 2016).

In a report from 2015 Danish EPA gives an overview of the amounts of rigid PVC products supplied, the amounts PVC waste and the recycling of it (Miljøstyrelsen, 2015b). Furthermore, it gives an overview of the resource and environmental aspects of use, waste management and recycling of rigid PVC as well as the financial implications of recycling of rigid PVC waste. Among other things the report presents estimates of the amounts of lead and cadmium that is exported in the recycled PVC waste and how much of that is accumulated in products that still remain in the ground and in buildings. Calculations in the report show “that with the optimal collection in Denmark it will be possible to collect more than 5,000 tonnes of lead in the period up to 2050. Old pipes underground constitute around 50% of this quantity and it is uncertain whether they will be collected. Quantities of cadmium collected in the same period amount to around 70 tonnes”. It is further concluded in the report “that the economy of collection and separation of PVC in Denmark is poor, whether separation is manual or mechanical. It is a statutory requirement that PVC must be collected separately and that a significant proportion of the waste is recycled. The agreement entered between the Ministry of the Environment and WUPPI along with other collection schemes ensure that this target is met. The agreement ensures a high degree of collection and a separation with a high proportion going to recycling. The manual separation creates some additional employment in Denmark. Alternatively, PVC materials can be exported as mixed plastics separated mechanically at facilities in the neighbouring countries. This gives a much better collection economy”. Thereby the report provides a possibility to formulate policies for further handling hazardous substances in rigid PVC that may appear as waste in the coming years. There has been a long discussion between authorities, the industry and NGO’s about the use of PVC products, their contents of heavy metals and other hazardous substances as well as the recycling and the disposal of PVC waste. The discussion around 2010–2015 is referred to in the

above report, but some of the earlier discussion is referred to in an EU Green Book on “Environmental Questions about PVC” (European Commission 2000).

1.3.2 Food-grade recycled PET

The consulting company, Nextek, has together with the Australian juice company, Emma & Tom’s, as well as recycling companies, VISY and Sustainability Victoria, developed a 100% recycled PET juice bottle. High quality rPET was used to manufacture juices bottles for trials and testing and a Life Cycle Analysis (LCA) was conducted on the rPET process (Nextek 2016).

Another example on recycling and use of high quality rPET is the plastic manufacturing company Færch’s development of a rPET tray for meat products (Færch, 2016).

1.3.3 Reuse of milk crates for distribution of milk products

Another example on closed loop recycling is the milk product manufacturer Arla’s use of milk crates to distribute their products. The milk crates are reused, but there is a loss, which has to be replaced with new milk crates. Earlier these supplementary crates were manufactured from virgin plastic, but new test showed that they can be manufactured from 100% recycled plastics instead (McKinnon *et al.* 2016).

2. Legislative framework and standards for products and waste

In this chapter first the different strategies existing on national level are reported, and then legislation and standards with an impact on this area is described.

2.1 National strategies for recycling without hazardous substances in the Nordic countries

In the Nordic countries there are also national strategies for recycling without hazardous substances.

2.1.1 *Denmark*

Denmark has the same targets for recycling packaging as the rest of EU. In the strategy for waste prevention (Denmark without waste II) it is mentioned that “the consumers should buy products and services that uses less resources, contain less problematic substances and generate less waste”. In this way the latest national waste prevention strategy supports the phasing out of hazardous substances in materials that can be recycled. But as it also appears from the above, Denmark does not have a comprehensive strategy, which directly link recycling and phasing out of hazardous substances.

However hazardous substances in plastic products, whether based on virgin materials or recycled plastics, are regulated through various legislation. Some regulation, e.g. regulation of phthalates are only relevant for plastics as it is only used here, but other regulation, e.g. regulation of heavy metals is not directed towards plastics specifically, but aims to phase out hazardous substances in general, independent on in which applications the substances are found. Additionally, the government has approved and updated the “Implementation Plan for the Stockholm Convention about Persistent Or-

ganic Pollutants” (Miljøstyrelsen, 2013). This implementation plan describes the present situation in Denmark with regards to phasing out the persistent organic pollutants, and also actions to strengthen the phasing out of the substances in the coming years. Similar plans exist in all Nordic countries.

Furthermore, the Danish EPA has issued a “List of Unwanted Substances” (“Listen over uønskede stoffer”, LOUS). A fourth version of the list was issued in 2009, including 40 substances. The Danish EPA recommends companies to seek ways to phase-out of the substances mentioned on the list. For each of the substances the Danish EPA has established a strategy for phasing out the substance, and the status for implementing each of these strategies is shown on EPA’s website (<http://mst.dk/virksomhed-myndighed/kemikalier/fokus-paa-saerlige-stoffer/listen-over-uoenskede-stoffer/status-for-lous/>). As the list includes several substances found in plastic products, the list will in the long run indirectly reduce the hazardous substances in plastic waste for recycling.

In order to assess the potential risk of hazardous substances in consumer products, the Danish EPA has within the last decade conducted a long range of projects, resulting in about 150 reports, published in the series “Survey of chemical substances in consumer product”. Several of these surveys are made for plastic products, some of which may be recycled and thereby carry further the hazardous substances. A few of these surveys are mentioned below:

In 2015 the Danish EPA published a survey on CMR Substances (Carcinogenic, Mutagenic and Reprotoxic) in Toys – Market Surveillance and Risk Assessment (Miljøstyrelsen 2015d). The objective of the project was:

- to identify the presence of CMR substances in toy products, based on literature studies of existing investigations and knowledge
- to analyse the content and migration of CMR substances for a number of selected products
- to make a risk assessment of products with a significant content/migration of CMR substances.

The chemical analyses of the selected toy products were conducted according to the following procedure:

- Screening analyses of 28 products.
- Quantitative analyses of 24 selected CMR substances from the screening.
- Migration analysis of two CMR substances selected from an overall worst-case risk assessment based on 100% migration.

The overall conclusion of the project was that CMR substances exist in a wide range of toy products but in concentrations that are below the permitted limits of each CMR substance. Under worst-case assumptions, the health assessment of 10 CMR substances that appeared in the highest concentrations in 11 selected toys, showed no risk for these substances that can be assessed.

Also in 2015 The Danish EPA conducted a survey and health assessment of phthalates in toys and other products for children (Miljøstyrelsen 2015e). The purpose of the project was to provide an overview of children's exposure to phthalates with anti-androgen effects from toys, childcare articles and other products for children as well as to perform a market surveillance on the requirements in legislation concerning phthalates in toys and childcare articles. Furthermore, the purpose of the project was to investigate whether other products for children contain and release phthalates in concentrations which may be problematic for children. The project included first a market survey of the three types of products. Then followed an investigation of whether phthalates had been identified in former projects, and if so, which phthalates. Furthermore, applicable legislation regarding phthalates was described for toys, childcare articles and other products for children.

The survey provided the basis for the purchase of products for chemical analysis for the content of phthalates. Based on the survey, 34 toy products and seven childcare articles were selected. Furthermore, it was decided to purchase 35 other products for children for chemical analysis for a content of phthalates.

The conclusion of the project was that exposure to a few phthalates in single products, examined as a part of the project, does not constitute a risk but that the total exposure to more phthalates with antiandrogen effects from several different sources in a realistic worst-case scenario may constitute a health risk for 6-year-old children. A large part of the risk is due to the use of a few products with high contents of phthalates

as well as assumptions that phthalates are still present in food like it was some years ago – which probably is an overestimation in relation to the real situation today.

Also in 2015 the Danish EPA published a report from a survey of the potential exposure risk from hazardous substances that might be present in second hand materials and products that children and young people apply for creative activities (Miljøstyrelsen, 2015a). The objective of the project was to assess, if the potential exposure during processing and the subsequent use of the products constitute a health risk. 26 products from 10 product groups were selected for chemical analysis in order to assess, if the problematic substances can be liberated during the creative production and use of the products. Some of the products investigated were older plastic products, and some of the substances analyzed included: DEHP, PAH and heavy metals. The project has only found that the use of cord as jewelry constituted a potential risk due to the content of lead at concentrations above 500 mg/kg. However, it should be emphasized that the project cannot “acquit” the application of used products and materials in general.

In 2008 the Danish EPA published a survey of emissions as well as environmental and health risk assessment of chemical substances in artificial grass lawns (Miljøstyrelsen, 2008). The background for the project was the increasing use of artificial grass fields for primarily football courses, but also for golf-greens, playgrounds etc. The artificial grass fields are primarily made of rubber granulates from car tires (infill), covered with green plastic grass, mostly made of PE, PP or nylon. It was estimated that there by August 2007 were 45 such football fields in Denmark, and that 100–120 tons rubber granulate is used for each field. The fields are used during the whole year, and during winter time salt is used for de-icing and removal of snow. The potentially hazardous substances investigated included the following: zink, DEP, DBP, BBP, DIBP, DCHP, DEHP, nonylphenole, bis-sebacat, cyclohexanamin and phenol 2,4-bis. According to the results of the project, there seems not to be any health risk, except a potential allergy risk for vulnerable people. With regards to environmental risks there seem to be a risk of discharge of a number of environmentally hazardous substances, if the drain water is led to nearby waterways. However, there is a need for more monitoring programmes.

In 2014 the Danish EPA initiated a project (Miljøstyrelsen, 2016) addressing the waste phase of consumer products, and more specifically, whether the possibilities for recycling are hindered by problematic substances contained in the products. The overall aim was to develop a method to describe and assess whether chemical substances contained in consumer products prevent recycling of the materials used in the products,

or prevent recycling of other materials in the waste fraction in which the consumer products end up in when disposed of. In order to develop the method, nine consumer product categories were selected. Of these nine product categories six of them contained plastic materials. Two product categories were selected for a more detailed analysis, including “outdoor clothing” and “plastic parts from electrical and electronic equipment” (EEE). The problematic substances in outdoor clothes are phthalates in rain jackets and perfluorinated substances in impregnated outdoor clothes. Most outdoor clothes are probably disposed of when it does not serve its function anymore, but in some cases it might be recycled and used as fillers in furniture cushioning or as insulation materials. In these cases the phthalates and perfluorinated substances are brought further to other products. In case of EEE the problematic substances might be BFRs and heavy metals (from old products). In practice these plastic fractions are disposed of by incineration, as they are not allowed to be recycled. However, the plastic fractions from other newer EEE products are without these problematic substances and can be recycled. As both waste of old and newer EEE products are collected together the segregation is difficult, the content of brominated substances and heavy metals still reduce the possibilities for recycling of a valuable plastic fraction. This will lead to less materials being recycled. (Miljøstyrelsen, 2016). There are however a few examples on smaller amounts of WEEE of high quality plastics without hazardous substances that are being recycled, e.g. are plastics from end-of-life freezers recycled.

2.1.2 Finland

In Finland, reports, a guide document and recommendations for management of hazardous substances have been published.

National Programme on Dangerous Chemicals. The interim assessment and the revision 2012. The programme recommends several measures to be taken to minimise chemical-related environmental risks and human health hazards. The national programme contains a few measures related to management of plastic waste. The recommendations include further research into nanomaterials, especially use in plastic materials which may be present in regular consumer goods that ends up in municipal waste management. Also the use of flame retardants in plastics waste may be cause emissions in waste treatment plants, e.g. during the crushing processes. The national programme is currently under new interim assessment and an updated programme will be published in 2017 (Anon, 2013).

National implementation plan for the Stockholm convention on Persistent Organic Pollutants (POPs). The National Implementation Plan (NIP) reviews the general principles of the Stockholm Convention, as well as the provisions entailed by it. The NIP provides an overview of the current status and the main trends in emissions of the substances covered by the Convention and their environmental concentrations (including, in particular, dioxins, furans and PCB compounds) as well as the provisions related to the management of waste containing these substances. The possible effects of POP compounds on different organisms are also dealt with briefly. The NIP furthermore contains a National Action Plan (NAP), which the parties to the Stockholm Convention must develop to reduce the emissions of unintentionally produced POPs. The implementation plan does not contain specific recommendations for plastic waste. The plan is subjected for a review in 2017 (Seppälä *et al.*, 2012).

In 2015, the Finnish Environment Institute published a report (Myllymaa *et al.* 2015) about occurrence, identification and separation of selected POPs in some selected waste streams (WEEE; ELV and C&DW). Special focus has been on following 6 POP substances: c-PeBDE, c-OBDE, HBCD, SCCP, c-DBDE and TBBPA. The report contains information from literature about measured concentrations in different waste streams.

In 2016, a guide for management of POP containing wastes and their application to WEEE and ELV was published by the Ministry of the Environment (Anon, 2016). The guide gives the instructions on types of waste to be classified as POP waste. The guide presents in more detail how the management of ELV and WEEE containing BFRs should be organised in order that the requirements of the POP Regulation are fulfilled. The guide is intended for the municipal and state environmental permit and supervisory authorities, companies in whose operations POP waste may be generated, waste management companies, and waste management consultants.

Finland has also defined national targets for material recycling of plastic packages (Government decree 517/2014 concerning packages and package wastes). Currently the decree requires a recycling rate of at least 16%. Under producer responsibility in Finland, a collection system (500 collection points for collection of consumer plastic package and 30 collection points for industrial plastic packages in Finland) is mandatory.

The Finnish Waste management plan (WMP) for the coming years is under revision. Both the current and the new WMP emphasises safe waste management and recycling. In the WMP under preparation a special focus is on safe waste management of electronic wastes.

2.1.3 Norway

In Norway, the regulations dealing with chemicals and waste concerning plastics are tasks dealt with by Norwegian Environment Agency (Miljødirektoratet). Miljødirektoratet surveys waste directives and constraints on material fractions to be recycled. All EU waste directives will be included in the EEA agreement, and must subsequently be implemented in Norwegian law.

Targets for plastics recycling are defined for packaging in which case the goal is 36% material recycling and 62% energy recovery (Grønt Punkt, 2015). For plastics containing hazardous substances, there are no specific goals but as these are handled as hazardous waste, general targets for such materials such as safe handling and reduction of produced volumes applies. A national waste strategy defines Norway as a Party to the Stockholm and Basel Conventions and implements the EU POP-regulation which puts restrictions on recycling of POPs (Miljøverndepartementet, 2013).

Waste regulations define limits on content for what is to be considered hazardous waste to be incinerated (Avfallsforskriften, 2004).

National targets are defined for relevant environmental goals – <http://www.miljos-tatus.no/nasjonale-mal/>. In particular:

- Pollution shall harm neither health nor environment.
- Releases of substances that are hazardous to health or environment will be eliminated.
- The rate of growth of the amount of waste shall be lower than the rate of economic growth.

An action plan describing how Norwegian authorities shall reach the 2020 target for substances harmful to the environment has been developed. The target is to stop the emissions by 2020 (Klima- og miljødepartementet, 2015).

2.1.4 Sweden

Sweden has Environmental Objectives; a Generational Goal and sixteen environmental goals of which two are especially relevant for this project. They are “A Non-Toxic Environment” and “A Good Built Environment”. The most important precision of the Generation Goal is that by 2020 recycling is resource efficient and as far as possible free from hazardous substances.

According to two of the six more detailed precisions of “A Non-toxic Environment” are that the use of particularly hazardous substances has as far as possible ceased and that information on substances that are dangerous to health or the environment is available for materials, chemical products and other products.

“A Good Built Environment” includes a precision of a resource-efficient waste management where the resources in the waste is used to the highest extent possible while at the same time the impact and risks for health and environment are minimised.

The Swedish government has stipulated eight interim targets for hazardous substances. The interim targets address particularly hazardous substances, as well as hazardous substances. The interim target concerning hazardous substances states that decisions taken in the EU and internationally shall include measurements meaning that:

- In 2015, substances toxic for reproduction and allergenic substances are seen as particularly hazardous substances in relevant legislative framework.
- In 2018, particularly hazardous substances are subject to examination or phasing out in all legal frameworks in all areas of use.
- In 2018, particularly hazardous substances are only used under strictly restricted conditions in production processes.
- In 2018, the expression “particularly hazardous substances includes substances with other hazardous properties than those already included in current specific criteria in 2018.

The aim of the interim target on particularly hazardous substances is to decrease the use and eventually phase out these substances.

There is also an interim target about “Information about Dangerous Substances in Products”. The target means that information on substances in materials and products that are hazardous to health and to the environmental is made available during the full life cycle of the material or product and that it is available for all priority groups.

The interim target regarding “Toxic and Resource-Efficient Cycles”, should result in that the EU legal framework for waste, chemicals and products are mainly complementary and coordinated so they control the toxic and resource-efficient recycling. Another result from this target is the principle of high and equivalent requirements for the content of hazardous substances in virgin and recycled materials is established by a decision where appropriate.

The Swedish Chemical’s Agency was in 2010 commissioned by the Swedish Government to develop an action plan for A non-toxic everyday environment. In 2014, the commission was prolonged to 2020. Within the action plan, the EU chemical legislation and supervision of hazardous substances in products are prioritised. In addition, the Swedish EPA has been given the task to contribute to the action plan from a life cycle perspective by the governmental commission “Resource-efficient and non-toxic cycles”. In summary, the core in the governmental commission is to increase recycling without risks for environment and health due to spreading and exposure of hazardous substances (Naturvårdsverket, 2016b).

During 2015, the Unit for Enforcement of Rules – Pesticides and Articles at the Swedish Chemicals Agency monitored the chemical content in plastic articles. 52 companies were inspected, and 160 samples analyzed. The articles were typical everyday articles such as bathroom products, garden equipment, working gloves, bags and sports equipment, and mainly made from soft plastics. The targeted substances were phthalates listed as SVHC on the Candidate list or restricted in toys or childcare articles according to Annex XVII in REACH, dimethylformamide/methylacetamide listed as SVHC on the Candidate list, short chain chlorinated paraffins (SCCP) banned according to the POPs Regulation, as well as cadmium regulated by the Directive on packaging and packaging waste. Lead was also analyzed as from June 1st it will be regulated according to Annex XVII in REACH.

14 of 160 articles analysed contained restricted substances in levels above the limit values for products of which the most common substance was short chain chlorinated paraffins. Except these articles, 24 articles contained substances on the candidate list in the REACH Regulation in levels above 0.1 percentage by weight. The Swedish Chemical’s Agency draws the conclusion from the supervision that a lot of articles on the Swedish market, mostly articles made of PVC, contain substances with hazardous properties, and that the control of these kinds of articles should continue. The agency also means that the total amount of hazardous substances in use and in the waste flow may be of large impact even though the levels in a single article may be low (KEMI, 2015).

In a draft for a guidance document (Naturvårdsverket 2016b) the Swedish EPA states that substances that are cancerous, reprotoxic and mutagenic (CMR-substances) and also substances that are persistent, bioaccumulative and toxic (PBT, vPvB) should be phased out. These criteria are similar to the EU definition of Substances of Very High Concern (SVHC). Also endocrine disrupting chemicals and highly allergenic substances and mercury, cadmium and lead should be considered as particularly hazardous substances. The Swedish EPA lists seven points for increased and safe recycling of materials where priority is on i.e. recycling of “clean” materials. The list and its seven points stretches from points number one and two, giving “a green light for recycling” towards the last two points giving “a red light for recycling”. The Swedish EPA also states that materials with known low content of hazardous substances could be used for special applications, that recycling of materials with a large potential but also problems with hazardous substances should be improved. Materials that contain particularly hazardous substances should not be recycled.

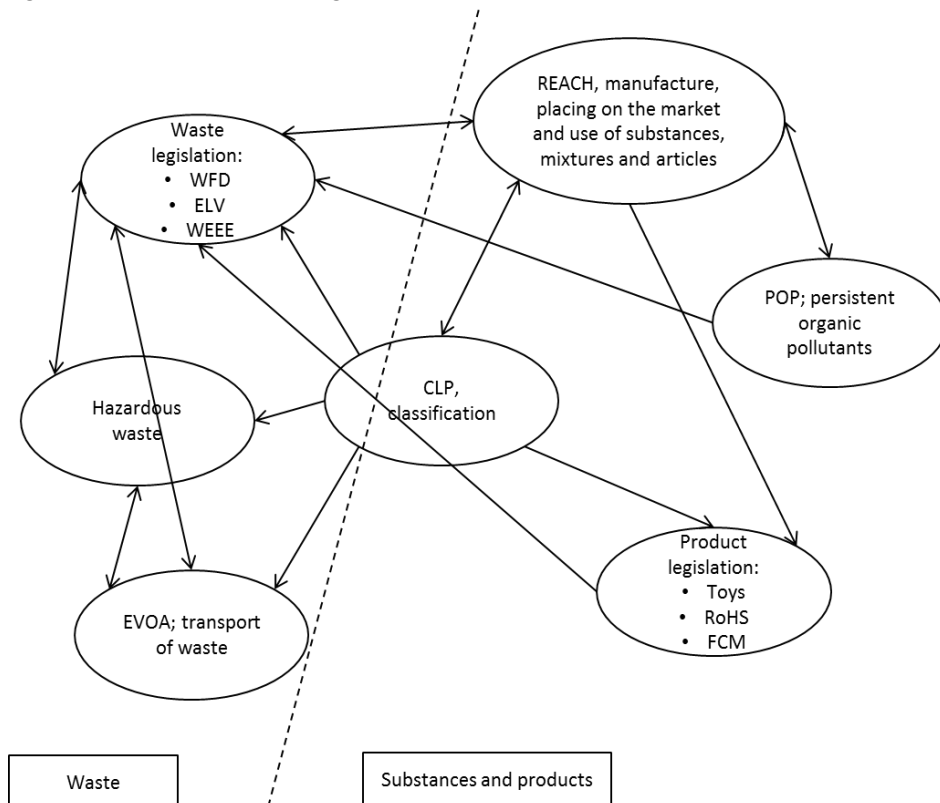
2.2 Legislation and standards

The following chapter includes a summary of relevant legislation and standards on both the EU and the national Nordic level having an impact on the possibility to recycle plastic waste with a content of hazardous substances or limit the recycling possibilities. The legislation and standards brought up in this chapter includes both regulations targeting hazardous substances in general, products as well as in waste, and is not an exhaustive list.

2.2.1 Legislations

In Janssen *et al.* (2016) the following picture is drawn on links between different legislations that are further described in the chapter:

Figure 2: Links between different legislation



Source: Janssen *et al.* 2016.

This chapter begins with legislation related to substances, products and materials and then moves on to waste regulations. Under each chapter the legislation’s impact on recycling of plastics is described.

The chemical content in plastic products is regulated through various frameworks, i.e. the same product can be regulated by several pieces of legislation. Some product groups are regulated to a high extent with higher demands, such as toys, whereas others are not as strictly regulated. Below relevant legislations are listed.

2.2.2 REACH

The EU regulation REACH (Regulation No 1907/2006) stands for Registration, Evaluation, Authorisation and Restriction of Chemicals and came into force in 2007. The aim of the regulation is to ensure that all substances are manufactured and used safely (REACH concerns use of substances in products manufactured in EU or imported to EU).

According to REACH manufacturers and importers of chemical substances of at least one tonne per year must register the chemical substances to ECHA, the European Chemical's Agency. Unregistered chemical substances cannot be marketed on the EU market. REACH applies in principle to all chemical substances and puts pressure on companies to identify and manage the risks linked to the substances they produce and/or market in the EU. The companies producing or importing the substances have to assess the hazards and potential risks presented by the substance. Substances may be identified as SVHCs if they are CMR, PBT or vPvB according to REACH (Annex XIII). Restricted substances can be found in Annex XVII, but does not have any connection to the definition of SVHC. The majority of substances in REACH are not covered by restrictions.

A Member State or ECHA, at the request of the European Commission, can propose a substance to be identified as a SVHC. Listing of a substance as an SVHC on the so-called Candidate list by ECHA is the first step in the procedure for authorisation of use of a chemical. Substances on the candidate list can be used in mixtures and articles, but there is obligation to provide information about use in articles to ECHA and to users. The first Candidate list¹ was published in October 2008 and the last update was made in December 2015. The list is updated twice a year. After a two-step regulatory process, SVHCs may be included in the Authorisation List (Annex XIV) and become subject to authorisation.² These substances cannot be placed on the market or used after a given date, unless an authorisation is granted for their specific use, or the use is exempted from authorisation. Substances on the authorisation list as per January 11th 2016 concerning plastics are listed in Table 6.

¹ <http://echa.europa.eu/candidate-list-table>

² <http://echa.europa.eu/addressing-chemicals-of-concern/authorisation/recommendation-for-inclusion-in-the-authorisation-list/authorisation-list>

Table 6: Substances in plastics on the authorisation list as per January 11th 2016

Substance	Function
Bis (2-ethylhexyl) phthalate (DEHP)	Plasticiser
Dibutyl phthalate (DBP)	Plasticiser
Benzyl butyl phthalate (BBP)	Plasticiser
Diisobutyl phthalate (DIBP)	Plasticiser
Acrylamide (monomer)	Intermedia – Co-monomer
Hexabromocyclododecane (HBCDD)	Flame retardant
Lead chromate	Pigment
Lead chromate molybdate sulfate red	Pigment
Lead sulfochromate yellow	Pigment

The requirement on authorisation is only applicable on products manufactured within the EU, and not on imported products. Waste is in principle not addressed in REACH.

REACH (Annex XVII) also restricts the use of certain substances, sometimes linked to specific product groups. As an example six groups of phthalates used in plastics are regulated under Annex XVII, of which three are also on the authorisation list. Toys and childcare articles, which can be placed in the mouth by children, containing the following phthalates concentrations greater than 0.1% by weight of the plasticised material shall not be placed on the market:

- Di-'isononyl' phthalate (DINP).
- Di-'isodecyl' phthalate (DIDP).
- Di-n-octyl phthalate (DNOP).

Polymers are exempted from registration and evaluation under REACH as polymers generally are of low concern due to high molecular weight.

However, according to Article 6(3), the manufacturer or importer of a polymer "must submit a registration for the monomer substance(s) or any other substance(s) that have not already been registered by an actor up the supply chain, if both the following conditions are met:

- The polymer consists of 2% weight by weight (w/w) or more of such monomer substance(s) or other substance(s) in the form of monomeric units and chemically bound substance(s).

- The total quantity of such monomer substance(s) or other substance(s) makes up 1 tonne or more per year (the total quantity in this context is the total quantity of monomer or other substance ending up chemically bound to the polymer).” (ECHA, 2012).

ECHA has published a guidance document on how polymers and monomers comply with REACH” (ECHA, 2012).

In REACH (article 33) there are information requirements linked to the SVHC on the candidate list in articles. Article 33 describes the suppliers’ obligation to provide information about SVHCs if the content exceeds 0.1% in the article they market. There should be sufficient information to allow safe use. If asked for by a consumer, the information shall be provided within 45 days free of charge. An article that is an article according to the definition in REACH will always remain an article even if it added together with other articles to a complex article like for example a car.

The companies are responsible for the safe use of a chemical substance throughout its life cycle. They are required to write a chemical safety report, in which exposure scenarios should be included. Exposure scenarios should describe how a substance is used in a safe way, during its manufacture and use, and carry this information to the users. Exposure scenarios are a fairly new tool, and it is not clear how they should be written to work as they are meant to. Exposure scenarios and safety data sheets are only transferred between professional users. When an article is produced, the chain of information is broken and the information “lost”. For articles there is no obligation to provide exposure scenarios or safety data sheets, and not to consumers either. In practice the information asked for within REACH is “lost” in the consumer part of the value chain meaning that the information is never transferred to the waste stage. The safety data sheets do contain a section on how chemical products should be taken care of when they become waste. Waste is however commonly in the form of articles, where such information is not required.

REACH and plastics recycling

Plastic recyclers must comply with the REACH obligations of manufacturers (for substances and mixtures) or producer of articles if they produce articles from waste. Mechanical processing, and all forms of recovery, resulting in one or several substances, mixtures and articles that have ceased to be waste is considered as a manufacturing process according to European Plastic Recyclers (2016). However, this interpretation is

debated as the description of a manufacturing process in REACH (art 3.8) might also be interpreted to exclude recycling. In general recyclers have to deal with the fact that the material they are using comes from many different sources and that information on content of hazardous substances given according to article 33 is most often lost on the way. Recyclers have to provide Safety Data Sheets (SDS), apply CLP notification and comply with restrictions and authorisations if they are substances/mixtures manufacturers. If they make articles, they have to apply the relevant registration, notification and information obligations (European Plastic Recyclers, 2016), including the information requirements given in article 33.

The ECHA guidelines on waste and recovered substances (ECHA, 2010) provide support to recovery operators on how to comply with REACH. The guideline is thus not always easy to understand, as interviewees in the project have highlighted.

A plastic polymer is a chemical substance within REACH. Additives to the substance that are necessary for the stability of the process, or impurities from the manufacturing process are part of the substance according to Article 3(1) in REACH (KEMI, 2014a).

Intentional additives that are added for other reasons than stabilising, and have not reacted with the polymer, are regarded as separate substances and are thus not part of the polymer. Plastic granules, for example, are often regarded as a mixture of several substances (KEMI, 2014a).

Recycled plastic material can include impurities in the form of additives that were added to the original plastic material, but serve no function in the recycled material. When sorting mixed waste it is often impossible to obtain recovered materials of 100% purity, i.e. which are free of alien elements. These elements can be for example stones, plastics, rubber and sand or remainings of paints, coatings etc. According to the ECHA guidance impurities of this kind, both from waste management and from original plastic material, should be regarded as a part of a substance if they do not exceed 20% (w/w). If the content of impurities is below 20% (w/w) they are in other words considered part of the polymer. However, if the additives are recycled on purpose they considered to be separate substances under REACH, and it is the same for impurities exceeding 20% (w/w)(ECHA, 2010). This 80/20 rule is currently being discussed further by the European Commission and the member states as there is no consensus about the interpretation.

It can, however, be difficult to conclude whether a constituent of a recovered material is a substance or an impurity. There is no legal definition of an impurity in REACH.

The ECHA guidance on substance identification thus defines an impurity as “an unintended constituent present in a substance as produced”. It may originate from the starting materials or be the result of secondary or incomplete reactions during the production process. While it is present in the final substance it was not intentionally added.” To a polymer recovery operator this means that in order to comply with REACH they need to identify intended substances in the recovered material. By intended substances means substances originally present in the polymeric material added to the polymer to adjust or improve the properties or appearance of the polymeric material. Impurities, such as originating from substances originally present in the polymeric material to be recovered do not need to be registered, as their presence is covered by the registration of the monomer substances. This makes it important for the polymer recovery operator to know the origin of the recovered polymeric material (ECHA, 2010).

When the type of substance or impurity of the recovered material is determined, and identified and documented the recovery operator examines whether the exemption criteria under Article 2(7)(d) of REACH are fulfilled. Article 27(d) means in brief that substances that result from recovery processes, if they are the same as already registered by any registrant, is exempted from registration according to REACH.

The need for knowledge of substances included in plastics manufactured from recycled material sometimes makes it hard for the recycler, since they may not know the content of the waste they are receiving and it is not always possible to make detailed analysis of all incoming material.

For the SVHCs recycled plastic waste containing these substances must carry information if the material contains SVHCs exceeding 0.1% (w/w). Some SVHCs are banned from use, but far from all. The SVHCs that are not allowed in new plastics products might still be introduced in the waste stream by plastic products put on the market in the past, or from plastics products manufactured outside EU/EEA. According to article 33 in REACH it is not compulsory to analyse or measure SVHCs in the products they market, but they are required to be able to provide information regarding SVHCs that are present in levels exceeding 0.1% (w/w).

A SVHC that is high on the agenda in the EU when it comes to plastics recycling is DEHP that might be present in soft PVC. DEHP is placed on the authorisation list (Table 1) meaning that the phthalate cannot be placed on the market unless an authorisation is granted. The European Commission recently (April 2016) granted authorisation to

three recycling companies.³ The authorisation means that the companies are allowed to have DEHP present in recycled soft PVC, in compounds and in dry-blends, thus enabling recycling of soft PVC (PlasticsNews, 2016).

Clients buying recycled plastic compounds or plastic products may require that the products/ compounds are free of SVHC-substances (Bibi 2014). This is confirmed in the interviews. A Swedish compounder interviewed in the project writes a kind of certificate based on good faith that their products are essentially free from SVHCs. The key information in this certificate is that this assessment is made by properly trained staff. They also state in writing that they do not analyze for SVHCs. The vast majority of clients are satisfied by this certification (Eriksson, 2016). Testing for SVHCs is challenging and would be very costly and difficult due to the fact that it is a very heterogeneous material. There are laboratories offering stating that they can perform "SVHC -tests" exist, but how the tests are performed and their reliability have not been further investigated in this project. The tests have no legal standing, in the sense that they are not in any way referenced to in the legislation concerning SVHCs, which make their contribution to consumer safety doubtful (Eriksson, 2016).

The RoHS directive

Directive 2011/65/EC on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic equipment (EEE) (the RoHS directive) became effective in 2006 with the purpose of limiting the use of hazardous substances in electrical and electronic equipment, and to contribute to the protection of human health and the environmentally sound recovery and disposal of WEEE. The substances restricted in EEE under RoHS directive are listed in Table 7.

³ VinyLoop Ferrara (based in Italy), Stena Recycling (Sweden) and Plastic Planet (Italy).

Table 7: Substances restricted under RoHS

Substance	Maximum concentrations
Lead (Pb)	0.1%
Mercury (Hg)	0.1%
Cadmium (Cd)	0.01%
Hexavalent Chromium (Cr VI)	0.1%
Polybrominated Biphenyls (PBB)	0.1%
Polybrominated Diphenyl Ethers (PBDE)	0.1%
*Bis(2-Ethylhexyl) phthalate (DEHP)	0.1%
*Benzyl butyl phthalate (BBP)	0.1%
*Dibutyl phthalate (DBP)	0.1%
*Diisobutyl phthalate (DIBP)	0.1%

Note: *From 2019.

According to the RoHS directive (article 6.1), the Commission has to review the list of restricted substances in Annex II on the basis of scientific facts and taking the precautionary principle into account.

The RoHS directive and plastics recycling

The RoHS directive influences the possibilities to use recycled material in production of electrical and electronic equipment since it makes it necessary to know what is in the waste. Since plastics recyclers today have problems with identifying all possible substances present in plastics this would be an obstacle to solve. The RoHS directive applies for electrical and electronic equipment put on the market in the EU, both imported and domestically manufactured products.

2.2.3 SAICM

SAICM refers to the Strategic Approach to International Chemicals Management and was adopted in 2006 by the International Conference on Chemicals Management (ICCM). The policy framework sets the target that chemicals are produced and used in ways that minimize the adverse effects on environment and human health by 2020.

SAICM and plastics recycling

The Chemicals in Products programme (CiP) within SAICM is an ongoing activity on the policy and practical facets of access to information on the chemicals contained in everyday products. The activities focus on increasing the availability and access to the information actors need – throughout the life-cycle of products – so that they can properly manage those products and the chemicals in them. One of the potential outcomes of CiP is “enhancing the safe recycling and reuse of materials and products” (SAICM, 2016). The lack of information on the chemical content in plastics is seen as a problem for recycling.

Rotterdam Convention

The aim of the Rotterdam Convention is to protect the environment and human health and contribute to a more environmentally friendly use of certain chemicals by promoting shared responsibility and common efforts among parties within the international trade of some hazardous substances. This will be achieved by facilitated information exchange about the chemicals’ properties, by implementing a national decision approach for import and export of such chemicals (the so-called PIC approach), and by communicated taken decisions to the parties. The PIC approach together with the information exchange are the two most important provisions in the Rotterdam Convention.

Rotterdam convention and plastics recycling

The convention could have an impact on export or import of plastic waste for recycling if the plastic waste contains any chemicals listed in the Annex III of the Rotterdam convention. Annex III includes especially pesticides and some industrial chemicals (here of relevance: specific flame retardants (e.g. c-OctaBDE, PentaBDE) and PFOS). The importance of the Rotterdam convention is mainly of concern for plastic waste containing the specific flame retardants and PFOS.

2.2.4 *The Toy Safety Directive 2009/48/EC*

Since toys have to be safe for children to play with and should contribute to child development and play in a non-harmful way the directive on the safety of toys aims to ensure a high level of protection of children against risks caused by hazardous substances in toys, especially substances classified as CMR, allergenic substances and certain metals.

There are rules on chemicals that apply specifically to toys according to the toy safety directive and are valid for toys produced or imported to EU. The rules apply in parallel to other EU legislation. In the toy safety directive there are migration limits for 19 substances, primarily metals. The migration limits differ dependent on the material type the migration occurs from. CMR substances must not be used in accessible parts in toys beyond the concentrations limit according to CLP. 55 allergenic fragrances are prohibited and another 11 have to be indicated on the label because they are potentially allergenic. Nitrosamines and nitrosable substances are prohibited for use in toys intended for use by children under 36 months or in other toys intended to be placed in the mouth if the migration of the substances is equal to or higher than 0,05 mg/kg for nitrosamines and 1 mg/kg for nitrosable substances.

The toy safety directive and plastics recycling

It is stated in the directive Annex II, part II (Chemical Properties), point 1: "Toys shall comply with the relevant Community legislation relating to certain categories of products or to restrictions for certain substances or mixtures", this means that any recycled material to be used for the production of toys will have to comply with the directive and hence any other relevant legislation applicable to toys.

There are also requirements in the directive regarding documentation for substances and materials used in the production of toys, this may also contribute to reluctance to use recycled materials since the traceability of those differ.

In a report from the Swedish Chemical's Agency (KEMI, 2012) the regulations set on content of hazardous substances in toys was shown to make the producers more reluctant to using recycled materials.

2.2.5 Product Safety Directive

Directive 2001/95/EC on general product safety provides a generic definition of a safe product. A product is deemed safe once it conforms to the safety provisions provided in European legislation or national legislation of Member States adopted in accordance with EU law. The Directive aims at ensuring that products within the EU are safe regarding health risks from chemicals as well as ensuring the function of the product. Producers must according to the directive inform consumers of the risks associated with the products they supply.

Product safety directive and plastics recycling

The directive does not distinguish between products manufactured from virgin materials, and products of recycled materials. In addition, the directive does not include any specific requirements regarding hazardous substances.

2.2.6 *The POPs Regulation*

The Stockholm Convention entered into force in 2004 and is an international agreement with the aim of reducing and eliminating production, use and release of persistent organic pollutants (POPs). The convention comprises production (both intentional and unintentional), use, waste management and environmental supervision of POPs. The Stockholm Convention currently includes 28 substances. All countries signing the convention shall present implementation plans to limit or phase out emissions of POPs.

In all the Nordic countries the obligations of the Stockholm convention, the POP-protocol of the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) and the Basel Convention provisions for POP-waste are fulfilled by the implementation of Regulation (EU) No 850/2004 of Persistent Organic Pollutants. The regulation is the EU tool of limiting substances listed in the Stockholm Convention and the POPs Protocol. The regulation originally covered 16 substances / groups of substances with POP properties in the UNECE Protocol and 12 in the Stockholm Convention. The regulation currently bans or restricts the production and use of the following substances: adrin, chlordane, chlordecone, dieldrin, endrin, hexabromobiphenyl, mirex, toxaphene; DDT, heptachlor, hexachlorobenzene, PCBs, HCH including lindane, PCDD/PCDF, PAHs, hexachlorobenzene; hexachlorobutadiene (HCBD), hexa-, hepta-, tetra- and pentaBDE (PBDEs), pentachlorobenzene, perfluorooctane sulfonates, polychlorinated naphthalenes (PCN), and short-chain chlorinated paraffins (SCCPs). In addition decabromodiphenyl ether (decaBDE) and dicofol are under consideration.

The Annexes of the POP Regulation are dedicated to prohibitions and restrictions of intentionally produced substances (Annex I and II), release reduction measures (Annex III) and waste management provisions (Annex IV and V). A German impact study concerning 9 new or candidate POP substances ordered by the Commission was published in 2011. The aim of the report was to provide background information for new legislation. This report contains information about the source of the selected substances relevant for plastics (e.g. HCBD, SCCP, PFOS, PBDE, C-pentaBDE, C-octa-BDE)

entering articles, waste and environment. Also mass flows are analyzed for these substances. The report contains a compilation of analytical measurement methods for the detection of new and candidate POP concentrations in different relevant matrices (including also an evaluation of available screening methods). The report also discusses the impact on waste management and also effects of proposed limit values on recycling. The report recommends strict limit values for new and candidate POPs in order to eliminate POPs directly upon becoming waste and would prevent that the POPs would be diluted due to recycling in new products (European Commission, 2011).

According to Article 7 in the regulation and in line with the provisions of Article 6 of the Stockholm Convention, waste consisting of, containing or contaminated by any substance listed in Annex IV shall be disposed of or recovered in such a way so that the POP content is destroyed or irreversibly transformed provided that the content of the listed substances in the waste is exceeding concentration limits specified in Annex IV. Annex IV includes 14 substances.

The POPs Regulation and plastics recycling

POP substances relevant in plastic wastes are compiled in Table 8. For example, Mirex, Polybrominated diphenyl ethers (PBDEs) used as flame retardants) and Short Chain Chlorinated Paraffins used as plasticisers and also as flame retardants are listed. These compounds have been used in a wide range of products, mainly consumer products (e.g. electronics, carpets, construction materials).

Table 8: POP substances and concentration limit specified in Annex IV and Annex V in the POP regulation. Here only POP substances relevant for plastic waste are listed

Substances/substance groups classified as POP substances in regulation	POP Regulation	Lower concentration limits specified in Annex IV	Upper concentration limits specified in Annex V
Mirex	EU Regulation No 850/2004	50 mg/kg	5,000 mg/kg
Hexabromobiphenyl	EU Regulation No 850/2004	50 mg/kg	5,000 mg/kg
PBDEs – Sum of the concentrations of tetrabromodiphenyl ether, pentabromodiphenyl ether, hexabromodiphenyl ether and heptabromodiphenyl ether	Regulations EU No 756/2010 & 1342/2014	1,000 mg/kg	10,000 mg/kg
Perfluorooctane sulfonic acid and its derivatives (PFOS)	Regulation EU No 756/2010	50 mg/kg	50 mg/kg
Alkanes C10-C13, chloro (short-chain chlorinated paraffins) (SCCPs)	Regulation EU No 1342/2014	10,000 mg/kg	10,000 mg/kg
Candidate POP substances (note! Relevant for plastic waste)			
HBCDD		(proposed: 1,000 mg/kg)	(proposed: 1,000 mg/kg)
deca-BDE		to be established	to be established

The POPs regulation influences plastic recycling in two ways. Firstly by stating that all products containing POPs over the limit values in Annex IV should be destroyed or irreversibly transformed. There are however some exceptions made for products containing recycled material. Articles and preparations containing concentrations below 0.1% of PBDEs (tetra-, penta-, hexa- or hepta-bromodiphenyl ether) are allowed when they are produced partially or fully from recycled materials. This exception was introduced to allow for continuation of recycling of materials as the threshold for the flame-retarded parts of articles produced from non-recycled materials was lowered to 0.001% by weight (DG Environment, 2015). Secondly, the regulation prohibits the use of POPs in new products, which leads to less POPs in products, and in waste streams to recycling. The latter also functions as a kind of quality requirement for recycled plastics that are ready for the market.

A BAT/BEP guidance⁴ for recycling has been developed by UNEP. According to the guidance document, the down-cycling of some PBDEs containing wastes in specific products with non-sensitive use such as lumber or pallets is possible even if not recommended. In such cases, the recycled products need to be well labelled to ensure safe end of life management.

In Finland, the POP regulation was in the interviews seen as the biggest challenge for plastic waste recycling (especially WEEE). This means that the occurrence of POP substances in WEEE needs to be carefully monitored, prior to recycling, and unsuitable fractions containing POP substances exceeding the limits to be removed and directed to final treatment. The most important issue related to recycling of plastics is the content of PBDEs flame retardants in e.g. car scrap and WEEE (Miljøstyrelsen, 2013).

According to Swedish stakeholders, PBDEs and PFOS are especially challenging as they might be present in a wide range of applications, and there is no complete overview of the use.

In a report from The Swedish Chemical's Agency (KEMI, 2012), stakeholders from different sectors of the industry (manufacturers of flooring systems, interior products, toys and children's products, fashion clothes and accessories, high-end sportswear, large and small home-appliances, mobile phones and entertainment systems and ICT solutions) it was found that the main obstacles to increasing the use of recycled materials was the risk that the material contains hazardous substances, costs associated with measures to avoid such risks and limited availability of the material.

2.2.7 *Waste Framework Directive (WFD)*

Waste classification

The classification of waste as non-hazardous or hazardous is regulated by the Waste framework directive (WFD) 2008/98/EC. Classification criteria related to the properties that may render waste hazardous are regulated in the revised Annex III to the WFD (Annex III), while classification criteria related to the waste source and waste type is regulated in the European List of Waste (LoW).

⁴ <http://chm.pops.int/Portals/o/download.aspx?d=UNEP-POPS-NIP-GUID-BATBEPBDE.En.docx>

The legislation was revised in 2014 in order to be more aligned with the chemicals regulations and the CLP Regulation. The classification is primarily based on the European List of Waste (2014/955/EU). In some cases a particular type of waste on the list can be either hazardous or non-hazardous depending on the specific properties of the waste and in these cases the waste status has to be assessed based on its hazardous properties. The Commission Regulation No 1357/2014 defines the hazardous properties for hazardous waste classification as well as substance-specific limit values. It also refers to other properties that may render a waste material hazardous but it does not always prescribe the test methods to be used to assess these properties.

In Table 9 examples of critical concentration limits for specific phthalates in the waste classification are given. When the limits are exceeded, the waste is classified as hazardous waste which set requirements and limitations in waste managements. In practice, the recycling of waste is challenging if waste is classified as hazardous. The assessment procedure also applies POP substances (e.g. flame retardants, limits not included in the table below).

Table 9: Examples of critical concentrations in waste for specific phthalates in case of mirror entries in List of waste. If exceeded the waste is classified as hazardous waste according to Commission Regulation (EU) No 1357/2014

Substance	Limit concentration	Note!
DEHP	0.3%	'Mutagenic': Wastes which may cause a mutation that is a permanent change in the amount or structure of the genetic material in a cell.
BBP	0.3%	see above
DBP	0.3%	see above
DIBP	0.3%	see above

End of waste concept

The Waste Framework Directive (WFD) 2008/98/EC includes the option to set so – called End – of – Waste (EoW) criteria under which specified waste fractions shall cease to be waste. If these criteria are fulfilled, the material will no longer be classified as waste, but will instead become a product subject to free trade and use (following requirements in the EU regulations). EoW criteria are always voluntary to use. Article 6 of the WFD regulates the circumstances under which certain specified types of waste

cease to be waste. This “end-of-waste” status is reached when the waste has undergone a recovery operation, including recycling, and complies with specific criteria to be developed in accordance with the following cumulative conditions:

- the substance or object is commonly used for specific purposes
- a market or demand exists for such a substance or object
- the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products
- the use of the substance or object will not lead to overall adverse environmental or human health impacts.

On the basis of article 6 in the WFD recyclable materials suitable for receiving EoW criteria were looked into by Joint Research Centre (JRC) within the Sustainable Production and Consumption (SUSPROC) project between 2005 and 2008. Among other outputs, the report “Study on the selection of waste streams for end-of-waste assessment” was published from the project. The work included identification of waste streams suitable for EoW criteria assessment. Plastic waste was selected as one of those waste streams, and as a result the report “End-of-waste criteria for waste plastic for conversion” was published in October 2014. Before suggested EoW criteria for plastic waste were released, EoW criteria for iron, steel and aluminum scrap entered into force in October 2011 through the adoption of regulation No 333/2011,⁵ for glass cullet through regulation No 1179/2012 that entered into force in June 2013, and for copper scrap through regulation No 715/2013, which entered into force in January 2014.

In the *suggested* EoW criteria for plastic waste certain sections relate to recycling of plastic waste containing hazardous substances. In order for waste plastics to cease to be waste criterion number 1.3 states that:

- The waste plastic, including its constituents, shall not be classified as hazardous following the definitions in Article 3 and Annex I of Regulation EC/1272/2008 (CLP).

⁵ COUNCIL REGULATION (EU) No 333/2011.

- The waste plastic, including its constituents, shall meet the conditions of commercialisation of SVHC laid out in Article 56 of Regulation EC/1907/2006 (REACH).
Article 56 states that a manufacturer, importer or downstream user shall not place a substance on the market if that substance is included in Annex XIV (List of substances subject to authorisation) unless authorisation is granted.
- The waste plastic, including its constituents, shall meet the prescriptions about the restriction of the commercialisation of persistent organic pollutants laid out in Article 3 of Regulation 850/2004/EC (POPs).
The production, placing on the market and use of substances listed in Annex I and Annex II, whether on their own, in preparations or as constituents of articles, shall be prohibited.

When reading the proposal on EoW criteria for waste plastics one should bear in mind that the term waste plastic is used “as a generic term referring to plastic from industrial or household origin which is collected, sorted, cleaned and in general reclaimed and processed for recycling. Other related terms in use in the industry to define one or more waste plastic types are recovered plastic, plastic scrap, plastic recyclate, and in particular in CEN standards, recycled plastic and plastic waste” (JRC, 2013). It is important also to note that the criteria is not decided and that it might just as well be subject to change.

In addition, within criterion 3.1 it is proposed that “plastic waste streams used as input shall, once received by the producer or importer, be kept permanently separate from the contact with any other waste, including other waste plastic grades. Particular attention shall be placed to the processing of input materials that may contain hazardous components in plastic, especially electric and electronic equipment waste (WEEE), C&DW and ELV. Treatment techniques resulting in the mixing of these materials, such as shredding before removal of hazardous components, shall be avoided.” (JRC, 2013). The proposed criterion is a way to tackle the risk of cases of dilution. There is, however, no criterion about dilution other than criterion 3.1.

Potential EoW criteria including concentration limits for hazardous substances would mean that the waste flows need to be well monitored. EoW criteria would call for professionalism in the whole recycling chain setting clear responsibilities of each stakeholder involved. Furthermore, documentation or records of the EoW material processing and quality testing are required. This means that the EoW concept is demanding for small scale operations with input materials coming from several providers.

In JRC (2013) it is mentioned that experience with other waste streams with established EoW criteria tells that the criteria are so far not commonly used. This is because complying with the criteria becomes costly and recycling of the materials while they are classified as waste, is often the preferred solution. Waste can be recovered and cease to be waste without EoW criteria, as is done for many streams where there are no criteria. Waste can also be exported for recovery in countries outside the EU without being a product.

The WFD and plastics recycling

The directive contains no specific recycling targets on plastic waste, but on recycling in general. The WFD states that by 2020 the preparing for re-use and recycling of waste shall be minimum 50% by weight, at least for paper, metal, plastic and glass from households and possibly from other sources similar to waste from households and 70% for C&DW. The directive also states that separate collection systems for at least plastic, paper, metal and glass shall be set up where technically, environmentally and economically practicable.

The limits listed in the WFD concerning hazardous substances are linked to the classification of waste. Waste can be classified as hazardous or non-hazardous depending on the content. However, only a small amount of plastic waste is classified as hazardous as there is no LoW-entry for all kinds of hazardous plastic waste. For example if a shoe contains DEHP over the limited concentrations the shoe will not be classified as hazardous since there is no LoW code for hazardous plastic waste from households. Consequently this means that the waste classification is mainly an issue for waste having a mirror code (e.g. construction waste). However, national deviations may apply even in case of no LoW entry for hazardous waste (probably this is rarely the case).

The “Circular Economy Package” under adoption by the European Commission includes revised legislative proposals on waste to stimulate Europe's transition towards a circular economy. In the proposal a common EU target for recycling 65% of municipal waste by 2030 is suggested (European Commission, 2016b).

The WFD can be seen as a directive promoting recycling and creating availability of recycled material.

2.2.8 *Directive 94/62/EG on packaging and packaging waste*

The directive sets up recycling targets for packaging in general, and specific targets for packaging of different materials. Plastic packaging shall be recycled to a minimum 22.5% by weight. In the proposed "Circular Economy Package" an increase of the recycling target for total packaging waste to 75% by 2030 is suggested (European Commission, 2016b).

The directive also states a sum of concentration levels (100 mg/kg) of lead, cadmium, mercury and hexavalent chromium present in packaging that shall not be exceeded. The directive regulates the content of certain metals in packaging.

The Packaging directive and recycling

The packaging directive gives incentives to recycling of plastics, and puts pressure on the member states to set up collection systems for packaging in order to achieve the set recycling targets.

2.2.9 *The ELV Directive*

Directive 2000/53/EC on end-of-life vehicles states the reuse and recovery shall increase to a minimum of 95% no later than January 1 2015 based on an average weight per vehicle and year. The according re-use and recycling rate is set to a minimum of 85%.

According to the directive the use of lead, mercury, cadmium and hexavalent chromium should be prohibited, and only be used in certain applications. The applications should be listed and regularly reviewed.

The ELV Directive and plastics recycling

The possibilities to reach the targets for recycling of ELV, set in the directive, are depending on the possibilities to recycle plastics. The view-points on this differ, in Sternbeck *et al.* (2016) it is stated that it is not recommended to recycle plastics from ELV due to relatively low volumes, a high number of hazardous substances in the ELV plastics, and technical and economic barriers. However, in other contexts recycling of plastics from vehicles has been concluded to have an important role to play in order to fulfill the 95 reuse and recycling target for vehicles as stated in the directive. In the research project REALIZE (Realizing resource-efficient recycling of vehicles) manual dismantling

of plastic components from ELVs was concluded to have a high potential for an increased recycling of vehicles. Initiatives to dismantle certain plastic components have started up (Cullbrand *et al.* 2015).

2.2.10 *The WEEE Directive*

The Directive on Waste Electrical and Electronic Equipment (Directive 2012/19/EU) aims at preventing WEEE, and where not possible the directive states that the WEEE should be subject to reuse, recycling and recovery to avoid disposal. Annex VII addresses substances, preparations and components that have to be removed from separately collected WEEE. According to the annex, plastics containing BFRs must be removed. Apart from the BFRs there are no other requirements on the removal of chemical substances in WEEE or in WEEE plastics.

The WEEE Directive and plastics recycling

The WEEE-directive mentions a minimum collection rate of WEEE that should be met in each member state and minimum recovery targets for different categories of EEE. In terms of impact on the recycling possibilities for WEEE plastics the legislation is clear that plastics containing BFRs should not be recycled and removed prior to recycling. This requirement puts pressure on the dismantlers and recyclers of WEEE to know which plastic components in the collected WEEE that contain BFRs.

2.2.11 *Recycled plastic materials and articles intended to come into contact with foods*

In the European Union, plastic is one of the most common food contact materials (EFSA, 2016). Regulation No 282/2008 on recycled plastic materials and articles intended to come into contact with foods sets up a framework specific to recycled plastics in addition to the provisions of the more general Regulation 2023/2006/EC on good manufacturing practice for materials and articles intended to come into contact with food. Regulation 2023/2006/EC aims to regulate the different materials, which food may get in contact with during production, distribution and selling, in order to avoid hazardous contamination of the food stuff. Food contact materials include materials and articles intended to come into contact with food, such as packaging and containers, kitchen equipment, cutlery and dishes (EFSA, 2016). The food contact materials must

be evaluated since chemicals may migrate from the material into the food. The food contact material must also be used so that it does not cause any safety concerns, so that the food composition is not changed in an unacceptable way and have negative effects on the food quality.

Recycled plastic materials and articles intended to come into contact with foods and plastics recycling

Recycled plastics can in theory be used in plastic packaging for food, under certain conditions. The recycled plastics need to comply with strict quality criteria and must obtain authorization to be put on the market, involving approval by the European Food Safety Authority (EFSA). So far, recycled plastics have only been used to a very limited extent in contact with food (JRC 2013). EFSA concluded in February 2015 that two processes converting HDPE bottles into trays for dried whole fruits and vegetables are safe (EFSA, 2016). The second example, and the process first approved by EFSA was recycling of PET beverage bottles into food contact material.

The requirements imposed by the regulation limit the possibilities for using recycled plastics in products in contact with food. This is shown by the very limited number of EFSA authorised processes.

2.2.12 Transboundary shipment of plastic waste and recycled plastics containing hazardous substances

Transboundary shipments of waste are regulated by the EC Regulation (1013/2006) based on the Basel Convention and the OECD Agreement on waste shipments.

Export to countries not in the EU, EFTA or OECD are governed by EC Regulation 1418/2007. Basel or OECD waste code determines whether the waste is covered by the prohibition, notification, disclosure and specific regulations of the importing country.

For transboundary shipment, waste must be characterized and the content of hazardous substances must be below defined limit values. The receiver of the waste must have necessary permits.

2.2.13 *Transboundary shipment of plastic waste and recycled plastics containing hazardous substances and plastics recycling*

The transboundary shipment regulation as such does not hinder nor encourage recycling.

2.2.14 *Standards for recycled plastics*

EU standards (CEN standards) for recycled plastics exist. The standards define methods of specifying delivery conditions for recyclates, and give the most important characteristics and associated test methods for recyclates intended for use in the production of semi-finished/finished products. The European standards exist for recycled PVC, PS, PE, PP and PET. There are also EU-standards for preparation of samples of recycled plastics prior to testing and for a system for sampling procedures for testing plastics waste and recyclates which take into account the specifics of the plastics waste and recyclates.

General standards as for food-grade materials apply to both virgin and recycled polymers. Resolution GMC 25/99 "Disposable multilayer PET packages intended to hold non-alcoholic carbonated beverages" permits the use of postconsumer recycled PET (rPET) and stipulates that the layer in direct contact with the beverage be exclusively of virgin PET with minimum thickness 25 µm (Rijk and Veraart, 2010). As today there is also food-grade rPET, this is not a strong limitation.

EuCertPlast

EuCertPlast (<http://www.eucertplast.eu/en/>) is an EU-wide certification aimed at post-consumer plastics recyclers. It was developed via a three-year project, which was co-financed by the European Commission under the Eco-Innovation Programme. In Norway, the biggest user of recycled plastics, Norfolier Greentec, uses only materials from EuCertPlast certified sources. In the other countries this is not mentioned by the interviewees.

The certification works according to the European Standard EN 15343:2007 and aims to encourage an environmentally friendly recycling of plastics by standardizing it, particularly focusing on the process for traceability and assessment of conformity and recycled content of recycled plastics.

Targets for EuCertPlast are:

- Increased plastics recycling rates.
- Innovative applications for plastics recycle.
- Increase of plastics industry transparency.
- Fulfil REACH requirements and food contact compliance for recyclers.

CENELEC

CENELEC is the European Committee for Electrotechnical Standardization (<https://www.cenelec.eu/>). CENELEC creates both voluntary and harmonized standards. CENELEC standards are intended to be technologically neutral and are developed thanks to the contributions of sector specific experts coming from all over Europe.⁶ CENELEC has 33 member countries and 14 affiliates. The CENELEC standards are referred to in the WEEE Directive and declare, for example, lists of forbidden substances connected to the Restriction of Hazardous Substances in Electrical and Electronic Equipment Directive (RoHS).

CENELEC has developed a standard for treatment of WEEE (EN 50625-1 Collection, Logistics & Treatment Requirements for WEEE – Part 1: General Treatment Requirements.).⁷

The CENELEC standard sets a requirement of maximum 2,000 parts per million (ppm) of bromine in the plastics that are sent for recycling. This requires large investments in sorting technology where several screening techniques might have to be used – for instance, XRF and flotation – to separate out materials which contain high levels of bromine (Lekbeck, 2015). A solution for smaller facilities to manage the requirement is a closer cooperation with producers having information on existing plastics additives in their products which can be used by the recycling industry.

⁶ www.cenelec.eu

⁷ http://ec.europa.eu/environment/waste/weee/standards_en.htm

3. Hazardous substances in plastic; materials, products and waste

Hazardous substances in plastics have to our knowledge not been systematically and extensively analyzed, and therefore, we have chosen to include the hazardous substances that are presently used (or have been used) in manufacturing of plastics. The table in Annex 1 in this report covers hazardous substances that are known to be used in manufacturing of plastics. The table originates from a report from the Danish Ministry of the Environment (Miljøstyrelsen, 2014) and includes substances from the following lists of hazardous substances:

- The Danish EPA's list of undesired substances (LOUS).
- The SVHC Candidate List under REACH.
- The Norwegian list of priority substances.
- ECHA's Registry of Intentions.
- CMR-substances likely to be present in plastic toys (as assessed by the Danish Technological Institute).
- Recognized alternatives to problematic phthalates and BFRs.

Annex 1 includes 144 groups of- or- single substances that are known to be hazardous and to be used in the manufacturing of plastics. In the table the substances are divided into what function they are used for, and for which types of plastics. The hazardous substances have been grouped in ten different groups as follows:

- antimicrobial substances (e.g. organic tin and triclosan)
- blowing agents (e.g. fluorinated greenhouse gases)
- heavy metal based colorants, stabilisers and catalysts (e.g. cadmium and lead and their compounds)

- flame retardants (e.g. BFRs and organo phosphates)
- monomers, cross linkers, hardeners, chain modifiers and catalysts (e.g. Bisphenol A and formaldehyde)
- organic based colorants (e.g. azo dyes)
- UV stabilisers, antioxidants and other stabilisers (e.g. dibutyltin dichloride)
- plasticisers (e.g. short chain chlorinated paraffins and many different phthalates)
- solvents- neutral and reactive (e.g. dimethylformamide)
- others (e.g. nonylphenol and PFOs).

Far from all substances in Annex 1 have been found in products. When performing chemical analysis, you only find what you are looking for. So if a substance has not been especially searched for in an analysis of plastic products, it will not be found. However, this does not mean that it cannot be present in the product, you just do not know if it is there or not.

3.1 Hazardous substances found in plastic products

In Table 10 the information on products in which hazardous substances have been found, is based on enforcement reports from the Swedish Chemical Agency (KEMI, 2015; 2016) and a report by Sternbeck *et al.* (2016), which was performed for the Swedish EPA. The enforcements were not randomized, but rather focused on plastics (mainly soft PVC) that are known to contain these substances. They also focused on articles that can be found in the home environment. The focus of these reports is on substances that are restricted through REACH and the Candidate list, and most are defined as SVHC within REACH. All these substances or substance groups are also included in Annex 1. Not all product groups have been analyzed for all substances. As described above this means that some other substances not analyzed for might also be present in the products. Most of these substances are deliberately/intentionally added to bring some sort of function to the plastic. Sometimes, however, hazardous chemical substances may be present as impurities from e.g. the raw materials used in the manufacturing of plastics.

The time aspect is of utmost importance in regards to which hazardous substances that are found in which types of products. For short-lived products such as plastic packaging it is fair to assume that a product is manufactured and becomes waste within a year's time. Substitution of hazardous substances in the manufacturing lever will therefore have a more or less immediate impact at the waste stage. For long-lived products such as e.g. PVC flooring however, we have to count with the presence of many generations of additives for a long period of time.

For recycled plastics, especially mechanically treated plastics, there is no reason to believe that the substances that were present in the products will not be present in the recycled plastics (if not sorted). Similar to the case for plastic products, extensive analyses of chemical content appears not to be performed extensively for recycled plastic or products made from recycled plastic. What was added during manufacturing of the product may leak out or be converted, but it differs between different substances. Although, in recycled plastics, additional chemicals may be used for the new application of the recycled material.

For the purpose of this report, products were divided into product groups according to:

- Consumer products including bathroom products, plastic shoes, bags, mattresses, sports equipment, garden goods, articles intended for pets, prints on clothes, oil cloths etc.
- Products for children including diapers, bibs, drinking bottles, toys, changing tables etc.
- Construction materials including pipes, floors, insulation material, wallpaper, adhesives and sealants etc.
- Electronics including tablets, TV:s, kitchen appliances, cellular phones etc.
- Furniture including textiles and upholstery for furniture.
- Vehicles including upholstery for car seats and car fittings. In the concept vehicles all types of vehicles is included (planes, trains, trucks, cars). However in reality the large stream of those are ordinary cars (turned in to ELV). In the report focus is put on ELV.
- Packaging and food packaging.
- Recycled plastics.

It is not always clear from the references used as basis for Table 10 and the table in Annex 1 from what type of plastics the analyzed products were made of, how the sampling was carried out or the concentration of hazardous substances in the products. We have chosen not to include concentrations in the table since they were not available for all products and substances, which would give a skewed image. In addition, it has to be made clear that Table 10 and the table in Annex 1 only include *examples* of hazardous substances found in plastic products. It does not mean that hazardous substances are always found in certain product types. References for the data in Table 10 are the same as for the table in Annex 1, where the references are also listed.

Table 10: Hazardous substances and product groups. For an extensive list on specific chemicals used in plastics, their function, the plastic types they are used in, what product types they have been found in and references, please see Annex 1. Note that the column “plastic types examples” are examples and not an exhaustive list

Hazardous substance group	Product examples	Plastic type examples
Consumer products		
Antimicrobial substances such as organic tin compounds	Shower curtains and rain wear	
Heavy metal based colorants, stabilisers and catalysts such as cadmium and lead and their compounds	Plastic shoes and bathroom products	
Monomers, cross linkers, hardeners, chain modifiers and catalysts such as Bisphenol A	Mattresses and sports shoes, thermo paper (receipts)	
Organic based colorants such as azo dyes	Clothes and bedding	PES, PA, acrylic
Plasticisers such as different phthalates and short-chained chlorinated paraffins (SCCP)	Bags and cases, garden goods, plastic shoes and articles intended for pets	PVC
Solvents –neutral and reactive, such as N, N-dimethylformamide (DMF)	Office supplies	
Others, such as nonylphenol and perfluorinated alkylated substances (e.g. PFOS and PFOA).	Sports shoes and mattresses (nonylphenol), textiles and non-stick products like pans (perfluorinated compounds)	

Hazardous substance group	Product examples	Plastic type examples
Products for children		
Antimicrobial substances such as organic tin compounds	Diapers and car seats	
Heavy metal based colorants, stabilisers and catalysts such as cadmium and lead and their compounds	Plastic toys and car seats, electronic toys	
Flame retardants such as BFRs and organo-phosphates	Baby products and toys	PUR foam
Monomers, cross linkers, hardeners, chain modifiers and catalysts such as bisphenol A and formaldehyde	Drinking bottles for children and stuffing in car seats, pacifier holders, CD-disc, stickers	Polycarbonate, epoxy
Organic based colorants such as azo dyes	Toys from textile and car seats	
Plasticizers such as different phtalates and short-chained chlorinated paraffins (SCCP)	Bath toys and masquerade toys	
Others, such as perfluorinated alkylated substances (e.g. PFOS and PFOA)	Children's clothes	
Construction materials		
Antimicrobial substances such as organic tin compounds	PVC-flooring and plastisol roofs	
Heavy metal based colorants, stabilisers and catalysts such as cadmium and lead and their compounds	Floor mats	
Flame retardants such as BFRs (e.g. HBCD)	Insulation material	EPS, XPS
Monomers, cross linkers, hardeners, chain modifiers and catalysts such as Bisphenol A	Vinyl floors	
Plasticisers such as different phtalates and short-chained chlorinated paraffins (SCCP)	Plastic floors and buildings	PVC
Others, such as nonylphenol and perfluorinated alkylated substances (e.g. PFOS and PFOA)	PVC floors, lightweight concrete	PVC

Hazardous substance group	Product examples	Plastic type examples
Electronics (WEEE)		
Heavy metal based colorants, stabilisers and catalysts such as cadmium and lead and their compounds	Casing for TVs and PCs and consumer electronics, shredder residue	HIPS, ABS, ABS-PC, PPO-PS
Flame retardants such as BFRs (e.g. c-OBDE, TBBPA ja c-DBDE)	Scanners and casings for TVs and video devices	ABS, HIPS, ABS-PC, PPO-PS
Plasticisers such as short-chained chlorinated paraffins (SCCP)	Kitchen appliances and game controllers	(Soft) PVC
Others, such as perfluorinated alkylated substances (e.g. PFOS and PFOA)	Photographic and electronic equipment and components	
Furniture		
Flame retardants such as BFRs, hexabromocyclododecane (HBCDD) and organo phosphates	Upholstery and filling in bean bags	PUR, EPS, PUR foam
Organic based colorants such as azo dyes	Textiles and upholstery for furniture	
ELV		
Flame retardants such as BFRs (e.g. c-DBDE)	Car fittings, shredder residue	PUR /PUR foam
Monomers, cross linkers, hardeners, chain modifiers and catalysts such as formaldehyde	Stuffing in car seats	
Organic based colorants such as azo dyes	Textiles in ELV	
Plasticisers such as short-chained chlorinated paraffins (SCCP)	Upholstery in ELV	
Packaging		
Heavy metal based colorants, stabilisers and catalysts such as cadmium and lead and their compounds	Soft PVC-packaging for toys	Soft PVC
Flame retardants such as BFRs	Packaging	EPS
Monomers, cross linkers, hardeners, chain modifiers and catalysts such as Bisphenol A	Packaging for cheese	
Plasticisers such as short-chained chlorinated paraffins (SCCP)	Packaging	

Others, such as nonylphenol and perfluorinated alkylated substances (e.g. PFOS and PFOA)

Food packaging

PS, PVC, HIPS

Hazardous substance group	Product examples	Plastic type examples
<p>Recycled plastic Heavy metal based colorants, stabilisers and catalysts such as cadmium and lead and their compounds</p>	<p>Recycled WEEE plastic</p>	<p>Recycled from: PET, PP, ABS PVC, possibly HIPS</p>
<p>Flame retardants such as BFRs</p>	<p>Recycled WEEE plastic</p>	<p>Recycled from: PET, PP, ABS PVC, possibly HIPS</p>

Plastic waste is sorted into plastic types, and the plastic types listed in Table 11 are the plastic types of the highest demand in Europe, (see also Figure 1). These plastic types are also recycled at least to some extent today. The level of recycling today has been rated according to high/medium/low. Note that the demand of the plastic types in the table is not the same as the fraction that ends up in the waste, due to different time-spans of different products, for example. For each plastic type, a few different product type examples have been included based on (Plastics Europe, 2015). The plastic types can in other words be used in a higher number of product groups than listed. The level of recycling of the plastic types varies depending on in which product group they end up. The number of hazardous substances or groups of hazardous substances that potentially can be used in the plastic type (Miljøstyrelsen, 2014) is not an absolute number but an approximation.

Table 11: Plastic types that to at least some extent are recycled today and their potential content of hazardous substances. PUR and some other plastic types were omitted (28%), making the sum of all plastics in the Table 72%

Plastic type	Product group example	Demand of plastic type	Levels of recycling today	Nr of hazardous substances potentially used in plastic type
HDPE ¹	Bulky waste ²	12%	Medium	2
	Packaging		High	
	Construction material		Low	
	ELV ³		Low	
LDPE ³	Bulky waste	17%	Medium	2
	Packaging		High	
	WEEE ⁴		Medium	
PP	Bulky waste	19%	Medium	20
	Packaging		High	
	WEEE		Medium	
	ELV		Low	
PET	Bulky waste	7%	Medium	2
	Packaging (bottles)		High	
PVC	Bulky waste	10%	Low	41
	Construction material		Medium/Low -rigid PVC	
	WEEE		Low	
	ELV		Low	
PS/PS-E	Construction material	7%	Low	6
	WEEE		Low	

Note: ¹ In the Table in Annex 1, PE is given as a separate type of plastic to HDPE and LDPE. In this plastic type, 17 different substances/substance groups can potentially be used (Miljøstyrelsen, 2014).

² Bulky waste is a type of consumer product plastic collected at recycling stations.

³ELV = End-of-life-vehicles.

⁴WEEE= waste of electric and electronic equipment.

For plastic type abbreviations, see Appendix 1.

3.1.1 Hazardous impurities and contaminants in plastics

Most of the hazardous substances mentioned in the section above and in the table in Annex 1 are added as part of the manufacturing of the materials. Hazardous substances are sometimes however unexpectedly found in plastics, as impurities or unintentional additions. PAHs can be found as impurities in plasticisers and carbon black and can therefore be found in plastics. Brominated dioxins/furans are known to have hazardous properties and are present as contaminants in commercial PBDE. They are also formed during the life cycle of PBDE and could therefore be present as impurities/contaminants in plastic products containing PBDE (or other BFRs). Especially in recycled plastics, the ingoing hazardous substances are often unknown. There is evidence that WEEE has been used for production of polymeric food-contact articles sold on the European market and that these articles contained BFRs (Puype *et al.*, 2015; Samsonok and Puype, 2013). Since most recycling of plastics takes place outside of the Nordic countries and largely also outside of the EU, the plastics that we export for recycling could potentially come back as parts of imported products (Sternbeck *et al.*, 2016). The extent of this has not been elaborated further, nor the control of imported products.

3.2 Risks related to hazardous substances and recycling

Most of the chemicals used as additives are able to migrate and thus are not bound in the plastic. Migration depends heavily on the physical-chemical properties of the substance depending on the substance's size, boiling point, vapour pressure, solubility in the plastic and the environment/material surrounding the plastic. Generally, consumers may be exposed to a substance with a high migration rate, but application of the substance is also of significance and the knowledge is here not detailed enough in order to give thorough exposure assessments regarding different consumer groups e.g. children vs. adults. As an example, a study by Palm Cousins and Loh Lindholm (2016) could not demonstrate that the normal use of DINP/DIDP-containing PVC floors or walls cause any health risks. Another study by Ionas *et al.* (2014), however, found flame retardants in children's toys. They speculate that recycled material had been used in the production of these toys, and that in some cases they may pose a health hazard to children. However, the Swedish EPA states that: "The levels of particularly hazardous substances are, if they are found in recycled materials, often many orders of magnitude lower than

what they may be in the virgin material. Intentionally added particularly hazardous substances are therefore generally expected to lead to a greater risk of harmful exposure of humans and the environment than the risk of exposure from recycled materials” (Naturvårdsverket, 2016c).

In order to perform actual risk assessments, it is necessary to know the chemical content of the recycled material. Rapid screening of complex matrices to get a picture of what the matrix contains can be useful and have been developed by e.g. Ballesteros-Gómez (2014; 2013). Emissions from materials or articles/products can also be analyzed, for example in emission chambers (Rauert *et al.*, 2014).

Plastic wastes can be grouped in the following categories:

- Plastic waste generally with low content of hazardous substances: e.g. packaging waste from food packaging.
- Plastic waste which might contain hazardous substances to some levels e.g. WEEE.
- Plastic waste which may contain high content of hazardous substances e.g. old PVC in construction materials.

Risks to the environment can also be related to the type of recycling. In case of chemical recycling (e.g. thermochemical conversion), the hazardous substance in the waste streams are not transferred into the new product.

The existing information on hazardous substances in plastics is information on what could normally be used in the production to reach different attributes. It can also be information on what substances that have been found when plastics have been analyzed for chemical content. In neither case, does this mean that the plastic product or plastic type always contains the target substances. The foreseen use of recycled material is also of importance since restrictions are set in regulations and by producers on allowed substances.

In order to purify the streams and set the accepted level of risk for recycled waste, further focus is needed on plastic waste generated in large amounts and potentially containing hazardous substances.

Five scenarios are presented below based on different levels of risk when it comes to spreading of hazardous substances to the environment. The scenarios are not realistic in the sense that recycling of plastics is already regulated to a relatively high extent compared to other materials, such as textiles, for example when it comes to content

(e.g. RoHs-directive) or recycling rates (e.g. Packaging directive). However, the scenarios should be regarded as principle ideas and pointed directions rather than realistic, detailed scenarios.

1. *Focus only on removing hazardous substances.* In theory, this scenario means that it is not possible to recycle plastics at all. This needs to be put into relation to what we are using these substances for today in new plastics products. If the substances cannot be accepted for recycling, they should not be accepted in primary production either. It is important that the demands set on the content are high and equal between virgin and recycled materials.
With the existing legislation there are examples of hazardous substances being phased out.
2. *Larger focus on removing hazardous substances than on resource-efficiency.* Only plastics known not to contain hazardous substances are recycled. It is important to keep different flows separated not to contaminate the clean flows. Traceability would also be of importance. In today's flows the purest fraction in terms of hazardous substances content seems to be plastic packaging waste.
This would be the scenario that to some extent is the closest one to the situation of today. There are limitations on content and also regarding sorting out plastics containing certain substances. The risk of spreading hazardous substances and the fact that recyclers have difficulties with guarantying the content makes recycling limited.
3. *Equal focus on removing hazardous substances and resource-efficiency.* Plastics known not to contain hazardous substances are sorted out for recycling. Plastics with the possibility to contain hazardous substances are sorted out and used in applications considered "safe" where the exposure to humans or the environment is limited. It will be necessary to keep different flows separated. An example from the handling today were this is implemented is the separation of restricted BFRs from WEEE. This is well-established, and results in secondary raw material with a relatively low risk of containing restricted BFRs.
4. *Larger focus on resource efficiency than on removing hazardous substances.* All plastics except the ones known to contain hazardous substances (such as BFR-containing plastics in WEEE) are sent to recycling, and the recycled plastics can be used in any application. This scenario includes accepting a risk that substances

originally intended for a specific application ends up in products where they are undesired.

5. *Focus only on resource efficiency. All plastics are recycled even though they might contain hazardous substances.* The diluting effect is seen as the solution to accumulation of hazardous substances. This means that large amounts of plastics become available for recycling, for example old plastics from demolition waste.

4. Identification and separation of hazardous substances in plastic wastes

In chapter 2 we listed hazardous substances present in different products. The fact that they are listed above does not mean that they have to be added in all products from that category. Adding to this plastic waste collected for recycling is collected as a mixed plastic fraction and might include a mix of items containing hazardous substances that by law need to be identified and separated, and plastic items that can be recycled without any constraints. This mix of items is especially evident when handling waste streams containing both newer and older items. For example in the WEEE stream both newer and older appliances are to be found, as well as plastic waste from C&DW where both post-consumer plastic waste and pre-consumer plastic waste, for instance when renovating. Even though plastic packaging waste is expected to include plastic packaging with a relatively short life time, it can as well include incorrectly sorted plastic items put on the market a long time ago such as old toys.

For plastics recycling, the heterogeneity of the plastic waste is a challenge as it requires sorting of a high number of polymers, which can be difficult in practical terms (difficult to separate certain plastic types from each other) as well as costly. Mixed plastic waste also makes it more difficult to know the content in the different plastic types and their possible content of hazardous substances.

Efficient methods are required to sort the mixed plastic waste, but the volume of the waste stream must also be sufficient for recycling to be economical.

In order to fulfill the demands of the market (hence the product legislation) a recycler or product manufacturer accepting waste or products from various sources need to take measures to identify hazardous substances that are not allowed to be transferred into new products (see Chapter 2). The waste source indicates to some extent what substances the plastics might contain. Mixing of waste streams may cause problems as this put more demands on characterization and sorting.

4.1 Traceability

In all Nordic countries there are no general register about hazardous substances in plastics or products that has been published by the authorities.

In the future, a key issue is to create a quality system for the low risk plastic waste materials collected at source. "A certificate" for the low risk plastic waste also covering proper management in later stages ensuring that the waste stream is not mixed with unsuitable waste streams, can provide an assurance that the waste has a low risk and the waste material can be recycled without extensive analysis protocols focused on checks of hazardous substances. However, a visual control of the waste material is always to be included to check impurities during use and storage (this links also to the technical suitability of the waste material).

4.2 Analyses of waste

For analysing content of material a homogenous sample is preferred which is not the case when looking at waste. This means that since waste coming in to a sorting facility / recycler will contain waste from different sources it will be hard to extrapolate the results from a previous analysis to the present batch. Since continuous sampling is expensive it becomes difficult for the recycler to perform it. If such methods were developed it will be much easier to increase recycling. It is actually not so far away and techniques for it are already available. It just has to be adjusted to the reality of plastics recycling.

4.3 Manual dismantling

Manual dismantling also plays an important role in identifying and separating plastic components containing hazardous substances in general. According to an interview study with Swedish recycling actors, random sampling in connection to WEEE dismantling is common practice. Identification of every single plastic item is not possible given the time and costs associated with such identification. Knowledge is built up about which plastic products that commonly contain hazardous substances, for example TV covers and computer screens. Using XRF-scanners on certain products of different brands has made it possible to produce a staff guidance document about the hazardous

substances content in different products making clear which products that need to be separated from other products or components, and instead sent to high-temperature combustion. When it comes to sorting plastics it is currently only plastics containing BFRs that are identified and separated (Bibi 2014). In Denmark the Danish Producer Responsibility, DPA System, has the overall responsibility for managing the handling of the WEEE. However, for the practical handling both municipalities, transport companies and specialised WEEE dismantling companies are involved. Typically, transport companies are collecting WEEE from municipal recycling stations, retail shops and larger companies. The collected WEEE is sent to specialised companies like DanWEEE Recycling AS, who are dismantling the WEEE, and collecting those parts they by experiences know can be sold on the market, e.g. larger plastics parts of well-defined types of plastic without hazardous substances. Even if plastic in general make up considerable part of the waste (around 40% by weight), it is the rare metals that are focus of the recycling business. Therefore, much of the plastic parts are sent for incineration or to other companies abroad. Further details on the Danish market for WEEE can be found in the report "DANISH WEEE MARKET – A study of markets, actors and technologies in treatment of WEEE in Denmark" (Miljøstyrelsen 2015c). The situation is similar to Denmark in all Nordic countries.

Pre-consumer plastic waste such as production plastic waste is often sent to recycling without major tests as the information on the contents of the plastics is provided by the supplier (Bibi 2014).

4.4 Automatic sorting

4.4.1 Analytical tools

Plastics containing BFRs may be identified using Near-Infrared (NIR), XRF scanners, fourier-transform infra-red spectroscopy (FT-IR), high performance liquid chromatography (HPLC), gas chromatography (GC) and mass spectrography (Retegan *et al.* 2010, (Markowski 2015). The tools can be hand-held devices or automated (Arends *et al.* 2015).

X-Ray Fluorescence analysers

As a consequence of the RoHs directive the content of lead, cadmium, mercury, and hexavalent chromium, the content of the BFRs PBB and PBDE, and the content of the phthalates DEHP, BBP, DBP, and DIBP cannot exceed maximum concentrations in electric appliances stated in the directive. According to the WEEE directive WEEE plastics containing BFRs must not be recycled.

XRF is a relatively cheap method, and does not need a laboratory, why it is often the preferred method to detect BFRs (Bibi 2014). By using XRF, bromine and chlorine in concentrations below one percent can be detected. The XRF tool does not distinguish between different kinds of BFRs why plastic waste containing legal BFRs might be identified and separated from the waste stream as well.

Laser induced breakdown spectroscopy

Laser induced breakdown spectroscopy (LIBS) is a very versatile method which potentially measures all elements in the periodic table, both in gas, solids and liquids. LIBS is for example widely used in the metal recycling industry (Applied Spectra, 2016). Due to long data acquisition time, LIBS is not used in plant for automatic sorting of plastics. It is, however, used in hand held instruments.

Comparison of methods

In-situ measurements of BFRs, for example in the sorting stage, using XRF seems to be a preferable method according to a Swedish study from 2010 (Retegan *et al.* 2010). The reason why XRF is chosen is due to the fact that the method is relatively cheap, does not need specific competence, and can be used on site. In addition, written instructions for the operators listing different WEEE plastic components generally containing BFRs are commonly used at the pre-treatment plants. These components are then removed manually.

A specific challenge in the review of literature data is the lack of standardization in the analyses of hazardous substances. In some studies the plastic fraction of the WEEE is separated and analysed from single products, while in other studies shredded waste have been collected during several months and prepared for analysis. Also expression of analytical results varies in the different studies making direct comparison difficult. (Leslie, H.A. *et al.* 2013).

The interviews conducted within the project confirm the picture provided by literature. A large compounder of both virgin and recycled plastics in Sweden controls that

RoHs substances, there among regulated BFRs, are not present in the purchased secondary raw material by using a XRF hand tool. The tests are often based on samples. The secondary raw material purchased comes from pre-consumer plastics waste, e.g. from extruding, but also from post-consumer plastic waste such as packaging waste. The majority of the compounds produced are sold to the vehicle industry, furniture industry and construction industry. Within the vehicle industry it is mostly about "invisible" black plastic parts. If RoHs substances are identified the raw material is sent back to the supplier. The reason to identify RoHs substances is according to the compounder primarily due to legislation, but also due to customer requirements.

4.4.2 Density separation

Density separation is mostly run as a wet process. The density separation technology can be applied to separate polymer types, polymers from other material and different polymer grades of one and the same type (Arends *et al.* 2015). It is also widely used to separate brominated plastics from the non-brominated plastics. The separation technique makes use of the fact that different polymers have different densities. For example by adding magnesium sulfate to water the density can be raised to 1.15. In such conditions bromine-free PS will float while bromine-containing PS will sink (Retegan *et al.* 2010). Polyolefins (PE, PP), which are lighter than water, can effectively be separated from PVC and PET with a higher densities than water. The separation of plastics with close densities, for example PVC and PET can be separated adjusting the density of the water using separation liquids (salts in the water) (JRC 2013). However, pure homogeneous target fractions cannot be achieved for polymer mixtures with overlapping density ranges (Schlummer, 2014). In terms of throughput and/or purity, centrifugal systems are more effective than static ones. Nevertheless, static systems are commonly applied industrially (Arends *et al.* 2015).

Several of the recycling companies interviewed in a study from 2010 meant that they in combination with density separation use XRF as a way to regularly check the accuracy of the identification and separation methods (Retegan *et al.* 2010).

Plastics containing BFRs are also be identified and separated through density separation. The technique makes use of the fact that plastics containing bromine commonly have a higher density than bromine-free plastics (Retegan *et al.*, 2010, Arends *et al.* 2015). The density separation method, like with the XRF, separates plastics based on bromine content. It is not able to distinguish between different types of BFRs,

meaning that also plastics containing non-regulated chemicals are sorted out and that a fraction of the plastics that could otherwise have been recycled instead is incinerated/lost (Retegan *et al.*, 2010).

Despite the available techniques to identify plastics with BFRs there are suggestions that there is no systematic control in connection to collection and pre-treatment of WEEE. Even though BFRs are captured in the heavier fraction using density separation, there are still low quantities of BFRs in the lighter fraction (Sternbeck *et al.* 2016). However the interviewees from the recycling industry mean that this is a small problem that doesn't causes large risks of spreading unwanted substances.

4.4.3 *Practical example*

An example of how WEEE plastics are treated in the Nordic countries is taken from the recyclers Sims and Kuusakoski in Sweden. As a first step the WEEE recycler Sims dismantle components with hazardous content as required in the WEEE directive, for plastics specifically plastics BFRs. Some appliances such as TV's are scanned with a XRF analyser to detect plastic containing bromine. After dismantling the remaining fraction is fragmented to reduce the size of the material. The following sorting processes entail magnets, eddy-current separators and optical sorting techniques. In addition to various metal fractions sent to recycling the processes also result in a mixed plastic fraction, which is further processed in a shredder. The content of plastics in the fraction is roughly 90%, and may contain BFRs that have not been removed in the manual dismantling stage. The plastic waste fraction is transported to Germany for further processing using density separation. Around half of the plastics reaching Germany is sorted out and sent to incineration. This plastic contains bromine, but can also be relatively heavy plastic types. The other half consists predominantly of polyethylene (PE), PP and ABS that are sold to new product manufacturing, mostly located in Asia (Karlsson, 2016).

Kuusakoski applies a slightly different approach to extract and recycle the plastic from the incoming WEEE. WEEE is firstly manually inspected by staff who determines the level of manual and mechanical treatment. Dismantling is applied to comply with the WEEE directive and XRF analysers are used to detect bromine. After dismantling the WEEE is shredded, primarily to extract metals. Smaller appliances are shredded together and larger appliances, often containing the same polymers, are shredded by product category. The plastic fractions resulting from the separation processes are either sold by specific product category that may contain one or two polymers or as a

mixed fraction of several polymer types. All plastic fractions are further processed by the buyers who separate the polymer types and re-granulate the plastic, which mostly takes place in Asia. A small amount of the extracted plastic is sold to buyers in the EU. In this case the separated bromine-containing plastics that have not been manually dismantled are shipped together with the rest of the plastics (Karlsson, 2016).

The fate of the separated plastic waste containing bromine

The picture given by literature and interviews reveals that plastic components containing bromine are commonly subject to manual dismantling with the help of “know-how” and XRF analysers followed by density separation. The manual dismantling seems to occur in the country where the WEEE has been collected whereas the further separation of bromine-containing plastics can take place abroad, within the EU or in non-EU countries. A common destination for WEEE plastics, at least for Swedish actors, seems to be Asia. The project group has found no reason to believe that WEEE plastics are treated differently in the other Nordic countries. The bromine-containing plastics are subject to incineration. When the separation of bromine-containing plastics occur abroad the fate might be more unclear (Schlummer 2014).

4.5 Facilitation of sorting and recycling

In plastic waste recycling it is crucial to develop a quality protocol to ensure appropriate waste materials for recycling. The quality scheme is material specific and depends also on the type of end-application. In practice the same quality requirements need to be fulfilled as for the virgin products.

Potential applications in term of recycling are (from the interviews):

- Plastic profiles.
- Plastic bag.
- Containers.

A generic scheme for quality assurance can be developed for evaluation of the acceptance of waste for recycling. A scheme should at least include following elements:

- Definition of the application of the plastic waste for collected for recycling.
- Definition of the origin materials accepted for recycling (e.g. list of non-acceptable origin).
- Guidance for collection of waste at sources (e.g. sorting).
- Guidance for visual inspection prior to reception of plastic waste (potentially including sampling guidance).
- Quality control programme (focus on key parameters including methods and action limits, e.g. impurities, hazardous substances).
- System for approval/rejection of products (for quality control).
- Qualification for persons involved in the quality assurance process.
- Requirements for cleanliness, e.g. acceptable levels of impurities.
- Documentation system.
- Training of staff.

The description of the quality control is one of the most important parts in the quality assurance scheme. The quality control programme describes how the compliance is evaluated in practice in a continuous production of recyclable plastic products.

The schemes developed for monitoring hazardous substances in construction products have been developed. Similar approach is also applicable for plastic wastes. Examples of elements to be covered are:

- Sampling plan for assessment of compliance with the acceptance criteria (note! Includes also visual inspection); definition of point for sampling during the whole material handling chain, guidance for taking samples, preparation of samples, transport of samples for testing.
- Methods or protocols for testing or inspection of the quality (typically focusing on key parameters critical for the application), e.g. list of technical standards for testing.
- Definition of testing frequency.

- Criteria for application (can also be threshold values for different application classes).
- Clear conditions for acceptance/rejection and handling of deviations in quality and acceptance deviations.
- Quality assurance in sampling and testing (e.g. need for third part controllers (independent)).
- Monitoring of processes to ensure effective all time (quality assurance system).
- Documentation (& chain of custody report), including data of the origin and report of phases in material handling. Typically standardised data sheets are used.

The waste source indicates what substances are contained in the plastics. A problem may come from mixing of waste streams as this put more demands on characterization and sorting. Companies like Revac AS handle separate waste streams like WEEE, construction and demolition as well as refrigerators.

Elemental determination of additives in plastics can be performed based on a high number of analytical procedures. The techniques generally used include atomic absorption spectrometry (AAS), inductively coupled plasma optical emission spectrometry (ICP OES), and inductively coupled plasma mass spectrometry (ICP-MS). ICP-MS is a powerful technique for trace and ultra-trace elemental determinations because of its detection limits, relatively simple spectra and capability for rapid multi-elemental and isotopic determination. The main drawback for the above mentioned techniques are the need for laboratory analyses as sample solutions in aqueous medium are needed, although it is possible to use solid samples. The most used analytical protocols involve microwave assisted digestion of polymers. The ISO 344 methods are applicable for the elemental analysis of polymers. (Santos *et al.* 2011).

5. Conclusions and discussion

The first general conclusion is that to be able to increase recycling in a safe way there are measures that need to be taken at different levels, both upstream and downstream as well as market solutions. Below some different areas are listed where actions might ease and increase recycling of plastics.

5.1 Legislation

The main issue with the legislation both concerning products and waste is that it is clear to the regulators and authorities, however, it is complicated and hard to understand the regulations for the regular recycler. The main finding from the project regarding regulations is that more regulations are not needed, rather explanations of the existing.

One area with improvement potential is guidance and clarifications related to the existing product and waste legislation. There are guidance documents from ECHA (ECHA, 2010; ECHA, 2012), but they need to be made easier to understand for actors involved in recycling of plastics. Even actors which are highly motivated to comply with existing rules and regulations find it difficult to know the requirements put on them. One example is when plastic waste should cease to be waste that causes trouble. Waste as defined in Directive 2006/12/EC is not a substance, mixture or an article why REACH requirements for substances, mixtures and articles do not apply. As soon as a material ceases to be waste, REACH requirements apply in principle in the same way as to any other material. However, the end-of-waste principles have been subject for long debate. A fitness check on the most relevant chemicals legislation (excluding REACH), as well as related aspects of legislation applied to downstream industries will be performed by the European Commission. A report should be available by the end of 2017. The fitness check will provide “essential input” to the Commission’s work on “assessing the interaction between waste, products and chemicals legislations to facilitate the

traceability of chemicals in the recycling process and limit unnecessary burden for recyclers” (European Commission, 2016a). That more practical guidance from Nordic authorities would be an effective measure can be seen already in this project.

The main concern in this study is that hazardous substances in plastic wastes may spread into the environment or come into contact with humans when plastic waste containing hazardous substances is mechanically recycled into new products. This concern is not to the same extent valid for chemical recycling where the liquids or gaseous chemicals are generated e.g. through thermochemical conversion. The concerns imply that the plastic waste flows where focus should be put in order to increase recycling should be relatively simple and clean (packaging) and that more concern is needed for other flows.

When discussing possibilities for recycling there are many factors to take into account: economy, hazardous substances, regulations, technology, material knowledge (including life span of products) etc. Another important aspect is that if recycling of the waste can comply with legislation it should be recycled; hence forbidding recycling of certain waste streams is not considered the right way to go. It is important also to acknowledge that the legislation does not only hinder recycling, it is also of great help when it comes to limiting the use of hazardous substances and hence decreasing the problem with recyclability.

Some EU-recycling targets might increase due to the “Circular Economy Package”. However, what is often reported and followed-up on national and EU level is not recycled plastics but collected plastics. Reporting varies between countries. If more focus was put on the actual recycling it would likely to push towards cleaner streams.

5.2 Market

In some cases it appears to be the lack of market that prevents recycling of plastics rather than other aspects. So creating/ establishing a market, most likely with the assistance from policy instruments, is relevant.

One conclusion from the project is that it is not always the fact that hazardous substances have been found in products made by recycled plastics that limits the market. It is more often quality of the material, of which one aspect is the potential content of hazardous substances and the insecurity from the buyers and the recyclers that they should sell/ buy something that is not in line with legislation.

In the debate of recycling or not recycling in order to avoid spreading hazardous substances it is, apart from valid risk assessments, important to remember that the whole recycling industry also needs to be economically sustainable. Some actions could be taken with this in mind:

- If substances added had been less hazardous the recycled raw material would be “more safe” to use in new products, and the possibility to use in different applications wider. Hence the raw material could be sold at a higher price. This would mean that more resources would have been available to sort out the plastics still containing hazardous substances.
- There should be higher attention put on the knowledge of the recyclers and their need for more information and guidance.

5.3 Traceability and analyses (knowledge of content)

One important aspect seen as a hinder towards recycling is the traceability of product content throughout the life cycle of products. Since there are demands from the legislation on knowing what products contain this implies that the recyclers also need to have that knowledge. However, as shown this information is often not available in the sorting and recycling stage of the value chain. Furthermore it is also complicated since waste are sometimes collected in mixed fractions giving at hand that knowledge regarding one waste stream could be useless if mixed with other waste streams. Products of different age present in the same waste streams also pose a problem.

As described in chapter 4.2 there are possibilities of rapid screening of complex matrices, such as recycled material. If methods for this could be further developed, material quality could be better ensured, and some of the traceability problems will be eliminated.

In the project description there is a question regarding if the content of hazardous substances is a large problem in plastics recycled in the Nordic region or if the largest problem is the content in recycled plastics from Asia/ other parts of Europe. From what the project has found it is traceability in general that is the problem. The plastics recycled in the Nordics will be clean and products produced within EU follows the EU legislation regarding content etc.

Another thing to develop in order to increase traceability is of course labelling of the product content that will stay on the product all the way to the recycling part of the value chain.

5.4 Product groups

Focus of the study has been to follow waste streams generated in large amounts:

- Packaging.
- Products for children.
- Furniture.
- Plastic waste from consumer products.
- Plastic waste from electronics.
- End-of-life vehicles.
- Construction materials.

The aim has been to identify plastic waste with low, medium and high risks for containing hazardous substances. Low risk wastes are generally wastes from food packaging with low content of hazardous substances. Plastic waste classified as hazardous waste based on content of hazardous substances are not generally suitable for mechanical recycling. However a very small share of all plastic waste is classified as hazardous, which means that the classification is not a sufficient method to conclude whether or not plastic waste is suitable for recycling. Non-hazardous plastic waste may as well be unsuitable for recycling due to its content of hazardous substances, hence only limiting recycling of hazardous plastic waste is not sufficient. Furthermore, wastes containing POPs are not allowed to be recycled. Aside from these exemptions, recycling should be seen as positive, and one should be careful not creating stricter requirements on recycled materials than on new materials.

These are the conclusions from the project when considering the different product streams and trying to reason about the different factors described above:

5.4.1 *Plastic waste from consumer products:*

Consumer products are a wide range of products having in common that they are used in our homes and that they don't belong to any producer responsibility scheme. Textiles, bathroom equipment and garden goods are examples of products included in this category. They vary both in size, type of plastics and lifespan. This is an unexplored waste stream in terms of types of plastics and the amounts of generated different types of plastics.

Normally these kinds of products are collected with the residual household waste and are sent to energy recovery. Some municipalities in Sweden and Denmark have started with collection of larger plastic items at recycling centers, so-called bulky waste. If so the collected plastics takes the same route for sorting as the collected plastic packaging waste, at least in Sweden. Plastic types in this waste stream can vary to a high extent, and therefore the potential number of hazardous substances/substance groups therein is also varying (Table 10). One of the main plastic types in the plastic bulky waste which is not recycled, at least not in Sweden, is PVC. PVC also has the potential to contain a high number of hazardous substances (Table 1). It has been discussed to collect also smaller items of plastics in a combined stream with packaging waste (material collection instead of fraction collection). The question is if that would make it easier for the recycler to get hold of amounts of desirable plastics or if that would ruin the possibly clean fractions of packaging. Parts of the product group might also be considered to fall under other possible collection systems e.g. textiles that might be a subject to producer responsibility or at least being separately collected to a greater extent.

Since consumer products is such a heterogeneous group, and chemical analyses of many different consumer products have been performed, a high number of different types of hazardous substances have been found in this category, see Table 11.

The large variety of substances, plastic types and life-span of products found in the consumer product plastic may impede recycling of this waste flow. However, finding more homogenous flows within the larger flow is most likely possible.

5.4.2 *Plastic waste from products for children:*

Within the product group we find for example diapers, car seats and toys. The reasoning for products for children is the same as for consumer products with the exemption that the demands set on the content in toys could possibly have a cleaner fraction of plastics arising from toys.

5.4.3 *Plastic waste from construction materials and products*

In fact it might be beneficial to divide this discussion into:

- Construction material – the waste will be of “today’s” date, it has the potential to be sorted at source and hence clean fractions will be available. The recycling potential is large but with hinders such as limited space at construction sites that for example limits the possibilities to source-separate.
- Demolition waste – often old materials, so both ageing and the fact that substances that are not allowed anymore might be present in the products is a reality to take into consideration. Plastics is found in flooring (often PVC), pipes etc.

The building sector consumes 20% of the plastics put on the market in the EU (see chapter 1) so the future potential of amounts available for recycling is large. Traceability will become extremely important. However, a previous project (Elander and Sundqvist, 2015) shows that demolition in a manner to allow recycling is also costly. Furthermore interviews with the building industries in Sweden gives at hand that they are reluctant to use recycled PVC due to the risk of creating problems with recycling in the future. So the potential is large for finding volumes, but the economy both in terms of getting the material and finding the market is tougher.

As explained in Chapter 2.2.1 the largest issue is PVC. Plastic construction products made from PVC have been found to contain a range of hazardous substances (Table 10). The number of hazardous substances/substance groups that can potentially be present in PVC is the largest out of all the plastic types in Table 1. In Denmark, rigid construction material-PVC is recycled, whereas most soft PVC landfilled. In the other Nordic countries much of the soft PVC is incinerated.

During spring 2016 there was an exception taken for recycling of PVC. Three recycling companies are now authorized have DEHP present in recycled soft PVC, in compounds and in dry-blends, thus enabling recycling of soft PVC (PlasticsNews, 2016).

5.4.4 *Plastic wastes from electronics*

WEEE is a large waste flow with possibilities to increase the amount of plastics recycled from. The plastics used are to great extent PP and PE but also PS and ABS.

The most regulated substances are BFRs, these come in two “forms” – prohibited and allowed. The RoHS-directive prohibits some and the WEEE-directive states that all plastics containing BFRs shall be sorted out. The fact that the sorting techniques used (see chapter 4.4.2) can't make a difference on what kind of BFRs that are present in the WEEE results in more plastics than necessary is being sorted out for incineration. Up to 50% of the incoming plastics may be sorted to incineration (Karlsson 2016).

Overall plastics from WEEE could be recycled to a greater extent than today. To increase the amounts to recycling even more the issues with BFRs would be needed to look into. Will the forbidden ones soon be phased out and could that mean that we could change the sorting and the legislation accordingly?

5.4.5 *Furniture*

Furniture falls under the same arguments as consumer products. No specific statistics on amounts is available. Furniture is often made of combined materials. Recycling is probably costly. Some products like garden furniture are completely made of plastics and could be more easily recycled.

5.4.6 *ELV*

As written in Chapter 2.2.1, there are different angles to recycling of plastics from ELVs. However, recycling of plastics from ELV becomes a necessity if the goal of 95% reuse and recycling of the weight of the car should be achieved. There are not the same legislations around BFRs as in WEEE.

ELVs contain for example HDPE, ABS, PP, and PVC (Table 11). HDPE is generally not a plastic type that has the potential to contain many hazardous substances, whereas PP and PVC have a higher potential content. Hazardous substances have been found in e.g. stuffing in car-seats and textiles in vehicles, and also in e.g. PUR (Table 10), which today is not a plastic type that is recycled to any large extent. Given the goal of recycling increased recycling of plastics from ELV is needed to be further looked into.

5.4.7 Packaging

Packaging is as seen in chapter 1.1 the largest product group. They are likely not to contain hazardous substances due to regulations on their content. They also, in general, have a short lifespan so degrading is of smaller importance. The potential for further sorting and larger flows is high. There is also already a collection system in place in all Nordic countries. Increasing collection of plastic packaging waste for recycling would likely be the easiest way to increase recycling of plastics without the risk of spreading hazardous substances.

Higher collection of plastic packaging waste would require that the waste stream is kept clean. Packaging plastic has been analyzed for many hazardous substances and therefore many hazardous substances have been found (Table 10). The type of plastic that the packaging is made from is important, since the different plastic types have the potential to contain quite few (e.g. HDPE, LDPE and PET) or a larger number (e.g. PP) of hazardous substances (Table 11). Packaging made from soft PVC has for example showed content of hazardous substances Table 10). A mixture of other plastics might increase the risk of contamination as could packaging from outside the EU.

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Sammenfatning

Farliga ämnen i plast – hur kan återvinningen öka?

Syftet med projektet är att skapa en kunskapsbas om hur plaståtervinning kan öka utan att öka risken att farliga ämnen sprids i miljön. Den första slutsatsen är att för att göra det möjligt att öka återvinningen på ett säkert sätt finns det åtgärder som måste vidtas på olika nivåer, både uppströms och nedströms samt marknadslösningar. Följande områden är av intresse:

- Lagstiftning: ny lagstiftning är inte nödvändigt, men harmonisering och tydlig vägledning till den befintliga är.
- Marknad: att skapa en säkerhet på marknaden vad gäller innehåll är nödvändigt.
 - Om ämnen som tillsätts hade varit mindre farliga hade det varit säkrare att använda återvunnen råvara i nya produkter.
 - Det bör vara högre uppmärksamhet kring återvinnarna och deras behov av mer information och vägledning.
- Spårbarhet och innehåll: Ytterligare arbete om märkning som når återvinnarna behöver utvecklas. Det behövs också utvecklas en systematisk strategi för riskbedömningar kopplade till återvinning.

Annex:

Hazardous substances used in plastics

Abbreviations

ABS	Acrylonitrile-butadiene-styrene.
BFR	Brominated flame retardant.
CA	Cellulose acetate.
C&DW	Construction and demolition waste.
CLP	Classification, labelling and packaging of substances and mixtures.
CMR	Carcinogenic, toxic for reproduction or mutagenic.
BFR	Brominated flame retardant.
EFSA	European food safety authority.
ELV	End-of-life vehicles.
EoW	End of waste.
EPA	Environmental protection agency.
EPS	Expandable polystyrene.
FEP	Fluoroethylene propylene.
HDPE	High density polyethylene.
HIPS	High impact polystyrene.
LIBS	Laser induced breakdown spectroscopy.
LDPE	Low density polyethylene.
LoW	List of waste.
NIP	National implementation plan.
NIR	Near-Infrared.
PA	Polyamide.
PBT	Polybutylene terephthalate.
PC	Polycarbonate.
PE	Polyethylene.
PEEK	Polyether ether ketone.

PBT	Persistent, bioaccumulative and toxic.
PES	Polyester.
PET	Polyethene teraphthalate.
PMMA	Polymetamethylacrylate.
POP	Persistent organic pollutant.
PP	Polypropylene.
PPE	Polyphenylene ether.
PPO	Polyphenylene oxide.
PPS	Polyphenylene sulphide.
PS	Polystyrene.
PTFE	Polytetrafluorethylen.
PUR	Polyurethane.
PVA	Polyvinyl acetate.
PVC	Polyvinyl chloride.
PVDC	Polyvinylidene chloride.
PVDF	Polyvinylidene fluorid.
RoHS	Restriction of Hazardous Substances.
Saran	Thermoplastic copolymers of vinylidene chloride with monomers of vinyl chloride, acrylonitrile, acrylic esters or unsaturated carboxyl groups.
TPU	Thermoplastic polyurethane.
UP	Unsaturated polyester.
vPvB	Very persistent and very bioaccumulative.
WEEE	Waste electrical and electronic equipment.
WFD	Waste framework directive.
XPS	Extruded polystyrene.
XRF	X-ray fluorescence.

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Table 12: Hazardous substances known to be used in the manufacturing of plastics. Their function in the plastic, as well as the type of plastic they are used in are shown. The table also shows products in which some of the substances have been found. References are found in the table

Substance	CAS	Function	Plastic type	Found in product group	References
Antimicrobial substances				Consumer products, construction materials, products for children	
Arsenic and its compounds	7440-38-2, 7778-39-4, 58-36-6, 1303-28-2, 1327-53-3, 7784-40-9, 7784-42-1, 15606-95-8	Antimicrobial	Plasticised PVC, PUR, LDPE, PESs		1
Bis(tributyltin)oxide (TBTO)	56-35-9	Antimicrobial	PUR foam, other polymers (unspecified)		1
Organic tin compounds (tributyltin, triphenyltin, dibutyltin, dioctyltin)	76-63-1, 76-87-9, 379-52-2, 639-58-7, 76-87-9, 900-95-8, 56-35-9, 1461-22-9, 2155-70-6, 26354-18-7, 688-73-3	Antimicrobial, stabilizer	PUR foam, PVC, paint	Car seats, bags, shower curtains, PVC-flooring, ear protection equipment, vinyl wallpaper, adhesives and sealants, diapers, rainwear, Scotch Brite, beach ball, boards, gutters, plastisol roof, doors, sewage and water pipes, gutters, windows, blinds, etc.	1; 2; 3
Triclosan	3380-34-5	Antimicrobial	PE, PP, PVC, PES fibres, PA fibres		1
Blowing agents					
C,C'-azodi(formamide) (ADCA)	123-77-3, 97707-96-5	Blowing agents	PVC, PE, epoxy resins		1
Chloromethane, methyl chloride	74-87-3	Blowing agents	PS, PE, PP, PUR, phenol resins, acetylcellulose foam		1
Fluorinated greenhouse gasses (HFCs, PFCs and SF6)	811-97-2, 354-33-6, 420-46-2, 75-37-6, 460-73-1, 406-58-6, 75-73-0, 76-16-4, 76-19-7, 2551-62-4 etc.	Blowing agents	PUR foam, PS foam, phenolic foam		1

Substance	CAS	Function	Plastic type	Found in product group	References
Heavy metal based colorants, stabilisers and catalysts				Consumer products, products for children, construction materials, packaging, electronics	
Cadmium and its compounds	7440-43-9, 10108-64-2, 542-83-6, 7790-79-6, 4464-23-7, 7790-80-9, 17010-21-8, 1306-19-0, 0124-36-4, 1306-23-6 etc.	Pigment, stabiliser	PVC (stabiliser), all plastics (pigment)	Plastic shoes, soft PVC-packaging for toys, plastic toys, bags and cases, bathroom products, floor mats, electronic toys, packaging, casing for TV and PC:s, shredder residue from cases in electronics, shredder residue from mixed electronic plastics, recycled WEEE plastic	1; 2; 3; 4
Cadmium and its compounds	7440-43-9, 10108-64-2, 542-83-6, 7790-79-6, 4464-23-7, 7790-80-9, 17010-21-8, 1306-19-0, 0124-36-4, 1306-23-6 etc.	Pigment, stabiliser	PVC (stabiliser), all plastics (pigment)	Plastic shoes, soft PVC-packaging for toys, plastic toys, bags and cases, bathroom products, floor mats, electronic toys, packaging, casing for TV and PC:s, shredder residue from cases in electronics, shredder residue from mixed electronic plastics, recycled WEEE plastic	1; 2; 3; 4
Chromium and its compounds	1333-82-0, 7778-50-9, 7789-09-5, 10588-01-9, 7789-00-6, 13765-19-0, 7789-06-2, 24613-89-6, 12656-85-8, 1344-37-2, 1308-38-9, 7738-94-5, 7758-97-6, 7775-11-3, 7789-12-0, 778909-5, 10294-40-3, 13530-68-2, 13530-65-9, 14977-61-8, 37300-23-5, 11103-86-9, 18540-29-7 etc.	Pigment, catalyst	PVC, PE, PP etc		1
Chromium trioxide	1333-82-0	Catalyst	PE etc		1
Cobalt(II) diacetate	71-48-7	Pigment	PET		1

Substance	CAS	Function	Plastic type	Found in product group	References
Lead and its compounds	75-74-1, 78-00-2, 301-04-2, 1072-35-1, 1314-41-6, 1317-36-8, 1319-46-6, 1335-32-6, 1344-37-2, 6838-85-3, 7428-48-0, 7439-92-1, 7446-14-2, 7446-27-7, 7758-95-4, 7758-97-6, 12141-20-7, 12656-85-8, 13424-46-9, 13453-65-1, 15245-44-0, 16038-76-9, 16183-12-3, 17570-76-2, 24824-71-3, 25808-74-6, 53807-64-0, 61790-14-5, etc.	Stabiliser	PVC (stabiliser), all plastics (pigment)	Plastic shoes, electronic toys, consumer electronics, floor mats, packaging, casing for TV and PC:s, shredder residue from cases in electronics, shredder residue from mixed electronic plastics, recycled WEEE plastic.	1; 2; 3
Lead chromate	7758-97-6	Pigment	All plastics		1
Lead chromate molybdate sulphate red (C.I. Pigment Red 104)	12656-85-8	Pigment	All plastics		1
Lead sulfochromate yellow (C.I. Pigment Yellow 34)	1344-37-2	Pigment	HDPE, LDPE, PVC, CA, PP		1
Mercury and its compounds	55-68-5, 62-38-4, 100-57-2, 123-88-6, 593-74-8, 627-44-1, 628-86-4, 1335-31-5, 1344-48-5, 7439-97-6, 7487-94-7, 7546-30-7, 7783-35-9, 8003-05-2, 10112-91-1, 62-38-4, 103-27-5, 13302-00-6, 13864-38-5, 26545-49-3	Catalyst	PUR		1

Substance	CAS	Function	Plastic type	Found in product group	References
Flame retardants				ELV, furniture, electronics, products for children, construction materials, packaging.	
Boric acid	10043-35-3, 11113-50-1	Flame retardant	PS, PVC, synthetic rubber		1
BFRs PBDEs (PeBDE, OBDE, DBDE, HBCDD, TBBPA)	32534-81-9, 32536-52-0, 1163-19-5, 25637-99-4, 79-94-7, 3194-55-6, 134-51-7, 134237-52-8, etc.	Flame retardant	ABS, EPS, HIPS, PAs, PBT, PE, PP, epoxy, PES, PUR, PUR foam, recycled WEEE-plastic	Car seats, upholstery, furniture, casing to TV, personal computers, many groups under the WEEE, casing for electronics, cable Insulation, Insulation materials, packaging, electronics, scanner, TV, household appliances, upholstery for ELV, furniture, plastics for electronics, casing for TV and computers, car fittings, toys.	1; 2; 3; 4
Hexabromocyclodecane (HBCDD) and all major diastereoisomers	25637-99-4, 3194-55-6, 134237-50-6, 134237-51-7, 134237-52-8 (included in the group of BFRs)	Flame retardant	EPS, XPS, HIPS, polymer dispersions on textiles	Furniture (filling in bean bags), Insulation, electrical and electronic products, electronic waste.	1; 2; 3
Molybdenum trioxide	1313-27-5	Flame retardant	PES, PVC		1
Tris(2-chloroethyl)phosphate	115-96-8	Plasticiser, viscosity regulator with flame retardant properties	PUR, PES, PVC, PVA, PMMA, epoxy, PA, PC, PUR, thermoplastic PES and unsaturated PES		1
Organo phosphates (TCPP, TDCPP, TPP)	13674-84-5, 1067-98-7, 13674-87-8	Flame retardants, plasticisers	PUR (foam)	Furniture, baby products, casing for video devices	1; 2
Bis(hexachlorocyclopentadieno) cyclooctane	13560-89-9	Flame retardant	CPE, engineering thermoplastics, HIPS, PE, PP, thermosets		1
Decabromodiphenyl ethane (DBDPE)	84852-53-9	Flame retardant	CPE, Engineering thermoplastics, HIPS, PE, PP, thermosets		1
Ethylene (bistetra bromophthalimide) (EBTEBPI)	32588-76-4	Flame retardant	HIPS, PP, PP, PBT, OPET, PC, engineering thermoplastics		1

Substance	CAS	Function	Plastic type	Found in product group	References
Tetrabromobisphenol A bis (2,3-dibromopropyl) ether (TBBPA-BDBPE)	21850-44-2	Flame retardant	ABS, HIPS, Phenolic resins, epoxy-laminates		1
Tris(tribromoneopentyl) phosphate (TTBNPP)	19186-97-1	Flame retardant	PP		1
Tris(tribromophenoxy) triazine (TTBPTAZ)	25713-60-4	Flame retardant	ABS, HIPS		1
Triphenyl phosphate (TPP)	115-86-6	Flame retardant and plasticiser	PPE-HIPS, PC-ABS, CA		1
Bisphenol A bis-(diphenyl phosphate) (BAPP)	181028-79-5	Flame retardant	PPE (high impact) and HIPS		1
Melamine cyanurate	37640-57-6	Flame retardant	Polyacrylate, PBT, TPU, UP		1
Melamine polyphosphate	15541-60-3	Flame retardant	Epoxy resins, phenolic based composites, polyacrylate, PBT, PE, PP, TPU, UP		1
N-alkoxy hindered amine reaction products	191680-81-6	Flame retardant, UV-stabilizer	PE, PP		1
Phosphonate oligomer, polyphosphonate	68664-06-2	Flame retardant	Thermosets		1
Poly(phosphonate-co-carbonate)	77226-90-5	Flame retardant	Engineering plastics (and elastomers)		1
Resorcinol bis-diphenylphosphate	125997-21-9	Flame retardant	PPE-HIPS, PC-ABS		1
Aluminium diethylphosphinate	225789-38-8	Flame retardant	Epoxy, PA, PBT, PET, TPU		1

Substance	CAS	Function	Plastic type	Found in product group	References
Aluminium hydroxide	21645-51-2	Flame retardant	EVA, PE, thermosets		1
Ammonium polyphosphate (NH ₄ PO ₃) _n	68333-79-9	Flame retardant	PE, PP		1
3,5,24 Magnesium hydroxide	1309-42-8	Flame retardant	EVA, PA, PE, PP		1
Red phosphorus	7723-14-0	Flame retardant	Epoxy resins, polyacrylate, polyacrylate66, PP		1
Zinc borate	1332-07-06, 138265-88-0	Flame retardant	PUR, PVC, EVA, PE, PP		1
Tetrabromobisphenol A bis (allyl ether)	25327-89-3	Flame retardant	EPS		1
1,2,5,6- tetrabromocyclo- octane (TBCO)	3194-57-8	Flame retardant	EPS		1
2,4,6- tribromophenyl allyl ether	3278-89-5	Flame retardant	EPS		1
Tetrabromobisphenol A bis(2,3- di-bromopropyl ether) (TBBPA-DBPE)	21850-44-2	Flame retardant	EPS, XPS		1
Ethylenebis (tetrabromophthalimide) (EBTPI)	32588-76-4	Flame retardant	HIPS, PE, PP, thermoplastic PESs, PA, PC, ethylene co- polymers		1
Decabromodiphenyl ethane (DBDPE)	84852-53-9	Flame retardant	HIPS, PE, PP, thermosets and CPE		1
Diphenyl cresyl phosphate	26444-49-5	Flame retardant, plasticiser	HIPS (flame retardant), PVC (plasticiser)		1

Substance	CAS	Function	Plastic type	Found in product group	References
6H-Dibenz[c,e][1,2]oxaphosphorin, 6-oxide (DOPO)	35948-25-5	Flame retardant	Epoxies		1
Poly-(m-phenylene methylphosphonate)(Fyrol PMP)	63747-58-0	Flame retardant	Epoxies		1
Phosphoric acid, diethyl-, aluminium salt	225789-38-8	Flame retardant	Epoxies		1
1,3,4-Metheno-1H-cyclobuta[cd]pentalene (MIREX)	2385-85-5	Flame retardant – also known as	No information – highly unlikely that it is actually used		1
Antimony trioxide	1309-64-4	Flame retardant, stabiliser	Various plastics		1
Trixylyl phosphate	25155-23-1	Additive	No information		1
TDCP (Tris[2-chloro-1-(chloromethyl)ethyl]phosphate)	13674-87-8	Flame retardant	PUR		1
Tetrakis(2,6-dimethylphenyl)-m-phenylene biphosphate	139189-30-3	Flame retardant	Styrene based plastics		1
Monomers, cross linkers, hardeners, chain modifiers and catalysts				Products for children, (food) packaging, consumer products, construction materials, ELV	
Acrylamide	79-06-01	Intermediate – Co-monomer	Polyacrylamide, polyacrylonitrile copolymer		1
4-(1,1,3,3-tetramethylbutyl)phenol, (4-tert-Octylphenol)	140-66-9	Monomer, intermediate, component	Phenol resins		1

Substance	CAS	Function	Plastic type	Found in product group	References
Bisphenol A (BPA)	80-05-07	Monomer, antioxidant, crosslinking agent, component	PC, epoxy resins, phenoplast cast resin, PVC, rigid PUR foam, modified PA, unsaturated PES resin	Plastic toys, masquerade toys, pacifier clips, packaging for cheese, mattresses, vinyl floors, sports shoes, receipts, CD-disk for children, drinking bottle for children, construction kits for children, stickers for children.	1; 2; 4
Formaldehyde	50-00-0	Monomer	Melamine, phenolic resins, acetal resins, POM	Stuffing in car seats	1; 3
Formaldehyde, oligomeric reaction products with aniline	25214-70-4	Intermediate, hardener	Epoxy resins, high performance polymers		1
Phenol	108-95-2	Monomer	Bakelite (phenol-formaldehyde)		1
Hexahydro-methylphthalic anhydride and similar compounds	25550-51-0, 19438-60-9, 48122-14-1, 57110-29-9	Intermediate, hardener, chain cross-linkers	PESs, plasticisers manufactured from the substance, epoxies ¹		1
Hexahydro-2-benzofuran-1,3-dione and similar compounds	85-42-7, 13149-00-3, 14166-21-3	Intermediate/monomer, hardener	Epoxy resins		1
Hydrazine	302-01-2, 7803-57-8	Cross linker, chain extender, intermediate, flame retardant etc	PUR		1
4,4'- Diaminodiphenylmethane (MDA)	101-77-9	Hardener, intermediate	Epoxy coatings and composites, and the high-performance polymer PEEK		1
2,2'-dichloro-4,4'-methylenedianiline (MOCA)	101-14-4	Curing agent, cross-linker, chain extender or prepolymer	Mainly PUR (PU)		1

Substance	CAS	Function	Plastic type	Found in product group	References
4-tert-Butylphenol, 2,6-Di-tert-butylphenol	98-54-4, 128-39-2	Intermediate, co-polymer, chain terminator	Phenolic resins, PC		1
Methylene diphenyl diisocyanate (MDI), Toluene-diisocyanate, TDI	26447-40-5, 5873-54-1, 101-68-8, 26471-62-5, 584-84-9, 91-08-7	Intermediate	PUR		1
Styrene	100-42-5	Intermediate	PS, ABS, SAN, EPS , glassfiber reinforced products (styrenated PESs)		1
1,1-dichloroethylene, vinylidene chloride	75-35-4	Monomer	Saran		1
p-dichlorobenzene, 1,4-dichlorobenzene	106-46-7	Monomer	PPS		1
Acrylonitril	107-13-1	Monomer	ABS, SAN, ASA		1
1,3-butadiene	106-99-0	Monomer	HIPS		1
Allyl 2,3-epoxypropyl ether, allyl glycidyl ether, prop-2-en-1-yl 2,3-epoxypropyl ether	106-92-3	Intermediate	Epoxies		1
Butyl 2,3-epoxypropyl ether , butyl glycidyl ether	2426-08-06	Intermediate	Epoxies		1
1,3-bis(2,3-epoxypropoxy)benzene, resorcinol diglycidyl ether	101-90-6	Intermediate/monomer	Epoxies		1

Substance	CAS	Function	Plastic type	Found in product group	References
1,2-epoxy-4-epoxyethylcyclohexane, vinylcyclohexane diepoxide	106-87-6	Monomer, reactive dilutant	Epoxies		1
1,5-naphthylenediamine	2243-62-1	Intermediate	PUR		1
1,2-epoxybutane	106-88-7	Intermediate	Epoxies		1
Methyloxirane (Propylene oxide)	75-56-9	Intermediate/monomer	PUR, thermoplastics		1
TGIC, β -TGIC ¹	2451-62-9, 59653-74-6	Cross-linking or curing agent, stabiliser	PES. TGIC is an epoxy compound		1
Imidazole	288-32-4	Intermediate	PU and epoxy		1
1,4-Diaminobutane (Putrescine)	110-60-1	Intermediate	Nylon-4,6		1
Vinyl acetate	108-05-4	Monomer	PVA, VA/AA, PVCA		1
Organic based colorants				Furniture, products for children, ELV, consumer products	
Malachite green hydrochloride, malachite green oxalate	569-64-2, 18015-76-4	Colorant	Green coloured plastics.		1
Disperse Yellow 3 ²	2832-40-8	Colorant	Yellow coloured plastics		1
Solvent Yellow 14 ³	842-07-9	Colorant	Yellow coloured plastics		1
Azo dyes (general)	573-58-0, 1937-37-7, etc.	Colorant	PES, PA, acrylic	Textiles and upholstery for furniture, clothes, toys from textile, car seats, bedding.	2; 4

Substance	CAS	Function	Plastic type	Found in product group	References
UV stabilisers, antioxidants and other stabilisers					
1,4-benzenediol, 2,5-bis(1,1-dimethylethyl)-	88-58-4	Antioxidant	No information		1
Phenolic benzotriazols	3846-71-7, 3864-99-1, 25973-55-1, 36437-37-3	UV-stabilizer	Formaldehyde resins		1
N-2-naphthylaniline, N-phenyl-2-naphthylamine	135-88-6	Thermo stabilizer, antioxidant	PE, EVA, PIB		1
2-ethylhexanoic acid	149-57-5	Thermo stabilizer	PVC and as residue in PUR products		1
Dibutyltin dichloride	683-18-1	Stabiliser, catalyst	PVC, PUR		1
DMT EHMA, DMTC etc. ⁴	57583-35-4, 15571-58-1, 77-58-7, 753-73-1	Heat stabilizer, catalyst	PVC		1
TNPP (tris(nonylphenyl)phosphite)	26523-78-4	Stabiliser, antioxidant	PVC, LLDPE, HDPE		1
Plasticisers				Products for children, construction materials, consumer products, electronics, ELV, packaging	
1,2-Benzenedicarboxylic acid, di-C7-11-branched and linear alkyl esters (DHNUP)	68515-42-4	Plasticiser	PVC (mainly), foamed urethane		1
1,2-Benzenedicarboxylic acid, di-C6-8-branched alkyl esters, C7-rich (Diisophtalate)	71888-89-6	Plasticiser	PVC, one-component PURs and acrylics		1

Substance	CAS	Function	Plastic type	Found in product group	References
Alkanes, C ₁₀₋₁₃ , chloro (Short Chain Chlorinated Paraffins-SCCP)	85535-84-8, 108171-26-2, 287-476-5	Secondary plasticiser and flame retardant	PVC, rubber, elastomers, textile fiber cover	Soft plastic toys, masquerade toys, plastic floors, goods made from PVC or other soft plastic, bags and cases, low-price electronics, tablets, cellular phones, kitchen appliance, game controllers, bathroom products, sports equipment, garden goods, office supplies (writing tablet), road markings, buildings, packaging, upholstery in ELV, hand blenders.	1; 2; 3; 4
Medium-chain chlorinated paraffins (MCCP)	85535-85-9	Plasticiser and flame retardant	Soft plastic, PVC, and PES		1
Bis(2-methoxyethyl) phthalate (DMEP)	117-82-8	Plasticiser	Nitrocellulose, acetyl cellulose, PVA, PVC and PVDC		1
Benzyl butyl phthalate (BBP)	85-68-7	Plasticiser	PVC, PMMA, PA, thermoplastic PES	Plastic shoes, floors, print on t-shirt.	1; 2; 3
Bis (2-ethylhexyl)phthalate (DEHP)	117-81-7	Plasticiser	PVC, PMMA, ABS, PA, PS, thermoplastic PES	Car seats, products made from soft PVC plastic, plastic toys, masquerade toys, training gloves, oilcloths, bathroom products, downpipes, sports equipment, garden goods, articles intended for pets, floors, cables.	1; 2; 3; 4
Di (2-ethyl-hexyl) ter-ephthalate (DEHT)	6422-86-2	Plasticiser	PVC etc		1
Dibutyl phthalate (DBP)	84-74-2	Plasticiser, catalyst	PVC, PP, PVA-based adhesives, plasticiser-solvent	Soft plastic toys, products made from soft PVC plastic, floors.	1; 2; 3; 4
Diisobutyl phthalate (DiBP)	84-69-5	Specialist plasticiser	PVC, PS, nitrocellulose, celluloseether, polyacrylate and polyacetate dispersions	Soft plastic toys, products made from soft PVC plastic, bags and cases, bathroom products, articles intended for pets.	1; 3; 4

Substance	CAS	Function	Plastic type	Found in product group	References
DINP, DIDP, DPHP, DEP, DIPP, DHP ⁵	68515-48-0/28553-12-0, 68515-49-1/26761-40-0, 53306-54-0, 84-66-2, 605-50-5, 84-75-3, 84-61-7, 68515-50-4	Plasticiser	PVC and other plastic materials including PVA, cellulose plastics and PUR	Bath toys, soft plastic toys, masquerade toys, changing tables, plastic floors, plastic print (on clothes).	1; 2; 3; 4
Tributyl phosphate	126-73-8	Plasticiser	Cellulose based plastics etc		1
Sulfonic acids, C10 – C18-alkane, phenylesters (ASE)	91082-17-6	Plasticiser	PVC etc		1
Acetyl tributyl citrate (ATBC)	77-90-7	Plasticiser	PVC etc		1
Mixture of benzoates incl. DEGD	Mix of 120-55-8, 27138-31-4, 120-56-9	Plasticiser	PVC etc		1
COMGHA ⁶	Mix of 330198-91-9 and 33599-07-4	Plasticiser	PVC etc		1
Diisononyl adipate (DINA)	33703-08-1	Plasticiser	PVC etc		1
Diisononyl-cyclohexane-1,2-carboxylate (DINCH)	166412-78-8	Plasticiser	PVC etc		1
Dipropylene glycol dibenzoate (DGD)	27138-31-4	Plasticiser	PVC etc		1
Glycerol triacetate (GTA)	102-76-1	Plasticiser	PVC etc		1
Trimethyl pentaryl diisobutyrate (TXIB)	6846-50-0	Plasticiser	PVC etc		1

Substance	CAS	Function	Plastic type	Found in product group	References
"Phthalates on candidate list"/"Different phthalates"		Plasticiser		Plastic shoes, plastic floors, rubber coated fabric, toys.	2; 3
Solvents –neutral and reactive				Consumer products.	
2-Methoxyethanol	109-86-4	Solvent, chemical intermediate	Epoxy resins and polyvinylacetate		1
Trichloroethylene	79-01-6, 108-70-3	Intermediate	PVC		1
N,N-dimethylformamide (DMF)	68-12-2	Solvent, chemical intermediate	Polyacrylonitrile, PUR and polyvinylchloride	Office supplies.	1; 2; 4
1,2,3-Trichloropropane	96-18-4	Intermediate	Hexafluoropropylene		1
1,6-hexanediol diglycidyl ether	16096-31-4	Reactive dilutant, stabiliser	Epoxies, chlorinated vinyl resins		1
Dichloromethane, methylene chloride	75-09-02	Intermediate, blowing agent, moulding	PC		1
1,1,2-trichloroethane	79-00-5	Intermediate	Teflon		1
1,4-dioxane	123-91-1	Intermediate	Cellulose based polymers		1

Substance	CAS	Function	Plastic type	Found in product group	References
Others				Consumer products, (food) packaging, construction materials, electronics, products for children.	
Nonylphenol and its ethoxylates	104-40-5, 7311-27-5, 9014-90-8, 9016-45-9, 9040-65-7, 9051-57-4, 9081-17-8, 11096-42-7, 25154-52-3, 26027-38-3, 26571-11-9, 27177-03-3, 27177-05-5, 27177-08-8, 27986-36-3, 28987-17-9, 37205-87-1, 51811-79-1, 52503-15-8, 66197-78-2, 68412-54-4, 68584-47-4, 68891-21-4, 72580-36-0, 84852-15-3, 127087-87-0	Monomer, catalyst, antioxidant, (heat) stabilizer.	Phenol/formaldehyde plastic, epoxy, PUR foam, PVC	Food packaging, clothes, food packages, sports shoes, mattresses, PVC-floors.	1; 2
Octylphenol and its ethoxylates	140-66-9, 1806-26-4, 9004-87-9, 9036-19-5, 9063-89-2, 11081-15-5, 68987-90-6, 69011-84-3	Monomer, antioxidant in stabilizers, emulsifiers.	Phenol formaldehyde resin, PVC, styrene-butadiene copolymer		1
Perfluorinated Alkylated Substances (PFAS); PFOS, PFOA and similar compounds	15166-06-0, 2395-00-8, 24216-05-5, 3108-24-5, 33496-48-9, 335-64-8, 335-66-0, 335-67-1, 335-93-3, 335-95-5, 376-27-2, 3825-26-1, 39186-68-0, 41358-63-8, 423-54-1, 53517-98-9, 68141-02-6, 68333-92-6, 69278-80-4, 72623-77-9, 72968-38-8, 85938-56-3, 89685-61-0, 90179-39-8, 90480-55-0, 90480-56-1, 90480-57-2, 91032-01-8, 93480-00-3	Dispersing agent	PTFE, FEP, PVDF	Plastic floors (uncertain results), textiles, synthetic mats, childrens clothes, paper and food packaging, non-stick products such as pans, photographic and electronic equipment and components, building materials, surface treatment, lightweight concrete.	1; 2; 3

Substance	CAS	Function	Plastic type	Found in product group	References
Henicosafuoroundecanoic acid etc. ⁷	2058-94-8, 376-06-7, 307-55-1, 72629-94-8, 375-95-1, 335-76-2	No data	No data		1
Polyaromatic Hydrocarbons (PAHs)	50-32-8, 56-55-3, 120-12-7, 192-97-2, 193-39-5, 205-82-3, 205-99-2, 207-08-9, 218-01-9, 65996-93-2, 90640-80-5, 90640-81-6, 90640-82-7, 90640-86-1, 91995-15-2, 91995-17-4, etc.	Impurity in plasticisers and carbon black.	Soft plasticised plastics, ABS and PP, etc. All plastics coloured black.		1
Potassium hydroxyoctaoxidizincatedichromate	11103-86-9	Corrosion inhibition	Epoxy, PUR, alkyd, isocyanate-cured PES, pigmented acrylic resins as topcoats/primers		1
Disodium tetraborate etc. ⁸	1330-43-4, 1303-96-4, 12179-04-3	Buffering agent, production of plastics, resins, nylon.	Formaldehyde resins		1

- Note: ¹1,3,5-Tris(oxiran-2-ylmethyl)-1,3,5-triazinane-2,4,6-trione (TGIC) & 1,3,5-tris[(2S and 2R)-2,3-epoxypropyl]-1,3,5-triazine-2,4,6-(1H,3H,5H)-trione (β -TGIC).
- ² N-[4-[(2-hydroxy-5-methylphenyl)azo]phenyl]acetamide, C.I. Disperse Yellow 3.
- ³ 1-phenylazo-2-naphthol, C.I. Solvent Yellow 14.
- ⁴ Dimethyltin bis(2-ethylhexylmercaptoacetate) (DMT EHMA), Dioctyltin bis(2-ethylhexyl mercaptoacetate), Dibutyltin dilaurate, Dimethyltin dichloride (DMTC).
- ⁵ Di-"isononyl" phthalate (DINP), Di-"isodecyl" phthalate (DIDP), Bis(2-propylheptyl) phthalate (DPHP), Diethyl phthalate (DEP), Diisopentyl phthalate (DIPP), Dihexyl phthalate (DHP), Dicyclohexyl phthalate, Diisohexyl phthalate.
- ⁶ Mixture of 12-(Acetoxy)-stearic acid, 2,3-bis(acetoxy)propyl ester and octadecanoic acid, 2,3-(bis(acetoxy)propyl ester (COMGHA).
- ⁷ Hencosafluoroundecanoic acid, Heptacosafuorotetradecanoic acid, Tri-cosafluorododecanoic acid, Pentacosafuorotridecanoic acid, heptadecafluorononanoic acid and nonadecafluorodecanoic acid.
- ⁸ Disodium tetraborate, anhydrous Disodium tetraborate decahydrate Disodium tetraborate pentahydrate.



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Hazardous substances in plastics

The aim of the project is to create knowledge on how plastics recycling can increase without increasing the risk of emitting hazardous substances to the environment.

The first general conclusion is that to be able to increase recycling there are measures needed at different levels. The following areas are of interest:

- Legislation: new legislation is not necessary, but harmonisation and clear guidance to the existing one is.
- Market: to create a market safety on content is needed.
- If substances added are less hazardous the recycled raw material would be "more safe" to use.
- There should be higher attention put on the knowledge of the recyclers.
- Traceability and content: Further work on labelling reaching the recycle part of the value chain needs to be developed. It is also needed to develop a systematic approach towards risk assessments linked to recycling.



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