National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

Plastics that contain hazardous substances: recycle or incinerate?

RIVM Letter report 2016-0025
M.P.M. Janssen et al.

National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

Plastics that contain hazardous substances: recycle or incinerate?

RIVM Letter report 2016-0025
M.P.M. Janssen et al.

Colophon

M.P.M. Janssen (author),RIVM
J. Spijker(author),RIVM
J.P.A. Lijzen (author),RIVM
L.G. Wesselink (author),RIVM

Contact:
Martien Janssen
Centre for the Safety of Substances and Products
martien.janssen@rivm.nl

This study was commissioned by the Ministry of Infrastructure and the Environment as part of the REACH Substances (M/260025/15) and Waste to Resource (M/260036/15) projects. The report is the English version of report 2015-0163 'Plastics met gevaarlijke stoffen: recyclen of verbranden?

This is a publication by:
The Dutch National Institute for Public Health and the Environment
Postbus 1 | 3720 BA Bilthoven
The Netherlands
www.rivm.nl/en

Publiekssamenvatting

Plastics met gevaarlijke stoffen: recyclen of verbranden?

Om de hoeveelheid beschikbare grondstoffen minder aan te spreken wordt gestimuleerd om materialen zoveel mogelijk opnieuw te gebruiken in nieuwe producten. Recycling is echter lastig bij materialen die gevaarlijke stoffen bevatten, bijvoorbeeld omdat deze stoffen kankerverwekkend, slecht afbreekbaar of giftig zijn. De neiging bestaat om materialen die dergelijke stoffen bevatten te vernietigen door verbranding. Plastics zijn daar een voorbeeld van.

Het RIVM stelt voor om bij de afweging tussen verbranden of recyclen een breder milieuperspectief voor ogen te houden. Bijvoorbeeld door er rekening mee te houden dat minder energie nodig is om plastics uit een gerecycled product te maken dan nieuw plastic te vervaardigen. Tegelijkertijd moet nadrukkelijk worden gegarandeerd dat mens en milieu niet blootstaan aan gevaarlijke stoffen uit het gerecycled materiaal.

Dit is de conclusie van een onderzoek naar de vraag hoe om te gaan met materialen die gevaarlijke stoffen bevatten. Het rapport schetst de huidige afvalverwerkingspraktijk, de technische achtergrond van de recycling van deze materialen en de complexe wetgeving rond recycling. De dilemma's zijn uitgewerkt in enkele casussen: de brandvertrager HBCDD (hexabroomcyclododecaan) in piepschuim en weekmakers, en cadmium en lood in plastic buizen (PVC).

Aanbevolen wordt om voor oplossingen voor te recyclen materialen de wettelijke kaders voor de toelating van stoffen op elkaar af te stemmen. Zo is het raadzaam het afvalbeleid en het beleid voor gevaarlijke stoffen over elkaars werkgebied te laten meedenken en de gehele recycleketen in ogenschouw te nemen om te bepalen waar obstakels zitten.

Kernwoorden: afval, recycling, PVC, EPS, SVHC, gevaarlijke stoffen, uitfasering, zeer zorgwekkende stoffen, HBCDD, DEHP, cadmium

Synopsis

Plastics that contain hazardous substances: recycle or incinerate?

Over the last decade interest in the circular economy and therefore in recycling has increased considerably. This interest is prompted by the awareness that natural resources are not unlimited and that the extraction of new resources can cause considerable environmental damage.

One of the problems of recycling is that the materials may contain substances that pose a risk to man and the environment. So the possible advantages of recycling, such as more energy-efficient and CO2-efficient production, should be weighed against the potential effects of these substances.

This report focuses on a few cases where hazardous substances have been incorporated into potentially recyclable material: the flame-retardant hexabromocyclododecane (HBCDD) in Styrofoam (extruded polystyrene), and the plasticiser DEHP, cadmium and lead in polyvinyl chloride (PVC). The report outlines the technical background to the recycling of these materials, current practice and the complex legislation on recycling, and it ends with some policy recommendations.

Keywords: waste, recycling, PVC, EPS, SVHC, hazardous substances, phasing-out, HBCDD, DEHP, cadmium

Contents

Summary

Plastics can contain additives that make them more stable, softer or flame-retardant. However, these substances can also pose a risk to people and the environment. European policy focuses on banning these hazardous substances and the promotion and development of new, safer additives for plastics. This development will make plastics suitable materials for recycling in the future, which will reduce the consumption of raw materials and energy and cut CO2 emissions.

So, can the existing stock of plastics that contain hazardous substances still be recycled? Current legislation prohibits this as a rule, unless specific legal exemptions are granted for specific applications and for each substance. This is not easy as it means coordination of a complex set of laws being coordinated for substances, products and waste materials. A successful example is the use of cadmium-containing recycled plastic in construction applications such as cable ducts, window frames and intermediate layers in new PVC pipes.

In the legislative process these exemption clauses for recycling are a reaction to the substances or products policy. From a circular economy point of view it would be appropriate to turn the legislation process upside down by ascertaining the large-scale applications in which the recycling of contaminated plastics is actually safe for people and the environment. The exposure risk of specific applications would then be central to this; this could result in less strict specific product requirements.

A good example is the reuse of construction and demolition waste in the Netherlands. The product requirements are geared to the permissible leaching of contaminants into the soil and groundwater. This simple, transparent policy framework provides clarity to the market and has resulted in a reuse percentage of 95%.

This kind of approach requires a legislative process in which the stakeholders, who now act separately in legislation relating to substances, products and waste materials, get together round the table at an early stage.

New, tighter concentration standards are currently being drawn up in an EU context for the two cases covered in this report. These are lead and hexabromocyclododecane. This may restrict the future recyclability of PVC and expanded polystyrene. We recommend that for specific large-scale applications of these plastics the exposure for people and the environment be quantified and evaluated. Whether for this product-oriented approach some 'room for manoeuvre' in the policy needs to be sought can be determined in part by quantification of the CO2 reduction brought about by recycling. An international approach is required if this policy 'room to manoeuvre' is to be achieved.

The production of materials such as iron, steel, glass, paper, aluminium and plastics is energy-intensive and contributes approximately 20% to

global emissions of greenhouse gases such as CO_2. The recycling of these materials is less energy-intensive and reduces emissions of CO_2. Plastics are the least recycled of the above-mentioned materials: in Europe approximately 25%. So the European and Dutch policy on waste, resource efficiency and the circular economy focuses on reusing plastics as much as possible and for as long as possible.

However, plastics may contain additives such as heavy metals, plasticisers or flame-retardants. These are substances that have a clear function, but that they are sometimes hazardous because they do not degrade, accumulate in the environment and are toxic or carcinogenic. These substances are labelled as being dangerous for the environment or 'Substances of Very High Concern' (SVHC).

The European substances policy focuses on phasing these SVHCs out, on the one hand by banning these substances from the market and on the other hand by processing waste streams containing these substances, in a controlled way, for example in waste incinerators. However, this processing releases the carbon in plastic waste as $CO_{2;}$ and the production of new plastics also consumes energy and produces CO_2 emissions.

Key is to find the right balance between boosting recycling and reducing CO_2 emissions on the one hand and reducing the quantity of hazardous substances in the economy on the other hand. What does this balance look like when it comes to the reuse of waste plastics that contain hazardous substances?

This is the question tackled by this report. We look in greater detail at practices relating to two plastics, polyvinylchloride (PVC) and expanded polystyrene (EPS). These plastics contain four hazardous substances that are the focus of this report: cadmium and lead compounds as stabilisers in hard PVC, di-2-ethylhexyl phthalate (DEHP) as a plasticiser in soft PVC, and hexabromocyclododecane (HBCDD) as a flame-retardant in EPS.

These plastics have to satisfy policy and legislation in the field of chemical substances, waste materials *and* products during their lifecycle. Moreover, the policy field is dynamic, as over time new hazardous substances may be included in laws. Whereas new legislation on hazardous substances in plastics is a strong incentive for innovative, safe applications it can give rise to uncertainty about the reuse of ‘old’ contaminated recyclate for recycling companies and the customers who purchase recyclate.

Against this background of complexity and uncertainty we will look at whether and how the policy works effectively and consistently in managing both objectives: that of safety and that of the circular economy.

First of all we will discuss the main conclusions regarding the phasing-out of hazardous (SVHC) substances. Then we will look at the trends in the recycling of PVC and EPS. Then we will take a look in greater detail at the interface of substances, products and waste materials legislation.

And from this perspective we will make recommendations about the reuse of contaminated plastics.

Successful phasing-out of hazardous substances
Table 1 presents an overview of the European policy that relates to the plastics and substances in this study.

Legislation, sometimes in collaboration with voluntary agreements with industry (cadmium and lead), has resulted in a rapid, successful reduction in the quantities of hazardous substances in plastics that this report discusses, see Figure 1. HBCDD volumes are not yet falling, but manufacturers indicate that there are alternatives available. The 'authorisation' that they have requested – a permitted postponement period – within the REACH legislation should provide extra time that is required for a smooth transition to these alternatives.

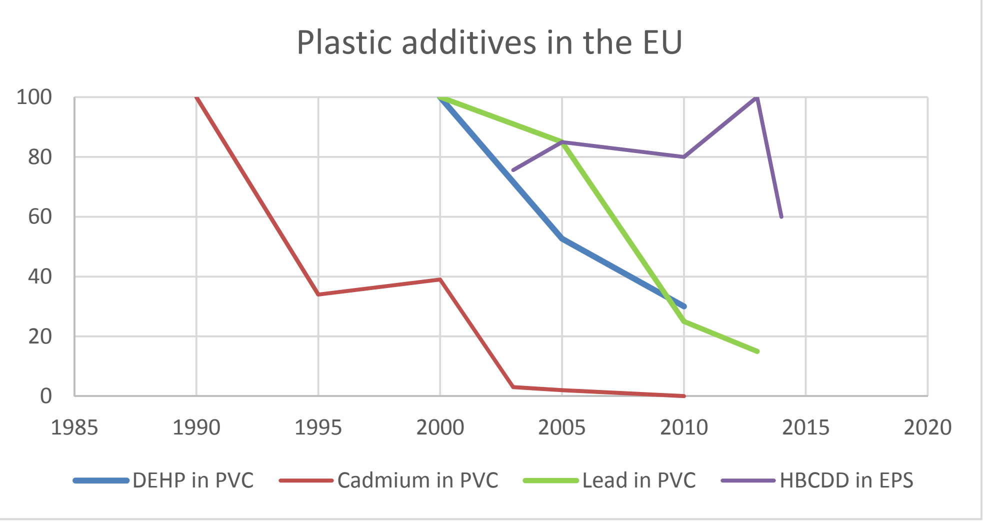

Figure 1 DEHP, cadmium and lead compounds added to PVC in the EU, per substance scaled to 100.

The policy on hazardous substances is thus effectively resulting in a reduction and ultimate ban on these substances and thus effectively aims to introduce innovative, new and safer additives to plastics. One example is the replacement of cadmium and lead compounds as stabilisers in plastics with calcium. This will make these plastics better recyclable in the future.

Table 1 European Regulations regarding hazardous substances in plastics (largely in accordance with COWI et al, 2013)

	Cadmium compounds	**Lead compounds**	**DEHP**	**HBCDD**
Substances	• REACH Annex XVII, list of restrictions • REACH Candidate List of SVHC (*) • Classification, Labelling and Packaging (CLP) Regulation (of hazardous substances) Annex VI	• REACH Annex XVII, list of restrictions • REACH Candidate List of SVHC (*) • REACH Annex XIV, list of authorisations • Classification, Labelling and Packaging (CLP) Regulation (of hazardous substances) Annex VI	• REACH Annex XVII, list of restrictions • REACH Candidate List of SVHC (*) • REACH Annex XIV, list of authorisations • Classification, Labelling and Packaging (CLP) Regulation (of hazardous substances) Annex VI	• REACH Annex XIV, list of authorisations • REACH Candidate List of SVHC (*) • POP Regulation (EC) No 850/2004 (**) • Classification, Labelling and Packaging (CLP) Regulation (of hazardous substances) Annex VI
Products	• Directive 2009/48/EC related to toy safety • Directive 2005/90/EC on the marketing/use of certain dangerous substances and preparations • Directive 2002/72/EC relating to plastic materials in contact with food • Directive 2000/53/EC on End-of-Life Vehicles (ELV) • Directive 2011/65/EC on Restriction of Hazardous Substances (RoHS) • Directive 94/62/EC of 20 December 1994 on packaging	• Directive 2009/48/EC related to toy safety • Directive 2005/90/EC on the marketing/use of certain dangerous substances and preparations • Directive 2002/72/EC relating to plastic materials in contact with food • Directive 2000/53/EC on End-of-Life Vehicles (ELV) • Directive 2011/65/EC on Restriction of Hazardous Substances (RoHS) • Directive 94/62/EC of 20 December 1994 on packaging and packaging waste	• Directive 2009/48/EC related to toy safety • Directive 2005/90/EC and 2005/84/EC on the marketing and use of certain dangerous substances and preparations • Directive 93/42/EEC on medical devices • Directive 2002/72/EC relating to plastic materials in contact with food	• Directive 2002/72/EC relating to plastic materials in contact with food

	Cadmium compounds	Lead compounds	DEHP	HBCDD
	and packaging waste			
Waste materials	• Directive 2008/98/EC on Waste, referring to CLP regulation and POP Regulation (EC) No 850/2004	• Directive 2008/98/EC on Waste, referring to CLP regulation and POP Regulation (EC) No 850/2004	• Directive 2008/98/EC on Waste, referring to CLP regulation and POP Regulation (EC) No 850/2004	• POP Regulation (in prep.) • Directive 2012/19/EU on electronic waste

(*) some lead compounds have already been included in Annex XIV
(**) POPS: persistent organic pollutants.

Recycling of PVC and EPS, trends

PVC

Figure 2 shows developments in the European recycling of PVC, separated into hard and soft PVC. Recycling is on the increase and the PVC industry, united in the Vinylplus programme, indicates that it is on course to achieve its objective of 0.8 Mtonnes of PVC recycling in 2020.

It is not known how much PVC is released every year as waste. The total annual amount of plastic waste in the EU is estimated at 25.9 Mtonnes. We estimate that approximately 10.5% of this is PVC. The objective of 800,000 tonnes of PVC recycling in 2020 would then account for approximately 30% of the amount of PVC waste released.

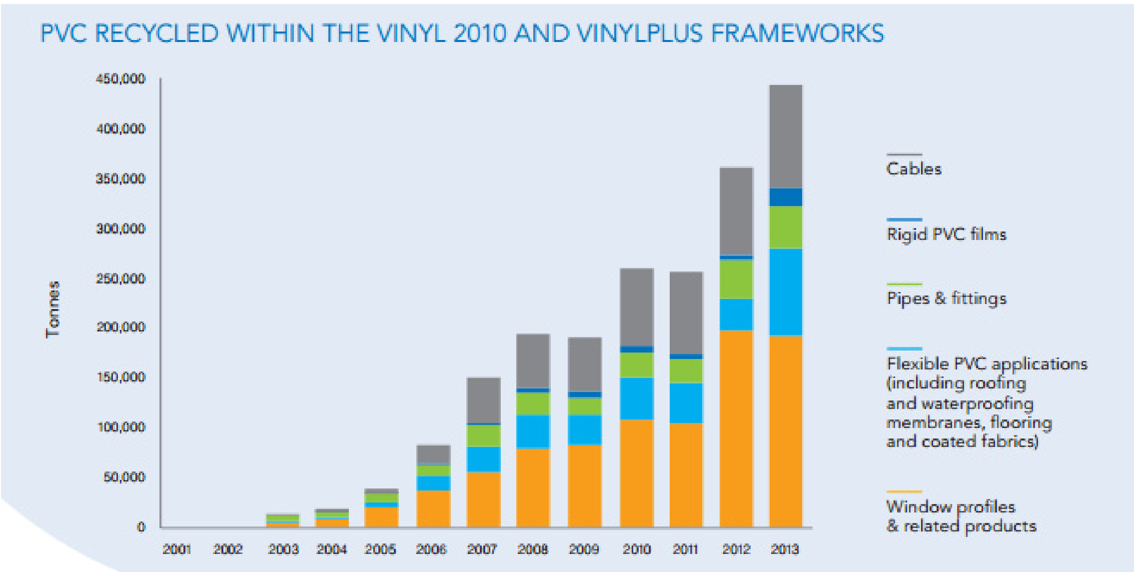

Figure 2 PVC recycling in the EU (source: Vinylplus progress report, 2014a)

EPS (the Netherlands)

The EPS (expanded polystyrene) that is released in the Netherlands as waste consists of two main streams: approximately two thirds packaging waste and one third insulation material. The period in which packaging

EPS is used is very short, probably often shorter than a year, whereas that of insulation materials in houses and building can be ten years or more. A great proportion of EPS from packaging is currently recycled, in particular for insulation applications in construction (Stybenex, 2013).

At the moment very little EPS insulation material is recycled; most of it is incinerated in incinerators. This is because of the relatively low waste volumes, the lack of a collection structure and the relatively high transport costs related to the low density. Because of the long life of EPS in insulation applications the large stocks of expanded polystyrene in houses and buildings will be gradually released as waste over the next few decades.

Recycling of contaminated PVC and EPS?
Hazardous substances are being successfully phased out and the recycling of PVC at least is on the increase. Is it a given that safety objectives and 'circular' objectives go together? Or is there some tension at the interface of the two? What, for example, are the potential recycling opportunities for HBCDD-containing insulation EPS that will be released in the future in large quantities during renovation and demolition work?

The starting point of the current EU Chemical Substances Policy is that (new) concentration limits for hazardous substances that are laid down in substances and/or product policy also apply to recyclate from old products in which these substances were permitted previously. The processing and reuse of contaminated plastic recyclate is therefore permitted only if derogated. Examples for various plastic - hazardous substance combinations are illustrated below in greater detail.

PVC - cadmium
Cadmium additives stabilise PVC. They make PVC better resistant to heat and weathering as a result of UV radiation. However, cadmium is carcinogenic and toxic for the aquatic environment and over the last few years has therefore no longer been used in the EU on the basis of voluntary agreements concluded with industry (see Figure 1). The European REACH legislation that was drawn up in 2006, laid down that Cd content in PVC products should not be higher than 0.01 percentage by weight. At the beginning of the 1990s this concentration limit had already been laid down in the predecessor to REACH, the Existing substances directive (1976/769/EEG). In 2011 the limit for recycled material in specific applications was raised to 0.1%. This provided possibilities for the recycling of PVC waste in specific applications for buildings, such as cable ducts, window frames, doors and gutters, and as an intermediate layer in pipes for non-drinking-water applications. If recycled PVC is used in these products, this has to be indicated using a specific label. This exception, a so-called derogation, will be reviewed in 2017.

PVC - lead
Lead too is a commonly used stabiliser in PVC. Thanks in part to legislation in individual EU member states regarding the use of lead-containing drinking-water pipes the European industry agreed on a voluntary basis that the use of lead as a stabiliser in PVC would be

banned as of 2015. In addition, the use of lead in electric and electronic equipment, packaging and new cars has also been legally regulated, see Table 1. This has resulted in a great reduction in the use of lead compounds in PVC, see Figure 1, and in the introduction of calcium-containing stabilisers as a replacement.

Since 2012 lead compounds that are used in PVC have been on the so-called candidate list of the REACH regulation. On the basis of the candidate list a substance can in the future be designated as an SVHC substance under Annex XIV of REACH. If that should happen, the maximum permissible lead content in new products will probably be 0.1 percentage by weight. In anticipation of this the European PVC sector warns of a potential future termination of the recycling of PVC. Tauw (Ooms and Cuperus, 2013) indicates in a study for the PVC sector that the biggest bottlenecks in recycling disappear if 1% lead is permitted in a content of 1% in PVC applications such as window profiles, floors and pipes (with the exception of drinking water pipes).

PVC - plasticisers
Soft PVC is soft as a result of the plasticisers that are added in percentages by weight that vary from 1 to 30%. Di-2-ethylhexyl phthalate (DEHP) was until recently the most commonly used plasticiser in soft PVC plastics. Because of the toxicity for reproduction DEHP was added to the candidate list of the REACH regulation as an SVHC in 2008. In 2011 DEHP was added to the so-called REACH authorisation list, Annex XIV. This means that as of 2015 the use of DEHP in PVC is banned in the EU, unless it is authorised for specific applications. In addition, DEHP is regulated by product legislation for toys, food packaging, cosmetics and electric and electronic equipment, see Table 1.

The above-mentioned legislation has now resulted in a great decrease in the use of DEHP (see Figure 1) and its replacement by other, safer plasticisers in PVC. In 2014 and 2015 two authorisations were granted for specific DEHP applications: the manufacture of rotor blades for plane engines and the production of solid propellants and engine fillings for missiles and tactical missiles respectively. There is also another decision-making procedure under way regarding the granting of authorisation for several other applications, including for the use of recycled soft PVC with DEHP as a plasticiser in the production of new articles.

Under REACH there is an exception to the requirement to obtain authorisation for DEHP when DEHP is used in mixtures containing a maximum of 0.3% and therefore in new products that are produced from these mixtures. At the moment there is no commercially viable process that can remove DEHP from PVC adequately. This means that the only legal route for contaminated soft PVC waste is that of incineration, possibly with the recovery of heat, or that of the high-temperature decomposition of PVC polymers into new raw material for the chemical industry. This is less favourable from an energy point of view than the direct recycling of PVC into new products.
Several European recycling companies have therefore requested authorisation to process collected soft PVC for use in, among other things, construction materials (exterior), floors, mats, shoe soles and

garden hoses. ECHA has advised the European Commission to grant authorisation for seven years.

EPS - HBCDD

EPS from packaging probably contains no hazardous substances and a lot of it is currently being recycled, mainly in insulation applications in the construction industry. Insulation EPS, used in the built environment, contains hexabromocyclododecane (HBCDD). This is a bromine-containing flame-retardant with a clear safety function: as a flame-retardant. However, it has recently been demonstrated as part of REACH that this substance is persistent, bioaccumulative and toxic (PBT), that it meets the POP criteria of the Stockholm Convention and the European POP Regulation, and is therefore dangerous to the environment. Within various legislative processes standardisation and phase out of HBCDD is on the agenda:

- In 2008 HBCDD was added to the candidate list as an SVHC under the REACH regulation. In 2011 HBCDD was added to the REACH authorisation list (Annex XIV). This means that HBCDD can be used until the "sunset date" of August 2015 and that its use after that date is permitted only if it is authorised by the European Commission. A considerable number of the market players in the EU have requested this authorisation for the use of HBCDD in insulation EPS. The authorisation has not yet been granted: ECHA[1] has recommended a transitional period of two years. Alternatives to HBCDD are available but the parties that have applied for the authorisation state that extra time is required for a smooth transition to these alternatives.
- In 2013 the Stockholm Convention on Persistent Organic Pollutants (POPs) decided to include HBCDD in Annex A of the Convention, aimed at elimination. This includes an exception for the application of HBCDD in insulation EPS. This exception is valid for five years.
- Decisions taken under the POP convention are adopted into the European POP Regulation and thus become legislation for EU countries. This process runs parallel to the authorisation of HBCDD under REACH. As part of this POP Regulation the HBCDD content above which waste is regarded as POP waste and needs to be processed in such a way that HBCDD is destroyed is being discussed. The current discussion is about content values in the range of from 0.01% to 0.1%. There is also a discussion about what unintended residual content may be present as an impurity in new products that are brought onto the market (including recyclate). The value proposed by the Commission for this was 0.001%. This proposal was rejected on 26 May 2015 by a majority of the member states; a new proposal of September 2015 is based on 0.01%. A decision has still to be taken about this.

Under both REACH and the POP convention (and the EU legislation based on this) there is clear, consistent guidance about the phasing-out of HBCDD from the economy, see Figure 1.

[1] The European Agency for Chemical Substances (ECHA) supports the European Commission in the enforcement of EU legislation regarding chemical substances.

Recycling of contaminated EPS?
Insulation EPS contains a HBCDD content of 0.7%. The still-experimental 'solvolyse' technology can potentially reduce this HBCDD content in EPS to approximately 1/100th of the original content. The market perspective for this technology will be greatly determined by the definitive concentration limit for the permissible residual content in recyclate. In the case of the value now proposed of 0.001% this market perspective is not favourable as this value is below the value that can be achieved using solvolyse.

From hazardous waste to approved raw material?
If a hazardous substance in recyclate is actually permitted to be processed into new products, as an exception, the question is how legislation relating to waste materials should be adapted in line with this. This can be summarised as follows.

First of all, the REACH and CLP regulations set requirements for communication in the chain regarding the environmental and health risks represented by substances. If this information chain is broken in the waste phase – for example because waste is supplied from unknown sources – the recyclate producer has to reascertain the contaminants and risks related to these substances, wherever necessary using measurements. It must also be made clear whether the material is ordinary waste or hazardous waste.

In general there are specific (administrative) rules and permit procedures under waste materials legislation for the processing, use and transport of waste materials. These rules remain formally valid until the waste status is explicitly, legally, removed.

This can be done using the so-called End of Waste (EoW) mechanism under the European Waste Framework Directive, article 6. From a legal point of view a waste substance becomes a raw material again if the EoW criteria are met.

European EoW criteria have been drawn up for metal scrap and collected glass. If there are no EoW criteria at EU level, a member state can draw these up itself. In the Netherlands they were recently drawn up for stony construction and demolition waste. For plastic waste the Commission has recently drawn up a criteria document, but this has not yet resulted in legislation concerning EoW criteria. There are no EoW criteria for plastic waste as yet for the Netherlands either.

The above-mentioned Commission document states that plastic recyclate can be given EoW status only if the original plastic waste does not need to be regarded as hazardous waste on the basis of the CLP and the POP regulation[2] and the recyclate is permitted on the market under the REACH regulation[3]. In practice this means for the cases that we are discussing in our study that the reuse of cadmium-containing plastic

[2] The Waste Framework Directive defines chemical waste but does so on the basis of the CLP and POP regulations..
[3] In 2008 the European Commission, in response to questions from Parliament, stated that recyclate can be brought onto the market as a substance, a mixture or an article (EC, 2008).

recyclate meets these criteria in specific applications and thus could be formally declared to be raw material. This also goes for authorised applications of DEHP-containing plastic recyclate, if the Commission and the member states make a positive decision about the submitted authorisation request.

The situation is different for the case of lead in PVC. In anticipation of possible new REACH legislation in which a maximum lead content of 0.1% may apply (SVHC status), the PVC sector states that a limit of 1% lead content is required to guarantee PVC recycling in construction materials to be continued. This value is well above the threshold value for hazardous waste of 0.1%. To make the recycling of lead-containing PVC waste possible, a REACH exception clause will be necessary. A parallel modification of the hazardous waste threshold value will be necessary if formal raw-material status is to be granted to lead-containing PVC waste.

These examples illustrate that it is legally possible to convert hazardous waste materials into raw materials but also that it can be complex.

Conclusions and recommendations
The case histories in this report outline the following picture.

The recycling of plastics that contain hazardous substances involves three types of legislation: for substances, for products and for waste. Each of these, understandably in view of its history, focuses primarily on its own domain. The characteristics are:

- The starting point of the substances legislation in REACH or the POP regulations, based on the CLP hazard classification, is that one single concentration limit (standard) applies to a substance, for all products. In principle no distinction is made between permissible contaminants in ‘virgin’ and recycled raw materials for new products.
- New hazardous substances, or the tightening-up of existing standards, can enter legislation via different routes, via international conventions, via specific product legislation or via the REACH regulation.
- The different legislation routes are each based on different risk assessment methods for hazardous substances. Thus, standards from different forms of legislation are not nessesarily the same.
- To obtain a formal ‘End of Waste’ status all the applicable legislation has to be complied with.

This complex combination results in practice in only temporary exceptions being made, per substance and application, so that plastics that contain historical contaminants can be recycled in order to reduce the consumption of primary raw materials.

Successful examples of this are the use of cadmium-containing recycled plastic in construction applications such as cable ducts, window frames and intermediate layers in new PVC pipes. It has been demonstrated that a broader standardisation is permissible because the risks for people and the environment remain limited; and because these products are reused wherever possible in the same product groups (‘closed loop’), as a result of which contaminants do not diffusely disappear into other products. A decision will have to made for lead in hard PVC as to whether the same exception situation is possible.

Legislation should encourage innovative purification techniques
HBCDD-containing insulation EPS will soon disappear from the European market as a result of legislation. However, it is still present in very large quantities in houses and buildings and over the next few decades it will be released gradually but in large quantities due to renovation and demolition.

The still-experimental Solvolyse process can purify HBCDD in EPS to 1% of the original amount used. However, this is insufficient to be regarded as permitted recyclate under the proposed modification to the POP regulation. The market perspective for this potential recycling technology is therefore decreasing: an illustration of the tension between the stimulation of recycling on the one hand and the reduction in the quantity of hazardous substances on the market.

Simplified policy to boost circularity?
The creation of some 'legal room to manoeuvre' for the safe recycling of plastics that contain hazardous substances is a response to the complex legislation concerning substances and products that was employed at an earlier stage.

The opposite approach that puts recycling and circularity at centre stage would be to ascertain with various stakeholders from the areas of substances, products and waste materials the specific applications in which recycling is safe for people and the environment. The primary assessment framework for the safe use would then be the exposure potential of specific applications. It could at the same time be made transparent what energy savings and what reduction in CO_2 emissions would be generated by the safe recycling into this kind of specific application compared with the increased exposure caused by the specific recycling applications if these were allowed onto the market.

This kind of approach requires a process in which the stakeholders who now act separately in substances, products and waste materials legislation sit down around the table together at an early stage. In this way a joint picture can be drawn and clarity can be created earlier about changes to legislation regarding a safe, circular economy.

A good example of this is the reuse of stony construction and demolition waste in the Netherlands. The environmentally safe use of this is determined only by the Decree on Soil Quality. This sets out the maximum permissible leaching of several contaminants from reused waste materials into the soil and groundwater. This simple, transparent policy framework provides clarity to the market and has resulted in a reuse percentage of 95%.

The conditions for this successful approach to increasing circularity are summarised in Figure 3 in a conceptual model (the 'sandwich') for optimum recycling. This translates (1) clear general policy conditions into (2) simple product criteria. For the (re)use of materials and products a (3) product-specific risk assessment is important that (4) is accepted by society. Last but not least (5) the collection of waste and its processing into raw material must of course be, or have the potential to be, economically feasible.

This kind of conceptual model can serve as a tool in the above-mentioned stakeholder process, as the different stakeholders provide an overview of the entire system from their own subareas. This can help with deciding in which direction solutions should be sought.

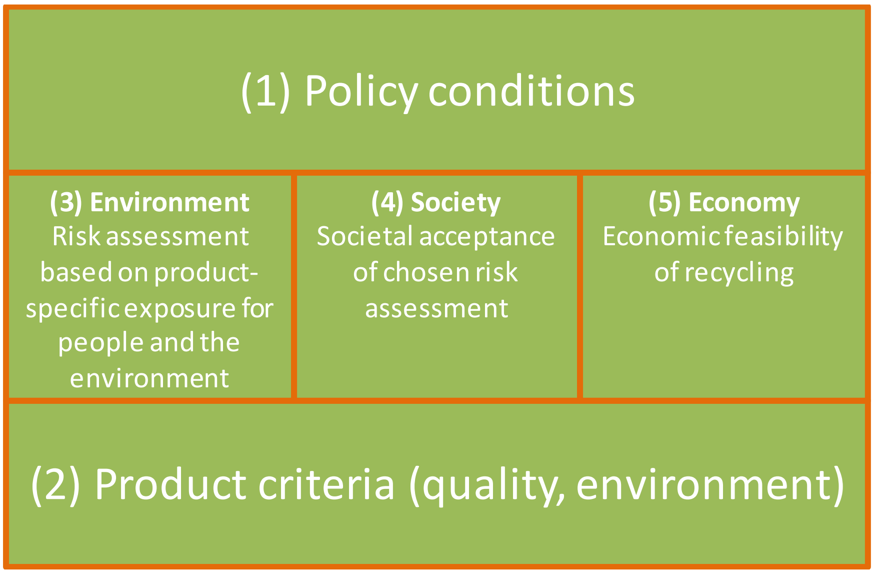

Figure 3 Illustration of the 'sandwich' for optimum recycling

1 Introduction

1.1 Background and objectives

Over the last five years there has been increasing interest at policy level in making the economy circular and therefore in recycling. In June 2013 the Secretary of State for Infrastructure and the Environment informed the Lower House about the programme 'Waste to Resource' (VANG). This programme is the Dutch implementation of the European programme that aims to bring about a raw-materials-efficient Europe: Roadmap to a Resource-Efficient Europe, COM (2011) 571.

Sustainability and the efforts to achieve a circular economy are major pillars of this policy. The main characteristics of a circular economy mentioned in the Letter to Parliament are:

- optimum use of raw materials
- no waste, no emissions
- sustainable use of sources.

One of the operational objectives mentioned by the Secretary of State in her letter is to focus the existing waste policy on the circular economy and innovation and to remove possible bottlenecks.

The production of materials such as iron, steel, glass, paper, aluminium and plastics is energy-intensive and contributes approximately 20% to global emissions of greenhouse gases such as CO_2 (Ecofys, 2013). Recycling of these materials reduces emissions of CO_2. Plastics are the least recycled of the above-mentioned materials: in Europe approximately 25% (Plastics Europe, 2015). So the European and Dutch policy on waste, 'resource efficiency' and the circular economy focuses on reusing plastics in the economy as much as possible for as long as possible.

However, plastics can contain additives such as heavy metals, plasticisers or flame-retardants. These are substances that have a clear function in the plastic but that are sometimes hazardous because they do not degrade, accumulate in the environment and are toxic or carcinogenic. These substances are labelled as being dangerous for the environment or 'Substances of Very High Concern' (SVHC).

The European chemical substances policy focuses on gradually removing these SVHC from the economy. On the one hand by no longer allowing these kinds of substances on the market and on the other hand through the controlled processing – for example in waste incinerators – of waste streams, such as plastics, in which these substances occur. However, the carbon in plastics is released as CO_2, and the production of new plastics also consumes energy and produces CO_2 emissions.

So it is a matter of finding the right balance between boosting recycling and reducing CO_2 emissions on the one hand and reducing the quantity of hazardous substances in the economy on the other. What does this balance look like when it comes to the reuse of waste plastics that contain hazardous substances?

This is the question tackled by this report. We look in greater detail at practices relating to two plastics, polyvinylchloride (PVC) and expanded polystyrene (EPS). These plastics contain four hazardous substances: cadmium and lead compounds as stabilisers in hard PVC, di-2-ethylhexyl phthalate (DEHP) as a plasticiser in soft PVC, and hexabromocyclododecane (HBCDD) as a flame-retardant in EPS.

In their lifecycle these plastics have to satisfy policy and legislation in the field of chemical substances, waste materials *and* products. Moreover, the policy field is dynamic, as over time new hazardous substances may be included in laws. Whereas new legislation on hazardous substances in plastics is a strong incentive for innovative, safe applications on the one hand, on the other hand it can give rise to uncertainty for recycling companies and the recyclate customers about the reuse of ‘old’ contaminated recyclate.

Against this background of complexity and uncertainty we will look at whether and how the policy works effectively and consistently in managing both objectives: that of the safety and that of the circular economy.

First of all we will discuss the main conclusions about the phasing-out of hazardous (SVHC) substances, then we will look at the trends in the recycling of PVC and EPS. Then we will take a look in greater detail at the interface of substances, products and waste materials legislation, and from this perspective we will make recommendations about the reuse of contaminated plastics.

1.2 Material and methods

We selected the cases by first of all compiling a list of substances that are included in annex XIV (requiring authorisation) and annex XVII (restrictions) of the REACH regulation and substances that are included in the European POP Regulation (EC 850/2004). On the basis of expert judgement substances were then selected that could possibly occur in articles and could therefore be a problem in waste processing/recycling. The list was then discussed with the managers of the waste materials database at the Department of Public Works and Water Management.

The plasticiser DEHP in PVC and the flame-retardant hexabromocyclododecane (HBCDD) in polystyrene (EPS) were chosen on the advice of policy officials at the Ministry of Infrastructure and the Environment. Both cases were current in 2014 because of the authorisation requests regarding DEHP and HBCDD under REACH and the proposals for an HBCDD concentration standard under the European POP regulation. For both cases practical experience within RIVM was used and relevant literature was collected. The literature search for DEHP and PVC revealed that the developments relating to cadmium and lead compounds in PVC were interesting and represented a useful addition to the information for DEHP. So cadmium and lead were also included in the description of the recycling of PVC.

1.3 Delimitation

Two topics that are relevant with regard to hazardous substances in plastics are not covered in this report:

- We do not look at the consequences of the waste status of plastic recyclate that contains hazardous substances with regard to the obligations relating to administration, permits (environmental law) and cross-border transport (EVOA). These consequences are particularly significant in the case of a 'hazardous waste' status.
- Authorisation under REACH can restrict or ban the entry onto the market of hazardous substances. Products imported from outside the EU ('Articles' in REACH terms) can however still contain increased concentrations of hazardous substances that are banned for European products. There is a duty to report this in REACH. Imports from outside the EU are not covered by this report.

2 Effectiveness of substances legislation

2.1 Policy and legislation

Table 2 provides an overview of the European policy that relates to the plastics and substances in this study. In the lifecycle of a product to waste and back to raw material a material has to comply with various laws:

- A substance as such, or in mixtures or articles, should comply with the safety requirements set by the REACH regulation. If a substance is included in the REACH Annex XVII as an SVHC, it is allowed on the European market only if the production is authorised or if a specific application is included in Annex XIV with restrictions.
- Other legislation that governs the permissible use of chemical substances in products are specific product guidelines for, for example, food packaging material, electronics and cars (see Table 2) and the European POP regulation.
- In the case of the reuse of waste the risks of the reuse or the recycled materials for people and the environment should be restricted (article 6.1.d, Waste Framework Directive (WFD)). The rules for the processing of hazardous waste are stricter than those for non-hazardous waste.
- The classification as hazardous waste is based for CMR substances on the principles of the Globally Harmonised System as implemented in Europe through Classification, Labelling and Packaging (CLP) regulation 2008/1272/EG. For so-called POP substances the classification as hazardous waste is based primarily on the POP regulation. This is set out in the Commission's decision 2014/955/EG. This applies in this report to, for example, HBCDD. The classification that is used in REACH for 'Substances of Very High Concern' (SVHCs) on the basis of CMR properties is also based on the CLP regulation.

Figure 4 illustrates the relationships between the various directives and regulations.

Table 2 European Regulations regarding hazardous substances in plastics (largely in accordance with COWI et al, 2013)

	Cadmium compounds	**Lead compounds**	**DEHP**	**HBCDD**
Substances	• REACH Annex XVII, list of restrictions • REACH Candidate List of SVHC (*) • Classification, Labelling and Packaging (CLP) Regulation (of hazardous substances) Annex VI	• REACH Annex XVII, list of restrictions • REACH Candidate List of SVHC (*) • REACH Annex XIV, list of authorizations • Classification, Labelling and Packaging (CLP) Regulation (of hazardous substances) Annex VI	• REACH Annex XVII, list of restrictions • REACH Candidate List of SVHC (*) • REACH Annex XIV, list of authorisations • Classification, Labelling and Packaging (CLP) Regulation (of hazardous substances) Annex VI	• REACH Annex XIV, list of authorisations • REACH Candidate List of SVHC (*) • POP Regulation (EC) No 850/2004 (**) • Classification, Labelling and Packaging (CLP) Regulation (of hazardous substances) Annex VI
Products	• Directive 2009/48/EC related to toy safety. • Directive 2005/90/EC on the marketing/use of certain dangerous substances and preparations • Directive 2002/72/EC relating to plastic materials in contact with food • Directive 2000/53/EC on End-of-Life Vehicles (ELV) • Directive 2011/65/EC on Restriction of Hazardous Substances (RoHS) • Directive 94/62/EC of 20 December 1994 on packaging and packaging	• Directive 2009/48/EC related to toy safety. • Directive 2005/90/EC on the marketing/use of certain dangerous substances and preparations • Directive 2002/72/EC relating to plastic materials in contact with food • Directive 2000/53/EC on End-of-Life Vehicles (ELV) • Directive 2011/65/EC on Restriction of Hazardous Substances (RoHS) • Directive 94/62/EC of 20 December 1994 on packaging and packaging	• Directive 2009/48/EC related to toy safety. • Directive 2005/90/EC and 2005/84/EC on the marketing and use of certain dangerous substances and preparations • Directive 93/42/EEC on medical devices • Directive 2002/72/EC relating to plastic materials in contact with food	• Directive 2002/72/EC relating to plastic materials in contact with food

	waste	waste		
Waste materials	• Directive 2008/98/EC on Waste, referring to CLP regulation and POP Regulation (EC) No 850/2004	• Directive 2008/98/EC on Waste, referring to CLP regulation and POP Regulation (EC) No 850/2004	• Directive 2008/98/EC on Waste, referring to CLP regulation and POP Regulation (EC) No 850/2004	• POP Regulation (in prep.) • Directive 2012/19/EU on electronic waste

(*) several lead compounds are already included in Annex XIV
(**) POPS: persistent organic pollutants.

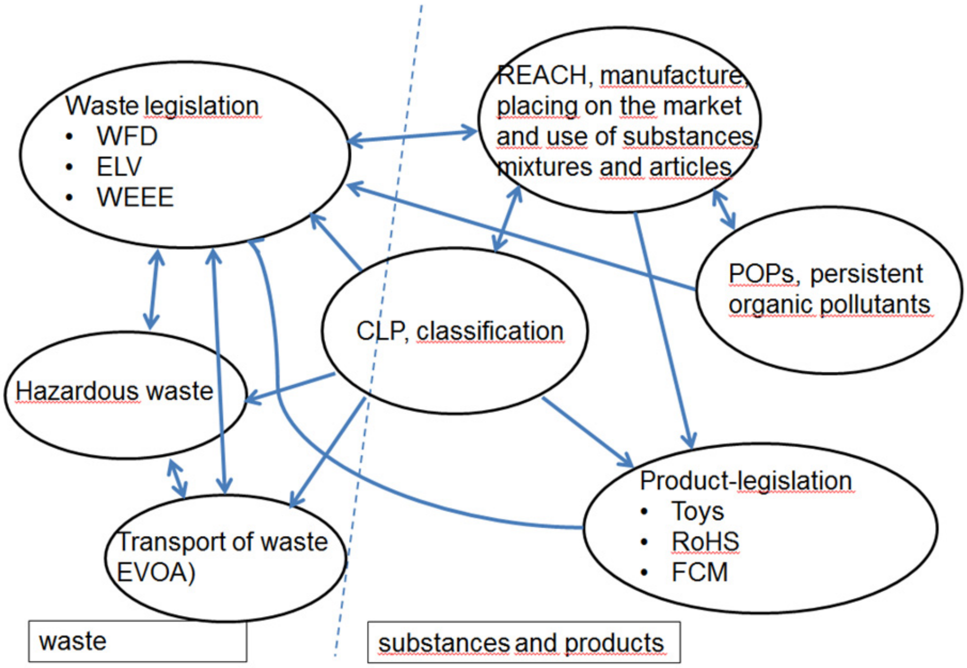

Figure 4 Simplified relationship between several European directives and regulations

2.2 Effectiveness of substances legislation

Legislation, sometimes in collaboration with voluntary agreements with industry (cadmium and lead), has resulted in a rapid, successful reduction in the hazardous substances in plastics that this report discusses, see Figure 1. HBCDD volumes are not yet falling, but manufacturers indicate that there are alternatives available. The 'authorisation' that they have requested – a permitted postponement period – within the REACH legislation should provide extra time that is required for a smooth transition to these alternatives.

The policy on hazardous substances is thus effectively resulting in a ban on these substances and thus effectively aims at innovative, new, safer additives to plastics. One example is the replacement of cadmium and lead compounds as stabilisers in plastics with calcium. This will make these plastics better recyclable in the future.

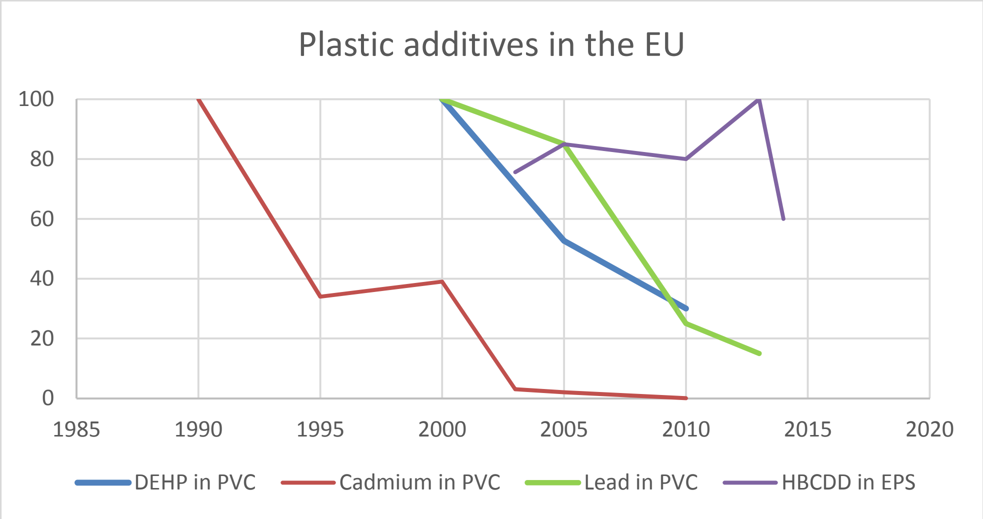

Figure 5 Additives of DEHP, cadmium and lead compounds to PVC in the EU, per substance scaled to 100

3 Recycling of PVC and EPS

3.1 PVC

Polyvinyl chloride, PVC, is one of the most commonly used plastics (Federatie NRK, Stuurgroep PVC & Ketenbeheer, 2005). PVC has several advantages over other plastics in that it is relatively resistant to the effects of the weather, it burns poorly, it copes well with chemicals and it is corrosion-resistant.

PVC is used a lot in pipes, insulation for electricity cables, clothing and furniture, buildings (roof panels, window frames) and flooring (see Gensch et al., 2014, among others).

Annual market demand in the EU for PVC, as a raw material for new products, is approximately 4.9 Mtonnes. Around 70% of this is as a raw material for products in building and construction work (pipes, window frames, floors, etc.). Other applications are packaging (8%), automotive and electronics (5%) and other applications such as boots, soles, etc. (18%) (Plastics Europe, 2013).

Two types of PVC can be distinguished: hard PVC and soft PVC. Plasticisers, such as phthalates, are used to obtain soft PVC. Phthalates are not used in hard PVC (Howick, 2009). In addition to plasticisers, stabilisers (including barium, zinc and lead) and flame-retardants are also used. These additives can caused problems in the waste stage. An overview of the applications and the percentages of plasticisers, stabilisers, fillers and other additives is given in EC (2000). The extent of recycling is determined by whether the PVC is post-consumer PVC or manufacturing scrap; the latter category is more uniform. A detailed description of PVC recycling can be found in Stringer & Johnston (2001).

PVC can be recycled in various ways. The PVC Steering Group describes the various methods of PVC recycling:

a. Mechanical recycling. This consists in reducing and processing PVC. Depending on the application mechanical recycling can take place up to ten times as it does not result in a shortening of the molecule chains.
b. Chemical recycling (feedstock recycling). The raw materials, in particular carbon, are recovered.
c. Energy recovery (incineration). This can be used for non-sortable contaminated plastics.
d. Landfilling. This can be used for non-recoverable products and residual materials.

PVC is recycled on a large scale and there are various application areas. A reuse rate of 40% is quoted for pipes, and percentages of between 65% and 100% for window frames (EC 2011). The “Mechanical Recycling of PVC Wastes” report by the European Commission (EC, 2000) describes in fairly great detail how the market for recycled PVC looks and what opportunities exist. Separate collection of specific PVC applications results in a high-quality recyclate that can be used for the same application. In the case of mixed collection and a larger variation in composition the recycling potential is lower and there is 'downcycling' (EC, 2000). This produces fewer high-quality products. For recycling the waste stream needs to be a certain minimum size and it helps if this is homogenous.

Figure 6 shows developments in the European recycling of PVC, split into hard and soft PVC. Recycling is on the increase and the PVC industry, united in the Vinylplus programme, states that it is on track to achieve the objective of 800,000 tonnes of PVC recycling in 2020.

The amount of PVC that is released as waste each year is unknown (to us). If we apply the ratio PVC / total plastics entering the market as new material each year in the EU to the (known) total amount of plastic waste that is released each year in the EU (25.2 Mtonnes), this gives an estimated 2.6 Mtonnes of PVC waste each year (Plastics Europe, 2013).

At the moment 0.45 Mtonnes of PVC waste are recycled. The goal of the PVC sector for 2020 is 0.8 Mtonnes (approx. 30%).

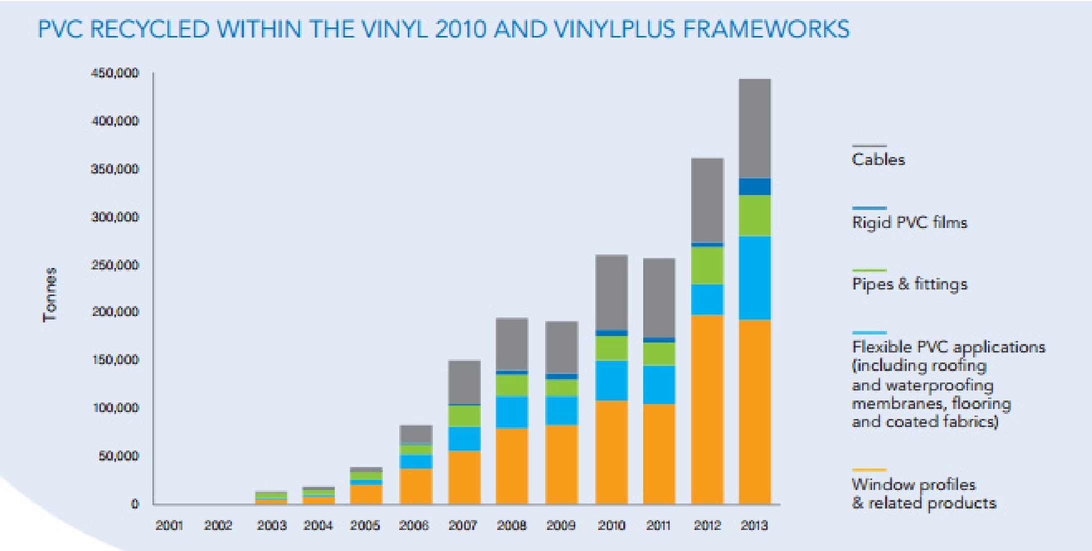

Figure 6 PVC recycling in the EU (source: Vinylplus, 2014a)

3.1.1 *Removal of hazardous substances from collected PVC*

Both US patents and research carried out in Japan indicate that there is interest in removing plasticisers from PVC waste. The method has been described in various laboratory studies (including Osada & Yoshioka, 2009; 2012). The methods that are described in these articles are not yet available commercially, but there are suggestions that they will possibly be available in 10-30 years. Other sources also indicate that extraction methods are not yet available on a large scale.

The VinylPlus website mentions several research projects that are not by definition focused on the removal of DEHP from PVC waste (VinylPlus, 2014b). The ReMapPlus project is also mentioned; this focuses on difficult-to-process soft PVC.

The Dutch PVCCLEAN project looks, with various partners, at the removal of the metals cadmium and lead from PVC for recycling (Jetten, verbal communication, 23 October 2014).

3.2 EPS

Expandable polystyrene beads are produced via the polymerisation of monostyrene, obtained from oil, and the addition of the expanding agent pentane and, if desired, a flame-retardant (HBCDD) (INTRON, 2010).

Extruded polystyrene (EPS) has been used for many decades in the food and packaging industry and in construction and civil engineering (groundworks, road construction and waterway construction sectors). In road construction it is used a lot in the laying of roads, and in residential and non-residential construction it is used in thermal and noise insulation. In INTRON (2010) it is reported that expanded polystyrene (EPS) is being used increasingly often as a banking material in civil engineering as it has several advantages over sand.

EPS is fairly inflammable. Flame-retardants are used in EPS for construction applications to prevent the material catching fire. The strict fire regulations for construction EPS do not apply to EPS that is used in the packaging industry (EUMEPS, 2011a). The flame-retardant HBCDD has been on the market since the 1960s and has been used by BASF since the end of the 1980s in EPS (Bilitewski et al., 2012).

3.2.1 Market demand

In Europe 70% of EPS is used in building and construction, 25% in packaging and 5% in other applications (PlasticsEurope, 2015b). Most of the 43.5 kilotonnes of EPS that were used in building and construction work in 2009 were used in floor, wall and roof insulation, and a small percentage was used in public works (Consultic, 2011).

3.2.2 Recycling

Approximately 30% of EPS is recycled in the Netherlands, see Table 3. Consultic (2011) reports that the Netherlands leads the way in this. The recycled EPS comes almost entirely from packaging. Approximately 50% of this packaging waste is recycled and approximately 50% is incinerated (with energy recovery), see Table 3. In the recycling process the EPS is shredded and added to the production process; it is possible to add 20% of shredded EPS to new EPS. This shredding and processing process can take place 5-7 times before the EPS has to be removed. Shredded EPS beads provides less insulation than new material (Duijve, 2012).

Table 3 Recycling of EPS from packaging and construction in the Netherlands in 2009 (according to Consultic, 2011)

NL 2009 EPS post-consumer waste	**Total Generation**			**Recovery in kt**				**Disposal**
	kg	kg/cap	%	Mech recycling as EPS	Mech recycling as EPS	Energy recovery	Total	kt
Packaging EPS	12.5	0.8	65.4%	5.3	0.7	5.2	11.2	1.3
Construction EPS	6.6	0.4	34.6%	0.4	0	4.9	5.3	1.3
Total	19.1	1.2	100%	5.7 30%	0.7 4%	10.1 53%	16.5 87%	2.6 13%

Consultic (2011) also reports that the recycled material comes mainly from the packaging of electronic goods. Most of it is recycled into EPS applications in construction, such as applications in foundations. The EPS that comes from construction mainly ends up in waste incinerators.

For Europe the EUMEPS (2014) website refers to three types of recycling:

- Recycling into new ‘insulation boards’, with up to 25% mixing with virgin material
- Recycling in non-foam applications such as clothes hangers, flower pots, garden benches and fence posts
- Mixing with cement for the production of light-weight concrete blocks.

Waste EPS, in contrast to waste PVC, is largely processed locally because of the volume/weight ratio (EUMEPS, 2011a). There are considerable differences between the European countries when it comes to recycling percentages (Consultic, 2011).

The removal of hazardous substances from collected EPS
The removal of brominated flame-retardants (BFRs) is regarded as a good way of making possible the recycling of polymers that contain BFRs. The British Waste & Resources Action Programme published a report in 2006 which stated: “Mechanical separation followed by a solvent-based process that removes brominated flame retardant additives from the BFR-containing polymers is likely to be a better environmental and commercial option for treatment of WEEE plastics than landfill, incineration with energy recovery or feedstock recycling.” (WRAP, 2006). The report delivers positive results: “A combination of the Creasolv and Centrevap processes, although more expensive in capital cost terms, has potential to provide the benefits of both process options, delivering finished polymer with very low levels of BFR content and essentially particle-free”. Although the report focuses on WEEE polymers, the starting point will also apply to EPS. The results have not yet, as far as is known, been used in practice.

The Fraunhofer Institute in Germany has ten years' experience with the removal of hazardous substances from polymers using solvolyse. Over the last few years this technique has also been used to remove HBCDD from polystyrene (BMBF, 2012). At the moment research is being carried out into whether this technique can be scaled up to an industrial scale for EPS.

4 Recycling of contaminated PVC and EPS?

Hazardous substances are being successfully phased out and the recycling of PVC at least is on the increase. Do safety objectives and circular objectives go together or is there a tension at the interface of the two? What, for example, are the potential recycling opportunities for HBCDD-containing insulation EPS that will be released in the future in large quantities during renovation and demolition work?

The starting point of the current policy is that (new) concentration limits for hazardous substances that are laid down in substances and/or product policy also apply to recyclate from old products in which these substances were permitted previously. The processing and reuse of contaminated plastic recyclate is therefore permitted only if derogated. Examples for various plastic - hazardous substance combinations are illustrated below in greater detail.

4.1 PVC - cadmium

Cadmium additives stabilise PVC. This makes PVC better resistant to heat and weathering as a result of UV radiation. However, cadmium is carcinogenic and toxic for the aquatic environment and over the last few years has therefore no longer been used in the EU on the basis of voluntary agreements with the industry (see Figure 1). The European REACH legislation that was drawn up in 2006, laid down that Cd content in PVC products should not be higher than 0.01 percentage by weight. In 2011 this limit for recycled material in specific applications was raised to 0.1%. This provided possibilities for the recycling of PVC waste in specific applications for buildings, such as cable ducts, window frames, doors and gutters and as an intermediate layer in pipes for non-drinking-water applications. If recycled PVC is used in these products, this has to be indicated using a specific label. This exception, a so-called derogation, will be reviewed in 2017.

4.1.1 Brussels policy process

In 2010 at the fifth meeting of the Competent Authorities for REACH and CLP (CARACAL) the proposal was discussed for a ban on cadmium compounds in PVC. The proposal aimed at a total ban on the use of cadmium compounds in PVC, except for certain PVC applications in which the use of cadmium-containing recycled PVC is permitted. This exception was granted on a temporary basis for reasons of it resulting in a more efficient use of resources (PVC recycling) and reduced CO_2 emissions. The proposal included among other things the use of recycled PVC in the inner layer of pipes where cadmium migration is limited and the risk of exposure is low. A workshop was held to discuss the effects and the possible risks to the environment of the use of recycled PVC. It appeared that several member states considered this a backward step. Questions were also asked about the removal of cadmium from PVC, the labelling of PVC that consists (in part) of recycled material and problems that could occur in the waste stage. As a result of the discussions provisions regarding recycled PVC were included in the REACH entry that regulates the use of cadmium and cadmium compounds (entry 23). This sets out, among other things, for what products the recycled PVC can be used, that the cadmium content should be less than 0.1%, and that this PVC should be labelled with the label "recovered PVC" (EC, 2010).

4.2 PVC - lead

Lead is also a commonly used stabiliser in PVC. Thanks in part to legislation in individual EU member states concerning the use of lead-containing drinking water pipes the European industry has agreed, on a voluntary basis, to ban the use of lead as a stabiliser in PVC from 2015. In addition, the use of lead in electric and electronic equipment, packaging and new cars is also regulated by law, see Table 2. This has resulted in a large decrease in the use of lead in PVC, see Figure 5, and in the introduction of calcium-containing stabilisers as replacements.

4.2.1 Brussels policy process

Since 2012 lead compounds that are used in PVC have been on the so-called candidate list of the REACH regulation. On the basis of the candidate list a substance can in the future be designated as an SVHC substance under Annex XIV of REACH. If this happens, the maximum permissible content of lead in new products will probably be 0.1 percentage by weight. In anticipation of this the European PVC sector is warning of a potential future termination of PVC recycling. Tauw (Ooms and Cuperus, 2013) indicates in a study carried out for the PVC sector that the main bottlenecks in recycling disappear if 1% lead is permitted in PVC applications such as window profiles, floors and pipes (except for drinking water pipes).

Various visions on lead as an SVHC substance

If a substance is suspected of potentially being an SVHC substance, the European Commission or a European member state can decide to draw up an annex XV dossier for this substance. This happened in 2012 for lead salts (Fatty acids, C16-18, lead salts). In the comments to the annex XV dossier for the designation of lead salts (Fatty acids, C16-18, lead salts) as SVHC and the "response to comments" of ECHA (ECHA, 2011) Germany advocates a wait-and-see approach before designating "Fatty acids, C16-18, lead salts" as being SVHC, and it prefers to wait for the results of the voluntary agreements with the European PVC sector rather than start a REACH procedure: "…Based on our current understanding of the authorisation process companies conducting recycling of lead-containing PVC may be obliged to acquire an authorisation for their recycling use. If recycled PVC was subject to authorisation, this would clearly contradict sustainability efforts. Similar considerations would also be relevant for lead battery recycling."

The same "response to comments" shows that Norway takes a completely different position to Germany: "The Norwegian CA supports that fatty acids, C16-18, lead salts should be identified as a substance of very high concern and should be included in the Candidate List."

4.3 PVC - plasticisers

Soft PVC is soft as a result of the plasticisers that are added to it, in percentages by weight that vary from 1 to 30%. Di-2-ethylhexyl phthalate (DEHP) was until recently the most commonly used plasticiser in soft PVC plastics. Because of its toxicity for reproduction DEHP was placed on the candidate list of the REACH regulation as an SVHC in 2008. In 2011 DEHP was included in the so-called authorisation list, Annex XIV, of REACH. The use of DEHP in PVC in the EU is therefore banned from 2015, unless this is authorised for specific situations. In addition, DEHP is regulated by product legislation for toys, food packaging, cosmetics, and electric and electronic equipment, see Table 2.

The above-mentioned legislation has now resulted in a great decrease in the use of DEHP (see Figure 15) and replacement by other, safer plasticisers in PVC. In 2014 and 2015 two authorisations were granted for specific DEHP applications: the manufacture of rotor blades for plane engines and the production of solid propellants and engine fillers for missiles and tactical missiles respectively. ECHA has advised the Commission to grant authorisation for the next four years to three large European DEHP producers (ECHA, 2015). The Commission must shortly make a decision about authorisation on the basis of this advice.

Under REACH the maximum permissible DEHP content in new products is 0.3 %[4]. At the moment there is no commercially viable process that can remove DEHP from PVC adequately. This means that the only legal route for contaminated soft PVC waste is that of incineration, possibly with the recovery of heat, or that of the high-temperature decomposition of PVC polymers into new raw material for the chemical industry. This is less favourable from an energy point of view than the direct recycling of PVC into new products.

Several European recycling companies have therefore requested authorisation to process collected soft PVC for use in, among other things, construction materials (exterior), floors, mats, shoe soles and garden hoses. ECHA has advised the European Commission to grant authorisation for this too for four years (see below).

4.3.1 *Brussels policy process*

In 2013 VINYLOOP FERRARA S.p.A., Stena Recycling AB and Plastic Planet srl submitted two authorisation requests for the recycling of PVC that contains DEHP. These authorisation requests concerned:

- formulation of recycled soft PVC containing DEHP in compounds and dry blends
- industrial use of recycled soft PVC containing DEHP in polymer processing by calandering, extrusion, compression and injection moulding to produce PVC articles

See ECHA (2014a) and for details ECHA (2014b).

The request by Vinyloop cs states that DEHP no longer fulfils a technical function (plasticiser) but rather that it occurs as an undesired impurity in the collected waste and thus ends up in the recyclate. It also states: "Nevertheless, the limited presence of DEHP in the recyclate may

[4] the 0.3% applies as DEHP is classified as 1B reprotoxic (CLP Regulation). For carcinogenic and mutagenic substances the threshold is 0.1%.

facilitate its processing into new PVC articles by reducing the amount of pure (or ‘virgin’) DEHP or other plasticizers that can be added to the compounds before new flexible PVC articles are produced.” ECHA (2014a). There were various comments on this in the consultation (ECHA, 2014c). ECHA advised the Commission to grant authorisation for the next seven years to three European DEHP recyclers (ECHA, 2015). The Commission must shortly make a decision about authorisation on the basis of this advice.

> Restrictions can be imposed on the use of certain substances on the basis of other regulations in addition to REACH. In 2013/2014 the Austrian UBA drew up a document on the use of PVC in electric and electronic equipment and the release of DEHP during the recycling of this PVC for a review of the directive relating to restrictions on the use of certain hazardous substances in electric and electronic equipment (RoHS) (Austrian UBA, 2014). The UBA held two meetings with Plastics Europe about the recycling of soft PVC, DEHP authorisation, and the exposure to DEHP that is released at plastic recyclers in the light of the planned recycling authorisation under REACH for DEHP in recyclate.
>
> The UBA expected that, on the basis of legislation on the use of DEHP, the opportunities for PVC recycling would be restricted because of the fact that recycled plastic PVC is used mainly for “low-value articles” such as shoe soles and (garden) hoses and that the restricted opportunities for recycling and the formation of considerable quantities of hazardous waste would have a negative impact on waste management. The Austrian UBA proposes a maximum DEHP concentration for Electric and Electronic Equipment (EEE) of 0.1%, which will result in significantly lower risks (Austrian UBA, 2014). The current amount of DEHP in EEE is between 5% and 10%.
>
> Following the publication of the Austrian UBA report Oeko-Institut (Gensch et al 2014) drew up a document about ‘restricted substances” under RoHS2. This document concluded that a restriction on PVC, or on the various additives, could have an impact on PVC recycling opportunities. As a result of this it was stated that substance assessments in the future should take into account the effects on recycling.

4.4 EPS - HBCDD

HBCDD is a bromine-containing substance with a clear safety function: as a flame-retardant. However, it has recently been demonstrated that this substance is persistent, bioaccumulative and toxic (PBT) and is therefore dangerous to the environment.

EPS from packaging in principle contains no HBCDD and large amounts of it are currently recycled, mainly in applications in the construction industry such as insulation material.

Insulation EPS, used in the built environment, contains HBCDD in percentages of from 0.7% to 3% (UNEP, 2010). Other applications in which 0.5-1% of HBCDD can occur are: EPS fillings in beanbags, 'health mattresses' and similar products (Tohka & Zevenhoven, 2001). Various legislation projects are underway to standardise and phase out HBCDD.

4.4.1 *Brussels and the international policy process*

In 2008 HBCDD was placed on the SVHC candidate list under the REACH regulation. In 2011 HBCDD was added to the REACH authorisation list (Annex XIV). This means that HBCDD can be used until the "sunset date" of August 2015 and its use after that is still permitted if it is authorised by the European Commission. Many of the market players in the EU have applied for this authorisation for the use of HBCDD in insulation EPS. The authorisation has not yet been granted: ECHA has recommended a transition period of two years. Alternatives for HBCDD are available but the parties that have applied for authorisation state that extra time is needed for a smooth transition to these alternatives[5].

In 2013 the Stockholm Convention on Persistent Organic Pollutants (POPs) decided to include HBCDD in the Annex A of the Convention, aimed at elimination. This includes an exception for HBCDD in insulation EPS. This exception is valid for five years.

Decisions taken under the POP convention are adopted into the European POP regulation and thus become legislation for the EU countries. This process runs parallel to the authorisation of HBCDD under REACH. As part of this POP regulation discussions are currently taking place about the HBCDD content above which waste is regarded as POP waste and has to be processed in such a way that HBCDD is destroyed. The current discussion is about contents in the range of from 0.01% to 0.1%. There is also a discussion about what unintended residual content may be present as an impurity in new products that are brought onto the market (including recyclate). The value proposed by the Commission for this was 0.001%. This proposal was rejected on 26 May 2015 by a majority of the member states; there is as yet no new proposal.

So under both REACH and the POP convention (and resulting EU legislation) there is clear, consistent guidance about the phasing-out of HBCDD from the economy, see Figure 5.

4.4.2 *Recycling of contaminated EPS?*

Duijve (2012) states that the presence of the flame-retardant HBCDD is a major obstacle to EPS recycling. This also applies to other bromine flame-retardants in polymers (Kemmlein et al., 2008). In view of the amount of insulation material used worldwide, there is still a huge amount present in the economy. Tohka & Zevenhoven (2001) even state that the presence of flame-retardants is one of the most important factors hampering the recycling of polymers.

The removal of brominated flame-retardants (BFRs) is regarded as a good way of making possible the recycling of polymers that contain BFRs. The British Waste & Resources Action Programme published a report in 2006 which stated: "Mechanical separation followed by a

[5] http://www.reachcentrum.eu/tags.html?tag_title=Authorisation.

solvent-based process that removes brominated flame retardant additives from the BFR-containing polymers is likely to be a better environmental and commercial option for treatment of WEEE plastics than landfill, incineration with energy recovery or feedstock recycling." (WRAP, 2006). The report delivers positive results: "A combination of the Creasolv and Centrevap processes, although more expensive in capital cost terms, has potential to provide the benefits of both process options, delivering finished polymer with very low levels of BFR content and essentially particle-free". Although the report focuses on WEEE polymers, the starting point will also apply to EPS. The results have not yet, as far as is known, been used in practice.

Insulation EPS contains HBCDD contents of 0.7%. The still-experimental 'solvolyse' technology can potentially reduce this HBCDD content in EPS to approximately 1/100th of the original content. The market perspective for this technology will be greatly determined by the definitive concentration limit for the permissible residual content in recyclate. In the case of the value now proposed of 0.001% this market perspective is not favourable per se.

5 From hazardous waste to approved raw material?

If a hazardous substance in recyclate is actually permitted to be processed into new products as an exception, the question is how legislation relating to waste materials should be adapted in line with this. This can be summarised as follows.

5.1 Reach and End-of-Waste Criteria

First of all, the REACH and CLP regulations set communication requirements in the chain regarding the environmental and health risks represented by substances. If this information chain is broken in the waste stage – for example because waste is supplied from unknown sources – the recyclate producer has to reascertain the contaminants and the risks related to these substances, wherever necessary using measurements. It should also be made clear whether it is ordinary waste or hazardous waste.

Measuring contaminants
For many substances it is technically possible to ascertain whether there are certain substances in the supplied materials and whether the products to be supplied meet the specifications. Techniques that are often mentioned are:

- X-ray fluorescence (XRF) screening
- Gas chromatography mass spectrometry (GCMS) screening
- GCMS Quantitative analysis

The first two can be used to screen whether certain substances or elements occur in the material. However, they are not quantitative and XRF is restricted to elements. XRF can, for example, demonstrate that bromine (Br) is present in the plastic in question but not in what form. From a legal point of view this has consequences: some bromine compounds are banned, whereas others are not.
A quantitative analysis carried out using GCMS can provide an impression of the concentrations. The problem is that this technique requires sophisticated sampling and a well-equipped laboratory and does not provide a result immediately. This means that it takes a few days for samples to be reprocessed and analysed.

In general there are specific (administrative) rules and permit procedures under waste materials legislation for the processing, use and transport of waste materials. These rules continue to formally apply until a waste stream has had the predicate waste explicitly, legally, removed.

This can be done via the so-called End of Waste (EoW) mechanism under the European Waste Framework Directive, article 6. From a legal point of view a waste substance becomes a raw material again if the EoW criteria are met.

European EoW criteria have been drawn up for metal scrap and collected glass cullet. If there are no EoW criteria at EU level, a member state can draw these up itself. In the Netherlands they were recently drawn up for stony construction and demolition waste. For plastic waste the

Commission has recently drawn up a criteria document, but this has not yet resulted in legislation concerning EoW criteria. These criteria do not yet exist for the Netherlands either.

The above-mentioned Commission document states that plastic recyclate can be given EoW status only if the original plastic waste has not been designated as hazardous waste on the basis of the CLP and the POP regulation[6] or, if this is the case, the processing method is recognised under the Basel Convention and the recyclate is permitted on the market under the REACH regulation[7]. In practice this means for the cases that we are discussing in our study that the reuse of cadmium-containing plastic recyclate meets these criteria in specific applications and thus could be formally declared to be raw material. This also goes for authorised applications of DEHP-containing plastic recyclate, if the Commission and the member states make a positive decision about the submitted authorisation request.

The situation is different for the case of lead in PVC. In anticipation of possible new REACH legislation in which a maximum lead content of 0.1% may apply (SVHC status), the PVC sector states that a limit of 1% lead content is required to guarantee PVC recycling in construction materials. This value is well above the valid threshold value for hazardous waste of 0.1%. To make the recycling of lead-containing PVC waste possible, a REACH exception clause will be necessary. A parallel modification of the hazardous waste threshold value will be necessary to be able to grant lead-containing PVC waste a formal raw materials status.

These examples illustrate that it is legally possible to convert hazardous waste materials into raw materials but also that it can be complex.

5.2 Signals in practice

The European Commission (EC, 2013) notes in its memorandum for CARACAL 12 about DEHP recycling: "Article 3(17) of the WFD sets out that recycling means any recovery operation by which waste materials are reprocessed into products, materials or substances (please note that REACH covers in its scope substances, mixtures and articles), whether for the original or other purposes. Recycling processes thus defined do not mean that the output material will automatically not be waste". It also states: "REACH is a piece of legislation applicable to products, therefore substances, mixtures and articles subject to a recycling process will only cease to be waste if they also comply with REACH requirements."

The European Commission also argues in the document that, if there are no EoW criteria, then the supply of pellets, powder etc. by a recycler to a plastic converter is still waste. The plastic converter is then regarded as a waste processer. So putting recyclate onto the market as waste is regarded as one of the possibilities. Recyclate can, according to the

[6] The Waste Framework Directive defines chemical waste but does this on the basis of he CLP and POP regulations.
[7] In 2008 the European Commission stated, in response to questions from parliament, that both recyclate and substances, as well as mixtures and articles, can be brought onto the market (EC, 2008).

European Commission, also be brought onto the market as a substance, as a mixture or as an article (EC, 2008).

The reaction of the UEAPME, the European umbrella organisation for small and medium-sized enterprises (SMEs), to this was that most plastic converters do not receive the material as waste and do not have a waste permit. UEAPME states that compliance with REACH (authorisation) or waste legislation (hazardous waste) represents a considerable administrative burden (EC, 2013).

Results of the European Plastic Zero project indicate that many stakeholders assume that it is easier to regard plastic as waste than to bring it onto the market as a new product because of the REACH obligations. Plastic Zero states that compliance with the obligation to provide information to the chain about the effects on people and the environment is regarded as a 'heavy administrative burden' (Plastic Zero, 2013). Although the effects on people and the environment are included in the objectives of the Waste Framework Directive (WFD), the WFD does not include a clear obligation to provide information to customers. There is an obligation to provide information to the European Commission concerning the classification of the waste. Article 7.2 of the WFD states that a member state should inform the Commission immediately if a waste substance is designated as hazardous waste. Classification under the WFD refers to appendix III of the directive and then to the old CLP directive. The classification as hazardous is basically the same as that which is adopted in REACH.

VinylPlus, the umbrella organisation for PVC manufacturers, stabiliser and plasticiser manufacturers and plastic converters, states that if plastic converters receive material that is labelled as waste, they should comply with the waste legislation with the associated permits and accounts. Thus, they will transfer buying only virgin material, which deals with the above-mentioned problem (obtaining a waste permit). Moreover, there will be few plastic converters who want to switch from manufacturer to waste processer because of image problems.

6 Conclusions and recommendations

6.1 Picture based on the case histories in this report

The recycling of plastics that contain hazardous substances involves three types of legislation: for substances, for products and for waste. Each of these, understandably in view of their history, focuses primarily on its own domain. The characteristics are:

- The starting point of the substances legislation in REACH or the POP regulation, based on the CLP hazard classification, is that one single concentration limit (standard) applies to a substance, for all products. In principle no distinction is made between permissible contaminants in 'virgin' and recycled raw materials for new products.
- New hazardous substances, or the tightening-up of existing standards, can enter legislation via different routes, via international conventions, via specific product legislation or via the REACH regulation.
- The different legislation routes are each based on different risk assessment methods for hazardous substances. Thus, standards from different forms of legislation are not necessarily the same.
- To obtain a formal 'End of Waste' status all the applicable legislation has to be complied with.

This complex combination results in only temporary exceptions[8] being made, per substance and application, so that plastics that contain historical contaminants can be recycled in order to reduce the consumption of primary raw materials.

Successful examples of this are the use of cadmium-containing recycled plastic in construction applications such as cable ducts, window frames and intermediate layers in new PVC pipes. It has been demonstrated that a broader standardisation is permissible because the risks for people and the environment remain limited, including for the reason that these products are reused wherever possible in the same product groups ('closed loop'), as a result of which contaminants do not diffusely disappear into other products. A decision will has to be made for lead in hard PVC as to whether the same exception situation is possible.

[8] The guideline under REACH refers to periods of 4, 7 and 12 years; under the Stockholm Convention an exception has been negotiated for recycling of the POP-BDEs added in 2009 until at the latest 2030, on condition that the phasing-out of these substances is evaluated every four years.

Striving for product quality – some opinions from the field
Under the Construction Products Regulation (CPR), as well as under other legislation (refer, for example, to article 6c of the WFD), knowledge of product quality is a requirement, and this includes the presence of hazardous substances. Plastics recyclers often lack knowledge of the composition of the material to be recycled and the material to be sold (refer, for example, to Rietdijk, 2008). To meet the various types of legislation, as well as for reasons of product quality, it is necessary to have a clear idea of what exactly is in the recyclate. Some parties recognise the importance of technical specifications and good quality control (VinylPlus, 2014a), whereas other parties are reluctant (EERA, 2013). The German Wirtschaftsvereinigung Kunststoff (WVK, 2012) states in its comment on the document about End-of-Waste criteria for plastic waste drawn up by JRC (JRC-IPTS, 2014) that product quality should be regarded as the most important deciding factor. However, it advocates for not too detailed rules (WVK, 2012). In 2009 the UK Environment Agency drew up the quality protocol 'Non-packaging plastics. End-of-waste criteria for the manufacture of secondary raw materials from waste non-packaging plastics', which describes the stages from waste to secondary raw material. The quality of the new material is an important factor in this (UK-EA, 2009). To summarise, knowledge of the composition of the recyclate and product quality play an important role in recycling.

6.2 Legislation should encourage innovative purification techniques

HBCDD-containing insulation EPS will soon disappear from the European market as a result of legislation. However, it is still present in very large quantities in houses and buildings and over the next few decades it will be released gradually but in large quantities due to renovation and demolition.

The still-experimental Solvolyse process can purify HBCDD in EPS to 1% of the original contaminant. However, this is insufficient to be regarded as permitted recyclate under the proposed modification to the POP regulation. The market perspective for this potential recycling technology is therefore decreasing: an illustration of the tension between the stimulation of recycling on the one hand and the reduction in the quantity of hazardous substances on the market.

6.3 Simplified policy to boost circularity?

The creation of legal room to manoeuvre for the safe recycling of plastics that contain hazardous substance was employed at an earlier stage.

An approach that puts recycling and circularity at centre stage would be to ascertain with various stakeholders from the areas of substances, products and waste materials the specific applications in which recycling is safe for people and the environment. The primary assessment framework for the safe use would then be the exposure risk from specific applications. It could at the same time be made transparent what reduction in CO_2 emissions would be generated by the safe recycling into this kind of specific application compared with its definitive destruction. This can be balanced against the increased amount of

contaminant that would be allowed onto the market in these specific applications.
This kind of approach requires a process in which the stakeholders who now act separately in substances, products and waste materials legislation sit down around the table together at an early stage. In this way a joint picture can be drawn and clarity can be created at an earlier stage about changes to legislation for a safe, circular economy.

A good example of this is the reuse of stony construction and demolition waste in the Netherlands. The environmentally safe use of this is determined only by the Decree on Soil Quality. This sets out the maximum permissible leaching of several contaminants from reused waste materials into the soil and groundwater. This simple, transparent policy framework provides clarity to the market and has resulted in a reuse percentage of 95%.

The conditions for this successful approach to increasing circularity are summarised Figure 3 in a conceptual model (the 'sandwich') for optimum recycling. This translates (1) clear general policy conditions into (2) simple product criteria. For the (re)use of materials and products a (3) product-specific risk assessment is important that (4) is accepted by society. Last but not least (5) the collection of waste and its processing into raw material must of course be, or have the potential to be, economically feasible.

This kind of conceptual model can serve as a tool in the above-mentioned stakeholder process, as the different stakeholders provide an overview of the entire system from their own subareas. This can help with deciding in which direction solutions should be sought.

The role of the government is largely focused on the policy conditions. The two cases demonstrate that, if solutions are to be found, attention should be devoted to both waste processing and to authorisation for new (recycled) materials. Examples taken from the two cases in question in which solutions are sought are:

a. The sandwich application of PVC pipes where recycled material is processed in the inner layer and where the material is labelled. Points of attention here are:
    1. the closed loop (from pipe to pipe)
    2. the temporary nature of the application
    3. the evaluation requirements regarding exposure
    4. the labelling of the pipes that contain recycled material so that this can be recognised in the waste stage.
b. The use of EPS for recycling, with a study of whether the proposed limits could be restrictive for waste processing or for bringing new materials onto the market. Points of attention here are:
    1. the size of the stream and the feasibility of the processing techniques
    2. limits for hazardous waste and thus whether the material comes under the Basel Convention (limiting of processing methods)

3. limits on the use of new materials that could form a restriction for bringing the recycled material onto the market (exposure).

The examples demonstrate that solutions are to a certain extent substance-specific and case-specific. For the Ministry of Infrastructure and Environment the following points are important for its stance and for any facilitating of these solutions:

a. having an idea of the size of the material streams concerned
b. being aware of the developments in waste processing and the additives in the waste concerned
c. being aware of the stakeholders involved and their interests
d. having various management bodies take action regarding dossiers such as these and taking into account the sustainable processing of raw materials and the exposure for people and the environment
e. disseminating this kind of approach internationally.

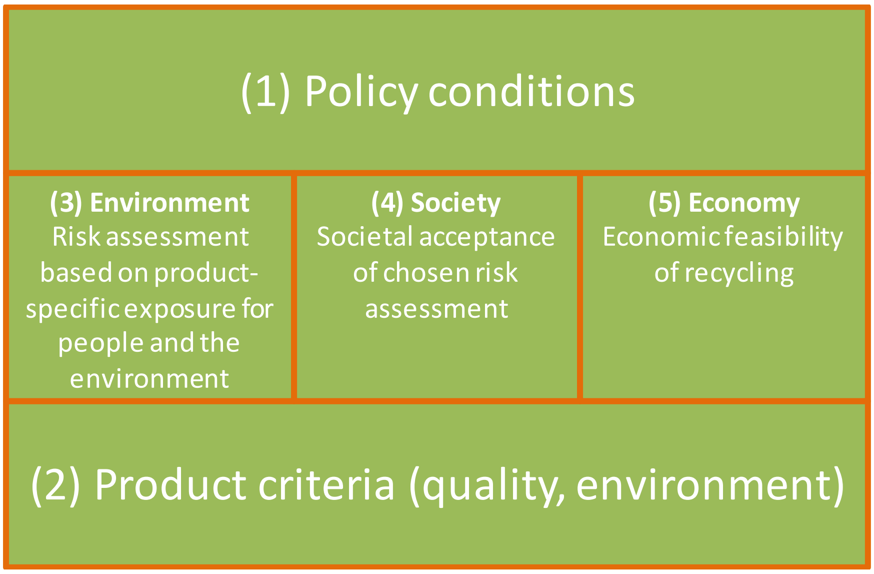

Figure 7 Illustration of the 'sandwich' for optimum recycling

Literature

- Austrian UBA. (2014). Study for the review of the list of restricted substances under RoHS2. Final report. Reference: ENV.C.2/ETU/2012/0021. http://www.umweltbundesamt.at/rohs2
- Bilitewski, B., R. Darbra, D. Barceló (2012). Handbook in Environmental Chemistry volume 18. Global Risk-Based Management of Chemical Additives I: Production, usage and environmental occurance. Volume 1. Berlin, Heidelberg, Springer Verlag
- BMBF (2012). Bundesministerium für Bildung und Forschung (BMBF). Reststoffe aus Shredderrückständen als Quelle hochwertiger Kunststoffprodukte (Poly-Ressource). http://www.creacycle.de/images/stories/2012.04_kmui-projektblaetter_poly-ressource.pdf
- Consultic (2011). Post-Consumer EPS Waste Generation and Management in European Countries 2009 EPS Packaging waste EPS Construction waste. Alzenau, Germany, Consultic.
- Cowi and Danish technology Institute (2013) Hazardous substances in plastic materials. http://miljodirektoratet.no/old/klif/publikasjoner/3017/ta3017.pdf
- Duijve M. (2012). Comparative assessment of insulating materials on technical, environmental and health aspects for application in building renovation to the Passive house level. University Utrecht, Master Thesis Energy science.
- EC (2000). Mechanical recycling of PVC. Study for DG XI of the European Commission.
- EC (2008). Parliamentary questions. Answer given by Mr Verheugen on behalf of the Commission. OJ C 291 13/11/2008. http://www.europarl.europa.eu/sides/getAllAnswers.do?reference=E-2008-0082&language=NL
- EC (2010). DRAFT SUMMARY RECORD. 5th Meeting of Competent Authorities for REACH and CLP 15-16-17 June 2010. http://ec.europa.eu/enterprise/sectors/chemicals/files/caracal/minutes-100615-17_en.pdf en http://ec.europa.eu/enterprise/sectors/chemicals/reach/caracal/index_en.htm
- EC (2011). COMMISSION STAFF WORKING DOCUMENT. IMPACT ASSESSMENT. Accompanying document to the COMMISSION REGULATION (EU) Amending Regulation (EC) No 1907/2006 of the European Parliament and of the Council on the Registration, Evaluation, Authorisation and restriction of Chemicals (REACH) as regards Annex XVII (Cadmium). SEC(2011) 633 final.
- EC (2013). Recycling and REACH. 12th Meeting of Competent Authorities for REACH and CLP, 13 - 14 March 2013. Doc. CA/28/2013. http://ec.europa.eu/enterprise/sectors/chemicals/reach/caracal/index_en.htm
- ECHA (2011). COMMENTS ON AN ANNEX XV DOSSIER FOR IDENTIFICATION OF A SUBSTANCE AS SVHC AND RESPONSES TO THESE COMMENTS. rcom_fatty_acids_c16-18_lead_salts_en. http://echa.europa.eu/nl/candidate-list-table/-/substance-

rev/2393/term http://echa.europa.eu/documents/10162/fc558666-f84e-4aa5-9eb1-aa1fd3a4cdc1

- ECHA (2014a). Adopted opinions and previous consultations on applications for authorization. http://echa.europa.eu/nl/addressing-chemicals-of-concern/authorisation/applications-for-authorisation-previous-consultations
- ECHA (2014b). Adopted opinions and previous consultations on applications for authorization. Substance details. http://echa.europa.eu/nl/addressing-chemicals-of-concern/authorisation/applications-for-authorisation-previous-consultations/-/substance/4804/search/+/term
- ECHA, (2014c): Comments on public consultation 0008-02. http://echa.europa.eu/nl/addressing-chemicals-of-concern/authorisation/applications-for-authorisation/comments-public-consultation-0008-02
- ECHA (2015). Adopted opinions and previous consultations on applications for authorization. http://echa.europa.eu/addressing-chemicals-of-concern/authorisation/applications-for-authorisation-previous-consultations
- Ecofys(2013) World GHG emissions flow chart 2010. http://www.ecofys.com/files/files/asn-ecofys-2013-world-ghg-emissions-flow-chart-2010.pdf
- EERA (2013). EERA position paper on sampling and analysis of WEEE plastics. Arnhem, EERA. http://www.eera-recyclers.com/news/eera-position-paper-sampling-and-analyses-weee-plastics
- EUMEPS (2011a). Life Cycle Assessment of the Industrial Use of Expanded Polystyrene Packaging in Europe. Case Study: Comparison of Three Fishbox solutions. http://www.fishboxes.info/wp-content/uploads/2012/04/EUMEPS_report_PwC_112211.pdf
- EUMEPS (2014). Recycling. http://www.eumeps.org/recycling_4499.html
- Federatie NRK, Stuurgroep PVC & Ketenbeheer. (2005). PVC. Feiten en policy. Leidschendam, NRK. http://www.pvcinfo.nl/download/PVC%20Feiten%20en%20Policy.pdf
- Gensch, C.O., Y. Baron, M. Blepp, D. Bunke, K. Monch. (2014). Study for the Review of the List of Restricted Substances under RoHS 2. Analysis of Impacts from a Possible Restriction of Several New Substances under RoHS 2. http://www.oeko.de/publikationen/download/2046/2014-627-en.pdf/.
- INTRON (2010). Updata levenscyclusanalyse (LCA) van Geoblock. "GEOBLOCK" scoort als licht ophoogmateriaal beter ten opzichte dan de zandvariant en is hiermee een duurzame oplossing. Sittard, INTRON. http://www.geoblock.nl/files/CROW-2010-CROW%20infradagen-PositionPaper%20GEOBLOCK-LCA%20Update%202010.pdf
- JRC-IPTS (2014). End-of-waste criteria for waste plastic conversion. Technical proposals. http://susproc.jrc.ec.europa.eu/activities/waste/documents/2014-JRC91637_ed2015.pdf
- Kemmlein, S., D. Herzke, J.R. Law (2009). Brominated flame retardants in the European chemicals policy of REACH—Regulation and determination in materials. J. Chromatogr A 1216(3):320-333.

- Ooms, J. and J.G. Cuperus. (2013). Impact of lead restrictions on the recycling of PVC. Deventer, The Netherlands, Tauw bv.
- Osada, F. and T. Yoshioka. (2009). Dechlorination of polyvinyl chloride in NaOH/ethylene glycol solution by microwave heating. J Mater Cycles Waste Manag (2009) 11:19–22.
- Osada, F. and T. Yoshioka. (2012). Dechlorination of Polyvinyl Chloride in NaOH and NaOH/Ethylene Glycol Solution by Microwave Heating. In: W. Cao (2012). The Development and Application of Microwave Heating, Chapter 6. http://www.intechopen.com/books/the-development-and-application-of-microwave-heating/dechlorination-of-polyvinyl-chloride-in-naoh-and-naoh-ethylene-glycol-solution-by-microwave-heating
- Plastics Europe (2013). Plastics the facts – 2013. Brussels Plastics Europe. http://www.plasticseurope.org/Document/plastics-the-facts-2013.aspx (data afgeleid uit figuur 5 en 6 en figuur 8).
- Plastics Europe (2015b). Expanded polystyrene (EPS). http://www.plasticseurope.org/what-is-plastic/types-of-plastics-11148/expanded-polystyrene.aspx
- Plastics Europe (2015). Plastics the facts – 2014/15 (data afgeleid uit figuur 5 en 6).
- Plastic Zero (2013). Plastic Zero Public Private Cooperations for avoiding plastics as a waste. Action 4.1. Market conditions for market recycling. LIFE10 ENV/DK/098. http://www.plastic-zero.com/media/30825/action_4_1_market_for_recycled_polymers_final_report.pdf
- Rietdijk, F. (2008). REACH geeft onrust in de recyclingbranche. GRAM, November 2008.
- Stybenex (2013). EPS: 100 procent recyclebaar, 100 procent duurzaam. http://www.synbratechnology.nl/uploads/EPS%20recycle%20folder%202013-04.pdf
- Tohka, A., R. Zevenhoven (2001). PROCESSING WASTES AND WASTE-DERIVED FUELS CONTAINING BROMINATED FLAME RETARDANTS. Final report for study funded by Ekokem Oy Ab support funding (apurahoitus) 2001. Espol, Helsinki University of Technology Department of Mechanical Engineering, report TKK-ENY-7.
- UK-EA (2009). Non-packaging plastics. End of waste criteria for the manufacture of secondary raw materials from waste non-packaging plastics.
- UNEP (2010). Hexabromocyclododecane Risk profile. UNEP/POPS/POPRC.6/13/Add.2 http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC6/POPRC6Documents/tabid/783/Default.aspx
- VinylPlus (2014a). Progress report 2014. http://www.vinylplus.eu/uploads/Modules/Documents/vinylplus-pr2014_en-2.pdf
- VinylPlus (2014b). Sector Projects. http://www.vinylplus.eu/progress/9/68/Sector-Projects
- WRAP (2006). Develop a process to separate brominated flame retardants from WEEE polymers. http://www.wrapcymru.org.uk/sites/files/wrap/BrominatedWithAppendices.3712.pdf

- WVK (2012). Ende der Abfalleigenschaft von Kunststoffabfällen. Stellungnahme der Wirtschaftsvereinigung Kunststoffe. http://wip-kunststoffe.de/wip/fileadmin/user_upload/news_downloads/1201_WVK_Abfalleigenschaft.pdf. Download 19 January 2015.