Environment International 94 (2016) 230–234

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Propelling plastics into the circular economy — weeding out the toxics first

H.A. Leslie [a,*], P.E.G. Leonards [a], S.H. Brandsma [a], J. de Boer [a], N. Jonkers [b]

[a] Institute for Environmental Studies (IVM), VU University Amsterdam, de Boelelaan 1087, 1081 HV Amsterdam, The Netherlands
[b] IVAM, University of Amsterdam, Plantage Muidergracht 24, 1018 TV Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 19 March 2016
Received in revised form 13 May 2016
Accepted 13 May 2016
Available online xxxx

Keywords:
Plastic
Recycling
WEEE
End-of-life vehicles
Flame retardants
Circular economy

ABSTRACT

The Stockholm Convention bans toxic chemicals on its persistent organic pollutants (POPs) list in order to promote cleaner production and prevent POPs accumulation in the global environment. The original 'dirty dozen' set of POPs has been expanded to include some of the brominated diphenyl ether flame retardants (POP-BDEs). In addition to cleaner production, there is an urgent need for increased resource efficiency to address the finite amount of raw materials on Earth. Recycling plastic enhances resource efficiency and is part of the circular economy approach, but how clean are the materials we are recycling? With the help of a new screening method and detailed analyses, we set out to investigate where these largely obsolete BDEs were showing up in Dutch automotive and electronics waste streams, calculate mass flows and determine to what extent they are entering the new product chains. Our study revealed that banned BDEs and other toxic flame retardants are found at high concentrations in certain plastic materials destined for recycling markets. They were also found in a variety of new consumer products, including children's toys. A mass flow analysis showed that 22% of all the POP-BDE in waste electrical and electronic equipment (WEEE) is expected to end up in recycled plastics because these toxic, bioaccumulative and persistent substances are currently not effectively separated out of plastic waste streams. In the automotive sector, this is 14%, while an additional 19% is expected to end up in second-hand parts (reuse). These results raise the issue of delicate trade-offs between consumer safety/cleaner production and resource efficiency. As petroleum intensive materials, plastic products ought to be repaired, reused, remanufactured and recycled, making good use of the 'inner circles' of the circular economy. Keeping hazardous substances – whether they are well known POPs or emerging contaminants – out of products and plastic waste streams could make these cycles work better for businesses, people and nature.

1. Introduction

The Stockholm Convention bans toxic chemicals on its persistent organic pollutants (POPs) list in order to promote cleaner production and prevent POPs accumulation in the global environment (UNEP, 2015). The original 'dirty dozen' set of POPs has been recently expanded to include some of the brominated diphenyl ether flame retardants (POP-BDEs). These BDEs entered the market in the 1970s and are an example of regulatory failure to act prior to large volume production and global contamination of our products and the biosphere. It has been estimated that between 1.3 and 1.5 million tonnes of commercial pentaBDE (c-PentaBDE), octaBDE (c-OctaBDE) and decaBDE (BDE209) mixtures have been produced between 1970 and 2005 (Table S1) (UNEP, 2010). The penta- and octaBDE mixtures are now listed as POPs, while BDE209 is still a candidate POP under review (UNEP, 2014).

In addition to cleaner production, there is an urgent need for increased resource efficiency to address the finite amount of raw materials on Earth (Hoekstra and Wiedmann, 2014). Recycling plastic enhances resource efficiency and is part of the circular economy approach (Ellen MacArthur Foundation, 2013) (Fig. 1), but how clean are the materials we are recycling? Debates are ongoing regarding bans of POPs and substances of very high concern (SVHC) designed to reduce our exposure to toxic, bioaccumulative and persistent chemicals via plastics, but at the cost of eliminating recycling streams that are contaminated with these substances. With the help of a new screening method and detailed analyses, we set out to investigate where the POP-BDEs were showing up in Dutch automotive and electronics waste streams, calculate mass flows and determine to what extent they are entering the new product chains. This study fills a data gap for BDEs in plastic waste streams in the Netherlands.

* Corresponding author.
E-mail address: heather.leslie@vu.nl (H.A. Leslie).

http://dx.doi.org/10.1016/j.envint.2016.05.012
0160-4120/

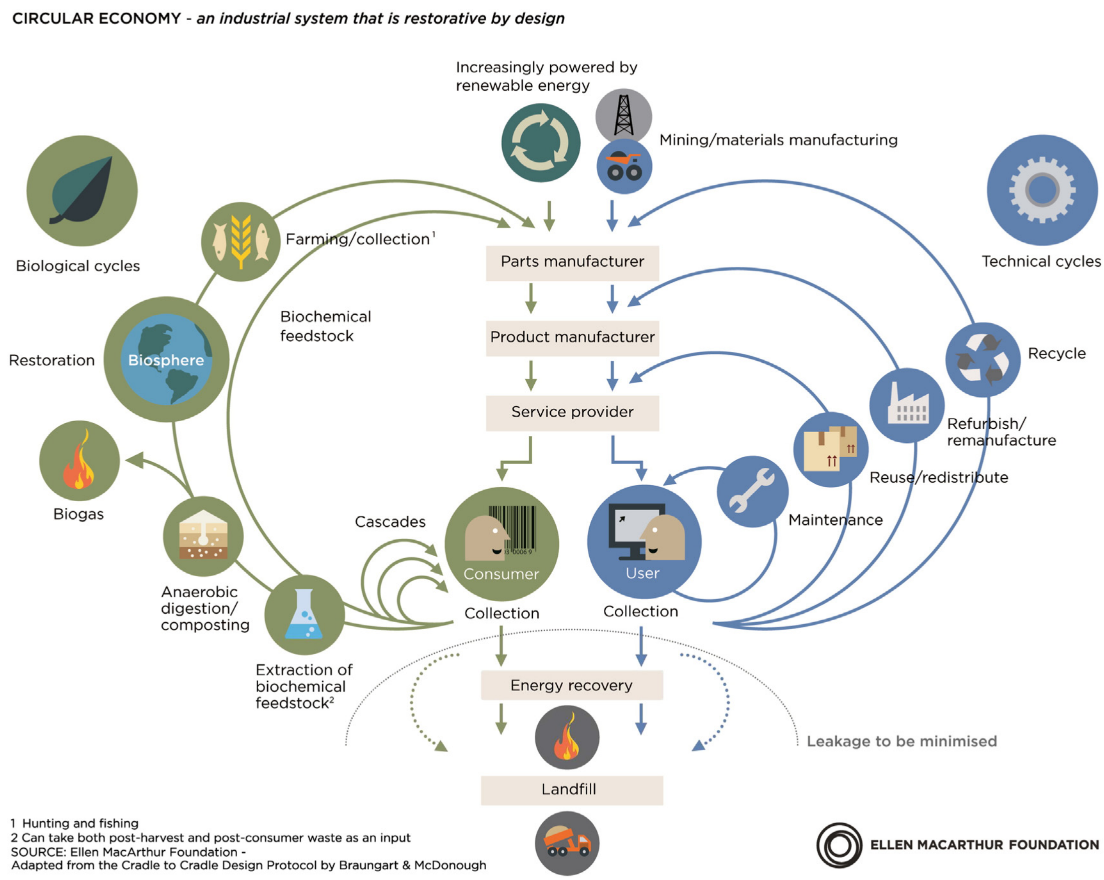

Fig. 1. Circular economy designed for regeneration: biological (L) and technological (R) cycles separated. Reprinted with permission from Ellen MacArthur Foundation.

2. Materials and methods

This study consisted of three steps, starting with studying how end-of-life vehicle (ELV) and waste electrical and electronic equipment (WEEE) plastic waste materials that possibly contain POP-BDE are sorted, separated, disposed of, recycled, landfilled, incinerated and/or exported in the Netherlands. The plastics from ELV and WEEE were targeted because of prevalent flame retardant usage in these sectors, particularly in the polyurethane (PUR) foam used in cars and the acrylonitrile butadiene styrene (ABS) used in electronic goods. Plastic waste flow data was collected from interviews with key actors in the Dutch waste sector and from reports and scientific literature. For both ELV and WEEE there are national organizations coordinating the collection, processing and documentation of plastic waste material in the Netherlands.

The second step was the sampling of materials identified in the waste streams described above for BDE analysis in whole waste products, shredded materials and new products. Samples were taken of new plastic products manufactured using recycled plastic and sold in the Netherlands (such as toys and household/office items). Plastic samples were prepared by cutting and shredding them into small pieces.

A new, cost-effective, fast screening method using a 'direct probe' coupled to atmospheric pressure chemical ionization-high resolution time-of-flight-mass spectrometry (APCI-HRTOF-MS) (Ballesteros-Gomez et al., 2013) was used to determine the presence or absence of BDEs. Briefly, a glass probe is brought directly into contact with the shredded plastic material, removing large particles with a lint-free cotton cloth, and introducing the sample into the mass spectrometer (MS) source. The LOD of the direct probe APCI-HRTOF-MS method is in the range of 0.5–25 pg (absolute), or 0.025% w/w in samples. The method can be used to screen samples for POP-BDEs, so that the more laborious solvent extraction procedures can be performed when quantifiable amounts are present. In total 90 samples were selected for determination of the BDE concentrations for a set of 25 congeners. Samples of waste material or recycled plastic products that dissolved in dichloromethane were brought into solution directly. The plastics that were insoluble in the organic solvent were extracted by shaking in the organic solvent for at least 4 h followed by ultrasonic extraction for at least 15 min. Internal standards (BDE58, (Stapleton et al., 2008)C-BDE209) and toluene were added to each sample extract. In every series, a procedural blank and a JRC/IRMM reference sample of poly(ethylene terephthalate) (PET) containing BDE47, BDE99, BDE183 and BDE209 were measured for quality control. A set of 25 BDE congeners were measured in the extracts by gas chromatography with the electron capture negative ionization technique and mass spectrometry detection (GC/ENCI-MS), using a highly sensitive method described by De Boer et al. (De Boer et al., 2001; De Boer and Wells, 2006).

Characterizing the size of these waste streams and the brominated flame retardant (BFR) concentrations associated with them revealed how much plastic waste laced with these chemicals was being processed on an annual basis and what its fate was.

3. Results

3.1. BDE levels in plastics for reuse and recycling

The highest concentrations of BDEs listed as POPs in the Stockholm Convention (POP-BDE) in single items were found in samples from cars from the US and in WEEE (Table 1). A maximum concentration of 25,000 μg/g was measured in the polyurethane foam of an old car seat (manufactured in 1997), in which the c-PentaBDE mix congeners were predominant. A number of WEEE items, such as a desktop scanner, were found to contain BDE congeners originating from the c-OctaBDE mix and the fully brominated diphenyl ether, BDE209. BDE209 was