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Intentionally added microplastics in products

Final report



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Amec Foster Wheeler Environment
& Infrastructure UK Limited



Report for

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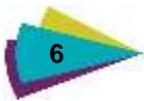
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1 Introduction

1.1 Purpose of this report

Amec Foster Wheeler has been contracted by the European Commission to provide services on 'intentionally added microplastics in products' (contract 07.0201/2016/745509/SER/ENV.B.2). Amec Foster Wheeler is working in partnership with Peter Fisk Associates Limited ('PFA'), Umweltbundesamt GmbH ('EAA') and Burges Salmon LLP ('Burges Salmon') acting as subcontractors to Amec Foster Wheeler for the purposes of this contract.

This is the final report for the project which will be reviewed by the Commission's inter-service steering group (ISSG). The report contains the results of the project including the market analysis, substance identification, risk assessment and analysis of alternatives and their costs). Note that the risk management options analysis is provided as a separate, stand-alone document.

1.2 Background

Microplastics, most commonly defined as man-made plastic items smaller than 5 mm¹, are of particular concern for the marine and inland aquatic environment. The potential impacts of microplastics present in products on the (aquatic) environment and possibly human health have generated concerns in Member States of the European Union and worldwide, with several implementing or proposing bans/restrictions taking various different forms.

On 20 June 2016, the Council, in its conclusions on the EU action plan for the circular economy, reiterated the need for preventing marine litter, and in particular plastics, from ending up in the environment in order to achieve a significant reduction by 2020. The Council called upon the Commission to propose robust measures to reduce discharge of macro- and micro-sized plastic debris in the marine environment by 2017 at the latest, including a proposal for a ban on micro-plastic particles in cosmetics, and proposals to address other products generating marine litter as appropriate.

Furthermore, on 3 April 2017, the Council adopted the conclusions of 24 March 2017 on "International ocean governance: an agenda for the future of our oceans". This extended the request for the Commission to include a proposal for a ban on "micro-plastic particles in products which could include personal care products and detergents, and proposals to address other products generating marine litter as appropriate".

This report concerns microplastics that are intentionally added to products, such as personal care products, detergents, paints, abrasives, agriculture and others. While these are all potential sources of microplastics present in the environment, there are various other sources such as fragmenting from larger pieces of plastic, or generated from sources such as fibres from washing clothes. These other sources are not covered in the present study but are covered in a parallel study².

1.3 Objectives of the study

The objective of this study was to address the use of microplastics in products, with particular emphasis on microbeads, which consist of man-made conventional plastics (which means synthetic polymers that take a solid form at ambient temperatures in the environment); those include polyethylene, polypropylene, polystyrene, polyamide (nylon), polyethylene terephthalate, polyvinylchloride, acrylic, polymethylacrylate, [...] (non-exhaustive list).

¹ Note that this is the definition quoted in the Terms of Reference for this project. Further elaboration on the definition of microplastics can be found in Section 2.

² Investigating options for reducing releases in the aquatic environment of microplastics emitted by (but not intentionally added in) products. Study for the European Commission by ICF and Eunomia, ongoing.

It includes preparation of a Risk Management Option Analysis (RMOA), applying the procedures established by Member States in the frame of their work in the group of Risk Management Experts (RiME) to provide a sound basis for the decision on the appropriate regulatory measure to control the risk^{3,4}.

The contract aimed to carry out an environmental and human health risk assessment, as well as gathering information for a socio-economic analysis of the impacts of any possible risk management action relating to placing on the market and use of microplastics intentionally added in products.

The assessments have been prepared in a format which could be used by the Commission as the basis for regulatory action. The results have been developed in a way that they could, depending on the decision on the risk management option to be taken by the Commission, serve as a basis for a restriction proposal under REACH, to be completed by the European Chemicals Agency (ECHA), or provide analytical input to the Commission's impact assessment, in line with the Better Regulation Guidelines⁵.

The assessment work has followed the guidance provided by ECHA⁶.

1.4 Structure of this report

This report is structured as follows:

- ▶ First, Section 2 presents the substance identification. This includes a discussion of the definition of microplastics for intentional addition to products and identifying and describing their composition and uses (polymers, function, shape and size, and a longlist of the products).
- ▶ Section 3 contains a detailed mapping of market information (such as tonnage of microplastics used) for intentionally added microplastics in products manufactured and placed on the market in the EU in each of the sectors identified in the preliminary list of products outlined in Section 2.
- ▶ Together, substance identification and market analysis provide a foundation for the following sections by providing an understanding of the composition of microplastics and the range of their intentional uses and associated volumes.
- ▶ Then, Section 4 presents the environmental risk assessment of intentionally added microplastics. The framework for the assessment is described, including the analysis of data and the results in terms of environmental exposure to microplastics, migration of additives from microplastics and possible effects of intentionally added microplastics.
- ▶ Section 5 identifies and assesses alternatives to the uses of microplastics in products, including the possible risks and the expected costs of their use. It also presents some high-level conclusions on socio-economic effects of possible regulatory actions on microplastics in products. The Risk Management Options Analysis (RMOA) is provided in a separate document which follows ECHA's template for RMOAs.

³ The purpose of the risk management option analysis (RMOA), available at: <https://echa.europa.eu/addressingchemicals-of-concern/substances-of-potential-concern/rmoa>.

⁴ Examples for RMOAs are available at: <https://echa.europa.eu/addressmg-ehemicals-of-concern/siibstances-ofpotential-concern/pact>.

⁵ See European Commission 'Better Regulation Guidelines'.

⁶ Guidance for the preparation of an Annex XV dossier for restrictions; in preparation. 2007 edition available at: https://echa.europa.eu/documents/10162/1364_l/restriction_en.pdf.

2 Substance identification

2.1 Introduction

This section presents the results of task 2, the substance identification. This entails choosing a definition of microplastics for intentional addition to products and identifying and describing their uses in terms of which substances are used, their function, shape and size, and a longlist of the products they are used in.

First, Sections 2.2 and 2.3 outline the basis for determining a working definition of microplastics by clarifying available definitions for microplastics and related terminology. Section 2.4 then presents and discusses the working definition developed in this study. Sections 2.5 and 2.6 present the results in terms of the identified microplastics, their shapes and sizes based on the working definition.

2.2 Indicative definition of microplastics

Since there is no agreed definition of microplastics among stakeholders and the scientific community, a **reasonable definition of microplastics for intentional addition to products** had to be chosen and described in detail. It is based on the characteristics given in the Terms of Reference⁷ by the Commission:

“Microplastics, most commonly defined as man-made plastic items smaller than **5 mm**, [...]”

“The objective of the contract is to address the use of microplastics in products, with particular emphasis on microbeads, which consist of **man-made conventional plastics** (which means **synthetic polymers** that take a **solid form** at ambient temperatures in the environment); those include polyethylene, polypropylene, polystyrene, polyamide (nylon), polyethylene terephthalate, polyvinylchloride, acrylic, polymethylacrylate, [...] (*non-exhaustive list*).”

2.3 Available definitions

All plastic is made of polymeric material, but not all polymers are plastic. For clarification of these two concepts we will give the definitions of “polymer” and “plastic” below and add further information on bioplastics and biodegradability.

Polymer

In accordance with **REACH** (Article 3(5)), a polymer is defined as a substance meeting the following criteria (ECHA 2012)⁸:

- (a) Over 50 percent of the weight for that substance consists of polymer molecules (see definition below); and,
- (b) The amount of polymer molecules presenting the same molecular weight must be less than 50 weight percent of the substance.

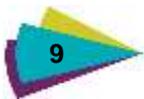
In the context of this definition:

- ▶ A "polymer molecule" is a molecule that contains a sequence of at least 3 monomer units, which are covalently bound to at least one other monomer unit or other reactant.
- ▶ A "monomer unit" means the reacted form of a monomer substance in a polymer (for the identification of the monomeric unit(s) in the chemical structure of the polymer the mechanism of polymer formation may, for instance, be taken into consideration).

⁷ Specific terms of reference under the framework contract ENV.A.3/FRAU/2015/0010 – Service contract on Intentionally added microplastics in products

⁸ Guidance for monomers and polymers - Guidance for the implementation of REACH, Version 2.0, April 2012, European Chemicals Agency.

https://echa.europa.eu/documents/10162/23036412/polymers_en.pdf



- ▶ A "sequence" is a continuous string of monomer units within the molecule that are covalently bonded to one another and are uninterrupted by units other than monomer units. This continuous string of monomer units can possibly follow any network within the polymer structure.
- ▶ "Other reactant" refers to a molecule that can be linked to one or more sequences of monomer units but which cannot be regarded as a monomer under the relevant reaction conditions used for the polymer formation process.

Plastic

Plastic as defined by IUPAC (IUPAC 2012)⁹ - **Generic term used in the case of polymeric material that may contain other substances to improve performance and/or reduce costs.**

- ▶ Note 1: The use of this term instead of polymer is a source of confusion and thus is not recommended.
- ▶ Note 2: This term is used in polymer engineering for materials often compounded that can be processed by flow.

The terms and definitions used in the plastics industry are also collated in the International Standard document **ISO 472 "Plastics – Vocabulary"**¹⁰. ISO 472 defines **plastic** as "**material which contains as an essential ingredient a high polymer and which, at some stage in its processing into finished products, can be shaped by flow**"

- ▶ Note 1 to entry: **Elastomeric** materials, which are also shaped by flow, are **not** considered to be **plastics**.
- ▶ Note 2 to entry: In some countries, particularly the United Kingdom, the term "plastics" is used as the singular form as well as the plural form.

An overview of the **different types of plastic** is published on the website of PlasticsEurope, an association of plastic manufacturers in Europe. It lists the classical thermoplastics as well as thermosets, elastomers and bio-based materials, as follows:

- ▶ Bio-based plastics;
- ▶ Biodegradable plastics;
- ▶ Engineering plastics;
- ▶ Elastomers;
- ▶ Epoxy resins;
- ▶ Expanded polystyrene (EPS);
- ▶ Fluoropolymers;
- ▶ Polyolefins (PO);
- ▶ Polyethylene terephthalate (PET);
- ▶ Polystyrene (PS);
- ▶ Polyurethanes(PUR);
- ▶ Polyvinyl chloride (PVC); and
- ▶ It also distinguishes thermoplastics and thermosets¹¹.

⁹ Terminology for biorelated polymers and applications (IUPAC Recommendations 2012). Pure and Applied Chemistry. 84 (2), 377–410, 2012.

¹⁰ Public access of Terms and Definitions ISO 472:2013 is free of charge at <https://www.iso.org/obp/ui/#iso:std:44102:en>

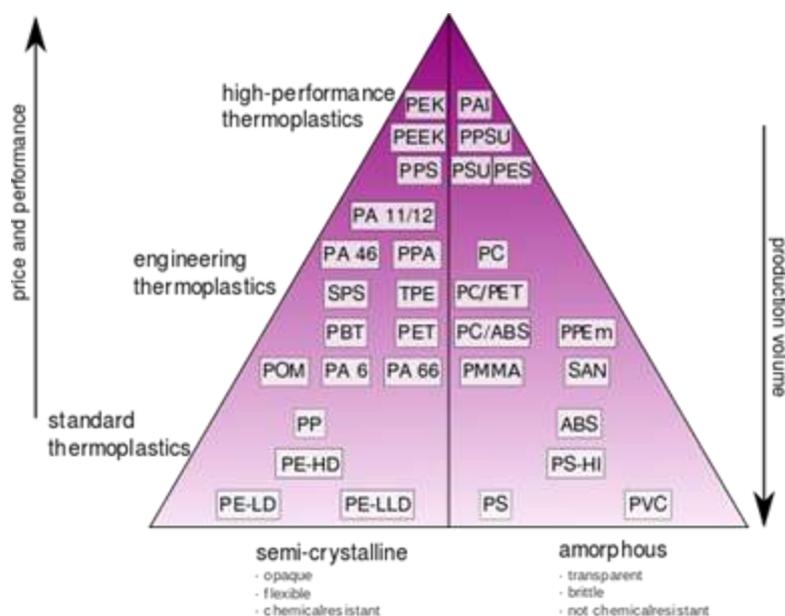
¹¹ Source: PlasticsEurope Website, <http://www.plasticseurope.org/what-is-plastic/types-of-plastics-11148.aspx>

More details on **thermoplastic materials** and their performance and production volume are shown in Figure 2.1. They are capable of being softened repeatedly by heating and hardened by cooling. In the softened state they can be shaped by flow repeatedly into articles by moulding, extrusion or forming (ISO 472:2013).

Thermosetting materials are capable of being changed in to a substantially infusible and insoluble product when cured by heat or by other means such as radiation (ISO 472:2013). Examples for thermosets are e.g. polyurethane, polyester or epoxy resin.

Elastomers do return rapidly into their initial dimensions and shape after substantial deformation by a weak stress and release of stress (under room temperature test conditions, ISO 472:2013). Typical elastomers are Polybutadiene (PBT), Styrene-Butadiene rubber (SBR) or synthetic Polyisoprene (IR).

Figure 2.1 Examples for thermoplastic polymers of different performance and production volume



Source: https://en.wikipedia.org/wiki/High-performance_plastics, image made available under the Creative Commons CC0 1.0 Universal Public Domain Dedication)

Bioplastic and biodegradable plastic

Bioplastic as defined by IUPAC (IUPAC, 2012): **Biobased polymer derived from the biomass or issued from monomers derived from the biomass** and which, at some stage in its processing into finished products, can be shaped by flow.

- ▶ Note 1: Bioplastic is generally used as the opposite of polymer derived from fossil resources.
- ▶ Note 2: Bioplastic is misleading because it suggests that any polymer derived from the biomass is environmentally friendly.
- ▶ Note 3: The use of the term “bioplastic” is discouraged. Use the expression “biobased polymer”.

Examples for biobased plastics are Polylactic acid (PLA), Polycaprolactone (PCL), and a variety of Polyhydroxyalkanoates (PHA).

Other related terms as defined by IUPAC (IUPAC2012):

- ▶ Biodegradable: qualifier for macromolecules or polymeric substances susceptible to degradation by biological activity by lowering of the molar masses of macromolecules that form the substances.
- ▶ Degradation: Degradation that results in desired changes in the values of in-use properties of the material because of macromolecule cleavage and molar mass decrease.

- ▶ **Composting:** Process of biological decomposition of organic matter performed by microorganisms, mostly bacteria and fungi.

Other related terms as defined by ISO 472:

- ▶ **Biodegradation:** degradation caused by biological activity, especially by enzymatic action, leading to a significant change in the chemical structure of a material.
- ▶ **Degradation:** irreversible process leading to a significant change in the structure of a material, typically characterized by a change of properties (e.g. integrity, molecular mass or structure, mechanical strength) and/or by fragmentation, affected by environmental conditions, proceeding over a period of time and comprising one or more steps.
- ▶ **Composting:** aerobic process designed to produce compost:
 - ▶ Note 1: Compost is an organic soil conditioner obtained by biodegradation of a mixture consisting principally of vegetable residues, occasionally with other organic material, and having a limited mineral content.

Definitions of microplastics used in existing and proposed national bans

An overview of existing measures targeting microplastics including the definition of microplastics they address is provided in Section 4.7.5 of the Risk Management Options Analysis (RMOA), which is provided in a separate document. In summary, France and Italy have issued a ban on exfoliating or cleaning rinse-off cosmetic products containing microplastics, with an exception relating to particles of natural origin (France). In the US, a Federal Law was approved in 2015 banning the use of microbeads defined as “any solid plastic particle less than 5mm in size and intended to be used to exfoliate or cleanse”. In Canada the Microbeads in Toiletries Regulation effective from July 2018 will prohibit shower gels, toothpaste and facial scrubs containing plastic microbeads.

The ‘functionality’ of the microplastics is integral part of the definitions used in existing and proposed national bans. However, the functionality in the product does not appear to be linked to potential release to the environment or subsequent risks.

Definition of microplastics discussed in ISO

Currently, a microplastic-related standardisation is also being discussed in an ad-hoc working group “microplastics” of the ISO Technical Committee ISO/TC 61/SC 5/AHG 112. It deals with plastics in the environment, the standardisation of terms and methodologies for quantification. More information is expected to be published by the end of 2017.

2.4 Working definition of microplastics

Developing the working definition

A “working definition” of microplastics was used in the early stages of the study, as set out below.

This was discussed with the Commission and the inter-service steering group at the inception meeting on 20 January 2017, and resulted in a deliberately broad “working definition” of microplastics that was the guideline for the initial research done for task 2 “Substance Identification”. The working definition has been refined during the course of the study, as described in the remainder of this report.

The keywords included man-made, synthetic polymers, solid at ambient temperature, particulates with particle sizes smaller than 5 mm and considered additional properties such as the lower size limit, the dissolution in water (water solubility), and the biodegradability. Also, bio-based microplastics were looked at.

¹² <https://www.iso.org/committee/49318.html>

The working definition of microplastics - status after inception meeting on 20 January 2017 (now superseded)

<p>Man-made, conventional plastics / synthetic polymers</p> <ul style="list-style-type: none"> thermoplasts (PE, PP, PS, PA, PET, PVC, PMMA, Acrylic, etc.) thermosets (resins), elastomers (rubbers) petro-based and bio-based analogues (e.g. bio-PET) bio-based polymers (e.g. PLA, PHA, PCL) Polysiloxanes <p>Solid form at ambient temperature (in the environment)</p> <ul style="list-style-type: none"> Define solid form via melting temperature > 20 °C @ 101.3 kPa (includes waxes) (water) soluble polymers, hydrogels bio-degradable polymers <p>Particle size below 5 mm include nanometre size</p>
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Reviewing the working definition

When the definition was developed it was recognised that it was deliberately broad and would need to be refined during the course of the work. It was discussed again with the inter-service steering group at the interim meeting on 7 June 2017. The aim was to focus the **updated microplastics definition on characteristics with highest certainty that means a solid rationale and evidence in data.**¹³

The characteristics with higher uncertainty about being part of the category microplastics are noted and commented in the following. Both the industry consultation and literature review suggest that water soluble plastics or polysiloxanes are not perceived to be microplastics at all. This is not to say that they do not have any associated risks, but that those risks are considered to be different to those associated with microplastics. Such plastics could therefore be considered in a separate initiative.

Reviewed working definition of microplastics - status after interim meeting on 7 June 2017

<p>Microplastics consist of man-made, conventional plastics.</p> <p>Microplastics also include bio-degradable plastics, bio-based analogue plastics, and bio-based alternative plastics.</p> <p>Microplastics are solid and water-insoluble particles.</p> <p>Microplastics have particle size below 5 mm and include nanometer sized plastics as well (nanoparticles).</p>

The reviewed working definition relates to the term **plastics** as described in Section 2.3. The **solid form** of particles in the environment (at ambient temperature and pressure of 101.3 kPa) is defined via a melting point above 20 °C (Verschoor 2015)¹⁴ (includes waxes). When produced with varying degree of polymerisation (number of monomer units), the melting point of a polymer can be affected. For some

¹³ It should be noted that this definition is considered relevant for intentionally added microplastics, whereas the parallel study (investigating options for reducing releases in the aquatic environment of microplastics emitted by but not intentionally added in products) may conclude that a different definition is appropriate for the different sources of microplastics.

¹⁴ A.J. Verschoor: Towards a definition of microplastics - Considerations for the specification of physico-chemical properties. RIVM Report 2015-0116. <http://www.rivm.nl/bibliotheek/rapporten/2015-0116.pdf>

polymers this means that they are available as both liquid and solid. Thermosetting plastics, however, will decompose rather than melt.

Microplastic can be produced from both **petro-based and bio-based raw materials**. There is no evidence that the raw materials play a role in decision making about potential risks associated with the microplastics. A common example are PET (bottles) derived from either petrochemicals or sugar cane; their chemical and physical properties and their behaviour in the environment are identical. Any other bio-based alternative microplastics such as PLA or PHA are a priori included as microplastics until there is proof for their low potential risk.

Biodegradation (ECHA June 2017)¹⁵: The biologically mediated degradation or transformation of substances usually carried out by microorganisms.

Microplastic includes **biodegradable** microplastics. At the moment, neither a standard test method nor a measure for biodegradability in fresh water, marine environment, biota or soil is available (for microplastics, as opposed to traditional chemicals). A variety of conditions has to be considered such as aerobic/anaerobic, humidity, pH, temperature, UV-radiation, time, agitation and of course the material characteristics such as molecular weight, crystallinity, crosslink density, solubility and shape of the material (Andrady 2007)¹⁶. Apart from the lack of a measure for the acceptable degree of degradation in diverse environmental compartments, the emerging (intermediate) degradation products are unknown. Furthermore, recent research suggests that biodegradable and petroleum-based microplastics exhibit comparable effects on aquatic life due to ingestion¹⁷.

Microplastic does not exempt **oxo-degradable** microplastics because they allow for a reduction of particle size due to functional breaking points in the material; it disintegrates to more and smaller plastic particles.

Microparticle (IUPAC 2012): Particle with dimensions between 1×10^{-7} and 1×10^{-4} m. (Note: The lower limit between micro- and nano-sizing is still a matter of debate.)

Microplastic covers all particle **sizes below 5 mm** (maximum extension in one or more dimensions), and includes the **nanometer range as well**. In material safety data sheets the particle size of microplastics is sometimes given as “mean particle size”, “maximum particle size” or even as “x % particles below y μm ”. Having these numbers but no further information on the particle size distribution, the presence of nanosized particles is theoretically possible. It is worth noting that available definitions from existing and proposed national bans (as discussed in Section 2.3) do not include lower size limits. However, the IUPAC definition of microparticle supports a lower size limit of 100 nm. Furthermore, the inclusion of a lower size limit could avoid addressing substances at the molecular level. Hence, the inclusion of a lower size limit remains debated and should be considered in the future when more information on particle size distribution and effects of different particle sizes becomes available.

Microcapsule (IUPAC 2012): Hollow microparticle composed of a solid shell surrounding a core-forming space available to permanently or temporarily entrapped substances.

It is to be decided whether an arbitrary particle (e.g. seed) that is smaller than 5 mm falls into the category of microplastics if it is coated with a plastic layer, regardless of the layer's thickness and weight contribution. In principal the IUPAC term “microcapsule” is suitable. In fact, just a few percent of the product weight are microplastic. It would thus be misleading to equate the total amount of plastic-coated seeds on the EU market to microplastics.

¹⁵ Guidance on Information Requirements and Chemical Safety Assessment, Chapter R.7b: Endpoint specific guidance, Version 4.0, June 2017, European Chemicals Agency. https://echa.europa.eu/documents/10162/13632/information_requirements_r7b_en.pdf

¹⁶ A.L. Andrady: Biodegradability of Polymers. In: Physical Properties of Polymers Handbook (ed. J.E. Mark), Springer Materials, 2007.

¹⁷ Straub, S., Hirsch, P. E., & Burkhardt-Holm, P. (2017). Biodegradable and Petroleum-Based Microplastics Do Not Differ in Their Ingestion and Excretion but in Their Biological Effects in a Freshwater Invertebrate *Gammarus fossarum*. *International Journal of Environmental Research and Public Health*, 14(7), 774. <http://doi.org/10.3390/ijerph14070774>

Comments on other polymers (not part of the working definition of microplastics)

The following polymers and polymer characteristics are currently associated with high uncertainty about fulfilling the criteria for microplastics.

1. Water soluble polymers and hydrogel forming polymers;
2. Inorganic polymers (e.g. polysiloxanes);
3. Modified natural polymers (nitrocellulose, vulcanized rubber, cellulose acetate...).

Water soluble polymers and hydrogel forming polymers

A scientific review on **polymer dissolution** indicates that polymers do not dissolve instantaneously. The dissolution is controlled by either the disentanglement of the polymer chains or by the diffusion of the polymer chains through a boundary layer at the polymer-solvent interface.

The solubility in solvents is influenced not only by the molecular weight but also by the architecture of the polymer, i.e. if it is linear or branched. Copolymerisation can also change solubility (Miller-Chou & Koenig 2003)¹⁸. In general, copolymerisation is used to meet specific needs of a manufactured plastic, and obtain the required properties.

The definition of polymer dissolution by IUPAC (IUPAC 2012) is “Process of dispersion of macromolecules in a liquid medium where they are solvated.”

In standard tests the **water solubility** (in mg/l) of a substance is measured in distilled water at 20 °C. In the implementation of REACH, water solubility below 10 mg/L is related with a low water solubility of a substance (ECHA Dec.2016)¹⁹. Polyacrylic acid, Polyacrylamide (PAM), Polyethyleneglycol (PEG), Polyvinyl alcohol (PVA), and Polyvinylpyrrolidone (PVP), among others, are water soluble.

Hydrogel forming polymers are a group of water soluble polymers that are cross-linked and have many polar groups; they have the ability to form hydrogels, in which water is tightly held in the polymer network by hydrogen-bonding (IUPAC 2011)²⁰. These so called **superabsorbent polymers (SAP)** are added to disposable hygienic products such as sanitary towels, nappies, incontinence pads or products for liquid spill absorption (oil, acids, blood), but they have also found their way into agricultural and horticultural applications (Table 2.1, e.g. PAM, PVP) . The applications as soil additives bring the polymers in direct contact with the environment where they remain or dissolve or degrade. Apart from the water retaining function, these polymers build coatings for seeds and fertilisers. In addition, they are also used in oilfield drilling fluids. Since they are water soluble we do not consider them further in this study. Note that PVP is an accepted food additive.

Table 2.1 Water soluble polymers that partly categorise hydrogels (when cross-linked)

Polymer	Abbreviation
Polyacrylamide	PAM
Polyvinylpyrrolidone	PVP
Polyacrylic acid	PAA
Polyvinylamine	PVAm
Acrylates crosspolymer	
2-Acrylamido-2-methylpropane sulfonic acid	AMPS

¹⁸ B.A. Miller-Chou, J.L. Koenig: A review of polymer dissolution. Progress in Polymer Science, 28, 1223-1270, 2003

¹⁹ Guidance on Information Requirements and Chemical Safety Assessment, Chapter R.7a: Endpoint specific guidance, Version 5.0, December 2016, European Chemicals Agency. https://echa.europa.eu/documents/10162/13632/information_requirements_r7a_en.pdf

²⁰ S. Slomkowski, J.V. Aleman, R. G. Gilbert, M. Hess, K. Horie, R.G. Jones, P. Kubisa, I. Meisel, W. Mormann, S. Penczek, R.F.T. Stepto: Terminology of polymers and polymerization processes in dispersed systems (IUPAC Recommendations 2011). Pure and Applied Chemistry, 83 (12), 2229–2259, 2011

Polymer	Abbreviation
Poly(ethylene vinyl acetate)	EVA

Additional note regarding the quantification of dissolved microplastics in the environment:

The effects of microplastics in the environment are related to the physical shape, monomers and additives leaching out from the particle as well as pollutants adsorbing at the surface of the particle. It is the current **state-of-the-art in microplastic analysis to separate solids** (plastics and other particles, Hohenblum et al. 2015)²¹ from environmental samples by sieving/filtration, density separation or selective chemical/enzymatical treatment.

The quantification of dissolved polymers in environmental samples requires a different methodological approach and other analytical protocols. To our knowledge the presence or impact of dissolved polymers in marine or fresh water environment has not been described yet.

Inorganic polymers and modified natural polymers

It is suggested that a separate study is needed to gain an overview of the multitude of inorganic polymers (Table 2.2) and modified natural polymers (e.g., nitrocellulose, vulcanized rubber) and if they are intentionally added as solid particles. It may not be appropriate to start assessing and potentially restricting the wider range of polymers in products through an initiative largely intended to tackle plastic litter in the environment.

A screening of **polysiloxanes** for microplastic characteristics (as discussed at the kick-off meeting) resulted in polytrimethylsiloxysilicate (TMSS) being identified as used as solid ingredient with particles of 10 µm minimum size (average: 20-100 µm). It forms films in cosmetics, skin care and sun care applications. According to the current working definition it is not microplastic, the same holds true for the very common cosmetics ingredient Polydimethyl siloxane (PDMS, Dimethicone) that is liquid at room temperature. However, TMSS was the only one out of hundreds or thousands of different types that was identified as having microplastic characteristics and being solid at room temperature, and which is intentionally added as a particle.

A quick literature screening of **phosphorus, boron and sulphur**-based inorganic polymers resulted in no evidence for a wider use of their particles intentionally added to products.

Table 2.2 Inorganic polymers

Polymer backbone	Examples
Si based	Polysiloxanes –Si-O-Si-O– Polysilazanes –Si-N-Si-N-
P based	Polyphosphazenes –P-N-P-N–
B based	Polyborazylens –B-N-B-N–
S based	Polythiazyls S-N-S-N

2.5 List of microplastics

The following conclusions provide an input to tasks 3-5 of this study, notably the risk assessment and the risk management option analysis (RMOA). Note that this includes additional information from literature review that is not presented in the sector-specific market analysis, which focuses on tonnages.

²¹ P. Hohenblum, B. Liebmann, M. Liedermann: Plastic and microplastic in the environment. Environment Agency Austria, Report REP-0551, Vienna 2015. <http://www.umweltbundesamt.at/fileadmin/site/publikationen/REP0551.pdf>

The first list resulting from the literature survey contained **more than 130 synthetic polymers**, and could have been easily extended even further if we considered the multitude of polymers' structural variations such as different architectural variations or their combination in copolymers.

In accordance with the updated working definition of microplastics (Section 2.4), we identified **14 conventional plastics** that form solid particles at room temperature and do not dissolve in water. In order to prioritise the polymers, we have summed up the number of product categories that particles are added to intentionally. The ten rough categories are cosmetics, personal care, detergents, paints/coatings/inks, industrial abrasives, agriculture, pharmaceuticals, waste water treatment, construction and "other".

It was agreed that we would further investigate (in the risk assessment) the most common and most widely applied polymer, which is **Polyethylene (PE)** together with **Polyurethane (PU)**, which shows up on the market in many variations (thermoplasts, thermosets) and different product categories. **Styrene/acrylates copolymer** is used in printer toners (5-30 µm particle size) as well as in leave-on cosmetics (powders; for opacifying purpose added in nanosize), a possible pathway of emitted particles is into the human lungs. The final selection of polymers for a detailed investigation in Task 3-5 considered their market share, and the feedback from the stakeholder consultation. There may be merit in adding PMMA and PA as polymers for the risk assessment case studies (Table 2.3).

Table 2.3 Microplastics with intentional use in products (non-exhaustive)

Polymer	Abbreviation	No of product categories
Polyethylene	PE	4
Polymethylmethacrylate	PMMA	4
Polytetrafluoroethylene	PTFE	4
Polyamide	PA (PA6, PA6.6, PA6.12, PA12)	4
Polyurethane	PU	3
Styrene/Acrylates copolymer		3
Melamine-formaldehyde resin	MF	3
Urea-formaldehyde resin	UF	3
Polypropylene	PP	2
Polyacrylonitrile	PAN	2
Expanded polystyrene	EPS	2
Poly-ε-caprolactone	PCL	2
Polyethylene terephthalate	PET	1
Polycarbonate	PC	1

Other plastics that fulfil the above microplastic criteria are **Polyhydroxyalkanoates (PHA)** and **Polyactic Acid (PLA)**. They are produced from bio-based feedstock, and are reported to be biodegradable. An agreed measure for biodegradability of microplastics would help decide whether to exclude biodegradable plastics from the microplastic definition or not. Should there be an accepted proof, these bioplastics could be then evaluated as microplastics alternatives.

The Styrene/Acrylates copolymer was presented in Table 2.3 and suggested for further investigation. Among commercially relevant copolymers we found that acrylonitrile butadiene styrene (ABS) is intentionally added to cosmetics, while styrene/butadiene copolymer (SBR) is used as binder in polymer concrete. Table 2.4 gives examples for other microplastics for which **cannot be confirmed that they are present in the product as solid particles**.

Table 2.4 Potential microplastic candidates (not confirmed particles in product)

Polymer	Abbreviation
Acrylonitrile-butadiene styrene	ABS
Styrene/butadiene copolymer	SBR
Acrylic resin	
Alkyd resin	
Epoxy resin, e.g. Bisphenol A epoxy resin	e.g., DGEBA
Polyvinylacetate	PVAc
Polyvinylbutyral	PVB
Polyvinylidene chloride, Polyvinylidene fluoride	PVDC,PVDF
Polyacrylates, Acrylates copolymer	
Polybutylene terephthalate	PBT
Polystyrene	PS
Polyvinylchloride	PVC

A possible source of information on a particular plastic product's physical state is the material safety data sheet (MSDS). We reviewed product information from manufacturers such as BASF, Dow Chemicals, AkzoNobel, Polysciences, SNF or micropowders, mainly on polymers where general literature did not give sufficient information. It was decided to randomly choose from manufacturers and MSDS, in particular for the numerous acrylic (co-)polymers and other copolymers. In fact, not all MSDS contain data on melting point and water solubility. Due to this lack of information there are plastics that are intentionally added to products but which cannot be categorised yet.

In case of solid plastics that are added to **paints, varnishes, lacquers, and (powder) coatings** it is possible that particles are emitted into the environment while a person applies the product onto a surface or afterwards by rinsing brushes and paint rolls. Once the product layer is dried or cured, the particles should become embedded completely and become an integral part of the layer. Considering wear and tear over time, however, it is assumed that this product category can be a source for secondary microplastics (these are being covered in the parallel study). Examples are **Acrylic resin, Alkyd resin, Epoxy resin, Polyvinylacetate, Polyvinylbutyral, Polyvinylidene chloride, and Polyvinylidene fluoride** (see Table 2.4).

Many film forming polymers added to cosmetic products are reported to build thin layers. The layer thickness can vary from 10-1 000 µm, preferably 20-500 µm (information for **Polyacrylates**). No information on particle size in the product could be obtained for the film forming polymers **PET, PS, and PVC**.

Microplastics suggested for further evaluation

Type	Justification for selection
Polyethylene PE	High market share Many applications (4 categories) Low concern reactive functional groups (RFG) Least hazardous polymer
Polyurethane PU	High market share Many applications (3 categories) High concern reactive functional groups RFG Most hazardous polymer
Polymethylmethacrylate PMMA	Many applications (4 categories) High concern RFG High level hazardous monomer
Polyamide PA	Many applications (4 categories) Low-medium level of hazardous monomer
Styrene/Acrylates copolymer	Many applications (3 categories) High concern RFG High level hazardous monomer

Information on Reactive Functional Groups (RFG) according to Deloitte 2014²².
Information on hazard classification according to Lithner et al. 2011²³.

2.6 Functions and shape/size

The following gives an overview of microplastics' functions and fields of application. Note that this includes additional information from literature review that is not presented in the sector-specific market analysis, which focuses on tonnages. The use of microplastics in products goes beyond their exfoliating function; it influences emulsification, viscosity, binding and film forming. The variety of functions was investigated and – where applicable – related to particle shape and typical size. The resulting functions are an input for Task 5, to help identify alternative substances. A much more detailed list of product categories, polymers, functions and size ranges (including references) is in Appendix A.

Table 2.5 Microplastic functions in different products

Function	Products
Abrasive/exfoliating	Cosmetics, detergents, industrial blasting abrasives
Emulsifier, suspending agent	Cosmetics, detergents, paints
Binding	Cosmetics, paints, inks, concrete
Filler	Construction (wall and joint fillers, self levelling compounds/screeds)
Control release of ingredients	Pharmaceuticals (nanocapsules), cosmetics, fertilisers, crops, detergents (enzymes)
Film forming	cosmetics, polishing agents
Surface coating	paper making, polishing agents,
Improved chemical and mechanical resistance	Coatings, paints, floor coatings, polymer cement
Fluid absorbents	nappies, water retainer for farming, agriculture, horticulture

²² Deloitte: Technical assistance related to the review of REACH with regard to the registration requirements on polymers, final Report for DG ENV, 2014.

²³ D. Lithner, A. Larsson, G. Dave: Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. Science of the Total Environment, 409, 3309-3324, 2011.

Function	Products
Thickening agent	paints, cosmetics, concrete, oilfield use (drilling fluids)
Aesthetics	coloured microplastics in make-up, structural effects of paints, enhanced gloss level of paints
Flocculant	Waste water treatment, oilfield use, paper making
Dewatering	Paper making, dewatering of sewage sludge, manure
Dispersing agent	Paints, coatings (pigments)
Opacifying agent	Cosmetics
Anti-static agent	Cosmetics / hair care

3 Market analysis

3.1 Introduction

This sub-section presents market information for each of the sectors identified in the preliminary list of products (see 3.3).

First, Section 3.2 provides an overview of the sources used in the market analysis.

Section 3.3 describes the focus of the market analysis in terms of which sectors have been investigated with regards to their use of microplastics. A full list of all uses of microplastics that could be identified is provided as well.

The following sections present, by sector, available information on:

- ▶ Volumes of microplastics used in products.
- ▶ Main substances, their shapes and sizes.
- ▶ Volumes of products containing microplastics.
- ▶ Size of product market or wider sector.
- ▶ Product use definition.
- ▶ Functionality of microplastics.

Then, Section 3.11 draws conclusions with a focus on key inputs from this task to other tasks of this study, such as tonnages and concentrations of microplastics used.

3.2 Information sources

The information is based on literature review and a targeted consultation with industry stakeholders.

The literature review focused on available estimates of manufactured and imported quantities of products and uses associated with microplastics. Relevant sources of information included academic studies, country-specific reports and industry data (such as Cosmetics Europe and AISE (International Association for Soaps, Detergents and Maintenance Products)), as well as available economic and trade statistics from Eurostat and the European Commission. In the absence of comprehensive EU-wide microplastics volume estimates by product groups, we have collated available country and/or individual product type specific estimates, where available.

In late January and early February 2017, initial contact was made with a range of industry associations, in order to identify their likely willingness to provide information for the study. A draft questionnaire was produced, reviewed by the European Commission and sent to the industry associations in early March, along with a letter of introduction provided by the Commission to assist with the consultation. The table below lists the organisations that have been approached and indicates whether they answered the questionnaire or provided a response in another form.

Table 3.1 Overview of organisations contacted (in alphabetical order), sectors covered and form of response provided

Organisation	Sector covered	Answered questionnaire	Other responses
AESGP	Self-medication industry		Stated they believe their sector is not a user of intentionally added microplastics; decided not to respond to this survey.
AISE	Soaps, detergents and maintenance products	✓	
CEFIC	Chemical industry		Provided no input to the study.
CEPE	Paint, printing ink and artists' colours	✓	
Cosmetics Europe	Cosmetics and personal care industry	✓	
EFFCI	Cosmetic Ingredients		Provided qualitative input.
EFMA	Fertilisers		Provided no input to the study.
EFPIA	Pharmaceutical industry		Stated they believe their sector is "only marginally affected"; decided not to respond to this survey.
EOSCA	Oilfield speciality chemicals (offshore chemicals)	✓	
Eureau	Drinking water and waste water service operators		Provided qualitative input. Provided information on removal of microplastics in waste water treatment plants (WWTP) and will give feedback on the approach to removal in WWTP in the risk assessment.
FEPA	Abrasives		Provided qualitative input.
Fertilizers Europe	Fertilisers		Provided no input to the study.
OSPAR [not an industry association]	Government cooperation mechanism to protect the marine environment of the North-East Atlantic		Provided qualitative input.
Oxo-biodegradable plastics association	Oxo-biodegradable plastics		Provided no input to the study.
Plastics Europe	Plastics manufacturing		Provided qualitative input.
PPG	Polyelectrolytes producers (used in water treatment, mineral extraction, oilfield solutions, paper manufacturing)		Provided no input to the study.
UEAPME	Craft, small and medium-sized enterprises		Provided no input to the study.
UNITIS	Cosmetic ingredients industries and services		Provided no input to the study.

Source:
Amec Foster Wheeler targeted stakeholder consultation February-April 2017.

3.3 Scoping of products covered

List of products covered in the market analysis

A list of product categories containing intentionally added microplastics has been agreed with the Commission and was used to scope the boundaries of the market analysis. This was based on early literature review results, input from Task 2 (substance identification), input from the Commission's inter-service steering group, as well as coordination with the parallel study on 'Investigating options for reducing releases in the aquatic environment of microplastics emitted by (but not intentionally added in) products'. The list of product category includes:

Sector	Use
Oil and gas	Drilling fluids
Agriculture	Fertilisers (nutrient prills)
Paints/coatings	Anti-skid powder
	Laser printer inks
Personal care products	Leave on
	Rinse off
Detergents	Commercial
	Domestic
Industrial Abrasives	Abrasive media
Others	Dentist polish
	EPS beads in furniture, insulation

While this list sets the focus of the market analysis, particularly the targeted stakeholder consultation, any additional uses of intentionally added microplastics that were cited in the reviewed literature have been included in the following analysis.

Full list of products

An aim of this study is to provide a comprehensible and manageable list of products that contain deliberately-added polymers that fulfil the study's working definition of microplastics. While several product categories are well known to contain microplastics (personal care, detergents, paints), others have been identified and verified (Table 3.2). These product categories with intentional use of microplastics were also co-ordinated with the parallel study's principal investigator Eunomia. Table 3.2 also indicates possible emission pathways as a starting point for the environmental impact assessment.

Note that this list was developed in parallel to the market analysis and thus may contain products which were not addressed in detail in the market analysis and the associated targeted stakeholder consultation.

Some product categories contribute to the emission of microplastics primarily during the product's production or in case of inadequate waste management, for example EPS beads used in furniture or soft toys. However, it is of note that EPS is also used in agriculture where it improves soil aeration.

A more detailed summary table with product examples for every category, relevant polymers, functions and typical size ranges for microplastics is given in Appendix A. Note the difference between information from literature review and information reported back from the consultation.

Table 3.2 Product categories and potential emission pathways into the environment

Category	Sub-Category	Emission pathways
Cosmetics and Personal care products	Rinse off	Waste water, direct human uptake
	Leave on	Solid waste (makeup remover), waste water, direct human uptake
	Superabsorbents	Solid waste (disposable hygienic products)
Detergents		Waste water (solid waste)
Paints/Coatings/Inks	Building, Road, Marine	Paint spill during application (-> soil, water); waste water (rinse brush), formation of secondary microplastics
	Paper making (drainage aid; coating)	Waste water, solid waste
	Laser printer inks	Direct human uptake (inhalation); solid waste (no particles, layer)
	Domestic polishing agents (floor)	Waste water, formation of secondary microplastics? (abrasion?)
Industrial abrasives	Abrasive media	Most likely: recovery for reuse + filter masks for workers; possible: waste water; direct human uptake (lungs)
Agriculture	Controlled release fertilisers (nutrient pills), crops	Dissolution of polymer coating (encapsulated ingredient/fertiliser is released over time), no evidence that particle shape remains
	Soil enhancement (water retention)	Soil, ground water?
	Dewatering of manure	Soil, ground water?
Medical applications	Pharmaceuticals (additive in drug formulations, controlled release, nanocapsules)	Direct human uptake, (waste water if not dissolved)
	Dental polymers for cavity filling, sealants, dentures, abrasive in dental polish	Direct human uptake, waste water
Waste water treatment	Flocculation agent, sewage dewatering	Through sewage onto agricultural land
Construction	Polymer concrete Fibre reinforced concrete (PP, Nylon, PET) Insulation (EPS)	During construction period: emission of product into water, soil after demolition of buildings into environment (water, soil)
Others	Furniture / soft toys (e.g. expanded PS)	Solid waste
	Adhesives and sealants	no evidence that particle shape remains (solid waste)
	Oil and Gas (Drilling fluids, flocculant)	Unintentional releases in the marine (or terrestrial) environment

Sources: See Appendix A

3.4 Personal care products

Tonnage

According to the response to the consultation from Cosmetics Europe – the European trade association for the cosmetics and personal care industry – 714 tonnes of microbeads were used in the EU in their industry in 2015. This figure is based a Cosmetic Europe survey²⁴ conducted in 2016 and covering use during 2015, using the following definition of microbeads:

- ▶ Plastic microbead: Any intentionally added, 5mm or less, water insoluble, solid plastic particle used to exfoliate and cleanse in rinse-off personal care products.
- ▶ Plastic: Synthetic water insoluble polymers that are repeatedly moulded, extruded or physically manipulated into various, solid forms which retain their defined shapes in their intended applications during their use and disposal.

According to Eunomia (2016)²⁵ Cosmetics Europe confirmed with respect to an earlier similar survey that their members, all of which were surveyed, account for 90% of the cosmetics market. Assuming this is true for the present survey as well, and assuming non-members of Cosmetics Europe use similar amounts of microplastics per total product output as Cosmetics Europe members, the above figure could be uplifted by 10% to account for the share of the market not covered by the survey. This would yield 793 tonnes.

The types of microplastics (covered by the above definition) used in this sector are listed by product in the section below. It is important to note that Eunomia (2016) concluded that there is potential for microplastics to appear in many more forms within personal care products, but there was a lack of information on whether polymeric ingredients in personal care products are solid, and on their persistence of these ingredients in the marine environment.

The Danish Environmental Protection Agency (2015)²⁶ found that polymer materials in personal care products include thermoplastics (e.g. polyethylene, polypropylene, polystyrene and polytetrafluoroethylene) and thermosets (e.g. polyester and polyurethanes) and a size range of particles between 2µm (toothpaste) and 1 240µm (facial cleaner).

Regarding trends in use, the Cosmetics Europe survey also suggests that the use of plastic microbeads for exfoliating and cleansing purposes in wash-off cosmetic and personal care products decreased by 82% between 2012 and 2015²⁷. This is due to a voluntary industry initiative to discontinue the use of such products, supported by a Cosmetics Europe recommendation.

Eunomia (2016) has attempted the most comprehensive estimate of the overall tonnage of microplastics in personal care products in the literature thus far. The authors estimate that between 3 800 and 7 500 tonnes of microplastics are used in personal care products in addition to the products covered by the Cosmetics Europe definition and survey. This is based on the following definition:

- ▶ Synthetic polymers and/or copolymers (plastics).
- ▶ Solid phase materials (particulates, not liquids).
- ▶ Insoluble in water.
- ▶ Non-degradable.
- ▶ Small size (maximum 5 mm, no lower size limit is defined).

While the authors note that the accuracy of this estimate is very uncertain due to the limited data available and simplifying assumptions, this indicates that a significantly higher overall tonnage of microplastics can be

²⁴ <https://www.cosmeticseurope.eu/news-events/reduction-use-plastic-microbeads>

²⁵ Eunomia (2016). Study to support the development of measures to combat a range of marine litter sources. Report for the European Commission DG Environment. January 2016.

²⁶ Denmark EPA (2015). Microplastics: Occurrence, effects and sources of releases to the environment in Denmark (Environmental project No. 1793, 2015).

²⁷ <https://www.cosmeticseurope.eu/news-events/reduction-use-plastic-microbeads>

expected in personal care products in total than in the limited range of products covered by the Cosmetics Europe survey data provided in the targeted stakeholder consultation for this project. It should also be noted that Eunomia include shampoos in this figure; however we understand that this is already covered by the Cosmetics Europe survey data on rinse-off products so this should potentially not be included.

Cosmetics Europe has confirmed that since the publication of the Eunomia (2016) report they have completed a survey of its membership in respect of volumes of microplastics in leave on products²⁸. According to Cosmetics Europe this survey indicates (for 2015) tonnages for leave on products (according to Cosmetics Europe's definition) in the range of 4-5 times lower than the Eunomia estimations for leave on products (according to Eunomia's definition) plus decoratives and deodorants. Applying this to the lower and higher range Eunomia estimates (excluding shampoos), yields a range of approximately 540-1 120 tonnes of microplastics used in leave on personal care products (i.e. in addition to the 714-793 tonnes used in wash-off personal care products)²⁹. It is assumed that the definition of microplastics used in the survey of leave-on products is the same as that included within the Cosmetics Europe recommendation, though presumably the aspects relating to the function (exfoliating, cleansing) are not applicable in some products. An estimate of 605 tonnes is used in the latter stages of this report³⁰.

Based on 2015 data from Euromonitor, 300t of polyethylene beads are used in personal care products in 10 EU Member States bordering the Baltic Sea. Note that this represents a very small proportion (around 2%) of the total use of polymers used in personal care products according to the same source. A more detailed assessment of these polymers is included in Section 5.3. Extrapolating the above figures to the whole of the EU, it is estimated that around 980 tonnes of polyethylene beads were used in personal care products in 2015³¹. This is within the range estimated above based on information provided by Cosmetics Europe.

A 2016 report³² of the UK House of Commons Environmental Audit Committee quotes a figure of 680 tonnes of microbeads³³ being used annually in (rinse-off) cosmetic products in the U.K. The same figure is used in the UK Government's impact assessment and notification to the European Commission of the draft Environmental Protection (Microbeads) (England) Regulations 2017³⁴. This figure of 680 tonnes (along with a figure of 4 130 tonnes for the EU, Norway and Switzerland) was originally estimated by Gouin et al. 2015³⁵ using Euromonitor data for 2012, as well as data from a 2012 Cosmetics Europe survey. The 2012 Cosmetics Europe survey data suggested 4 073 tonnes of polyethylene and 287 tonnes of other microbeads, i.e. 4 360 tonnes of microbeads being used in the EU, Norway and Switzerland in total. As described above, Cosmetics Europe have reported an 82% reduction in the use of microbeads since the original data were collected in 2012. Taking this reduction into account would suggest some 785 tonnes of microbeads being used in the EU, Norway and Switzerland in 2015, which is in reasonable agreement with the 714-793 tonnes reported above.

Note that there is also ongoing work under the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic to quantify tonnes of microplastics discharged by OSPAR contracting parties. This was not available within the timescales for the present study.

To put these tonnage estimates into context of the wider sector, it is estimated that the total European market for personal care products comprises around 3-5 million tonnes³⁶, generating turnover of €43.6 billion

²⁸ According to Cosmetics Europe, their categorisation does not exactly coincide with that of Eunomia, and clarified they include in 'leave on' the following: skin care and cleaning products, products intended for application to the lips, make up, make up removing products, deodorants and anti-perspirants, sun protection products, hair care products, and others.

²⁹ Lower: $2,686t * 20\% = 537t$; upper: $4,488t * 25\% = 1,122t$.

³⁰ Based on $2,686t * 22.5\%$ (i.e. the middle of the range of 20-25%).

³¹ This is based on extrapolation from the manufacturers selling price of products in the 10 member states concerned (€13.8 billion as MSP in 2015) to the total EU sales (€45 billion) based on Cosmetics Europe statistical data.

³² UK House of Commons Environmental Audit Committee: Environmental impact of microplastics - Fourth Report of Session 2016-17. Available at: <https://www.publications.parliament.uk/pa/cm201617/cmselect/cmenvaud/179/179.pdf>

³³ Defined as "Any intentionally added, 5mm or less, water insoluble, solid plastic particle used to exfoliate or cleanse in rinse-off personal care products".

³⁴ Notification 2017/353/UK to the European Commission according to Directive (EU) 2015/1535. Available at:

http://ec.europa.eu/growth/tools-databases/tris/en/index.cfm/search/?trisaction=search_detail&year=2017&num=353&mLang=EN

³⁵ The UK House of Commons Environmental Audit Committee refers to evidence by Professor Richard Thompson, Plymouth University (<http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/environmental-audit-committee/environmental-impact-of-microplastics/written/31787.pdf>), which in turn refers to Gouin et al. 2015 (<http://www.ikw.org/fileadmin/content/downloads/Sch%C3%B6nheitspflege/SOFW>).

³⁶ No figure for total tonnage of personal care products sold in the EU was readily available. The range provided is based on estimates derived as follows:

in manufacture of perfumes and toilet preparations in the EU28 in 2015³⁷. According to Cosmetics Europe, the cosmetics and personal care market in Europe was valued at €77 billion at retail sales prices in 2015³⁸. Note that this is roughly consistent with the manufacturing turnover quoted above, considering retail selling prices have been estimated to be higher by a factor of 1.6 compared to manufacturer selling prices in the cosmetics industry³⁹.

In conclusion, the tonnage of plastic microbeads (intentionally added, 5mm or less, water insoluble, solid plastic particles) used to exfoliate and cleanse in rinse-off personal care products has decreased to 714-793 tonnes per year in the EU (by 2015) and is expected to decrease further due to the voluntary action taken by the cosmetics industry. However, when considering microplastics used for other purposes in other products (notably leave on products), the tonnage is expected to be significantly higher, in the magnitude of 540-1 120 tonnes higher (i.e. in addition to the 714-793 tonnes quoted above). There is no information available regarding the trends of this additional tonnage. In sum it is thus estimated that some 1 250-1 910 tonnes of intentionally added, 5mm or less, water insoluble, solid plastic particles are used in personal care products⁴⁰.

Uses/product groups identified

The following types of wash-off personal care products using intentionally added microplastics have been identified in Cosmetics Europe's response. Note that no data on individual types of leave-on products was available.

Table 3.3 Personal care products containing microplastics

Product category	Total quantity of microplastics present in the product category (tonnes)	Types of microplastics added (material/substance, particle shape and size)
Skin Care and Cleaning Products - Hand Cleaners (professional)	440.07	Polyurethane, sphere, 200-1 250 µm
Skin Care and Cleaning Products - Body Foot Scrubs	126.1	Polyethylene, sphere/bead/irregular, <1 mm
	0.7	Cellulose Acetate, irregular, 300 - 400 µm
	0.485	Polylactic Acid, sphere/irregular, < 315 µm
Skin Care and Cleaning Products - Face Scrubs	72.95	Polyethylene, sphere/beads/ovoid/irregular, < 1 mm
	1.33	Polylactic Acid, sphere/beads/irregular, < 315 µm
	0.1	Cellulose Acetate, irregular, 300 - 400 µm
Skin Care and Cleaning Products - Face Masks	42.1	Polyethylene, ovoid/sphere, < 1 mm

1. An average price of €9.19 per kg of EU trade of HS Code 33 - ESSENTIAL OILS AND RESINOIDS; PERFUMERY, COSMETIC OR TOILET PREPARATIONS is calculated from Eurostat trade data (EU trade since 1988 by HS2,4,6 and CN8 [DS-645593]).
2. Sales quantities of products under the NACE code 20.42 Perfumes and toilet preparations are estimated from PRODCOM data (Eurostat: Sold production, exports and imports by PRODCOM list (NACE Rev. 2) - annual data [DS-066341]), by subtracting quantities of exports from production and adding imports. For a large number of products, quantities were not available but only values (€). In these cases, values are divided by the average price of €9.19/kg to approximate quantities. This yields the lower end of the range.
3. Turnover in manufacture of perfumes and toilet preparations in the EU28 in 2015 (Eurostat: Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) [sbs_na_ind_r2]) is divided by the average price of €9.19/kg to approximate the quantity of products sold to generate the turnover. This yields the higher end of the range.

³⁷ Eurostat: Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) [sbs_na_ind_r2].

³⁸ <https://www.cosmeticeurope.eu/cosmetics-industry/>

³⁹ Source: https://www.cosmeticeurope.eu/files/6214/6407/3031/Cosmetics_Europe_Activity_Report_2014.pdf. Dividing turnover of €77 billion at retail sales prices by 1.6 suggest turnover at manufacturer selling prices of about €48 billion. This is reasonably close to the €43.6 billion manufacturing turnover according to Eurostat data, considering the 1.6 conversion factor constitutes an approximation.

⁴⁰ Note the later calculations use 605t for leave-on as a central estimate (537 tonnes and 1 112 tonnes as the high low ranges. See section 5.3 in the analysis of alternatives for further details.

Product category	Total quantity of microplastics present in the product category (tonnes)	Types of microplastics added (material/substance, particle shape and size)
Skin Care and Cleaning Products - Body Shower Gels	11.6	Polyethylene, sphere/bead, <450 µm
Skin Care and Cleaning Products - Face Cleaning Products	9.34	Polyethylene, sphere/bead/ovoid/irregular, <1 mm
	1.13	Nylon-11, sphere, 150 µm
Hair Care Products (Wash-off) - Shampoo	7.02	Polyethylene, ovoid/hexagonal, <315 µm
Skin Care and Cleaning Products - Foot care products	1.01	Polyethylene, sphere, < 1 mm
Skin Care and Cleaning Products - Soap Bars	0.046	Polyethylene, no information
TOTAL	714.0	

Source:

Cosmetics Europe response to Amec Foster Wheeler targeted stakeholder consultation February-April 2017.

As shown in Table 3.3, polyurethane spheres of 200-1 250µm contained in the product category “Skin Care and Cleaning Products - Hand Cleaners (professional)” account for more than half of the tonnage of microplastics reported in this industry. Polyethylene particles of various shapes smaller than 1mm contained in body foot scrubs, face scrubs and face masks makes up most of the rest (in sum about 240 tonnes).

As already mentioned above some sources in the literature indicate that further products contain microplastics when considering a wider definition of microplastics than that used by Cosmetics Europe.

Leslie (2014)⁴¹ establishes that plastic ingredients are part of the formulation for a variety of personal care products including toothpaste, shower gel, shampoo, creams, eye shadow, deodorant, blush powders, make-up foundation, skin creams, hairspray, nail polish, liquid makeup, eye colour, mascara, shaving cream, baby products, facial cleansers, bubble bath, lotions, hair colouring, nail polish, insect repellents and sunscreen. Plastic contents constitute more than 90% of the ingredients in some cases. However, it is unclear which of these uses can be considered microplastics and contribute to marine litter.⁴²

The Government of Canada (2015)⁴³ conducted a review of scientific literature on microbeads in personal care products. Eunomia (2016) has identified product groups for which one or more products has been found to contain microplastics and is included in the “Beat the Microbead” database⁴⁴. Both sources suggest that in addition to a range of wash-off products (scrubs/peelings, facial cleansers, shampoo, bath additives, shower and body wash, liquid/toilet soap) that are also covered by the Cosmetics Europe survey, microplastics have been found in the following products:

- ▶ Decorative colour cosmetics (make-up, nail polish).
- ▶ Skincare (“Prestige Skincare”⁴⁵, face care, hand care, body creams and lotions, lip salves, sun preparations).

⁴¹ H.A. Leslie, PhD (2014). Review of Microplastics in Cosmetics - Scientific background on a potential source of plastic particulate marine litter to support decision-making. IVM Institute for Environmental Studies. Available at http://www.ivm.vu.nl/en/Images/Plastic_ingredients_in_Cosmetics_07-2014_FINAL_tcm234-409859.pdf

⁴² See also the discussion on polymers that are not part of the working definition of microplastics in Section 2.4.

⁴³ Government of Canada (2015). Microbeads – A Science Summary. Environment and Climate Change, Government of Canada. http://www.ec.gc.ca/ese-ees/ADDA4C5F-F397-48D5-AD17-63F989EBD0E5/Microbeads_Science%20Summary_EN.pdf

⁴⁴ <http://www.beatthemicrobead.org/>. The inclusion of products in the database is based on the following definition of microplastics: “Products on this list have been found to contain ingredients which are commonly considered to be microplastic ingredients. These include but are not limited to Polyethylene (PE), Polypropylene (PP), Polyethylene terephthalate (PET), Polymethyl methacrylate (PMMA) and Nylon (PA).”

⁴⁵ This category was quoted in Eunomia (2016).

- ▶ Other hair care⁴⁶: hair colourings, hairsprays.
- ▶ Other toiletries: toothpaste, deodorants, shaving soaps, mouthwashes, insect repellents⁴⁷.

Function of microplastics in products

According to the response to the consultation from Cosmetics Europe, intentionally added microplastics fulfil the function of scrubbing, cleansing and exfoliating in personal care products.

Leslie (2014) indicates that polymers more widely fulfil a wide range of functions depending on the polymer type, size and shape of the ingredient and nature of the product it is used in. The authors list the following functions: “viscosity regulators, emulsifiers, film formers, opacifying agents, liquid absorbents binders, bulking agents, for an ‘optical blurring’ effect (e.g. of wrinkles), glitters, skin conditioning, exfoliants, abrasives, oral care such as tooth polishing, gellants in denture adhesives, for controlled time release of various active ingredients, sorptive phase for delivery of fragrances, vitamins, oils, moisturisers, insect repellents, sun filters and a variety of other active ingredients, prolonging shelf life by trapping degradable active ingredients in the porous particle matrix (effectively shielding the active ingredient from bacteria, which are too big to enter particle pores)”⁴⁸. As indicated above, many of these products may not constitute microplastics that contribute to marine litter, but may be examples of synthetic polymers used more widely.

3.5 Paints/coatings

Tonnage

According to the response to the consultation from CEPE – the European industry association for the paint, printing ink and artists' colours industry – 220 tonnes of microplastics are used in the EU in this industry. This figure is based on the following definition of microplastics:

- ▶ A solid non-biodegradable polymeric particle with physical dimensions between 1µm - 5 mm originating from anthropogenic sources.

The full tonnage reported by CEPE in the consultation belongs to one product group: waterborne building paints for walls and ceilings. The total tonnage of the waterborne building paints containing microplastics (covered by the above definition) is reported to be at the most 14 000 tonnes with a total value of €24 million, which indicates an average microplastics content of 1.6% w/w in these paints. Furthermore, it is reported that less than 1% of waterborne building paints contain microplastics. The types of microplastics used are reported to be either microspheres of acrylic polymer of 5-80µm diameter, and/or fibres of polyamide or polyacrylonitrile of 4-50mm length and 10 µm diameter.

The Danish Environmental Protection Agency (2015)⁴⁹ estimated that the total content of microplastics in building paint sold in Denmark is 200-350 tonnes. This is based on the following definition:

- ▶ Persistent, solid particulates composed of synthetic or semi-synthetic polymers and physical dimensions of 1 µm - 5 mm originating from anthropogenic sources.

This definition appears mostly consistent with the definition used by CEPE, provided persistent refers to being non-bio-degradable, but suggests a much higher tonnage of microplastics in this sector. Assuming paints with the same microplastics content as in Denmark are sold EU-wide, the Danish Environmental Protection Agency (2015) results imply 22 000-38 000 tonnes of microplastics in building paint sold in the EU. Note this is a rough estimate obtained by extrapolating the Danish figure to the EU based on the sales quantities of paints, varnishes and similar coatings, printing ink and mastics.⁵⁰

⁴⁶ Only listed in Government of Canada (2015).

⁴⁷ Only listed in Government of Canada (2015).

⁴⁸ Leslie (2014), page 19.

⁴⁹ Denmark EPA (2015). Microplastics: Occurrence, effects and sources of releases to the environment in Denmark (Environmental project No. 1793, 2015).

⁵⁰ Extrapolation was done by dividing the Denmark EPA (2015) figures with Denmark's share of estimated sales quantities under NACE code 20.3 (paints, varnishes and similar coatings, printing ink and mastics) in the EU28. Sales quantities of products under the NACE

RIVM (2016)⁵¹ estimated that emissions of microplastics to surface water from paints in the building and shipping sector in the Netherlands amount to 330 tonnes. This is based on the following definition:

- ▶ Microplastics are solid, synthetic polymer particles with a size smaller than 5 mm, with a low solubility in water (<1mg/L) and a low degradation rate⁵². Microplastics may contain non-polymeric additives, oils, fillers or other product aids.

The total tonnage of microplastics used was not provided. Also, note that RIVM (2016) considers any paint particles as microplastics that have a backbone of polymers despite containing other ingredients. It is unclear if all of these particles fulfil the criteria of being intentionally added microplastics according to the definition of this study, e.g. because they may be formed from polymers that are not considered solid plastics when added to the product. Assuming paints with the same polymer content as in the Netherlands are used EU-wide, the RIVM (2016) results imply 9 000 tonnes of polymer-containing paint particles being emitted to surface water in the EU. Note this is a rough estimate obtained by extrapolating the Dutch figure to the EU based on the sales quantities of paints, varnishes and similar coatings, printing ink and mastics.⁵³

According to Eunomia (2016)⁵⁴, an estimated 25% of marine paint (equivalent to about 14 000 tonnes)⁵⁵ and 25% of construction, buildings and road paint (equivalent to about 870 000 tonnes)⁵⁶ consist of polymers; these polymers are an integral part of many paints. However, it is unknown how much of this polymer content (if any) refers to intentionally added microplastics.

Note that there is also ongoing work under the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic to quantify tonnes of microplastics discharged by OSPAR contracting parties. This was not available within the timescales for the present study.

To put these tonnage estimates into context of the wider sector, it is estimated that the total European paints and coatings market comprises around 6 million tonnes worth some €20 billion⁵⁷ per year. According to Eurostat data, an estimated 14 million tonnes of paints, varnishes and similar coatings, printing ink and mastics are sold in the EU28⁵⁸, generating turnover of €39.7 billion⁵⁹. The table below shows, that the share of the paints and coatings on the European market that contain microplastics (assuming tonnage and value of products containing microplastics according to CEPE) is far below 1%, both in terms of turnover and tonnage.

code 20.3 are estimated from PRODCOM data (Eurostat: Sold production, exports and imports by PRODCOM list (NACE Rev. 2) - annual data [DS-066341]), by subtracting quantities of exports from production and adding imports.

⁵¹ Dutch National Institute for Public Health and the Environment (RIVM) (2016). Emission of microplastics and potential mitigation measures Abrasive cleaning agents, paints and tyre wear (RIVM Report 2016-0026), the Netherlands, 2016.

⁵² Defined as half-life with the following threshold values by compartment: Marine water < 60 days; Fresh or estuarine water <40 days; Marine sediment <180 days; Fresh or estuarine sediment <120 days; Soil <120 days.

⁵³ Extrapolation was done by dividing the RIVM (2016) figures with the Netherlands' share of estimated sales quantities under NACE code 20.3 (paints, varnishes and similar coatings, printing ink and mastics) in the EU28. Sales quantities of products under the NACE code 20.3 are estimated from PRODCOM data (Eurostat: Sold production, exports and imports by PRODCOM list (NACE Rev. 2) - annual data [DS-066341]), by subtracting quantities of exports from production and adding imports.

⁵⁴ Eunomia (2016). Study to support the development of measures to combat a range of marine litter sources. Report for the European Commission DG Environment. January 2016.

⁵⁵ According to Eunomia (2016), the marine paint market in the EU was 55,000 tonnes in 2002. Multiplying by 25% and rounding to two significant figures yields an estimated 14,000 tonnes of polymer content.

⁵⁶ According to Eunomia (2016), 3,465,000 tonnes of 'decorative' paint were sold in Europe in 2002. Multiplying by 25% and rounding to two significant figures yields an estimated 870,000 tonnes of polymer content.

⁵⁷ Vincentz Network (2014), available at <http://www.european-coatings.com/Markets-companies/Coatings-market/Global-demand-for-paint-coatings-to-reach-51.6-million-metric-tons#>. Note that value and tonnage were provided globally, but only tonnage was available for Europe, so value has been estimated by applying the global value per tonne with the European tonnage. Exchange rate used: €1=\$1.11 (2016 average exchange rate) according to the European Central Bank:

https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html.

⁵⁸ Sales quantities of products under the NACE code 20.3 (paints, varnishes and similar coatings, printing ink and mastics) are estimated from PRODCOM data (Eurostat: Sold production, exports and imports by PRODCOM list (NACE Rev. 2) - annual data [DS-066341]), by subtracting quantities of exports from production and adding imports.

⁵⁹ Turnover under the NACE code 20.3 in the EU28 in 2015 (Eurostat: Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) [sbs_na_ind_r2])

Table 3.4 Share of the wider European market for paints and coatings containing microplastics (according to CEPE consultation response)

	Waterborne building paints containing microplastics	European paints and coatings market (Vincentz Network)	EU28 paints, varnishes and similar coatings, printing ink and mastics market (Eurostat)
Tonnes	14 000	6 000 000	14 000 000
Share of market containing microplastics		0.23%	0.10%
€ million turnover	24	20 000	39 700
Share of market containing microplastics		0.12%	0.06%

Note:

The share of the market containing microplastics refers to the tonnes or turnover of paints containing microplastics according to the CEPE response as share of the tonnes or turnover of the wider market, according to the two different sources (businesswire, Eurostat).

Sources:

CEPE response to Amec Foster Wheeler targeted stakeholder consultation February-April 2017.

Vincentz Network (2014), available at <http://www.european-coatings.com/Markets-companies/Coatings-market/Global-demand-for-paint-coatings-to-reach-51.6-million-metric-tons#>.

Eurostat: Sold production, exports and imports by PRODCOM list (NACE Rev. 2) - annual data [DS-066341]; and Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) [sbs_na_ind_r2].

In conclusion, 220 tonnes of solid non-biodegradable polymeric particle with physical dimensions between 1µ - 5 mm originating from anthropogenic sources in waterborne building paints for walls and ceilings as indicated by CEPE is the only reliable quantitative estimate of the tonnage of intentionally added microplastics in the sector for Europe. However, other sources suggest that the tonnage of intentionally added microplastics in paints/coatings be might be significantly higher.

Uses/product groups identified

The following types of paints using intentionally added microplastics have been identified:

- ▶ (Waterborne) building paints, as quoted by CEPE and the Danish Environmental Protection Agency (2015) and discussed above.
- ▶ Marine paint and marine coatings. According to Boucher and Friot (2017)⁶⁰, several types of plastics including polyurethane and epoxy coatings, vinyl and lacquers are used in this product group. Eunomia (2016) also states that some 25% of marine paints are polymers. However, it is not clear how much of the plastics/polymers used (if any) constitute intentionally added microplastics⁶¹.
- ▶ Mepex (2014)⁶² and The Danish Environmental Protection Agency (2015)⁶³ mention the use of microplastics in anti-skid powder and printer toner, adding that printer toner contains styreneacrylate copolymer particles of about 2- 10 µm. No further detailed information was available for further analysis.

Function of microplastics in products

The following functions that intentionally added microplastics fulfil in paint products have been identified.

⁶⁰ Boucher, J. and Friot D. (2017). Primary Microplastics in the Oceans: A Global Evaluation of Sources. Gland, Switzerland: IUCN. 43pp. Available at www.iucn.org/resources/publications.

⁶¹ I.e. if these plastics are added as solid particles to the paint, or if they only form microplastics in the process of weathering of the paints/coatings in situ, which is in the scope of the parallel study on 'Investigating options for reducing releases in the aquatic environment of microplastics emitted by (but not intentionally added in) products'.

⁶² Sundt, P., Schulze, P. and Syversen, F. (2014). Sources of microplastics-pollution to the marine environment. Mepex report for the Norwegian Environment Agency. Available at <http://www.miljodirektoratet.no/Documents/publikasjoner/M321/M321.pdf>

⁶³ Denmark EPA (2015). Microplastics: Occurrence, effects and sources of releases to the environment in Denmark (Environmental project No. 1793, 2015).

According to the response to the consultation from CEPE, microspheres improve the ease of paint application, allow for thicker layers, and provide unique dried paint properties like elasticity and scratch resistance.

CEPE's response also states that microfibrils are added to paints for toughness and resistance against cracks.

The Danish Environmental Protection Agency (2015) quotes the following functions that intentionally added microplastics fulfil in paints:

- ▶ To provide surface effects (such as matting effects) or as a colour enhancer.
- ▶ To decrease the density of the paints.
- ▶ Pigments extenders/spacers (titanium oxide spacers).
- ▶ To improve the hardness and provide greater durability and scratch resistance.
- ▶ To apply structure (mainly waxes are used for this application).
- ▶ To provide "pop-up" effects.
- ▶ To provide glitter effects (similar applications in cosmetics and inks for textiles).

3.6 Detergents

Tonnage

According to the response to the consultation from AISE – the International Association for Soaps, Detergents and Maintenance Products – 142 tonnes of (intentionally added) microplastics are used in the EU in their industry. This figure is based on the following definition of microplastics:

- ▶ Microplastics: water insoluble solid plastic particles with a size less than 5mm that can be found as marine litter. Plastic: synthetic water insoluble polymers that can be repeatedly molded, extruded or physically manipulated into various solid forms which retain their defined shapes in their intended applications during their use and disposal.

The total tonnage of the products in this sector containing microplastics (covered by the above definition) is reported to be 3 572 tonnes, which indicates an average microplastics content of 4.0% w/w in these products. This reflects responses from companies that account for about 70-75% of the total EU market. Microplastics cover about 0.001 % of total production of AISE members (11.4 million of tonnes per year)⁶⁴. However, information on what proportion of the total products sold contain microplastics was not available for the majority of the market. According to the AISE response, the use of microplastics is decreasing with several of companies having announced their intention to reformulate their products with alternative materials to achieve more environmentally friendly products.

Extrapolating the AISE response to the whole sector on the basis that the responding AISE members account for about 70-75% of the total EU market yields an estimated 190-200 tonnes of intentionally added microplastics⁶⁵.

The types of microplastics used in the products in this sector are listed by product in the section below.

Two estimates of tonnage of microplastics in detergents have been identified in the literature. The German Federal Environment Agency (2015)⁶⁶ estimates that in Germany considerably less than 100 tonnes per year

⁶⁴ A.I.S.E. Activity & sustainability report 2015-2016. Available at https://www.aise.eu/documents/document/20160919160236-aise_ar15-16_v24_final.pdf

⁶⁵ Share of the total EU market according to the AISE response to the consultation in this project. Results are rounded to the closest 10 tonnes.

⁶⁶ Essel R., et al. (2015). Sources of microplastics relevant to marine protection in Germany. Federal Environment Agency. Available at <https://www.umweltbundesamt.de/en/publikationen/sources-of-microplastics-relevant-to-marine>

of microplastics are used in detergents, cleaning and maintenance products for commercial and industrial use⁶⁷. This figure is based on the following definition of microplastics:

- ▶ Non-degradable and water-insoluble solid plastic particles with a diameter of more than 1 micrometre and less than 5 millimetres.

This definition appears mostly consistent with the definition used by AISE, except that it sets a lower size limit and thus could refer to a subset of the AISE definition. Assuming detergents, cleaning and maintenance products with the same microplastics content as in Germany are sold EU-wide, the German Federal Environment Agency (2015) results imply considerably less than 500 tonnes of microplastics in detergents, cleaning and maintenance products for commercial and industrial use used in the EU. Note this is a rough estimate obtained by extrapolating the German figure to the EU based on the sales quantities of soap and detergents, cleaning and polishing preparations⁶⁸. The estimate is roughly consistent with the AISE response.

RIVM (2016)⁶⁹ estimated that 2.6 tonnes of microplastics⁷⁰ are used in abrasive cleaning products in the Netherlands. Extrapolating the RIVM (2016) results using the same assumptions as the extrapolation of the German Federal Environment Agency (2015) above, yields an estimate of about 50 tonnes of microplastics in abrasive cleaning products used in the EU. This is lower than the tonnage suggested by the AISE response.

Note that there is also ongoing work under the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic to quantify tonnes of microplastics discharged by OSPAR contracting parties. This was not available within the timescales for the present study.

To put these tonnage estimates into context of the wider sector, it is estimated that some 16 million tonnes of soap and detergents, cleaning and polishing preparations are sold in the EU28⁷¹, generating turnover of €26.9 billion⁷². The total European household care and professional cleaning and hygiene market is worth around €35.7 billion.⁷³ The share of the quantity of soaps, detergents and maintenance products on the EU market that contain microplastics (assuming tonnage of products containing microplastics according to AISE, extrapolated to the whole sector⁷⁴) is about 0.03%.

In conclusion, it is estimated that at least some 190-200 tonnes of particles with a size less than 5mm of synthetic water insoluble polymers (that can be repeatedly moulded, extruded or physically manipulated into various solid forms which retain their defined shapes in their intended applications during their use and disposal) are used per year in soaps, detergents and maintenance products in the EU.

⁶⁷ Note that a reply of the German government to a question by Members of Parliament (<http://dip21.bundestag.de/dip21/btd/18/107/1810740.pdf>) mentions 50 tonnes per year as ingredients in cleaning products used in private households, plus 10 tonnes of microplastics in commercial cleaning products, quoting the German version of the same German Federal Environment Agency (2015) study. Note that the study in question concludes “considerably less than 100 tonnes per year” are used in detergents, cleaning and maintenance products for commercial and industrial use (rounded from an initial estimate of 10 tonnes). The 50 tonnes figure for household use quoted in the Government reply could not be identified in the study, which concluded “There is currently no robust data on the quantities of microplastics used in detergents, cleaning and maintenance products for floors in private households.”

⁶⁸ Extrapolation was done by dividing the Federal Environment Agency (2015) figures with Germany’s share of estimated sales quantities under NACE code 20.41 (soap and detergents, cleaning and polishing preparations) in the EU28. Sales quantities of products under the NACE code 20.41 are estimated from PRODCOM data (Eurostat: Sold production, exports and imports by PRODCOM list (NACE Rev. 2) - annual data [DS-066341]), by subtracting quantities of exports from production and adding imports.

⁶⁹ Dutch National Institute for Public Health and the Environment (RIVM) (2016). Emission of microplastics and potential mitigation measures Abrasive cleaning agents, paints and tyre wear (RIVM Report 2016-0026), the Netherlands, 2016.

⁷⁰ This is based on the following definition: Microplastics are solid, synthetic polymer particles with a size smaller than 5 mm, with a low solubility in water (<1mg/L) and a low degradation rate⁷⁰. Microplastics may contain non-polymeric additives, oils, fillers or other product aids.

⁷¹ Sales quantities of products under the NACE code 20.41 Soap and detergents, cleaning and polishing preparations are estimated from PRODCOM data (Eurostat: Sold production, exports and imports by PRODCOM list (NACE Rev. 2) - annual data [DS-066341]), by subtracting quantities of exports from production and adding imports.

⁷² Turnover under the NACE code 20.41 in the EU28 in 2015 (Eurostat: Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) [sbs_na_ind_r2])

⁷³ <https://www.aise.eu/our-industry/market-and-economic-data.aspx>

⁷⁴ On the basis that the responding AISE members account for about 70-75% of the total EU market, the total tonnage of the products in this sector containing microplastics is estimated as ca. 5,000 tonnes (extrapolated from 3,572 tonnes of products of AISE members).

Uses/product groups identified

The following types of detergents using intentionally added microplastics have been identified in AISE's response.

Table 3.5 Soaps, detergents and maintenance products containing microplastics

Product category	Total quantity of microplastics present in the product category (tonnes)	Total quantity of products containing microplastics in the product category (tonnes)	Proportion of the total market of this product category containing microplastics (%)	Types of microplastics added (material/substance, particle shape and size)
Hard surface cleaner (Glass ceramic cleaner)	126	2 592	Data not available	Polyurethane CAS No. 9009-54-5 fine powder < 600 µm
Toilet cleaners (WC blocks)	12	797	9.5	Polyester/polyamide, Acrylic, PMMA, PET glitters
Stainless steel cleaner	3.5	176	Data not available	Polyurethane CAS:9009-54-5, <600µm
Other (Oven cleaner, laundry stain remover)	0.05	7.1	100	Rheology modifiers
Bathroom acid cleaner	Data not available	Data not available	Data not available	Polyethylene particles' size 200 - 320 µm
TOTAL	142	3 572	Data not available	

Source: AISE response to Amec Foster Wheeler targeted stakeholder consultation February-April 2017.

As shown in Table 3.5, the product category "hard surface cleaner (glass ceramic cleaner)" accounts for the vast majority of microplastics reported in this industry. It is reported that these products contain on average 4.9% w/w of fine polyurethane (CAS No. 9009-54-5) powder with particle sizes below 600µm.

The literature reviewed also mentions floor cleaning/maintenance products, as well as products for wood polishing as products that may contain microplastics. According to the German Federal Environment Agency (2015), German manufacturers of care and maintenance products use around 10 tonnes of emulsions which contain microparticles of polyethylene waxes in floor maintenance products. RIVM (2016)⁷⁵ identified, in a screening of over 400 products, eight products for floor cleaning and two products for wood polishing that contain ingredients that may be considered as microplastics.

Function of microplastics in products

The following functions that intentionally added microplastics fulfil in paint products have been identified.

According to the response to the consultation from AISE, polyurethane particles are used for gentle cleaning of hard surfaces such as ceramic/glass surface cleaners. A full overview of the function provided by microplastics in each of the product categories according to the AISE response is provided below:

- ▶ Hard surface cleaner (glass ceramic cleaner): Scrubbing/abrasive agent for ceramic hob cleaning. Cleaning without damaging.
- ▶ Toilet cleaners: Block cohesion improvement, aesthetics.
- ▶ Stainless steel cleaner: Abrasive agent.
- ▶ Other (oven cleaner, laundry stain remover): Rheology modifiers used to thicken the product.

⁷⁵ Dutch National Institute for Public Health and the Environment (RIVM) (2016). Emission of microplastics and potential mitigation measures Abrasive cleaning agents, paints and tyre wear. RIVM Report 2016-0026.

- ▶ Bathroom acid cleaner: Abrasive agent.

3.7 Oil and gas

Tonnage

No conclusive information on the tonnage of microplastics used in this sector was available.

An undated report with uncertain author⁷⁶ quotes a Cefas overview entitled “The discharge of plastic materials during offshore oil and gas operations”, which supposedly reports use of 532 tonnes of plastics (of which 496 tonnes in drilling, 36 tonnes in production and 3 tonnes in pipeline) and 7 475 tonnes of “possible plastics” in UK offshore oil installations in 2013. However, due to the unknown source the credibility of this information is uncertain.

Some information was available on estimated releases of microplastics in the two predominant off-shore oil producing countries in Europe, Norway and the UK. Mepex 2016⁷⁷ reports that about 2 tonnes of microplastics were released in offshore oil drilling in Norway in 2015, according to Norwegian Environment Agency consultation with operators. However it was noted that discharges may be larger due to uncertainty among the operators about whether certain substances were included in the definition of microplastics. In its response to the consultation, the European Oilfield Speciality Chemicals Association (EOSCA) reported that that in total the discharge of plastic materials contained in offshore chemical products in was estimated as 159 tonnes in the UK in 2013, not all of which are microplastics.

Note that there is also ongoing work under the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic to quantify tonnes of microplastics discharged by OSPAR contracting parties. This was not available within the timescales for the present study but is understood to include estimates for releases from oil and gas.

In conclusion, there is some evidence that suggests the use of microplastics in offshore oil and gas could be substantial, in the magnitude of hundreds of tonnes. However, sufficient data was not available to make a precise quantitative estimate. It is therefore recommended that this potential source be kept under review.

Uses/product groups identified

According to Mepex (2014)⁷⁸ drilling fluids based on plastic microbeads, such as Teflon strengthened particles, are used in oil and gas exploration and other kinds of rock drilling.

In its response to the consultation, the European Oilfield Speciality Chemicals Association (EOSCA), has indicated that microplastics are used in the following applications in the oil and gas sector:

- ▶ Drilling: cement additives and loss circulation material.
- ▶ Production: wax inhibitors.
- ▶ Pipelines: crosslinking chemicals.

Function of microplastics in products

Information on the specific function of microplastics in the applications listed above was not available.

⁷⁶ Available at: <https://www.slideshare.net/TimGibson23/microplastics-report-64879266>. Understood to have been written for IOGP.

⁷⁷ Sundt, P., Syversen, F., Skogesal, O. and Schulze, P. (2016). Primary microplastic-pollution: Measures and reduction potentials in Norway. Mepex report for the Norwegian Environment Agency. Available at <http://www.miljodirektoratet.no/Documents/publikasjoner/M545/M545.pdf>.

⁷⁸ Sundt, P., Schulze, P. and Syversen, F. (2014). Sources of microplastics-pollution to the marine environment. Mepex report for the Norwegian Environment Agency. Available at <http://www.miljodirektoratet.no/Documents/publikasjoner/M321/M321.pdf>

3.8 Agriculture

Tonnage

No response to the consultation was provided by industry associations in this sector that were contacted for this study.

Trenkel (2010)⁷⁹ reports the following tonnages for the consumption of polymer-based slow-and controlled-release fertilisers in “Western Europe” in 2005.

- ▶ Polymer coated fertilisers: 35 000 tonnes (of which coating material represents 3-15%).
- ▶ Sulphur-coated urea (SCU) / Polymer-coated sulphur-coated urea (PSCU): 5 000 tonnes (of which PSCU contains 2% polymer sealant)⁸⁰.

This yields an estimated 1 150-5 350 tonnes of polymers used in slow-and controlled-release fertilisers in Western Europe in 2005. According to Lubkowski (2012)⁸¹ it is expected that the production of slow/coated release fertilisers would increase by a factor of around 2 by 2020, so it seems reasonable to assume the above figures are higher today, at least by a factor of about 1.5, which uplifts the estimate to 1 725-8 025 tonnes. However, the estimate is associated with two main uncertainties: whether all of these polymers fulfil the definition of microplastics⁸², and the geographical scope of the data (“Western Europe”⁸³).

In conclusion, it is estimated that up to about 8 000 tonnes of polymers are used in slow-and controlled-release fertilisers in the EU. However, no sufficient information is available to estimate what share of these polymers constitute microplastics. This use would warrant further investigation.

Uses/product groups identified

According to GESAMP (2015)⁸⁴, the main use of intentionally added microplastics in agriculture are nutrient prills for controlled-release fertilisers. These prills are a coating often composed of a polymer such as polysulfone, polyacrylonitrile or cellulose acetate, which encapsulates nutrient combinations for fertilisation. As discussed above, Trenkel (2010) suggests that polymer-based slow-and controlled-release fertilisers can be broken down into Polymer coated fertilisers and polymer-coated sulphur-coated urea.

According to Ekebafé et al. (2011)⁸⁵, particles of synthetic polymers that potentially constitute microplastics are used also in the following additional agricultural applications:

- ▶ Polymeric biocides, herbicides and molluscicides: as rate controlling devices, combining the biological agents with the polymeric materials by encapsulation or heterogeneous dispersion, or as carrier for the agent by chemical combination.

⁷⁹ Trenkel, M. E. (2010). Slow-and controlled-release and stabilized fertilizers: An option for enhancing nutrient use efficiency in agriculture. IFA, International fertilizer industry association. Available at: http://www.fertilizer.org/imis20/images/Library_Downloads/2010_Trenkel_slow%20release%20book.pdf?WebsiteKey=411e9724-4bda-422f-abfc-8152ed74f306&=404%3bhttp%3a%2f%2fwww.fertilizer.org%3a80%2fen%2fimages%2fLibrary_Downloads%2f2010_Trenkel_slow+rele ase+book.pdf

⁸⁰ Note that only PSCU contain polymers, SCU don't. However, tonnage data refers to 2004/2005 and the source indicates that PSCU is increasingly replacing SCU, so for the purpose of estimating the tonnage of polymers used today it is assumed that this whole category consists of mostly PSCUs and contains 2% of polymer sealant.

⁸¹ Lubkowski, K. (2014). Coating fertilizer granules with biodegradable materials for controlled fertiliser. Environmental Engineering & Management Journal (EEMJ), 13(10). Available at: http://www.eemj.icpm.tuiasi.ro/pdfs/vol13/no10/Full/17_9_Lubkowski_12.pdf

⁸² Trenkel (2010) notes that polymer coatings can consist of thermoplastics or resins. No information on size distribution is provided.

⁸³ The term is not defined in Trenkel (2010), but companies from Germany, Italy and Norway are named as manufacturers from “Western Europe”, suggesting it may refer to at least the European Economic Area.

⁸⁴ GESAMP (2015). “Sources, fate and effects of microplastics in the marine environment: a global assessment” (Kershaw, P. J., ed.). (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Rep. Stud. GESAMP No. 90, 96 p.

⁸⁵ L. O. Ekebafé, D. E. Ogbefun, F. E. Okieimen (2011). Polymer Applications in Agriculture. Biokemistri 23, p.81-89.

- ▶ Water absorbents: lightly cross-linked networks of hydrophilic polymer chains that absorb water and swell to many times their original size and weight; or small dry crystals that absorb water similar to sponges made of gel-forming polymers or insoluble water-absorbing polymers⁸⁶.
- ▶ Water-soluble polymers for soil remediation.
- ▶ Drag-reducing polymers: Large polymer molecules, fibres or particles used in sprinkler irrigation systems.

Function of microplastics in products

The following functions that intentionally added microplastics fulfil in agriculture products have been identified.

According to GESAMP (2015), nutrient prills ensure the fertiliser diffuses into the soil over predetermined time periods of 3 to 18 months to offer a continuous nutrient supply to the plant roots. This enables a reduction of the quantity of fertiliser needed per unit area of cropland (also reducing the associated environmental impacts), as well as reducing time spent in fertilisation efforts.

Ekebafé et al. (2011) quotes the following functions of synthetic polymer particles in agricultural applications:

- ▶ Polymeric biocides, herbicides and molluscicides: “to protect the supply of the agent, to allow the automatic release of the agent to the target at controlled rates, and to maintain its concentration within the optimum limits over a specified period of time, thereby producing a great specificity and persistence.”
- ▶ Water absorbents: hold a large amount of water while maintaining the physical dimension structure, increasing water use efficiency, reducing irrigation frequency and enhancing soil permeability and infiltration rates, stopping erosion and water run-off.
- ▶ Polymers for soil remediation: Removal or recovery of metal ions from aqueous solutions.
- ▶ Drag-reducing polymers in a fluid cause reduction in the friction resistance in a turbulent flow compared to that of the fluid alone, reducing the energy requirements of sprinkler irrigation systems.

3.9 Industrial abrasives

Tonnage

No information on the tonnage of microplastics used in this sector was provided by the consulted industry association (FEPA – the Federation of European Producers of Abrasives).

The Danish Environmental Protection Agency (2015)⁸⁷ estimated that the consumption of microplastics⁸⁸ for use in sandblasting in Denmark is in the range of 5-25 tonnes per year. Assuming abrasives with the same microplastics content as in Denmark are sold EU-wide, the Danish Environmental Protection Agency (2015) results imply some 1 000-5 000 tonnes of microplastics used in sandblasting sold in the EU. Note this is a rough estimate obtained by extrapolating the Danish figure to the EU based on the sales quantity of abrasive products⁸⁹.

⁸⁶ The main types of hydrogels used are reportedly: (1) starch-graft copolymers obtained by graft polymerization of polyacrylonitrile onto starch followed by saponification of the acrylonitrile units, (2) cross-linked polyacrylates, or (3) cross-linked polyacrylamides and cross-linked acrylamide-acrylate copolymers containing a major percentage of acrylamide units (most used).

⁸⁷ Denmark EPA (2015). Microplastics: Occurrence, effects and sources of releases to the environment in Denmark (Environmental project No. 1793, 2015).

⁸⁸ As previous figures quoted from the Danish Environmental Protection Agency (2015), this is based on the following definition: Persistent, solid particulates composed of synthetic or semi-synthetic polymers and physical dimensions of 1 µm - 5 mm originating from anthropogenic sources.

⁸⁹ Extrapolation was done by dividing the Denmark EPA (2015) figures with Denmark's share of estimated sales quantities under NACE code 23.91 (abrasive products) in the EU28. Sales quantities of products under the NACE code 23.91 are estimated from PRODCOM

However, as shown below, other uses of microplastics (i.e. additionally to that covered by Danish Environmental Protection Agency (2015)) are reported by other sources, so the total tonnage of microplastics in this sector could be higher.

To put these tonnage estimates into context of the wider sector, it is estimated that the total European market for abrasive raw materials which are consumed in bonded and coated abrasive products and loose abrasives, comprises around 200 000 tonnes⁹⁰. According to Eurostat data, an estimated 500 000 tonnes of abrasive products are sold in the EU28⁹¹, generating turnover of €3.7 billion⁹².

In conclusion, the tonnage of microplastics used in industrial abrasives in the EU is very uncertain. Based on extrapolation from a Danish estimate, subject to high uncertainty, it is estimated that some 1 000-5 000 tonnes of microplastics could be used in sandblasting. Additional uses of microplastics are suspected in this sector for which no information on tonnage was available.

Uses/product groups identified

According to the response to the consultation from FEPA materials that potentially fulfil the definition of microplastics are used in the production of abrasives, but are not expected to be present in the final products, as they are either burned or cross-linked into a homogenous bond during the production process. Specifically, the following uses are reported:

- ▶ Inorganic bonded abrasives: Microplastics (e.g. PMMA) might be used as pore forming agents, but are reportedly completely burned during the firing process.
- ▶ Organic bonded abrasives / coated abrasives: Different types of resins (e.g. phenol-formaldehyde resins) and rubber particles that potentially constitute microplastics depending on the particle size and physical state of the used product (powder / liquid) are used in these abrasives as bond or as part of the bonding system. However, it is reported that as a bonding system or part of the bonding systems they are cross-linked during the production process and thus only a homogenous bond is present in the final product.
- ▶ Cut-off and grinding wheels: Sometimes polyethylene ($\varnothing < 0.5$ mm) is used as technical filler.

Cole, M., et al. (2011)⁹³ also reports microplastics use in airblasting technology, including blasting acrylic, melamine or polyester microplastic scrubbers at machinery, engines and boat hulls to remove rust and paint. Mepex (2014)⁹⁴ reports the use of microplastics as abrasive blasting media in Norway, particularly for surface cleaning and in some mechanical workshops in cases where it is important that the blasting media does not damage the surface of the treated item. Government of Canada (2015)⁹⁵ states that microbeads are used as abrasive media such as plastic blasting at shipyards.

The Danish Environmental Protection Agency (2015) registered use of microplastics in sandblasting, as discussed above (tonnage). Sandblasting solutions using microplastics as abrasive material were reported to be used in the following application areas in Denmark: building sanitation (e.g. removal of PCB), removal of paint from airplanes, cleansing of airplane wheel rims, cleansing of moulds used in the manufacture of plastics or rubber, cleansing of tanks used in the off-shore industry and in the marine industry, cleansing aboard ships, cleansing of turbine blades at power plants, trimming of Bakelite materials and removal of graffiti from walls.

data (Eurostat: Sold production, exports and imports by PRODCOM list (NACE Rev. 2) - annual data [DS-066341]), by subtracting quantities of exports from production and adding imports.

⁹⁰ <http://www.businesswire.com/news/home/20100330005726/en/Research-Markets-Abrasives-Industry-Europe-North-America>

⁹¹ Sales quantities of products under the NACE code 23.71 Abrasive products are estimated from PRODCOM data (Eurostat: Sold production, exports and imports by PRODCOM list (NACE Rev. 2) - annual data [DS-066341]), by subtracting quantities of exports from production and adding imports.

⁹² Turnover under the NACE code 23.91 in the EU28 in 2015 (Eurostat: Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) [sbs_na_ind_r2])

⁹³ Cole, M., et al. (2011). Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin. Vol 62 Is 12. Pages 2588–2597. December 2011.

⁹⁴ Sundt, P., Schulze, P. and Syversen, F. (2014). Sources of microplastics-pollution to the marine environment. Mepex report for the Norwegian Environment Agency. Available at <http://www.miljodirektoratet.no/Documents/publikasjoner/M321/M321.pdf>

⁹⁵ Government of Canada (2015). Microbeads – A Science Summary. Environment and Climate Change, Government of Canada. http://www.ec.gc.ca/ese-ees/ADDA4C5F-F397-48D5-AD17-63F989EBD0E5/Microbeads_Science%20Summary_EN.pdf

Function of microplastics in products

According to the response to the consultation from FEPA, microplastics fulfil two main functions in the industrial abrasives industry:

- ▶ Microplastics (e.g. PMMA) form pores in bonded abrasives when burned during the firing process.
- ▶ Different types of resins (e.g. phenol-formaldehyde resins) form the bond or part of the bonding system in organic bonded or coated abrasives.
- ▶ Some of the resins have – apart from its bonding function – additional functions like increasing the hardness of the product.
- ▶ Polyethylene is used as technical filler to improve the tool performance of some cut-off and grinding wheels.

In the uses as a blasting abrasive for cleaning identified in the literature (Danish Environmental Protection Agency (2015) and Mepex (2014)), the primary function is abrasion and cleansing. More specifically, microplastics are reported to function as an alternative to harder, more aggressive blasting agents, in order to prevent damage to the surface of the treated or cleaned items.

3.10 Other uses

The following other potential sources of intentionally added microplastics in products have been identified in the literature review conducted for the market analysis, but no detailed information was available for further analysis:

- ▶ According to Cole, M., et al. (2011)⁹⁶ microplastics use in medicine as vectors for drugs is increasingly reported. However, associations of the pharmaceutical and self-medication industries have indicated in their responses to the consultation that they believe microplastics are not used within their sectors in the EU⁹⁷.
- ▶ Government of Canada (2015)⁹⁸ quotes uses of microbeads in textile printing, automotive molding, anti-slip and anti-blocking applications, as well as biotechnology and biomedical research.
- ▶ Mepex (2014)⁹⁹ mentions the use of microplastics in dentist polish.
- ▶ Cornish Plastic Pollution Coalition (2017)¹⁰⁰ reports that plastic pellets sized 3.5 to 4mm across and marketed as Bio-Beads¹⁰¹ are used as part of the filtration process in some wastewater treatment plants, and have been released to the environment in spills in Cornwall. According to personal communication with EurEau, the European industry association of drinking water and waste water service operators, these Bio-Beads constitute microplastics and it was confirmed that they are used in some wastewater treatment plants, though their release is not intended during normal operation. The extent to which Bio-Beads are used across Europe is not known at this point. Given the above, microplastics used in wastewater treatment filtration processes

⁹⁶ Cole, M., et al. (2011). Microplastics as contaminants in the marine environment: A review. *Marine Pollution Bulletin*. Vol 62 Is 12. Pages 2588–2597. December 2011.

⁹⁷ EFPIA (pharmaceutical industry) stated "Member companies are only marginally effected". AESGP (self-medication industry, i.e. non-prescription medicines, food supplements and self-care medical devices) stated they believe their sector "is not a user of intentionally added microplastics".

⁹⁸ Government of Canada (2015). Microbeads – A Science Summary. Environment and Climate Change, Government of Canada. http://www.ec.gc.ca/ese-ees/ADDA4C5F-F397-48D5-AD17-63F989EBD0E5/Microbeads_Science%20Summary_EN.pdf

⁹⁹ Sundt, P., Schulze, P. and Syversen, F. (2014). Sources of microplastics-pollution to the marine environment. Mepex report for the Norwegian Environment Agency. Available at <http://www.miljodirektoratet.no/Documents/publikasjoner/M321/M321.pdf>

¹⁰⁰ Cornish Plastic Pollution Coalition (October 2017): Biobead pollution on our beaches. What we know so far...

<http://www.ramepbc.org/Biobead%20pollution%20on%20our%20beaches.%20CPPC.%20October%202017.pdf>

¹⁰¹ See also manufacturer's website: <http://www.fliewater.com/our-solutions/services/brightwatertm-baff%C2%AE-biological-aerated-flooded-filter>

are an area that requires further data collection and analysis. This report was only available shortly before submission of the present report.

- ▶ According to the Danish Environmental Protection Agency (2015)¹⁰², expanded polystyrene (EPS) is used in construction (wall insulation), packaging, furniture (beanbags), pillows and a few other unspecified applications. GESAMP (2015)¹⁰³, furthermore mentions the use of EPS in cool boxes, floats and cups, as well as buoys for mariculture/aquaculture.

In 2010, total consumption of EPS in Europe was about 1.6 million tonnes, of which 77% was used in building insulation, 21% in packaging, and 2% in other applications¹⁰⁴. While the majority of EPS is formed into blocks or shape moulded, a small portion is used as pellets of typically 1-5 mm diameter, without being formed into blocks, according to Danish Environmental Protection Agency (2015). Thus, in applications where they are not formed into blocks, these EPS pellets constitute intentionally added microplastics. While no literature was available to that effect, it is assumed that potentially at least a portion of each of the above applications contains EPS pellets as intentionally added microplastics. However, in construction which accounts for the vast majority of EPS used, it appears likely that EPS is mostly formed into blocks and thus is not an intentionally added microplastic use¹⁰⁵.

Note also that raw materials for plastics production (plastic pellets); rubber powder and granules for artificial turfs and other applications are identified in the literature (e.g. Danish Environmental Protection Agency (2015), Boucher and Friot (2017)¹⁰⁶, Cole, M., et al. (2011)) as a potential source of microplastics. These are covered in the parallel study on 'Investigating options for reducing releases in the aquatic environment of microplastics emitted by (but not intentionally added in) products'.

3.11 Conclusions

There are significant gaps in the literature, particularly regarding estimates of the quantities of microplastics used in the EU. Only some industry associations were able to provide data on uses of microplastics. **This does not imply that the sectors where quantitative data are available are those with the most significant uses.** Also, the complete lack of quantitative information for some sectors makes it impossible to estimate the overall tonnage of intentionally added microplastics used in the EU across all sectors. Furthermore, it is important to note that most estimates of quantities of microplastics based on the literature are extrapolated from national estimate and therefore associated with high uncertainty. Hence, estimates for some sectors are higher, but less reliable than those for other sectors, further limiting judgement on which uses are most significant. Lastly, it is important to note that even though efforts have been made to identify all significant sources of intentionally added microplastics, **it cannot be guaranteed that all relevant sources are covered, and thus it cannot be ruled out that further sources exist.**

With the above caveats in mind, Table 3.6 below provides an overview of the estimated quantities of microplastics used by sector. Key conclusions are presented below:

- ▶ Of the sectors for which information was available, **personal care products** exhibit the highest confirmed (with reasonable certainty) tonnage with 714-793 tonnes per year in the EU of plastic microbeads (<5mm) used to exfoliate and cleanse in rinse-off products, and in the order of 540-1 120 tonnes of microplastics (solid insoluble non-degrading plastic particles <5mm) used in leave on products. It is worth noting that the use of plastic microbeads used to exfoliate and cleanse in rinse-off products has reduced in recent years and is expected to decrease further due to voluntary industry action.

¹⁰² Denmark EPA (2015). Microplastics: Occurrence, effects and sources of releases to the environment in Denmark (Environmental project No. 1793, 2015).

¹⁰³ GESAMP (2015). "Sources, fate and effects of microplastics in the marine environment: a global assessment" (Kershaw, P. J., ed.). (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Rep. Stud. GESAMP No. 90, 96 p.

¹⁰⁴ European Manufacturers of Expanded Polystyrene (EUMEPS): <http://www.eumeps.construction/show.php?ID=4750&psid=hmotjteo>.

¹⁰⁵ Considering that in most construction applications, EPS blocks appear to be used according to European Manufacturers of Expanded Polystyrene (EUMEPS): <http://www.eumeps.construction/show.php?ID=4750&psid=hmotjteo>.

¹⁰⁶ Boucher, J. and Friot D. (2017). Primary Microplastics in the Oceans: A Global Evaluation of Sources. Gland, Switzerland: IUCN. 43pp. Available at www.iucn.org/resources/publications.

- ▶ **Paints and coatings** can be considered a significant use with 220 tonnes of microplastics use indicated in the consultation, which can be considered a reliable lower end estimate. Other sources indicate that the tonnage could be significantly higher, but this is subject to high uncertainty (due to either extrapolation or uncertainty over whether items fulfil the definition of intentionally added microplastics).
- ▶ For **detergents** consultation has indicated that some 190-200 tonnes of microplastics are used in the sector, which is considered a reliable estimate given that no other sources suggest a significantly higher tonnage.
- ▶ Based on one estimate, subject to high uncertainty (due to extrapolation), use of microplastics as **industrial abrasives** could be as high as 1 000-5 000 tonnes (sandblasting). However, information provided by the industry in the consultation does not confirm the use of microplastics for sandblasting and claims that, in its main applications in this sector, microplastics are not present in the final product as they are either cross-linked or burned during the production process.
- ▶ In all of the above sectors, the tonnage of microplastics accounts for a very small share of the tonnage of products sold in the whole sector.
- ▶ Use of microplastics in **oil and gas** specialty chemicals has been confirmed by the industry in the consultation, but no quantitative estimates were available. There is some evidence that suggests the use of microplastics in offshore oil and gas could be substantial, in the magnitude of hundreds of tonnes.
- ▶ In agriculture, it is estimated that up to about 8 000 tonnes of polymers are used in slow-and controlled-release fertilisers in the EU. However, no sufficient information was available to estimate what share of these polymers constitute microplastics.
- ▶ **For other uses** indicated in the literature no quantitative estimates were available. These uses require further data collection and analysis.

Table 3.6 also provides, where available, quantities of products containing microplastics and the concentration of microplastics therein. These are key inputs to the risk assessment.

It is worth noting that no organisation was able to provide information in the consultation within the timescales of the project according to the “working definition” for the project. Indeed, several organisations questioned this definition as being too broad to be workable. It is therefore not practicable to provide any quantitative information on the market based on the broad working definition. Consideration of a narrower definition might therefore be necessary if a more robust basis for decision making is needed, at least in the shorter term.

Table 3.6 Sector-level overview of tonnages and concentrations of microplastics in products

Sector	Product	Total tonnage of microplastics used by the sector in the EU (estimate based on consultation and literature)	Total tonnage of products containing microplastics sold by the sector in the EU	Concentration of microplastics in products that contain microplastics
Personal care	Rinse-off products containing exfoliating and cleansing microbeads (as indicated by Cosmetics Europe) Further product breakdown available (see Appendix B).	714-793 tonnes (exfoliating and cleansing microbeads in rinse-off products)	Unknown. It is estimated based on Eurostat data that the total European market for personal care products (with and without microplastics) comprises around 3-5 million tonnes in the EU28.	Unknown
	Leave on PCPs containing microplastics (as indicated by Cosmetics Europe in reaction to estimates from Eunomia 2016)	540-1 120 tonnes (Synthetic polymers and/or copolymers (plastics); Solid phase materials (particulates, not liquids); Insoluble in water; Non-degradable; and small size (maximum 5 mm, no lower size limit is defined)).	1.5 million according to Eunomia (2016)	Weighted average calculated from Eunomia (2016): 2.4% Range 0.005%-72% according to Eunomia (2016)
Paints/coatings	Waterborne building paints (as indicated by CEPE)	220 tonnes (Solid non-biodegradable polymeric particles with physical dimensions between 1µ - 5 mm originating from anthropogenic sources)	14 000 tonnes	Weighted average 1.6% w/w. Range approximately 1%-2%.
	All other	Other sources suggest it could be significantly higher, but estimates are very uncertain. Extrapolation from Danish Environmental Protection Agency (2015) (200-350 tonnes of microplastics in building paint sold in Denmark) suggests 22 000-38 000 tonnes.	Unknown. According to Eurostat data, an estimated 14 million tonnes of paints, varnishes and similar coatings, printing ink and mastics (with and without microplastics) are sold in the EU28.	0.4% in building paint sold in Denmark according to Danish Environmental Protection Agency. Unknown for other products.
Detergents	Soaps, Detergents and Maintenance Products Further product breakdown available (see Appendix B).	190-200 tonnes (water insoluble solid plastic particles with a size less than 5mm that can be found as marine litter) suggested by AISE is not contradicted by literature.	3 572 tonnes	Weighted average (all Soaps, Detergents and Maintenance Products): 4.0% Range (of weighted averages per product category): 0.7%-4.9%

Sector	Product	Total tonnage of microplastics used by the sector in the EU (estimate based on consultation and literature)	Total tonnage of products containing microplastics sold by the sector in the EU	Concentration of microplastics in products that contain microplastics
Abrasives	Sandblasting	Extrapolation from Danish Environmental Protection Agency (2015) (use in sandblasting in Denmark 5-25 tonnes) suggests 1 000-5 000 tonnes (Persistent, solid particulates composed of synthetic or semi-synthetic polymers and physical dimensions of 1 µm - 5 mm originating from anthropogenic sources), subject to <u>high uncertainty</u> .	Unknown. According to Eurostat data, an estimated 500 000 tonnes of abrasive products (with and without microplastics) are sold in the EU28.	Unknown
	Additional uses of microplastics are suspected in this sector for which no information on tonnage was available. Abrasives industry (FEPA) stated that in its main applications in this sector, microplastics are not present in the final product as they are either cross-linked (as part of the bonding systems) or burned (as technical filler) during the production process.	Unknown	Unknown. According to Eurostat data, an estimated 500 000 tonnes of abrasive products (with and without microplastics) are sold in the EU28.	Unknown
Oil and gas	Off-shore drilling and production	No precise quantitative estimate possible , but could be substantial (in the magnitude of hundreds of tonnes) according to some sources.	Unknown.	Unknown.
Agriculture	Nutrient prills / slow-and controlled-release fertilisers	Up to a maximum of about 8 000 tonnes (Trenkel 2010 suggests that 1 700-8 000 tonnes of polymers are used in these products in "Western Europe". no sufficient information is available to estimate what share of these polymers constitute microplastics in the EU)	Up to 40 000 tonnes according to Trenkel (2010) (refers to products containing polymers in "Western Europe").	Polymer coated fertilisers: up to 3-15% Sulphur-coated urea (SCU) / Polymer-coated sulphur-coated urea (PSCU): up to 2% According to Trenkel (2010), refers to polymers (an uncertain share of which constitute microplastics)
	All other	No quantitative estimate possible.		
Pharmaceutical industry		No quantitative estimate possible , but the industry claims no significant amounts of microplastics are used in the EU currently.		

Sector	Product	Total tonnage of microplastics used by the sector in the EU (estimate based on consultation and literature)	Total tonnage of products containing microplastics sold by the sector in the EU	Concentration of microplastics in products that contain microplastics
Water		No quantitative estimate possible , but the industry claims no significant amounts of microplastics are used in the EU currently.		

Source: Amec Foster Wheeler 2017, based on targeted stakeholder consultation February-April 2017, various literature and Eurostat data, as listed in detail in the previous chapters.

4 Risk assessment

4.1 Introduction and overview of approach

This section reports on Task 4 of the project: the environmental risk assessment of intentionally added microplastics.

The approach to the risk assessment has followed a framework similar to that used for chemical substances as far as possible. There are two main reasons for this:

1. The use of established methods for the assessment of exposure (e.g. environmental fate and distribution models, emission scenario documents, etc.) allows a good understanding of the methods applied, and that the information and techniques used have been subject to substantial review and regulatory scrutiny (i.e. the methods and information sources are accepted in the context of the risk assessment of chemicals).
2. Since the wider objective of the project is to assess if a restriction under the REACH Regulation is a feasible option to control the risk, and to-date restriction has been applied to specific chemical substances¹⁰⁷, using methods that are primarily aimed at the assessment of chemical substances (but can be adapted to assessing microplastics), it is appropriate to use the same methods for risk assessment because the risk outcomes can be clearly understood in the context of the REACH Regulation.

This section of the report describes the framework for the assessment, the analysis of data and the results of that analysis.

Note that changes were made to the data and assumptions in the risk assessment immediately prior to issuing this report (particularly improved estimates on microplastics use in certain sectors). The data presented in the main body of the report have been updated to reflect the new data but the data in the appendices have not yet been updated. The data in the appendices are therefore not yet consistent with the data in the main body of the report.

Approach – overview

This section gives an overview of the approach to the risk assessment indicating the key parts of the assessment. Further detail on the application of the approach to each part of the assessment is given in subsequent subsections (detailed information is presented in Appendix C and Appendix D to this report).

The focus of the risk assessment is the environment, including humans exposed via the environment. The methods applied follow the ECHA guidance as far as possible. A key feature of the assessment is that it takes account of the fact that microplastics are not substances as such, but particles (composed of polymers/resins) as defined in Task 2 (see section 2). Understanding is needed of the composition of microplastic beads and the possibility that residual monomer, and/or other additives and agents could be released from the particles themselves. It is equally important to understand the nature of the physical hazards that the microplastics present (both to aquatic organisms and to humans via the ingestion of food containing microplastics, in particular seafood).

The risk assessment has two sides: hazard and exposure. For this assessment, hazard has two aspects a) the physical hazard from the uptake of microplastics into organisms and b) possible toxic effects from the diffusion of either free monomer from the polymers that the microbeads are made from, and additives (including stabilisers, antioxidants, pigments etc., some of these may be added during the polymer processing stage, particularly if elevated temperatures are used), and/or substances that have been adsorbed onto or taken up into the microbeads (from products or from the environment).

For the exposure side, the principle of the assessment is similar to that used for chemical substances. It is based on understanding of the use pattern of products containing relevant microplastics and the concentration of beads in products, from which the amount (concentration) of microplastics entering the

¹⁰⁷ As opposed to plastic particles – which are a range of polymers of specific shape.

(aquatic) environment can be estimated. For that reason, the approach relies on the use of European Union System for the Evaluation of Substances (EUSES) model for the estimation of the fate and distribution of microplastic beads in the environment.

The EUSES model has been a standard tool for the environmental risk assessment for many years. It was developed by the EC JRC, prior to REACH and has been used by MSCAs and the EC for environmental risk assessment of chemicals. EUSES continues to be a recognised and standard tool for environmental risk assessment of chemicals and biocides within REACH and the Biocidal Products Regulation, respectively.

In simple terms EUSES uses information on the physico-chemical properties of a substance and built-in information on releases for different manufacturing and use processed for different chemical types to calculate concentrations of substances in different environmental compartments. Input values comprise properties information on the substance, volume use and use pattern information. Information on the (eco)toxicity of the substance can also be used such that no-effect concentrations can be calculated and compared to exposure values, to derive risk characterisation ratios (PEC/PNEC), however the model can be used to calculate exposure values alone.

It was agreed with the EC (project meeting on 6th June 2017) that an approach to exposure estimate using EUSES represented a practicable and understandable method as the model is well understood by European regulatory authorities and industry experts alike, and that it can be reasonably easily adapted for estimation of the environmental distribution of microbeads for this project. (Further detailed information on the application of the EUSES model in this study is set out in Appendix C of this report).

A number of different scenarios for different product types has been used to assess the amounts of microbeads that end up in environmental compartments and at what concentrations. The assumptions and uncertainties are clearly set out in relevant subsections below.

A key point (as with all assessments) is the wastewater/sewage treatment works (WWTW/STW) since the distribution (partition) in the works will determine the effluent and thus the mass and concentrations of particles going into the aquatic environment.

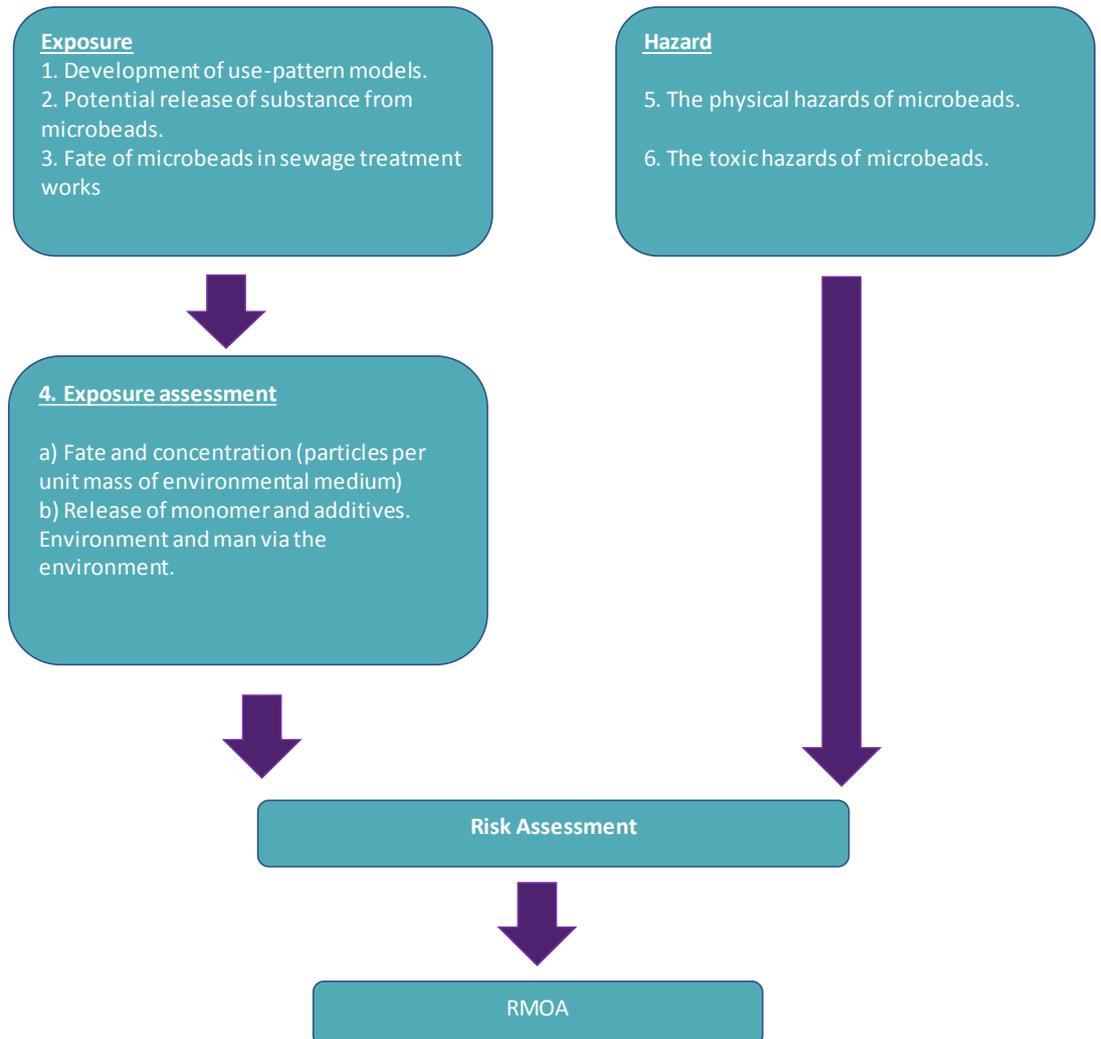
Once microplastics get into the environment, the environmental fate will be dependent on the behaviour in the relevant media. Certain features of the beads will determine this and are influenced by the definition of microplastics for this project (e.g. biodegradability and buoyancy).

In terms of outcomes, a ratio of environmental concentration to threshold effect level ('PEC/PNEC') approach is not followed, since it is not possible to derive a specific no-effect level for microbeads (see section 4.3). However, the quantification of exposure is critical to understanding the potential risk and also what measures could be applied to control the risk (i.e. RMMs), as well as to prioritising sources of microplastics from intentional use in products versus other sources.

As with other environmental assessments, the risk assessment includes both hazard and exposure of the environment (i.e. organisms dwelling in the environment ('wildlife')) and the general public who may be exposed in the environment (so-called 'man via the environment'), from water, food and air and other contact with environmental media. It does not include exposure in the workplace or consumer exposure through the use of consumer products however.

The figure below illustrates that approach in broad terms.

Figure 4.1 Risk assessment framework outline



The assessment of effects considers two different main aspects, a) the effects on organisms that are a result of the physical nature of the microbeads, and b) the possible toxic effects on organisms as a result of substances that are emitted from microbeads.

Effects on organisms in the environment (wildlife) are largely estimated from laboratory testing, this can be divided into physical effects (i.e. the harm caused by the physical presence of the microbeads themselves), and the toxic effects from the materials that the microbeads are made from or have adsorbed and released. There are potentially many substances that could be adsorbed in the environment, and the difficulty when assessing information from the environment is that it is almost impossible to distinguish between microplastics that are intentionally added (to products) and those formed from degradation of bulk plastics. The hazard profiles may be very different. It is known that bulk plastics have many additives, some of which may be hazardous.

In terms of effects on humans (via environmental exposure), both physical effects and toxicity effects are relevant.

For the present study, it is clear that physical and toxic effects need to be assessed for the environment and humans via the environment – as summarised in the figure below.

		Receptor	
		Organisms in the environment	Humans exposed via the environment
Effects	Physical	?	?
	Toxic	?	?

A non-exhaustive search of the literature was done and the indications of possible effects collated.

Uncertainties

When considering the predicted environmental concentrations (PEC), it is important to recognise that there are many significant uncertainties in the estimates. There are several sources of this uncertainty, these are summarised below.

- ▶ Microplastics cover a range of different polymers with different sizes, densities and properties. Simplifications have, by necessity, been used in the calculations and these simplifications introduce uncertainty.
- ▶ Modelling the environmental fate and behaviour of microplastics using the commonly available risk assessment tools, such as the EUSES model, is not straight forward for microplastics, and several adaptations have had to be used.
- ▶ There is uncertainty over the amounts of microplastics used, and the amounts subsequently released to the environment. In many cases, there is only limited information available upon which to base the exposure scenarios. **This has resulted in the use of a worst-case approach that is likely to overestimate the actual emissions to the environment.** In addition, the default methods for release estimation from ECHA (2016), which are based on chemical substances, may not always be applicable to releases of microplastics.
- ▶ It is not currently possible to reliably estimate the partitioning of microplastics between water and sediment. The approach taken here essentially assumes that the water concentrations and sediment concentrations are the **maximum** concentrations likely, in that it is assumed that a) all of the microplastic is in the water column and b) all of the microplastic is then in the sediment phase. In reality, the situation will be between these two extremes and this should be taken into account when considering the calculations.
- ▶ Concentrations based on particle numbers require assumptions to be made over the particle size. The current values reported assume a particle size of 200 µm. However, assuming a smaller particle size (e.g. 2 µm) would increase the predicted concentrations by a factor of up to around 1×10^6 , increasing the particle size (e.g. to 100 µm) would decrease the predicted concentrations by a factor of around 200.
- ▶ Removal of microplastics from effluent varies from treatment plant to treatment plant. This results in different amounts going to surface water and agricultural soil (by application of the sludge to agricultural land). In addition, sludge may undergo incineration (where the microplastic will be destroyed), rather than land-spreading.
- ▶ The predicted regional concentrations are uncertain for microplastics. The regional concentrations are steady-state concentrations obtained using a fugacity-based model. Such models may not be fully appropriate for microplastics. In addition, the timescales needed to achieve the predicted concentrations may be long. The regional concentrations act as a background concentration to the local PECs and so the local concentrations are presented both with and without the regional contribution in recognition of this uncertainty.

The results of the exposure assessment should be viewed in light of these uncertainties.

Modelling exposure to microplastics - more detailed approach

The exposure estimation is carried out following as closely as possible the principles outlined in the guidance for environmental exposure assessment provided by the European Chemicals Agency (ECHA) in relation to REACH Regulation (ECHA, 2016)¹⁰⁸. Thus, releases to the environment are considered on two spatial scales.

- ▶ **Local.** This is intended to be representative of the releases and concentrations associated in the immediate vicinity of a point source of release, such as an industrial facility or, in the case of consumer use, a waste water treatment plant serving a local population (this is the more relevant scenario in this case for microplastics in consumer products).
- ▶ **Regional.** This is intended to be representative of a heavily industrialised area where several point sources can contribute to the background concentration.

Based on the ranges of retention rates, Eunomia (2017) developed estimates for the range of retention that would be expected in each EU member state, taking into account the known types of treatment and the population served by each treatment plant type. The range of retention rates estimated by country ranged from 22% up to 94%, with average retention rates between 33% and 86%. The EU average retention rates were between 53% and 84%. Therefore, the EUSES model estimates for the amount retained (92% to sludge) are towards the upper end of the available estimates by Member State.

Lower estimate EU average	53% to sludge 47% to water effluent
Upper estimate EU average	84% to sludge 16% to water effluent
EUSES default estimate	92% to sludge 2% to water effluent

A more detailed account of the approach to the assessment is set out in Appendix C.

Data on relevant products

In terms of relevant products – from tasks 1 and 2 the plastic types are identified as being most relevant are shown in Table 4.1:

Table 4.1 Data on selected polymers

Polymer	Melting Point	Density
Polyethylene	> 95 °C	0.92-0.95 (low density-high density) [1], 0.854 [2]
Polyurethane	> 190°C [6]	1.2-1.4 [5], 1-1.25 [7]
Styrene/Acrylates copolymer	no data found	1-1.2 [3]
Polyacrylamide	> 300°C [4]	1.302[1], 1.189 [4]
PMMA (9011-14-7)	160 °C	1.2 [1], 1.159[2]
PA (Nylon-11, PA-11)	198 °C	1.04[1], 1.018[2]

References:

[1] <http://scientificpolymer.com/density-of-polymers-by-density/>

[2] <http://polymerdatabase.com/polymer%20physics/Polymer%20Density.html>

¹⁰⁸ ECHA (2016). Guidance on information requirements and chemical safety assessment. Chapter R.16: Environmental exposure assessment. Version 3.0, European Chemicals Agency, February 2016.

- [3] https://www.nicnas.gov.au/__data/assets/pdf_file/0007/8962/NA1FR.PDF
 [4] http://www.chemicalbook.com/ChemicalProductProperty_EN_CB7390058.htm
 [5] Saechtling H. (1986): Kunststoff Taschenbuch 23. Ausgabe, Carl Hanser Verlag München Wien
 [6] <http://www.spektrum.de/lexikon/chemie/polyurethane/7369>
 [7] <http://www.chemie.de/lexikon/Polyurethan.html>

Life cycle

The available information on use of microplastics in the EU is summarised in Table 4.2.

Table 4.2 Use pattern of microplastics in the EU

Sector	Product types	Total EU tonnage of microplastics (tonnes/year)	Source
Personal care	Rinse-off products containing exfoliating and cleansing microbeads	714	Information gathered for this study (Task 1)
	Leave-on products containing microplastics	540-1 120	Information gathered for this study (Task 1)
Paints and coatings	Waterborne building paints	220 tonnes/year	Information gathered for this study (Task 1)
	All other	22 000-38 000	Extrapolation from Danish Environmental Protection Agency (2015)
Detergents	Soaps, detergents and maintenance products	190-200	Information gathered for this study (Task 1)
Abrasives	Sandblasting	1 000-5 000	Extrapolation from Danish Environmental Protection Agency (2015)
	Other uses	Unknown	Information gathered for this study (Task 1)
Oil and gas		No quantitative estimate possible.	Information gathered for this study (Task 1)
Agriculture		No quantitative estimate possible.	Information gathered for this study (Task 1)
Pharmaceutical industry		No quantitative estimate possible but use is not thought to be significant.	Information gathered for this study (Task 1)
Water		No quantitative estimate possible but use is not thought to be significant.	Information gathered for this study (Task 1)

Specific use pattern relevant to the intentional use of plastic microbeads

This subsection summarises the main features of the use patterns that has been assessed (detailed information is presented in Appendix C).

Personal care and cosmetics and products (PCCP)

Based on the results of the industry survey, it is estimated that there are around 714 tonnes/year of microplastics used in 'rinse-off'¹⁰⁹ personal care products in the EU. The total amount of rinse-off products containing microplastics is unknown.

Another source (Eunomia, 2016) reported that there was evidence for use of microplastics in some 'leave-on'¹¹⁰ products and the total amount of microplastics used in personal care products could be between 4 500 and 8 200 tonnes/year, but this estimate is subject to high uncertainty. The weighted average concentration of microplastics in personal care products calculated from Eunomia (2016) is 2.4%, with a range of 0.005% to 72%.

New information from Cosmetics Europe indicates that there were 714 tonnes in wash-off PCP and 540 – 1 120 tonnes in leave-on PCP (with our best estimate of 605 tonnes). Based on this the total EU use would be 1 254-1 834 tonnes/year, with a best estimate of 1 319 tonnes year.

As the use in personal care products is an important use, in terms of the potential for release to the environment, it is also relevant to consider that there is some uncertainty over the amounts currently used within the EU. The above local release estimate is based on the total amount of microplastics used in the EU being as high as 8 200 tonnes/year. However, the survey of industry carried out for this project suggested a lower figure of 714 tonnes/year in rinse-off personal care products and a similar amount for leave-on personal care products (best estimate value of 605 tonnes). If this lower figure for the total EU use is assumed, using the same method as above, the local release from use of personal care products would reduce from 4.5 kg/day to 0.39 kg/day. Both of these local release figures are considered in the PEC calculations.

Paints and coatings

Around 220 tonnes of microplastics are used in the EU in water-based building paints. The total amount of such paint/coating produced in the EU containing microplastics is of the order of 14 000 tonnes/year. The weighted average concentration of microplastics in the paint/coating is 1.6% with a range of 1-2%.

Other estimates suggest that the total usage in paints/coatings within the EU could be significantly higher, at up to 22 000-38 000 tonnes/year, but this estimate is subject to a high uncertainty and has not been verified by any available data.

For the local scale assessment in this present study, it is assumed that 1 000 kg/day of microplastics are used on a formulation site over 220 days (this assumes that all of the 220 tonnes identified in the survey are formulated at one site).

For the regional assessment, it is necessary to consider that the total EU use in paints/coatings could be higher than 220 tonnes/year. Therefore, the higher (but more uncertain) estimate of 22 000-38 000 tonnes/year is taken into account.

Paints and coatings can potentially be used in industrial settings by professionals, and by consumers. The main uses of water-based paints and coatings containing microplastics, appears to be in building applications (coating walls and ceilings). Such uses are mainly carried out by professionals and consumers, but use in an industrial setting could also potentially be possible.

In order to estimate the regional release from industrial use it is necessary to know the total amount of paint that is used in industrial applications. This is not known specifically. Therefore, the regional emissions are estimated assuming that most of the use is in professional and consumer use (see below). In practical terms, this simplification will have only a limited impact on the total regional emissions from all uses as use of paints/coatings only makes a relatively small contribution to the total regional emissions (see Appendix C Section on total regional emissions).

¹⁰⁹ Products that the intended to be removed with water (that goes to waste water) as part of use, for example, shower gels, shampoo etc.

¹¹⁰ Products that are not intended to be removed with water as part of use, for example deodorants, hair gels, skin creams, makeup. Note that there is some contention on some products such as sun care lotions, since they may be quickly washed off, although that is not the intention.

For the purposes of this study, and in the light of not finding information to the contrary, we assume that once the paint has been applied and has dried, the microplastic will become an integral part of the coating and will not be available for subsequent release. Although loss of paint to the environment may occur during the service life of the article (e.g. by weathering, chipping and flaking) and at the end of the service life (e.g. during disposal), this will be as particles of paint rather than as the microplastics themselves. Therefore, these sources are not considered further. They are however considered in the parallel study on microplastics other than those intentionally added to products.

Soaps, detergents and maintenance products

Around 190-200 tonnes/year of microplastics are thought to be used in soaps, detergents and maintenance products. The weighted average concentration of microplastics in such products is around 4%, with a range of 0.7-4.9%. In tonnage terms, the highest usage of microplastics in this area is in hard surface cleaners (glass ceramic cleaners) but other products (e.g. toilet cleaners (WC blocks), stainless steel cleaners, oven cleaners and laundry stain removers) may also contain microplastics.

Cleaning products can be used by professionals and consumers. Industrial use of cleaning products is also theoretically possible, but there is insufficient information on whether this actually occurs for products containing microplastics.

Abrasives

Microplastics are used in the industrial abrasives industry, but the actual amounts used, and their exact functions, are unclear. It has been suggested that microplastics are used in sandblasting in amounts up to 1 000-5 000 tonnes/year in the EU. However, information provided by the industry does not confirm this use, but instead suggests that their main application is in the manufacture of abrasives and that they are either cross-linked or destroyed (combusted) during the manufacture process, and so are not present in the final abrasive.

As there is little information (and therefore considerable uncertainty) over the use of microplastics in abrasives, a worst case generic approach is taken in the exposure assessment.

Other uses where microplastics are used

There are other potential areas of use of microplastics in the EU, but insufficient information is available on which to carry out a reliable exposure estimate. For these industries, a purely default assessment is undertaken assuming that a total of 1 000 tonnes of microplastics is used in each industry.

Oil and gas industry

Microplastics are used in drilling fluids in oil and gas exploration, and other kinds of rock drilling. The amounts of microplastics or the concentrations used are not known, and so a nominal amount of 1 000 tonnes/year is assumed for a default worst case assessment based on ECHA (2016). The approach assumes that the microplastics are formulated into products before use. As noted in the market analysis, further work on use of microplastics in the oil and gas industry is ongoing under the auspices of OSPAR, and this is expected to yield better information on their use.

There is a specific exposure scenario for off-shore used of chemicals in the oil and gas industry fluids that have been within the CHARM model (CIN, 2005). However, in order to use this model, it is necessary to know the concentration/dosage of microplastics within the fluid. This is currently unknown (to the authors of this present study), and so it is not possible to use this model meaningfully for microplastics. Therefore, a default assessment using the methods from ECHA (2016) is carried out.

Agriculture

Microplastics could potentially be used in nutrient pills¹¹¹ for controlled-release fertilisers and other applications. These applications are similar in that they result in direct application to agricultural soil, and

¹¹¹ Pellets for the application of fertilisers to land.

potentially surface water by overspray etc. The amounts of microplastics or the concentrations used are not known and so a nominal amount of 1 000 tonnes/year is assumed for a default worst case assessment based on ECHA (2016). The approach assumes that the microplastics are formulated into products before use.

Most agrochemical products are used by professionals although consumer use is also possible. Both of these are considered as use is considered as a wide dispersive use in ECHA (2016). For such uses, the local source is a waste water treatment plant serving a population of 10 000, and releases from all professional and consumer within that population are assumed to enter the same waste water treatment plant, averaged over a year.

For the default assessment, it is assumed that 1 000 tonnes/year of microplastics are used in agricultural products. As agriculture is widespread throughout the EU, the regional tonnage is taken to be 10% of the total tonnage in line with ECHA (2016).

The default release factors above assume that the substance is mainly released to air or water, with a smaller release to industrial soil. However, in the case of agricultural use, the release will be mainly to agricultural soil, with a small release to surface water (from drift etc). Therefore, for the **default assessment here it is assumed that the release is 95% to agricultural soil and 5% direct to surface water (no waste water treatment is assumed in order to take into account direct releases into water courses are possible in this scenario)**

Other uses where no significant amounts of microplastics are claimed

During the consultation (for the present study (see Section 3)) industry claimed that there were no significant amounts of microplastics currently used within the EU in the pharmaceutical industry or the water treatment industry. Therefore, no exposure assessment is carried out for these areas.

Total regional emission

The total regional emission of microplastics is estimated as follows based on the preceding sections (above).

Air	7 253 kg/day
Water (before STP)	2 697 kg/day
Water (direct)	14 kg/day
Agricultural soil (direct)	260 kg/day
Industrial soil	1 540 kg/day

The emissions to the waste water treatment plant will partition between sludge and water resulting in indirect emissions to surface water and agricultural soil (via spreading of sewage sludge).

Results – Release and predicted concentrations (PECs) in water, sludge, sediment and soil

Estimates of the release rates for different use patterns at local and regional spatial scales have been calculated, such that it is possible to indicate the mass released for every unit mass used in a particular product or process – these data are presented in Table 4.3 below. It can be seen that, in terms of estimated release to the aquatic environment per unit volume use, that use of PCCP and soaps and detergents are expected to give the highest emissions (per unit mass of microplastics used).

Table 4.3 Release factors for use patterns

Use pattern	Release factor			Release factor water post STW		
	Air	Water (pre STW)	Industrial soil	53% removal	84% removal	92% removal
PCCP						
Formulation (worst case)	0	0.04	0	0.0188	0.0064	0.0032
Use (worst case)	0	1	0	0.47	0.16	0.08
Paints and coatings						
Formulation	0.000097	0.00005	0	0.0000235	0.000008	0.000004
Prof and Consumer use	0.011	0.01	0.0025	0.0047	0.0016	0.0008
Industrial use	0.02	0	0	0	0	0
Service life	0	0	0	0	0	0
Soaps, detergents and maintenance products						
Formulation	0	0.004	0	0.00188	0.00064	0.00032
Use	0	1	0	0.47	0.16	0.08
Abrasives						
Formulation	0.002	0.002	0.001	0.00094	0.00032	0.00016
Use ('sandblasting') industrial	1	0	0.05	0	0	0
Use ('sandblasting') professional	1	0	0.2	0	0	0
Oil and gas						
Formulation	0.025	0.02	0.0001	0.0094	0.0032	0.0016
Use	0.05	0.05	0.05	N/A	N/A	N/A
Agriculture						
Formulation	0.025	0.02	0.0001	0.0094	0.0032	0.0016
Use*	0	0.05	0.95	0.05		

* It is assumed that the release is 95% to agricultural soil and 5% direct to surface water (no waste water treatment is assumed in order to take into account direct releases into water courses are possible in this scenario)

It is important that data are considered in absolute as well as relative terms, since a process that has a low volume use and a high release rate may be the same in terms of the concentration that ends up in the environment as a process with high volume use and low releases. A summary of the total estimated EU emissions is presented in Table 4.4 below, these figures are based on the release rates and volume use (for detail see Appendix C).

Table 4.4 Annual release volumes for the EU for each use pattern

Use pattern	EU Release (tonnes per annum)			
	Air	Water (pre-STW)	Industrial soil	Total
PCCP¹				
Formulation	0	12	0	12
Use	0	1 318	0	1 318
Paints and coatings				
Formulation	2.25	1.17	0	3.39
Prof and Consumer use	419	380	93.6	892.6
Soaps, detergents and maintenance products				
Formulation	0	0.41	0	0.14
Use	0	200	0	200
Abrasives				
Formulation	50	50	25	125
Use ('sandblasting') industrial and professional	2 500	0	500	3 000
Oil and gas				
Formulation	20.55	16.44	0.081	37.1
Use	41.1	41.1	41.1	123.3
Agriculture				
Formulation	20.55	16.44	0.081	37.1
Use	0	50	949	1 000

¹ Information from Cosmetics Europe: 714 tonnes in wash-off PCP and 540 – 1 120 tonnes in leave-off PCP (with a best estimate of 605 tonnes). Based on this the total EU use would be 1 254-1 834 tonnes/year, with a best estimate of 1 318 tonnes year – the best estimate value is used. This assumes that all leave-on products are also washed to waste-water, when in reality only a fraction will be. Note that the figures for paints assume the higher (and more uncertain) estimate of usage.

Concentrations in environmental compartments were expressed as mass and number of beads. Detailed tables of concentrations in different environmental media are set out in detail in Appendix C. In terms of predicted environmental concentrations (PECs) assuming a worst-case sewage works efficiency of 53%, the following Table 4.5 summarises the highest environmental concentrations. Further detailed results for PECs for all uses and sewage work efficiencies of 53%, 84% and 92% are presented in Tables C9-C20 in Appendix C.

Table 4.5 Summary of selected highest predicted environmental concentrations (assuming STW efficiency of 53%)

Use	PEC mass	PEC particles	Compartment	Comment
PCCP Professional and consumer use - 0.72 kg/day	1 300 mg/kg dry wt	310 000 particles/kg dry wt	Freshwater sediment	
PCCP Formulation - high viscosity - medium scale	890 mg/kg dry wt	210 000 particles/kg dry wt	Marine sediment	
Paints and coatings Industrial use	48 mg/kg dry wt	11 000 particles/kg dry wt	Marine sediment	
Detergents Formulation - high viscosity products	1 200 mg/kg dry wt	280 000 particles/kg dry wt	Freshwater sediment	
Abrasives Formulation	31 000 mg/kg dry wt	7 500 000 particles/kg dry wt	Freshwater sediment	
Oil and gas Industrial use	17 000 mg/kg dry wt	4 000 000 particles/kg dry wt	Marine sediment	High degree of uncertainty as no information on use.
Agriculture Professional and consumer use	44 mg/kg dry wt.	11 000 particles/kg dry wt	Agricultural soil	

In line with release factors, the use of PCCP gives the highest concentrations of microbeads in the environment in sediment at local scale. High concentration from the oil and gas industrial use is subject to a lot of uncertainty since no information on use was gathered from consultations with the industry.

Regional scale estimates can be informative, since they give the combined background concentration. Summary data for PECs per unit mass and particles, assuming 53% STW removal, is in Table 4.6 below. The sediment compartment is estimated to have the highest concentrations of microbeads. (However note the assumptions (as in Appendix C) predicting that essentially all of the microplastic in the water phase will be associated with the suspended sediment and hence sediment.)

Table 4.6 Summary of regional predicted environmental concentrations (assuming STW efficiency of 53%)

Regional concentrations	Surface water	Marine water	Freshwater sediment	Marine sediment	Agricultural soil	Grassland
PEC (total) - mass	0.0023 mg/l	0.00024 mg/l	310 mg/kg dry wt.	95 mg/kg dry wt.	44 mg/kg dry wt.	36 mg/kg dry wt.a
PEC (total) – particles	0.56 particles/l	0.057 particles/l	74 000 particles/kg dry wt.	23 000 particles/kg dry wt.	11 000 particles/kg dry w	7 600 particles/kg dry wt.a

^a Concentration in natural soil.

The potential human exposure from consuming mussels from local sources has also been investigated. This assumes that a human consumes 115 g of fish/seafood per day and a human body weight of 70 kg. In terms of exposure of humans through the food chain Table 4.7 summarises estimates of particles assuming a 53% removal of microbeads in sewage works (detailed tables are presented in Appendix C).

Table 4.7 Summary of human intake of plastic microbeads from eating freshwater fish, marine fish and marine mussels

Scenario		Human intake– particles/ kg bw/day (see note a)		
		From fresh water fish	From marine fish	From marine mussels
Personal care products	Formulation - low viscosity - large scale	0.7	0.07	0.97
	Formulation - low viscosity - medium scale	0.39	0.039	0.55
	Formulation - low viscosity - small scale	0.10	0.011	0.15
	Formulation - high viscosity - medium scale	1.8	0.18	2.5
	Formulation - high viscosity - small scale	0.041	0.0042	0.058
	Formulation - creams - large scale	6.7	0.67	9.3
	Formulation - creams - medium scale	3.6	0.36	5.0
	Formulation - creams - small scale	0.75	0.075	1.0
	Professional and consumer use - 4.5 kg/d	1.5	0.15	2.1
	Professional and consumer use - 0.72 kg/day	0.27	0.027	0.3.8
Paints and coatings	Formulation	0.05	0.005	0.070
	Industrial use	0.033	0.0034	0.047
	Professional and consumer use	0.10	0.01	0.14
Detergents	Formulation - low viscosity products	0.14	0.014	0.19
	Formulation - high viscosity products	0.24	0.025	0.34
	Professional and consumer use	0.07	0.007	0.098
Abrasives	Formulation	6.7	0.67	9.3
	Industrial use (sandblasting)	0.033	0.0034	0.047
	Professional use (sandblasting)	0.033	0.0034	0.047
Oil and gas	Formulation	22	2.2	0.31
	Industrial use	n/a	3.5	0.49
Agriculture	Formulation	22	2.2	0.31
	Professional and consumer use	0.052	5.3E-03	0.074
Regional sources		3.3E-02	3.4E-03	0.047

Note: a) The accumulation factor used to estimate the human intake was determined on a concentration per fish basis. In order to use this in the ECHA (2016)/EUSES methodology it has been assumed that the fish used in the study would have been a few g in weight and so the accumulation factor reported approximates to an accumulation factor on a concentration per g basis.

Concentrations in water and sediment reported in the literature

A limited review of the literature (from the same literature sources used to look at reported effects) was done to gather reported measured concentrations of microplastics. Some data are available for marine and freshwater compartments, for both surface waters and sediment (no data were immediately available for

measured concentrations in soils). The purpose of reporting these data is to compare the values predicted by the modelling (PECs) with measured data. The table below summarises a limited set of data, concentrations and size ranges of particles are as reported in the sources. The sources reported 'microplastics', but the plastic type (e.g. type of polymer) was not necessarily reported.

Size (range)	Compartment	Conc.	Ref.	Comment
Not reported	Marine water Eastern North Atlantic - coastal - sea surface	0.01 – 0.32 cm ³ /m ³	Frias et al. 2014	From GESAMP 2015
Not reported	Marine water Mediterranean Sea - sea surface	Mean concentrations: 0.116 particles/m ² , 0.202 mg/m ²	Collignon et al. 2012	From GESAMP 2015
Not reported	Marine water Mediterranean Sea - sea surface	Mean concentrations: 0.94 particles/m ³ (Ligurian Sea) 0.13 particles/m ³ (Sardinian Sea)	Fossi et al. 2012c	From GESAMP 2015
>100 µm	Marine water Danish coastal waters North Sea Kattegat The Belt Sea	0.39±0.19 3.54 1.44 particles/m ³	Mintenig 2014	From Lassen et al. 2015
>300 µm	Marine water Swedish coast, close to the shore Kattegat The Sound The Baltic	1.08±0.22 4.0 0.56±0.40 particles/m ³	Magnusson and Norén 2011	From Lassen et al. 2015
>80 µm	Marine water Swedish west coast close to PE production plant	~102 550 particles/m ³	Norén 2007	From Lassen et al. 2015
>333 µm	Marine water The Gulf of Finland Turku harbour Archipelago Off shore	0.73 0.25±0.07 0.48 particles/m ³	Magnusson 2014a	From Lassen et al. 2015
>1.2 µm Granular particles	Marine water North Sea coast of Germany	64,000 ±194 000 particles/m ³	Dubaish and Liebezeit 2013	From Lassen et al. 2015
>500 µm	Marine water Western English Channel	0.27 particles/m ³	Cole et al. 2014	From Lassen et al. 2015
55 - 115 µm*	Freshwater sediment - Scheldt river (Belgium)	0.6 to 50.1 microplastics per gram of dry river sediment	Van Cauwenberghe 2015	Not reported if the source was intentionally added or degraded
Not reported	Marine sediment, beaches – Belgian coast	7.4 to 18.8 microplastics.kg- 1 dry sediment (median of 14.0 microplastics.kg-1),	Van Cauwenberghe 2015	Also report microplastics in deep sea sediments
Not reported	Marine sediment UK estuarine beach - surface to 3 cm deep	1 – 8 particles per 50 ml sediment	Browne et al. 2011	From GESAMP 2015
>38 µm	Marine sediment Danish coastal waters	100 (75 – 268) 120 (60 – 195)	Strand et al. 2013	From Lassen et al. 2015

Size (range)	Compartment	Conc.	Ref.	Comment
	North Sea & Skagerrak Kattegat Belt Sea Baltic Sea	380 (280 – 1 090) 335 (145 – 543) No. plastic particles/ kg- dry sediment		
>1.2 µm	Marine sediment Germany East Frisian Islands	210 plastic granules No. plastic particles/ kg- dry sediment	Liebezeit and Dubaish 2012	From Lassen et al. 2015
>1 µm	Marine sediment Dutch coast Rhine estuary North Sea Wadden Sea	3 305±295 455 (390 – 520) 770 No. plastic particles/ kg- dry sediment	Leslie et al. 2013	From Lassen et al. 2015
>38 µm	Marine sediment Belgian coast Harbours Continental shelf Beaches	167±92 97±19 93±37 No. plastic particles/ kg- dry sediment	Claessens et al. 2011	From Lassen et al. 2015
32 – 1,000 µm	Marine sediment Lagoon of Venice	1 445±458 No. plastic particles/ kg- dry sediment	Vianello et al. 2013	From Lassen et al. 2015

* < 1 mm rarely larger than 115 µm and most abundant in the size classes below 55 µm: this is true for 70 – 90%

For marine waters, the highest concentrations reported for European waters (as shown in the table above) were c. 100 000 particles/m³ (>80 µm) close to a PE production plant, and 64 000 particles/m³ (>1.2 µm) at the North Sea coast of Germany. At the lower end of the range were 0.39 particles/m³ (>100 µm) in the Danish North Sea and 0.56 particles/m³ (>300 µm) in the Baltic Sea (values for per litre concentrations will be 1 000x lower).

For sediment, the only freshwater value is 0.6 to 50.1 'microplastics' (assumed to mean particles) per gram of dry river sediment. For marine sediment the highest concentrations were c. 3 300 plastic particles/ kg dry sediment (>1 µm) for the Dutch coast (Rhine estuary), and the lowest a median of 14.0 microplastics/kg dry sediment (assumed to mean particles, size range not reported) for beaches on the Belgian coast.

It should be noted that, as for modelled data, the particle size is assumed to have a large influence on the number of particles per unit mass of environmental compartment. It should also be noted that this review of literature values is based on a limited set of literature only, and is done only for the purpose of comparing to the modelled values.

Comparing literature measured values to the PEC values for particles, as indicated for regional scale in Table 4.6, a surface water freshwater value is 0.56 particles/l (0.057 for marine) which compares to reported measured values of 64 particles/l at the higher end of the range and 0.00056 particles/l and the lower end of the range of values. For sediments, the freshwater PEC regional is 74 000 particles/kg dry wt, with 23 000 particles/kg dry wt for marine sediment. This is compared to measured values in the literature of 3 300 plastic particles/ kg dry sediment at the higher end, and 14.0 microplastics/kg dry sediment at the lower end. The uncertainty associated with these values should be noted.

Conclusions on environmental exposure assessment of plastics microbeads

The model EUSES was used to calculate the concentrations of plastic microbeads that could end up in different environmental compartments from different uses. Information on use patterns and relevant volumes of use and amounts of beads in products, and types of material used to make beads, was taken from other tasks in this project. Other studies were used to inform the removal rates in sewage treatments works. Results and conclusions are subject to considerable uncertainties, due to input variables and lack of data.

In conclusion, the EUSES model has been used and adapted to estimate the concentrations of microplastic beads in environmental compartments. Notwithstanding the considerable uncertainties and assumptions made in order to make these estimates, certain uses appear to lead to notable concentrations in environmental compartments. However, whether these concentrations (expressed in terms of mass or particle numbers) are significant in terms of environmental impact, it is not possible to say, although the numbers of particles estimated to be ingested by humans eating marine mussels would appear to be low. Review of the possible effects on organisms in the environment and humans is summarised later in this section.

4.2 Migration of additives from microbeads

This part of the assessment investigates the possibility that substances (i.e. free monomers or additives), in the polymer matrix of a microbead, can escape from the microbead into the environment. There is also the possibility that beads take up (absorb or adsorb) and subsequently release, substances into the environment. The concern here is that the beads act as a sink and a possible exposure source for other pollutants in the environment.

The principles and details of the method are set out in Appendix D.

Release of substances from plastic microbeads

A pragmatic approach to modelling the rate of release of unbound molecules from particles of foam, plastic, coating or other substrates using a diffusion model is set out in Appendix IV to the OECD ESD for plastics additives (OECD, 2009a citing Fisk *et al.*, 2006). In that document, diffusion of additives out of the polymer is described. This occurs due to a concentration gradient being established following loss from the surface. The loss from the surface is assumed reasonably to be faster than diffusion (polymers are relatively rigid compared to liquids or air).

In accordance with that model, the key assumptions are:

1. The substrate is a continuous matrix.
2. At the beginning of the modelled time period the additive is uniformly dispersed throughout the particle, but may diffuse freely so that a concentration gradient is established.
3. Additives are not chemically bound to the polymer, the only interactions being weak.
4. The concentration of the additive in the receiving compartment is assumed to be negligible / not influential.

It should be noted that:

- ▶ As levels of additive within the bead get very low, there is no longer a concentration gradient between the inside and the outside of the bead and the mathematics above does not apply. Therefore, it is not recommended to predict time to 100% loss using the above model.
- ▶ The model assumes negligible concentration in the receiving compartment. Therefore, it will not apply as the concentrations in the receiving compartment and the bead approach their equilibrium values.

Results

Detailed results are shown in Appendix D, Table D1 shows loss of additive per kg of beads over one day. A concentration of additive/monomer in beads of 1% and a maximum loss of 95% of the additive are assumed. Table D1 also shows the time taken to lose 20%, 50% and 95% of the additive.

The predicted times to 95% loss vary from less than 1 hour for a low molecular weight additive in a small particle to several years for a high molecular weight additive in a large particle.

Potential concentrations of additives in the environment

The results detailed in Appendix D suggest that, for particles in the typical size range, monomers/additives could be released quickly. For example, for an additive with MW of 500 g/mol in a 200 µm particle, 95% loss within 28 days is predicted. This suggests that a reasonable worst case is that most of the additive present in microbeads can escape into the environment. Therefore, the calculated predicted environmental concentrations (PEC) of microbeads can be combined with an estimate of the concentrations of additives in the beads to give a worst-case estimate of the amount of additive that could be introduced into the environment.

An estimate of the percentage of additives that could be present in microbeads is required. There is very little information about what additives are present in microbeads. The ESD plastics additives Appendix III, gives estimates of the maximum concentrations of different types of additives that may be present in different polymer types. It should be noted that although the numbers are estimates of reasonable worst-case amounts of additives that may be used in polymers, it does not necessarily follow that all of the possible additive types indicated for a given polymer will be present in all polymers of that type. The actual amounts and combination of additive types that will be used in a given type of plastic, will depend to a large extent on the final application or required properties of the final polymer.

Additives identified for the polymer types that are most relevant for microbeads include coupling agents, blowing agents, fillers, colourants, flame retardants, curing agents, (UV-)stabilisers, antioxidants, slip promoters, antistatic agents, and lubricants. Based on the descriptions of the purposes of these additive types given in the ESD, the following are considered most relevant to microbeads: stabilisers, colourants, and antioxidants. All are assumed to be present at ≤1%.

Results

Tables D3 and D4 (Appendix D) show the Predicted Environmental Concentrations (PECs) of microbeads multiplied by percentage of additive¹¹². A total additive content 1% weight for weight is assumed as a maximum (based on ESD) and also at 0.1% (since this is the percentage limit of an SVHC substance in a polymer beyond which the polymer would be considered to be SVHC.). The results are based on 53% removal in STP (since this is the lowest removal rate, however as stated previously, changing the retention rate in the STW just means changing the balance of what goes to the aquatic environment and what (via sludge) to soil (assuming that as a worst case all sludge is spread to agricultural land). A summary of results showing the regional concentrations and the maximum PEC amongst all uses assessed (for oil and gas formulation) is in Table 4.8.

¹¹² It could be better to calculate a total kg/d potentially released to the environment rather than individual compartment concentrations. For example, for formulation of PCCPs – there is a regional release of 30 kg plastic/day. Therefore, additive at 1% = regional release of 0.3 kg/d; additive at 0.1% = regional releases of 0.03 kg/d. It may be possible to make assumptions about the percentage of beads that actually contain a particular additive – (could be done using one as a case-study).

Table 4.8 Predicted environmental concentrations in environmental compartments for additives in microplastic beads at 0.1%

		Mass of additive present at 0.001 kg/kg (0.1%)							
Scenario		STP effluent (total) – mg/l	Sewage sludge - mg/kg dry wt.	PEC Surface water (total) – mg/l	PEC Marine water (total) – mg/l	PEC Freshwater sediment – mg/kg dry wt.	PEC Marine sediment – mg/kg dry wt.	PEC Agricultural soil – mg/kg dry wt.	PEC Grassland – mg/kg dry wt.
Regional	Regional concentrations	-	-	0.0000053	0.00000049	0.7	0.2	0.064	0.04
Maximum PEC of all uses assessed)		0.016	45	0.0016	0.00016	100	11	0.79	0.35

The predicted environmental concentrations in environmental compartments for additives in microplastic beads at 0.1% are summarised in the table below (detailed results are presented in Appendix D). The maximum for all uses at local scale and the regional scale is shown. It can be seen that releases from microbeads can lead to concentrations in environmental compartments and that the highest concentrations are in sediment compartments.

The concentration of additive is dependent on the concentration of microbeads. The highest local PECs are for formulation of products for use in the oil and gas industry and in agriculture. These are 1.6 mg/l for surface water, 100 000 mg/kg dw for freshwater sediment and 790 mg/kg dw for agricultural soil. If a particular additive were present at 0.1% in microbeads used for these applications and all of this additive were released, the concentrations released into these compartments would be 1.6 µg/l for surface water, 100 mg/kg dw for freshwater sediment and 0.79 mg/kg dw for agricultural soil. However, the PECs for these scenarios may be unrealistically high because there is little available information about the use patterns for these scenarios and a worst-case is assumed.

An example of a scenario with more available information is professional/consumer use of personal care products. In this scenario, a regional release of 195 – 2 250 kg/d is estimated. This leads to local PECs of 14 - 110 µg/l for surface water, 96 - 740 mg/kg dw for freshwater sediment and 44 - 90 mg/kg for agricultural soil. If a particular additive were present at 0.1% in microbeads used for this application and all of this additive were released, this would result in a regional release of 0.2 – 2.3 kg/d and local releases of 14 - 110 ng/l for surface water, 96 - 740 µg/kg dw for freshwater sediment and 44 - 90 µg/kg for agricultural soil.

It should be noted that after release from the microbead, the properties of the additive determine its behaviour. The additive will degrade and partition into different compartments according to its own physicochemical properties. Therefore, the calculated concentrations represent the maximum amount released into a particular compartment, not final concentrations.

Uncertainties

The mathematics of diffusion in solution and polymers is complex and some major simplifications have been made in generating the equations used here¹¹³. Key assumptions are outlined in Appendix D. One assumption is that the concentration in the receiving compartment is assumed to be negligible / not influential. This may not be the case as the concentration in water/beads approaches its equilibrium value.

The method for estimation of diffusion coefficient also represents a simplification. The calculation depends only on the molecular weight of the additives. In reality, the diffusion coefficient will depend on the combination of additive and polymer.

¹¹³ From ESD plastics additives

The calculated release times and amounts released therefore represent a rough estimate with an accuracy of an order of magnitude at best.

The predicted concentrations are calculated using a number of worst-case assumptions. The combination of these assumptions could mean that the concentrations are higher than would realistically be the case. These include assumptions made in calculating the PECs of the microbeads and the assumptions that all microbeads released to the local environment contain the specified concentration of a particular additive and that all of that additive is released within a relevant timeframe.

It should be noted that after release from the particle, the properties of the additive determine its behaviour. The additive will degrade and partition into different compartments according to its own physicochemical properties. Therefore, the calculated concentrations represent the maximum amount released into a particular compartment, not final concentrations.

Partitioning of substances of concern in the environment to microbeads

In order to investigate whether partitioning of substances of concern (such as synthetic organic substances that fulfil or potentially fulfil PBT/POPs criteria) that are already present in the environment, to microbeads could be important, a modelling approach which is commonly used for estimating the movement of substances in environmental compartments has been applied. This approach is described in more detail in Appendix D.

The fraction (amount) of polluting substance (e.g. SVHC) already in the environment predicted to be taken up by microbeads has been calculated for different conditions – i.e. with change in the concentration and based on different estimations for the relationship between the propensity for the substance to move from polymer to water – the plastic to water coefficient or $K_{\text{plastic-water}}$ (more detail is presented in Appendix D).

PECs for microbeads at local scale, uptake by plastic microbeads could be significant. The concentration associated with microbeads and suspended sediment increases with increasing $\log K_{\text{ow}}$ of the contaminant. The degree of partitioning to microbeads depends heavily on:

- ▶ How the microbead-water partition coefficient ($K_{\text{plastic-water}}$), is calculated.
- ▶ The concentration of microbeads in the environment.

Partitioning to microbeads is more important than partitioning to natural organic carbon for hydrophobic substances when the concentration of microbeads is similar to the concentration of organic carbon.

The default concentration of suspended sediment is 15 mg/l and the fraction of organic carbon is 0.1, giving a concentration of organic carbon of 1.5 mg/l. This is similar to the highest PECs for microbeads at a local scale. A lower concentration of microbeads results in preferential absorption to natural sediment even when the partition coefficient of microbeads is higher than that to organic carbon.

The partitioning of pollutants between water, natural organic carbon and microbeads has been estimated at the local scale. Some of the local PECs for microbeads in the environment are comparable to default concentrations of organic carbon. For example, in freshwater the REACH (Technical guidance R16) default concentration of suspended sediment is 15 mg/l of which a fraction of 0.1 is organic carbon (1.5 mg/l organic carbon). The highest freshwater PECs for microbeads are 1.6 mg/l; PECs for professional/consumer use of personal care products are 0.01-0.1 mg/l. Therefore, it is possible that partitioning to microbeads (rather than natural organic carbon) could be significant. This conclusion depends on how the water-plastic partition coefficient is calculated and appropriate values of $K_{\text{plastic-water}}$ are an important uncertainty.

Uncertainties

The model assumes a closed system at equilibrium with no losses by degradation, volatilisation, advection or any other mechanism.

There are uncertainties associated with the calculations of the prediction environmental concentrations of microbeads.

The results of the calculations presented in this section are highly dependent on the method used to calculate K_{polymer-water}. No definitive information is available on values of K_{polymer-water} for relevant contaminant and polymer combinations.

4.3 Effects

As mentioned in Section 4.1, the possible effects of intentionally added microplastics are divided into 'physical' effects (i.e. effects on organisms that are associated with the presence of microplastics on or within living organisms), and 'toxicity' effects (i.e. the release of substances from microplastics that cause toxic effects). In addition, also as illustrated in Section 4.1, the effects concerned include those on organisms in the environment, and also with human beings that may be exposed via the environment (through food, drinking water¹¹⁴ and air).

Effects of microplastics on environmental species

Microplastics are of a similar size to planktonic organisms and particulate matter naturally present in the environment as suspended particulates or sediment particles. Thus, microplastics are available for ingestion by freshwater and marine species. Ingestion of microplastics is therefore assumed to be relevant to filter, suspension and detritus feeders living in the water column and bottom sediments.

Direct ingestion of microplastics has been documented for a range of marine vertebrates and invertebrates, mainly from laboratory studies and results from field studies also indicate microplastic ingestion (Lusher, 2015). Indirect ingestion, i.e. ingestion of prey containing microplastics, can also occur. For example, trophic transfer has been demonstrated in laboratory studies from zooplankton to mysid shrimps (*Mysis spp.*) (Setälä *et al.*, 2014) and from mussels (*Mytilus edulis*) to crab (*Carcinus maenas*) (Farrell and Nelson, 2013 and Watts *et al.*, 2014). Other exposure routes may also apply. For example, microplastics can be taken up across the gills in crabs (Watts *et al.*, 2014) and in mussels (von Moos *et al.*, 2012).

Physical effects of microplastics on aquatic organisms

Physical effects of microplastics on aquatic organisms refers to the potential harm caused by the physical presence of the microbeads themselves in or on organisms.

Table 4.9 below summarises key findings from a non-exhaustive literature review. The review aims to give an overview of effects that have been observed in organisms following exposure to microplastics in key studies conducted to date, and to ascertain whether or not it is possible to identify any sort of dose-response type relationship.

The review focussed on studies that used plastic particles in the size range 0.1µm - 5mm. In order to get an overview of potential physical effects, all polymer types were considered. The majority of the studies used either polyethylene (PE) or polystyrene (PS), and two studies used polyvinylchloride (PVC). It is assumed that the nature of the polymer is not of high importance when discussing physical effects of microplastics, and thus the conclusions made can be considered as representative of the types of microbeads addressed in this current report.

¹¹⁴ However as indicated in Appendix C – Man exposed via the environment, water treatment is expected to remove microbeads from drinking water for humans.

Table 4.9 Summary of effects data

Organism	Exposure Duration (if known)	Reported effects	Concentration of particles in water/sediment [in organism if measured]	Plastic type/size (μm)	Comment (e.g. weathered particles?)	Reference
<i>Idotea emarginata</i> (marine crustacean – isopod)	6wk	No significant effects on mortality, growth, and intermolt duration Microplastics were not present in the tubules of the midgut gland	12 and 120 microbeads mg^{-1} food	1 – 100 μm (PS)	Polystyrene microbeads and fragments	Haemer <i>et al.</i> , 2014
<i>Tigriopus japonicus</i> (marine crustacean – copepod)	96 hr Two-generation chronic	No impact on survival of copepods (nauplius and adult females) in 96 hr acute test Decreased fecundity at all concentrations in both generations (0.5 μm and 6 μm) Decreased survival in F1 generation (0.5 μm and 25 $\mu\text{g mL}^{-1}$ and 0.05 μm and 1.25 $\mu\text{g mL}^{-1}$) and increased mortality in the F0 generation (0.05 μm and >12.5 $\mu\text{g mL}^{-1}$)	Up to 25 $\mu\text{g mL}^{-1}$	0.05, 0.5 and 6 μm (PS)	Polystyrene beads	Lee <i>et al.</i> (2013; abstract of)
<i>Centropages typicus</i> (marine crustacean – copepod)	24h	Decreased ingestion rates of total algae. Strong, logarithmic relationship between ingestion rate and microplastic concentration	$\geq 4\ 000$ particles mL^{-1}	7.3 μm (PS)	Commercial polystyrene spheres	Cole <i>et al.</i> , 2013
<i>Calanus helgolandicus</i> (marine crustacean – copepod)	24h 9d	Decreased ingestion of algal cells and carbon biomass. An extended 9d exposure indicated significantly decreased reproductive output, and no significant differences in egg production rates, respiration or survival.	75 particles mL^{-1}	20 μm (PS)	Unlabelled, additive-free polystyrene (PS) beads	Cole <i>et al.</i> , 2015
<i>Tripneustes gratilla</i> (echinoderm – sea urchin)	5d	Small not dose-dependent effect on larval growth (decreased body width) No significant effect on larval survival	1, 10, 100 and 300 particles mL^{-1}	10-45 μm (PE)	Commercial polyethylene microspheres Sea urchin larvae 5-8 days after fertilisation	Kaposi <i>et al.</i> (2014)

Organism	Exposure Duration (if known)	Reported effects	Concentration of particles in water/sediment [in organism if measured]	Plastic type/size (µm)	Comment (e.g. weathered particles?)	Reference
<i>Arenicola marina</i> (marine worm)	14d	Increased metabolism (18% increase in protein content) but no significant overall effect on the total Cellular Energy Allocation	110 particles g ⁻¹ sediment (natural) [Concentration in orgs after test (after 24-hour gut clearance): average 9.6 ± 1.8 particles g ⁻¹ tissue of size 10 µm and 30 µm]	10 - 90 µm (PS)	Coulter Standard latex beads	Van Cauwenberghe <i>et al.</i> (2015)
<i>Arenicola marina</i> (marine worm)	28d	Reduced feeding activity (no. of casts) at 5% dose. Reduced available energy reserves (1% and 5% doses). Increased phagocytic activity (0.5% and 5% doses – not dose-dependent)	0.5%, 1% and 5% by weight sediment (natural)	130 µm mean diameter (UPVC)	Clean, chemically-inert microplastics	Wright <i>et al.</i> , 2013
<i>Arenicola marina</i> (marine worm)	28d	Positive relationship between microplastic concentration with both uptake of microplastic and weight loss, and reduction in feeding activity at dose of 7.4% dry weight sediment	0 – 7.4% dry weight sediment	400 – 1 300 µm (PS)	PS pre-equilibrated in natively contaminated sediment ¹¹⁵	Besseling <i>et al.</i> (2013, abstract of)
<i>Mytilus edulis</i> (marine mussel)	14d	Increased metabolism (25% increase in energy consumption in the digestive gland) but no significant overall effect on the total Cellular Energy Allocation	110 particles mL ⁻¹ seawater (artificial) [Concentration in orgs after test (after 24-hour gut clearance): average 2.6 ± 0.4 particles g ⁻¹ tissue of size 10 µm]	10 – 90 µm (PS)	Coulter Standard latex beads	Van Cauwenberghe <i>et al.</i> (2015)
<i>Mytilus edulis</i> (marine mussel)	3d	Microplastics detected in the haemolymph after 3 d exposure and persisted there for over 48 d No adverse effects observed for the criteria investigated (oxidative status and haemocytes phagocytic ability)	40 particles.mL ⁻¹	3.0 and 9.6 µm (PS)		Browne <i>et al.</i> (2008; abstract of)

¹¹⁵ Without a parallel exposure to 'clean' microplastics, the relative impact of physical presence of the microplastics versus uptake of contaminants cannot be distinguished.

Organism	Exposure Duration (if known)	Reported effects	Concentration of particles in water/sediment [in organism if measured]	Plastic type/size (μm)	Comment (e.g. weathered particles?)	Reference
<i>Mytilus edulis</i> (marine mussel)	96hr	Accumulation in epithelial cells of the digestive system after 3 hrs, inducing a strong inflammatory response accompanied by histological changes. Measured biological effects became more severe with increasing exposure periods	2.5 g.L ⁻¹	>0 – 80 μm (industrial HDPE)		von Moos <i>et al.</i> (2012; abstract of)
<i>Mytilus edulis</i> (marine mussel)	7d exposure; 7d depuration	Increased haemocyte mortality and substantial modulation of cellular oxidative balance (increase in reactive oxygen species production in haemocytes and enhancement of anti-oxidant and glutathione-related enzymes in mussel tissues).	2 000 microbeads L ⁻¹ day ⁻¹ (corresponding to 32 μg L ⁻¹ day ⁻¹)	2 and 6 μm (PS)	Polystyrene beads	Paul-Pont <i>et al.</i> (2016)
<i>Crassostrea gigas</i> (oyster)	2 months	Decrease in oocyte number (-38%), diameter (-5%), and sperm velocity (-23%). Decrease (-41% and -18%) in D-larval yield and larval development, respectively, of offspring derived from exposed parents. Significant shift of energy allocation from reproduction to structural growth, and elevated maintenance costs (measured via dynamic energy budget and transcriptomic profiles)	0.023 mg L ⁻¹	2 and 6 μm (PS)	Virgin microplastics Adult oysters exposed during a reproductive cycle	Sussarellu <i>et al.</i> (2016)
<i>Dicentrarchus labrax</i> (marine fish - European seabass)	90d	Significant structural damage to the intestine (structural histopathological alterations in the distal intestine such as widening of lamina propria, detachment of mucosal epithelium from lamina propria, shortening and swelling of villi, vacuolation of enterocytes, increase of goblet cells and hyperplasia of goblet cells, and loss of regular structure of serosa)	Not reported	(PVC indicated)	PVC pellets	Peda <i>et al.</i> (2016; abstract)

Organism	Exposure Duration (if known)	Reported effects	Concentration of particles in water/sediment [in organism if measured]	Plastic type/size (μm)	Comment (e.g. weathered particles?)	Reference
<i>Dicentrarchus labrax</i> (marine fish - European seabass)	7d – 43d post-hatching (dph)	Significant (but slight) increase in average cumulative mortality rate at 45 dph for the 10^5 microbeads g^{-1} treatment, and significant increase in instantaneous mortality rate with the amount of beads scored per larvae at 14 and 20 dph but not at 34 dph. No impact on growth No indication of inflammation (1L-1 β biomarker)	10^4 and 10^5 microbeads g^{-1} diet	10 - 45 μm (PE)	Exposure to larvae 'Clean' microplastics	Mazurais <i>et al.</i> 2015
<i>Oryzias latipes</i> (freshwater fish – Japanese medaka)	2 months	Signs of liver stress (including glycogen depletion, fatty vacuolation and single cell necrosis)	10% by weight of diet (translates to 8 ng mL^{-1} of water)	<0.5 mm (PE)	Virgin plastic particles	Rochman <i>et al.</i> (2013)
<i>Oryzias latipes</i> (freshwater fish – Japanese medaka)	2 months	Female fish exhibited altered expression of a gene mediated by the oestrogen receptor in the liver (down-regulation of choriogenin H), but no altered expression for vitellogenin I and oestrogen receptor alpha. Male fish did not exhibit altered gene expression No histopathological changes in gonads, observed.	10% by weight of diet (translates to 8 ng mL^{-1} of water)	<0.5 mm (PE)	Virgin plastic particles	Rochman <i>et al.</i> (2014)
<i>Danio rerio</i> (freshwater fish - Zebra fish)	7d	5 μm microplastics accumulated in fish gills, liver and gut, and 20 μm microplastic accumulated only in fish gills and gut 5 μm and 70 nm microplastic caused inflammation and lipid accumulation in fish liver (at 2 000 $\mu\text{g L}^{-1}$), oxidative stress (increased activities of superoxide dismutase (at 20, 200 and 2 000 $\mu\text{g L}^{-1}$) and catalase (at 200 and 2000 $\mu\text{g L}^{-1}$) in fish livers), and alterations of metabolic profiles in fish liver (at 20, 200 and 2 000 $\mu\text{g L}^{-1}$)	20 mg L^{-1} (2.9×10^5 particles mL^{-1} for 5 μm PS-MPs and 4.5×10^3 particles mL^{-1} for 20 μm PS-MPs) (for uptake/accumulation testing) 20 $\mu\text{g L}^{-1}$ (1.1×10^8 particles mL^{-1} for 70 nm PS-MPs and 2.9×10^2 particles mL^{-1} for 5 μm PS-MPs), 200 $\mu\text{g L}^{-1}$ (1.1×10^9 particles mL^{-1} for 70 nm PS-MPs and 2.9×10^3 particles mL^{-1} for 5 μm PS-MPs), and 2 000 $\mu\text{g L}^{-1}$ (1.1×10^{10} particles mL^{-1} for 70 nm PS-MPs and 2.9×10^4 particles mL^{-1} for 5 μm PS-MPs)	5 μm and 20 μm (PS) (for uptake/accumulation testing) 70 nm (0.07 μm) and 5 μm (for toxicity testing)	Virgin PS	Lu <i>et al.</i> (2016)

Organism	Exposure Duration (if known)	Reported effects	Concentration of particles in water/sediment [in organism if measured]	Plastic type/size (μm)	Comment (e.g. weathered particles?)	Reference
<i>Pomatoschistus microps</i> (freshwater and marine fish - Common goby)	96 hr	Reduced activity of acetylcholinesterase enzyme (AChE - involved in neuro and neuromuscular transmission in fish) No significant effects for glutathione S-transferase activity or lipid peroxidation.	18.4 and 184 $\mu\text{g L}^{-1}$	1-5 μm (PE)	Exposure to juveniles (0+ group)	Oliveira <i>et al.</i> (2013)

Note PS = polystyrene, PE = polyethylene, PVC = polyvinylchloride, UPVC = unplasticised (rigid) poly(vinyl chloride), HDPE = high density polyethylene, LDPE = low density polyethylene

A number of studies have investigated effects of exposure to microplastics in zooplankton.

A study with the marine crustacean isopod species *Idotea emarginata* (Haemer *et al.*, 2014) showed no significant effects on mortality, growth, and intermolt duration when exposed to polystyrene microbeads of sizes 1 – 100 µm at 12 and 120 particles.mg⁻¹ food for 6 weeks. The authors also note that the microplastics were not present in the tubules of the midgut gland, which is the principal organ of enzyme-secretion and nutrient resorption.

However, Lee *et al.* (2013) found in a two-generation chronic toxicity study that on exposure to polystyrene microbeads at concentrations up to 25 µg mL⁻¹ the marine crustacean copepod *Tigriopus japonicus* exhibited decreased fecundity (0.5 µm and 6 µm beads), whilst smaller beads (0.05 µm and 0.5 µm) caused an increased mortality in the F0 and F1 generations. Meanwhile, the 96-hour acute study found no impact on the survival of the copepod (nauplius and adult females).

In a second copepod species, *Centropages typicus*, Cole *et al.* (2013) reported decreased algal ingestion rates on exposure to high concentrations (≥4 000 particles mL⁻¹) of 7.3 µm polystyrene spheres over 24 hours, with a strong, logarithmic relationship between the ingestion rate of total algae and microplastic concentration. Cole *et al.* (2013) also noted that polystyrene spheres coated the exoskeleton of copepods and concentrated between the external appendages, such as the swimming legs and feeding apparatus. However, this study did use high concentrations of particles.

A second study by Cole *et al.* (2015), this time with the copepod species *Calanus helgolandicus*, and using a lower concentration of slightly larger polystyrene beads (75 particles mL⁻¹; 20 µm in size) but same exposure length reported decreased ingestion of algal cells and carbon biomass. An extended 9-day exposure indicated decreased reproductive output, but there were no significant differences in egg production rates, respiration or survival.

A study with sea urchin (*Tripneustes gratilla*) larvae (Kaposi *et al.*, 2014) reported no significant effect on larval survival but a small not dose-dependent effect on larval growth, on exposure to 10-45 µm polyethylene microspheres at a range of concentrations from 1 particle mL⁻¹ to 300 particles mL⁻¹.

Studies are also available for the effects of microplastics on the deposit feeding marine lugworm species *Arenicola marina*.

Van Cauwenberghe *et al.* (2015) reported an increase in metabolism (18% increase in protein content) but no significant adverse effect on the overall energy budget⁸¹ on exposure of *Arenicola marina* to 110 particles g⁻¹ sediment of 10-90 µm sized polystyrene beads for 14 days.

Meanwhile, Wright *et al.* (2013) reported a reduction in feeding activity and available energy reserves, as well as a not dose-dependent increase in phagocytic activity (which the authors note as indicative of an inflammatory response), in *Arenicola marina* exposed to 130 µm polyvinylchloride microplastics at concentrations ranging from 0.5 to 5% by weight sediment over a 28-day period.

In addition, Besseling *et al.* (2013; abstract of) reported increased weight loss in *Arenicola marina* with increasing concentration up to 7.4% by weight sediment of 400 –1 300 µm sized polystyrene microplastics over 28 days, along with a reduction in feeding activity at the highest concentration. It is of note though that this study used microplastics that were pre-equilibrated in natively contaminated sediment, and without a parallel exposure to 'clean' microplastics, the relative impact of physical presence of the microplastics verses uptake of contaminants cannot be distinguished.

The marine mussel *Mytilus edulis* is another species for which a number of investigations of effects of microplastics have been carried out.

Van Cauwenberghe *et al.* (2015) reported an increase in metabolism (25% increase in energy consumption in the digestive gland) but no significant adverse effect on the overall energy budget⁸¹ on exposure of *Arenicola marina* to 110 particles mL⁻¹ seawater of 10-90 µm sized polystyrene beads for 14 days.

Using the same marine mussel species, Browne *et al.* (2008; abstract of) reported that a 3 day exposure to 3 and 10 µm sized polystyrene microplastics at 40 particles mL⁻¹ resulted in translocation from the digestive tract to the circulatory system. Microplastics were detected in the haemolymph within three days after exposure, and persisted there for over 48 days. No adverse effects on the mussels were observed for the criteria investigated (oxidative status and haemocytes phagocytic ability).

Von Moos *et al.* (2012, abstract of) also reported translocation for the same species of mussel. Polyethylene microplastics of size $>0 - 80 \mu\text{m}$ at 2.5 g L^{-1} were found to accumulate in epithelial cells of the digestive system (more specifically, the digestive tubules) after 3 hours of exposure. The authors also observed a strong inflammatory response accompanied by histological changes. With increasing exposure periods (up to 96 hours), the measured biological effects became more severe.

Paul-Pont *et al.* (2016) also studied effects on *Mytilus edulis* and reported increased haemocyte mortality and substantial modulation of cellular oxidative balance on exposure to 2 and 6 μm sized polystyrene microbeads at $2\,000 \text{ microbeads L}^{-1} \text{ day}^{-1}$ (corresponding to $32 \mu\text{g L}^{-1} \text{ day}^{-1}$) for 7 days.

Sussarellu *et al.* (2016) exposed adult Pacific oyster (*Crassostrea gigas*) for a 2-month period during a reproductive cycle to 2 and 6 μm polystyrene microplastics at 0.023 mg L^{-1} and reported reproductive effects (decreased oocyte number and sperm velocity and decreased larval yield and development). The authors also reported a shift of energy allocation from reproduction to structural growth, as well as elevated maintenance costs.

Studies with fish covering a number of different species are available.

Two studies have investigated effect of presence of microplastics on European seabass (*Dicentrarchus labrax*). Peda *et al.* (2016; abstract of) reported significant structural damage to the intestine on exposure to PVC microplastic pellets for 90d. Mazurais *et al.* (2015) investigated exposure of seabass larvae to 10 - 45 μm sized polyethylene microplastics for an exposure period from 7 days to 43 days post-hatching (dph) via what seems quite a high concentration in diet (10^4 and $10^5 \text{ microbeads g}^{-1}$). A significant (but slight) increase in average cumulative mortality rate at 45 dph for the $10^5 \text{ microbeads g}^{-1}$ treatment was reported, along with significant increase in instantaneous mortality rate with the amount of beads scored per larvae at 14 and 20 dph but not at 34 dph. The authors consider gut-obstruction-induced mortality as a potential factor, particularly during early larval stages. No impact on growth, nor indication of inflammation, was observed in the study.

In studies with Japanese medaka (*Oryzias latipes*) involving 2-month exposures to $<0.5 \text{ mm}$ sized polyethylene microplastics at 8 ng mL^{-1} reported signs of liver stress (Rochman *et al.*, 2013) and altered expression of a gene mediated by the oestrogen receptor in the liver for female fish (Rochman *et al.*, 2014). Rochman *et al.* (2014) propose that the down-regulation of the choriogenin H suggests that the virgin polyethylene may be capable of inducing an endocrine-disrupting effect, but Duis, K. and Coors, A. (2016) note that it is likely that the reduced choriogenin H gene expression is an effect of the glycogen depletion reported in the 2013 study by Rochman *et al.*, i.e. it should not be considered as endocrine disruption.

Lu *et al.* (2016) reported that 5 μm sized polystyrene microplastic at what appears to be a rather high concentration of 20 mg L^{-1} translocated to the liver in Zebra fish (*Danio rerio*). Toxicity tests at lower concentration ($20 - 2\,000 \mu\text{g L}^{-1}$) indicated inflammation and lipid accumulation at the highest dose, and oxidative stress and alterations of metabolic profiles (at all concentrations) in the liver.

Oliveira *et al.* (2013) exposed juvenile Common goby (*Pomatoschistus microps*) to 1-5 μm polyethylene microplastics at 18.4 and $184 \mu\text{g L}^{-1}$ and reported reduced activity of acetylcholinesterase enzyme (involved in neuro and neuromuscular transmission in fish) in the head of fish.

Physical effects – Summary

The literature reports a wide range of potential physical effects in aquatic organisms. The effects can be divided into the following:

- ▶ Reduced nutrition due to high fraction of microplastics in diet (or potentially, for smaller organisms or organisms at earlier stages of development, due to reduction in feeding activity/rate/capacity through the blockage of feeding appendages/alimentary canal).
- ▶ Structural damage, e.g. to intestine.
- ▶ Translocation into circulatory system and tissues causing particle associated inflammation and histological changes.

The following deals with these three potential types of effect in turn.

The effects documented in Table 3.8 and discussed in the above section represent a range of species and endpoints, as well as exposure duration and microplastic size and concentration. A brief summary of cases where effects were observed follows.

Studies with marine crustaceans indicate that microplastics can cause decreased ingestion rates (Cole *et al.*, 2013 and 2015 75 particles mL⁻¹; 20 µm) and reduced fecundity (Lee *et al.*, 2013 Up to 25 µg mL⁻¹; 0.5 and 6 µm), and for smaller microplastic (0.5 µm) at high concentration (25 µg mL⁻¹) increased mortality in F1 generations (Lee *et al.*, 2013). A small reduction in sea urchin larval growth has been reported (Kaposi *et al.*, 2014 1, 10, 100 and 300 particles mL⁻¹; 10-45 µm). Effects observed on marine worms include increased metabolism (Van Cauwenberghe *et al.*, 2015 110 particles g⁻¹ sediment; 10 - 90 µm), reduced energy reserves and increased phagocytic activity (Wright *et al.*, 2013 0.5%, 1% and 5%; 130 µm), reduced feeding activity (Wright *et al.*, 2013 and Besseling *et al.*, 2013 0.5%, 1% and 5%; 130 µm and 0 – 7.4%; 400 – 1 300 µm) and increased weight loss (Besseling *et al.*, 2013 0 – 7.4%; 400 – 1 300 µm). Effect observed on marine mussels include a strong inflammatory response accompanied by histological changes for smaller microplastics (size range >0 – 80 µm) and at high concentration (2.5 g L⁻¹) (von Moos *et al.*, 2012), increased metabolism (Van Cauwenberghe *et al.*, 2015 110 particles g⁻¹ sediment; 10 - 90 µm) and increased haemocyte mortality and substantial modulation of cellular oxidative balance for smaller microplastics (2 and 6 µm) (Paul-Pont *et al.*, 2016 2 000 microbeads L⁻¹ day⁻¹ (corresponding to 32 µg L⁻¹ day⁻¹)). Effects on fish, marine and freshwater species, range from signs of liver stress (Rochman *et al.*, 2013 and 2014, Lu *et al.*, 2016 10% by weight of diet (translates to 8 ng mL⁻¹ of water); <0.5 mm and 20-2 000 µg L⁻¹; 5 µm) to reduced activity of acetylcholinesterase enzyme (involved in neuro and neuromuscular transmission in fish) in the head of fish (Oliveira *et al.*, 2013 18.4 and 184 µg L⁻¹; 1-5 µm), as well as increased mortality of fish larvae at high concentration (10⁴ and 10⁵ microbeads g⁻¹ diet of size 10 - 45 µm) (Mazurais *et al.*, 2015).

The observed effects across the species tested may predominantly result from reduced nutrition as a result of fraction of microplastics in the diet (or potentially blockage of feeding appendages/alimentary canal), which in turn results in lower energy reserves and associated effects on other physiological functions such as growth and fecundity. Additional effects such as reduced predator avoidance and general fitness of organisms may also result from reduced nutrition, but would not be observed in standard laboratory studies.

Increased mortality has been observed for marine crustacean F1 generations and for fish larvae, both studies having high concentration of microplastics. In view of the smaller size of organism testing, it is possible that the observed increase in mortality is gut-obstruction-induced mortality. The increased mortality may also reflect a higher sensitivity of organisms in earlier life stages to nutrition lack as a result of fraction of microplastics in the diet.

It is important to note that aquatic organisms frequently ingest non-food particulate material (e.g., sand particles) or partially digestible material (such as fish scales, wood, shells of macroinvertebrates, etc.) which can be abundant in natural environments. Thus, organisms have evolved mechanisms to cope with unwanted non-food material. In addition, many studies have used concentrations of microplastics that exceed those commonly found in the environment. This presents a challenge for commenting on the environmental relevance of the effects observed.

Translocation of microplastics from the gut to circulatory system and/or tissues, sometimes associated with inflammation and histological changes, has been reported in a number of studies and species, including mussel, crab and fish. The process appears to be size-dependent, whereby microplastics of size <10 µm may have the potential to translocate whereas larger particles may not.

Browne *et al.* (2008; abstract of) and von Moos *et al.* (2012, abstract of) both report translocation of microplastics from the digestive tract: to the circulatory system after 3 days (72 hours) exposure in the case of Browne *et al.*; and to the epithelial cells of the digestive tract after 3 hours exposure in the case of von Moos *et al.* Browne *et al.* used 3 and 10 µm sized microplastics at 40 particles mL⁻¹, whereas von Moos *et al.* used microplastics of size range >0 – 80 µm at what appears to be a rather high concentration (2.5 g L⁻¹). Browne *et al.* (2008, as cited in Watts *et al.*, 2014) reported that 3 µm sized microplastic was detected in significantly higher amounts than 10 µm sized microplastic. Browne *et al.* (2008) reported no adverse effects for criteria investigated (oxidative status and haemocytes phagocytic ability), whereas Von Moos *et al.* (2012) observed a strong inflammatory response accompanied by histological changes in the mussels. In a study Farrell and Nelson (2013) mussels that had consumed polystyrene microplastics of size 0.5 µm were provided to crabs (*Carcinus maenas*), and microplastics were found in the haemolymph and tissues of the crabs after 21 days. Biological effects of the exposure were not investigated. This study indicates that

translocation from gut to circulatory system can also occur via ingestion of prey contaminated with microplastics. A later study by Watts *et al.* (2014), however, using the same species of crab and pre-exposed mussels but with larger microplastics of size 8-10 μm reported that no microspheres were detected in the haemolymph of the crabs, via diet (mussels) or via gill exposure. The authors suggest a size bias in the translocation of microplastics across the gut wall in crabs. This hypothesis is supported by a study by Lu *et al.* (2016) which reported that 5 μm sized polystyrene microplastic, at what appears to be a rather high concentration of 20 mg L^{-1} , translocated to the liver of Zebra fish, whereas 20 μm sized polystyrene microplastic did not. Toxicity testing by Lu *et al.* (2016) at lower concentrations of microplastic (20 – 2 000 $\mu\text{g L}^{-1}$) indicated inflammation and lipid accumulation (at the highest dose) and oxidative stress and alterations of metabolic profiles (at all concentrations) in the liver. On the other hand, a study with a marine crustacean isopod species reported that microplastics were not present in the tubules of the midgut gland after exposure to 1-100 μm sized microplastics at 12 and 120 particles. mg^{-1} food (Haemer *et al.*, 2014), with no significant effects on mortality, growth, and intermolt duration observed.

Toxic effects of microplastics on aquatic organisms

Toxic effects of microplastics on aquatic organisms refers to the potential toxic effects caused by the chemicals that can be associated with microplastics. Chemicals could originate from the ingredients that the microbeads are made from (e.g. free monomer and additives) and/or chemical contaminants that have accumulated on the microplastic from surrounding environmental media (e.g. persistent organic pollutants (POPs), persistent bioaccumulative and toxic substances (PBTs), and also potentially inorganic substances, such as toxic metals).

Transfer of such chemicals to organisms could occur via direct ingestion of microplastics, indirect bioaccumulation (bioconcentration from water (including sediment porewater) of chemicals that have leached from microplastics), or via ingestion of prey containing microplastics.

Transfer of contaminants from microplastic to tissues of aquatic organisms has been demonstrated by a number of studies, for example with lugworms (Browne *et al.*, 2013; for pollutants nonylphenol and phenanthrene and additives Triclosan and PBDE-47 from PVC microplastic and Besseling *et al.*, 2013 for pollutant PCBs from PS microplastic), amphipods (Chua *et al.*, 2014; for PBDEs from microplastic isolated from a commercial facial cleansing soap) and fish (Rochman *et al.*, 2013; for pollutant PAHs, PCBs and PBDEs from PE).

Fugacity models based on the chemical fugacity gradient between ingested plastic and organism tissue can be used to predict uptake (or depuration) of chemicals following ingestion of microplastics (Gouin *et al.*, 2011, Koelmans, 2015).

The assessment of magnitude of uptake that could result from specific microplastic types in the environment is complicated by the fact that contaminants originating from a range of different sources are already present in environmental organisms, in surrounding waters, and in the organic matter in organisms' diet. Uptake of contaminants into organisms may be predicted in some cases, but equally the presence of microplastics as part of an organisms' diet could result in a decrease in overall uptake of pollutants from diet, whereby the high sorption affinity of some plastics can result in reduced chemical fugacity of pollutants released on degradation of organic matter in the gastrointestinal tract (Gouin *et al.*, 2011). The relative contribution of microplastics as a source of pollutant accumulation in organisms compared to environmental sources (e.g. water, sediment particles, suspended organic matter, prey) is uncertain. Koelmans (2015) proposed that ingestion of microplastics seems to be a less important route at present concentrations compared to existing environmental pathways, and that marine organisms could in fact experience a trade-off, whereby the negative effects of transfer of additives to the organism is balanced by positive effects from reduced pollutant bioaccumulation (Koelmans *et al.* 2014 as cited in Koelmans, 2015). However, Koelmans (2015) also notes that for more degradable/metabolisable compounds, such as poly aromatic hydrocarbons (PAHs) and poly brominated diphenyl ethers (PBDEs), where absorption to microplastic may preserve these chemicals, the exposure via microplastic ingestion may have an increased role as an exposure pathway, and the reduced pollutant bioaccumulation, mentioned above, would be less relevant.

Laboratory studies give some insight into microplastic transfer of contaminants verses transfer from environmental media. Chua *et al.* (2014) found that the presence of clean microplastic in seawater led to smaller body burden of PBDEs in amphipods compared to seawater alone (Chua *et al.*, 2014 as cited in GESAMP 2016) and Browne *et al.* (2013) reported that lugworms (*Arenicola marina*) accumulated >250%

more phenanthrene (a PAH) and nonylphenol (a surfactant substance with suspected endocrine disrupting effects in vertebrates) in their tissues when exposure to the chemicals via 'pre-absorption' to sand compared to when exposed via 'pre-absorbed' microplastics. On the other hand, Besseling *et al.* (2013; abstract) demonstrated that presence of microplastic pre-absorbed with polychlorinated biphenyls (PCBs) (via equilibration in natively contaminated sediment) at 0.074% dry weight in natural marine sediment increased the bioaccumulation of PCBs in lugworms by a factor of 1.1 – 3.6. There was evidence that the bioaccumulation decreased again at higher concentrations of microplastic, though this was only significant for one PCB congener. Similarly, Rochman *et al.* (2013) reported that Japanese medaka (*Oryzias latipes*) exposed to microplastic pre-sorbed with PAHs, PCBs and PBDEs (via deployment in an urban bay for three months) at 10% plastic by weight of diet¹¹⁶ bioaccumulated PAHs, PCBs and PBDEs to a greater extent than when exposed to a diet containing virgin microplastics or no microplastics (these diets still contained PAHs, PCBs and PBDEs, due to use of cod liver oil in the synthetic food, but at lower concentration). Thus, there is evidence from laboratory data of increased pollutant uptake as a result of presence of environmentally-contaminated microplastics in the diet.

It is also worth noting findings from a study by Paul-Pont *et al.* (2016) where the impact of the presence of PS microplastic on bioaccumulation and depuration of fluoranthene in mussels (*Mytilus* sp.) was investigated. Although after 7 days of exposure, the concentration of fluoranthene in gills and digestive gland was the same for the fluoranthene alone and the fluoranthene plus microplastic exposure, after a 7-day depuration period it was found that the remaining fluoranthene concentration in digestive glands was higher for the fluoranthene plus microplastic exposure compared to the fluoranthene only exposure. The authors commented that this may be related to direct effect of microplastic on detoxification mechanisms, but noted that factors such as impaired filtration activity or presence of remaining beads in the gut may also be responsible.

Laboratory studies are available that assess the increased toxicity associated with presence of microplastics as a result of uptake of pollutants/additives.

Browne *et al.* (2013) investigated effects of pollutants nonylphenol and phenanthrene and additives triclosan (an antimicrobial substance) and PBDE-47 on mortality, feeding, immune function and oxidative stress of exposed lugworms (*Arenicola marina*) via sand and via PVC microplastic exposure. The worms were exposed to nonylphenol and phenanthrene via adsorption to clean sand and via adsorption onto microplastic which was subsequently mixed with clean sand. Triclosan and PBDE-47 were exposed only via adsorption onto microplastic which was subsequently mixed with clean sand. The authors report that the quantities of additives added to the plastic (5%-30% for PBDE-47 and 0%-5% for Triclosan) were realistic to proportions used by industry. Microplastic and sand mixes comprised 5% microplastic. The authors report reduced survival for worms exposed to sand plus microplastic pre-sorbed with triclosan, compared to worms exposed to sand plus microplastic that had not been pre-sorbed, and the presence of microplastic pre-sorbed with PBDE-47 or triclosan resulted in reduced feeding (casts per worm per day), though the effect with PBDE-47 was not significant. Worms exposed to either microplastic or sand pre-sorbed with nonylphenol exhibited reduced phagocytic activity of coelomocytes compared to the treatments with sand and those with sand plus non-pre-sorbed. A similar but not significant pattern was observed for triclosan, while no effects on phagocytic activity was observed phenanthrene and PBDE-47. No significant reduction in capacity to deal with oxidative stress was observed for exposure to any of the pollutants via either sand or microplastic.

A study by Rochman *et al.* (2013) with Japanese medaka reported that Japanese medaka (*Oryzias latipes*) exposed to microplastic pre-sorbed with PAHs, PCBs and PBDEs (via deployment in an urban bay for three months) at 10% plastic by weight of diet¹¹⁷ showed signs of stress in their livers (including glycogen depletion, fatty vacuolation and single cell necrosis) after a 2-month exposure. Fish exposed to a diet containing virgin microplastics, which still contained a (lower) concentration of PAHs, PCBs and PBDEs due to use of cod liver oil in the synthetic food, also exhibited effects but these were less severe. No effects on expression of a gene associated with defence mechanisms in the liver was observed. It was reported that one fish in the virgin microplastic treatment exhibited a precursor to a tumour in the liver and one fish in the marine-exposed microplastic treatment had a liver tumour (a hepatocellular adenoma). The authors note that

¹¹⁶ The authors report that: Diet and plastic dissociated at the surface and thus fish were exposed to plastic similar to the way they are in the wild (i.e. floating in the water column). As such, this translates to 8 ng of plastic per mL of water.

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formation and promotion of spontaneous tumours is very rare in medaka less than one year of age, but do not comment further on the tumour precursor and tumour formation.

Rochman *et al.* (2014) carried out a similar study using the same species, plastic type and exposure procedure, but investigating the endpoint of altered gene expression. Male fish exhibited altered expression of genes mediated by the oestrogen receptor in the liver (down-regulation of choriogenin H gene expression) on exposure to the marine-exposed microplastic treatment. Meanwhile, female fish exhibited down-regulation of vitellogenin I, choriogenin H and oestrogen receptor alpha on exposure to marine-exposed microplastic and down-regulation of choriogenin H on exposure to virgin microplastic treatment. The authors note that the down-regulation of genes observed in the female fish could reduce their fecundity. Response at the tissue level, via examination of the histopathology of the gonads, was also measured. This indicated no changes in fish from either plastic treatment, other than for one male fish in the marine plastic particle treatment where abnormal proliferation of germ cells was observed.

Oliveira *et al.* (2013) studied the effect of PE microplastic (1-5 μm at 0, 18.4 and 184 $\mu\text{g L}^{-1}$) on short-term toxicity of the PAH pyrene to juvenile (0+ group) common goby (*Pomatoschistus microps*). Fish were exposed for 96 hours to pyrene at 20 and 200 $\mu\text{g L}^{-1}$ in the presence and absence of microplastic. The authors note that the concentrations of pyrene used were environmentally relevant. Mortality, bile pyrene metabolites, and biomarkers involved in neurotransmission, aerobic energy production, biotransformation and oxidative stress were quantified. The presence of microplastics resulted in both a delay in pyrene-induced fish mortality and an increase in pyrene metabolites in the bile. Decreased isocitrate dehydrogenase¹¹⁸ (IDH) enzyme activity was observed in the microplastic plus pyrene treatment. Significantly reduced acetylcholinesterase (AChE) activity, which is indicative of adverse effects in neurofunction, was observed for pyrene alone, microplastic alone, and microplastic plus pyrene. The authors note that simultaneous exposure to both microplastic and pyrene did not increase significantly the inhibitory effect and thus the authors conclude that the mechanism for AChE inhibition appeared to be different for pyrene and microplastics, and for the purposes of this discussion we do not consider the effect further. No significant effects were found for glutathione S-transferase activity or lipid peroxidation.

These studies indicate that contaminants associated with microplastics can be taken up by organisms at high enough concentration to cause a toxic effect, and that greater negative impact can be observed in organisms exposed to a diet containing microplastics pre-sorbed with contaminants compared to a diet with non-pre-sorbed microplastics and/or a diet absent of microplastics. In the case of Browne *et al.* (2013), the additive Triclosan caused reduced survival of lugworms and reduced feeding activity, whilst the pollutant nonylphenol resulted in reduced phagocytic activity. Rochman *et al.* (2013 and 2014) reported that a mixture of pollutants PAHs, PCBs and PBDEs caused signs of liver stress as well as altered gene expression in livers of Japanese medaka, whilst pollutant pyrene caused a decrease in activity of an enzyme associated both with aerobic energy pathway and antioxidant system.

The contaminants and effects investigated in the above discussed studies represent a small part of the potential contaminants which could be associated with microplastics and transferred to organisms. In addition, the use of synthetic food in these studies (though the control diet used in studies by Rochman *et al.* (2013 and 2014) did contain contaminants) and laboratory organisms in the case of studies by Rochman *et al.* (2013 and 2014), and laboratory acclimatised organisms in the case of the study by Oliveira *et al.* (2013) means that the environmental relevance of the observed effects is unclear. None-the-less, these studies do provide evidence of the potential for toxic effects as well as physical effects to be exhibited on exposure of environmental organisms to microplastics.

Effects of microplastics on humans

Van Cauwenberghe and Janssen (2014) have documented the presence of microplastics in commercially grown blue mussel *Mytilus edulis* and Pacific oyster *Crassostrea gigas*, and estimated a potential annual dietary exposure of human to microplastics. Such organisms are cultured in natural conditions, mainly in coastal areas. Other commercial seafood species are likely to also be contaminated with microplastics, as well as commercially captured seafood. Seafood such as mussels and oysters represent a particularly

¹¹⁸ IDH is involved in the aerobic pathway of energy production and has an important action in the antioxidant system

relevant exposure route as the entire body is consumed, compared to for example fish species, where the gastrointestinal tract is generally removed, at least for larger fish.

Studies across a range of mammalian species, including rats, mice and humans, have demonstrated translocation of inert microparticulate matter <150 µm, such as starch and latex, across the mammalian gut via the intestinal lymphatic system, as documented by Hussain *et al.* (2001). More recently, Van Cauwenberghe (2015) investigated the potential translocation and toxic effects of microplastics using a human intestinal cell line (Caco-2). High concentrations (5.7×10^4 to 5.7×10^7 particles mL⁻¹) of 2 µm microplastics resulted in paracellular transport, i.e. transport between intercellular spaces, of 0.02 to 0.16% of the particles after one hour and 0.08 to 0.53% after 24 hours. Cytotoxic effects in the intestinal cells were not exhibited. Carr *et al.* (2012, as cited in Van Cauwenberghe and Janssen, 2014) have demonstrated intestinal translocation of latex microspheres of size 2 µm at 0.04 – 0.3% of particles. A 2016 statement report from the EFSA Panel on Contaminants in the Food Chain concludes that only microplastics smaller than 150 µm have potential to translocate across the gut epithelium causing systemic exposure, and only microplastics <1.5 µm may deeply penetrate into organs (EFSA CONTAM Panel, 2016). The report also notes that the absorption of microplastics is expected to be low ($\leq 0.3\%$ of particles).

The EFSA panel highlights that toxicity and toxicokinetic data are lacking for microplastics for a human risk assessment, whilst there is no legislation for microplastics as contaminants in food. Thus, further research is called for.

As for environmental species, toxicity to humans could also potentially occur as a result of exposure to contaminants associated with microplastics. The EFSA panel reports that the presence of microplastics in seafood would have a small effect on the overall exposure of humans to additives or pollutants, based on a conservative estimate.

Overall conclusion on effects (environment and humans)

A literature review of the potential **physical effects** of microplastic has identified that the effects observed across the environmental species tested may predominantly result from reduced nutrition as a result of fraction of microplastics in the diet (or potentially blockage of feeding appendages/alimentary canal), which in turn results in lower energy reserves and associated effects on other physiological functions such as growth and fecundity. The effects observed include:

- ▶ Decreased ingestion rates/reduced feeding activity.
- ▶ Reduced fecundity.
- ▶ Reduced energy reserves.
- ▶ Increased phagocytic activity.
- ▶ Increased weight loss.
- ▶ Inflammatory response accompanied by histological changes.
- ▶ Increased metabolism.
- ▶ Increased haemocyte mortality.
- ▶ Modulation of cellular oxidative balance.
- ▶ Liver stress.
- ▶ Reduced activity of enzyme involved in neuro and neuromuscular transmission.

Additional effects such as reduced predator avoidance and general fitness of organisms may also result from reduced nutrition, but would not be observed in standard laboratory studies. However, the significance of the effects listed above in terms of impact at the ecological level – i.e., there is an impact on populations of species and effects on the functioning of ecological communities, has not apparently been investigated.

Increased mortality has been observed for marine crustacean F1 generations and for fish larvae, both studies having high concentration of microplastics. In view of the smaller size of organism tested, it is

possible that the observed increase in mortality is gut-obstruction-induced mortality. The increased mortality may also reflect a higher sensitivity of organisms in earlier life stages to nutrition lack as a result of fraction of microplastics in the diet.

It is important to note that aquatic organisms frequently ingest non-food particulate material (e.g., sand particles) or partially digestible material (such as fish scales, wood, shells of macroinvertebrates, etc.) which can be abundant in natural environments. Thus, organisms have evolved mechanisms to cope with unwanted non-food material. In addition, many studies have used concentrations of microplastics that exceed those commonly found in the environment. This presents a challenge for commenting on the environmental relevance of the effects observed.

Nonetheless, one study¹¹⁹ compared differences between effects of primary microplastics (spherical beads), secondary microplastics (ground polyethylene beads) and mineral particles (kaolin clay), of similar size ranges, on the freshwater invertebrate *Daphnia magna* (water fleas that filter feed on algae and bacterial cells suspended in the water column). Although the main differences in effects appeared to be between primary and secondary plastics (for example the median effect concentration on reproduction (EC₅₀) was three times lower for secondary plastics than for primary plastics or kaolin), there were some differences in effects on feeding between primary and secondary plastics and kaolin, with the plastics having a significant effect on feeding, albeit a high particle concentrations. (It should be noted that the authors acknowledge that to adequately assess the potential hazards of microplastics, carefully designed experimental studies with varying microplastic contribution to the exposure media, polymer types, particle sizes and shapes are needed.)

Translocation of microplastics from the gut to circulatory system and/or tissues, sometimes associated with inflammation and histological changes, has been reported in a number of studies and species, including mussel, crab and fish. The process appears to be size-dependent, whereby microplastics of size <10 µm may have the potential to translocate whereas larger particles may not. Translocation is an important consideration for risk assessment, as if depuration of microplastics from the organism takes place at a slower rate than uptake rate, there is a potential for the organism to bioaccumulate microplastic in its tissues, and potentially causing longer-term effects.

If the level at which effects are reported on aquatic organisms (see Table 3.8 in this section) are compared with the concentrations that are estimated to be in the environment, then it is possible that there could be a risk. For example, Van Cauwenberghe et al. (2015) reported increased metabolism on 14 day exposure to the marine worm *Arenicola marina* at concentrations 110 particles g⁻¹ (i.e. 110 000 per kg (although not clear if this is wet or dry weight)) sediment (particle size 10 - 90 µm), and Besseling *et al.* (2013) reported weight loss, and reduction in feeding activity at dose of 7.4% dry weight sediment (which equates to 7 400 mg/kg dry weight), particle size 400 –1 300 µm. These effects compare with the highest predicted concentrations in sediment (see Table 3.4) of 1 300 mg/kg dry wt, 310 000 particles/kg dry wt (freshwater sediment from PCCP Professional and consumer use) and 17 000 mg/kg dry wt, 4 000 000 particles/kg dry wt (marine sediment from oil and gas Industrial use). Regional scale concentration in sediment (see Table 3.5 are 310 mg/kg dry wt (74 000 particles/kg dry wt) for freshwater and 95 mg/kg dry wt.(23 000 particles/kg dry wt.) for marine sediment). Note that the particle sizes tested were much smaller than those in the exposure estimates. For waterborne concentrations, the highest predicted concentrations in freshwater are 0.25 mg/L in marine water from formulation in oil and gas, which equates to 60 particles/L (at a particle size of 200 µm). This can be compared with effects (increased metabolism) reported by Van Cauwenberghe et al. (2015) on *Mytilus edulis* (marine mussel) at 110 particles /mL (which is 110 000 particle /Litre). Cole et al., 2013 reported decreased reproductive output in copepod crustaceans at 9 day exposure to 75 particles mL⁻¹ (which is 75 000 particle/L) – particle size 20 µm. **It should be noted that many of the effects reported with microplastic particles were not compared in the same test systems with particles of similar size and density but made of other materials (as a control), it is therefore not clear if these effects are particular to microplastics or would be found with any particles of similar size and mass.**

As described earlier in this report, concentrations predicted in this study through modelling are in the order of 0.56 particles for surface water and marine water, and values reported in the literature (microplastics from all sources) are in the range 0.00056 to 64 particles/l. There is considered to be insufficient available

¹¹⁹ Ogonowski M., Schür C., Jarsén Å., Gorokhova E. The effects of natural and anthropogenic microparticles on individual fitness in *Daphnia magna*. PLoS ONE. 2016;11:e0155063 doi: 10.1371/journal.pone.0155063.

information to derive a reliable no-effect concentration (e.g. PNEC) against which to compare these values. There is some literature which quotes lowest observed effect concentrations much higher than these values e.g. a LOEC value of around 30,000 items/L (assumed to be equivalent to particles/L) is quoted by Duis and Coors (2016)¹²⁰. However, research in this area is still emerging.

The potential **toxic effects** caused by the complex mixture of chemicals that can be associated with microplastics is challenging to quantify. Firstly, the assessment of magnitude of potential uptake of such contaminants from microplastics and the relative importance of such an exposure route compared to overall environmental exposure is complicated by the fact that contaminants originating from a range of different sources are present already in environmental organisms, in surrounding waters, and in the organic matter in organisms' diet. The assessment of impacts associated with uptake of contaminants from microplastics into organisms is further complicated by the fact that impacts would often be associated with mixtures of chemicals rather than a single contaminant.

There is evidence from laboratory data of increased pollutant uptake as a result of presence of environmentally-contaminated microplastics in the diet. There is also the possibility that microplastics may impact on depuration processes as well as initial uptake of contaminants.

Studies are available that indicate that contaminants associated with microplastics can be taken up by organisms at high enough concentration to cause a toxic effect, and that greater negative impacts can be observed in organisms exposed to a diet containing microplastics pre-sorbed with contaminants compared to a diet with non-pre-sorbed microplastics and/or a diet absent of microplastics. Effects documented include reduced survival, reduced phagocytic activity, liver stress and altered gene expression in liver.

Thus, there is some evidence of the potential for toxic effects as well as physical effects to be exhibited on exposure of environmental organisms to microplastics

The data available for effects of microplastics on environmental species spans a range far wider than the standard risk assessment endpoints of mortality, growth and reproduction. This presents a challenge for deriving reliable conclusions regarding hazard. In addition, inconsistent units have been used to describe the microplastic concentrations in the literature. Some studies report concentrations as items per volume, and some as mass per volume. In addition, some studies dosed the food directly, and report units as items or mass per weight of diet. The studies also vary with regards to key parameters, such as exposure method and duration, and size and source of microplastics.

In view of these considerations, though some effects and therefore possible impacts (risks) to the aquatic environment are expected, it is not possible at this stage to derive specific thresholds or establish a dose (concentration) response relationship. A recent publication by Connors *et al* (2017) presents some guidance towards the improvement of the reliability and relevance of ecotoxicological studies for use in environmental risk assessments.

Effects on terrestrial organisms have so far not been investigated, and thus this represents a knowledge gap for hazard assessment.

Effects of microplastics on **humans** via consumption of seafood has also been considered. Though there is evidence for the potential for microplastics smaller than 150 µm to translocate across the gut epithelium causing systemic exposure, albeit at a low percentage of applied microplastic, toxicity and toxicokinetic data are lacking. Therefore, specific thresholds of dose-response relationships cannot be established.

As for organisms in the environment, toxicity to humans could also potentially occur as a result of exposure to contaminants associated with microplastics. However, at present it seems, based on a conservative estimate, that presence of microplastics in seafood would have a small effect on the overall exposure of humans to additives or contaminants.

¹²⁰ Duis, K. & Coors, A. Environ Sci Eur (2016) 28: 2. <https://doi.org/10.1186/s12302-015-0069-y>.

5 Analysis of Alternatives

5.1 Introduction

This section evaluates a selection of potential alternative substances to microplastics in several applications. The information used for this analysis is drawn from consultation with industry (coordinated by European Trade associations), supplemented with research and information from publicly available sources. It is recognised that much detailed information will not be in the public domain and/or be proprietary and that research and development (R&D) activity is an ongoing activity.

The criteria considered are based on those set out by the European Chemicals Agency (ECHA) for analysis of alternatives, namely:

- ▶ Availability.
- ▶ Human health risks.
- ▶ Environmental risks.
- ▶ Technical and economic feasibility.

Overall the evidence suggests there is no one alternative for all applications, but alternatives are being actively introduced in a number of applications. There are a large number of potential alternatives, each with differing characteristics making them more or less appropriate for any one specific use. It is not practicable to evaluate all of them. Conversely the same potential alternatives are identified in several applications, hence a small number of alternatives have been assessed in detail below, but in each case we refer to a larger number of substances mentioned either in public consultation or research.

5.2 Microplastics - Indicative prices

The sections that follow examine the economic feasibility of alternative substances (amongst other factors). This includes evaluating the comparison price per tonne. This section briefly summarises public data on commercial prices from the public portal “Alibaba” to use as a basis for comparison. It is recognised these are indicative, that prices change and specific functionality/performance characteristics will influence the price, however no reliable data has been identified elsewhere and it is intended to provide an order of magnitude comparison to help judge the scale of economic costs likely to be incurred from substitution. On this basis ranges of costs are presented, the median value is then converted into Euro and an average taken of several prices. The same prices is used for alternative substances later in this section.

Table 5.1 Pricing information – microplastics

	Cost per tonne (low high)	Median cost per tonne in Euro	Overall average cost per tonne assumed in analysis
Flake Low molecular polyethylene Wholesaler	\$1 480-1 540	€1 300	
Agriculture SAP polymer water absorbing beads polymer sap fertilizer	\$1 500 – 2 500	€1 750	
Polypropylene, PP Resin, PP Plastic Raw Material, PP Granule Hot Sale	\$600, 1 250	€800	
PP plastic raw material, Glass Fiber Filled Polipropilene, PP+GF price	\$800- 1 200	€900	

	Cost per tonne (low high)	Median cost per tonne in Euro	Overall average cost per tonne assumed in analysis
Recycled PP/LDPE/HDPE/LLDPE white granules	\$500, 1 500	€900	
Overall			€1 100

Source: conducted July 2017. https://www.alibaba.com/trade/search?IndexArea=product_en&CatId=&fsb=y&SearchText=polypropylene
Exchange rate used 1 Eur+ 1.1412 US Dollar 7th July 2017. Source: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html
Note the overall average has been rounded to the nearest €100 to avoid spurious claims to accuracy.

5.3 Application 1: Personal care products

Particles of various plastics (Polyethylene and Polyurethane amongst others) typically < 1 mm are used in various wash-off and leave-on personal care products¹²¹ (see Section 3 for further details). These fulfil a wide range of functions: exfoliant, film forming, viscosity controlling, binder for powders, antistatic, dispersant, filler, silky feel, nanocapsules, bulking agent, slip modifier, skin conditioner, thickeners and suspending agents, stabilizers, glitter, cosmetic colours, and opacifying agent (see Appendix A).

This section presents a longlist of potential alternatives identified in the literature and the targeted stakeholder consultation undertaken for this study. Two alternatives are then chosen to be analysed in further detail regarding their feasibility to substitute microplastics in personal care products.

Longlist of potential alternatives

In their response to this study's targeted consultation, the personal care products industry coordinated by Cosmetics Europe suggested the following potential alternatives are being used to replace microbeads in response to their recommendation:

- ▶ Waxes: beeswax, rice bran wax, jojoba waxes.
- ▶ Starches derived from corn, tapioca and carnauba.
- ▶ Seaweed.
- ▶ Silica.
- ▶ Clay.
- ▶ Walnut powder.
- ▶ Other natural compounds.

As part of research in 2016, Greenpeace asked global cosmetics and personal care companies on their commitments to phase out "microbeads". On the basis of the companies' responses, Greenpeace developed a ranking of their commitments in terms of the protection of the oceans that the commitment is expected to provide¹²². The table below summarises the alternatives the ten highest ranked manufacturers report to use to phase out microplastics. It also shows the type of microplastics that are being substituted by these alternatives (i.e. the definition of microbeads being phased out).

¹²¹ Scrubs (body, face, hands), hair care (color, conditioner, style mousse), make up remover, toothpaste, tooth whitening gels, deodorant, manicuring products (cuticle treatment), body hair removal (wax strips), facial/eye cream, body lotion, decorative cosmetics (lip conditioner/stick, mascara, eye shadow, blush, make up powder, concealer stick), hair style mousse, shoe polish, facial moisturizers, anti-aging product, tanning lotions, sun creams, bleaching, styling gels

¹²² Greenpeace: Global Cosmetics and Personal Care companies' Microbead commitment ranking. 2016. Available at: <http://www.greenpeace.org.uk/press-releases/microbead-ranking-industry-disarray-shows-need-political-ban-says-greenpeace-20160720/>

Table 5.2 Overview of alternatives used by selected global cosmetics and personal care companies' to fulfil their microbead phase-out commitments

Company	Definition of microbeads to be phased out	Alternatives quoted to be used to achieve phase out
Beiersdorf	Solid polyethylene particles smaller than 5mm	<ul style="list-style-type: none"> • microcrystalline cellulose • cellulose • hydrogenated castor oil • hydrated silica <p>(Either individual raw materials or their composites)</p>
Colgate-Palmolive	Intentionally added, 5 mm or less, water insoluble, solid plastic particle typically used to exfoliate or cleanse in rinse-off personal care products	<ul style="list-style-type: none"> • Natural materials like Jojoba beads
L Brands	Intentionally added, 5 mm or less, water insoluble, solid plastic particle used to exfoliate or cleanse in hand soaps and scrubs	<ul style="list-style-type: none"> • "a non-plastic material"
Henkel	Solid microplastic particles (plastic particles with a size from one micrometer up to five millimeters) in cosmetic products / some 'rinse-off' facial and body cleansing products	<ul style="list-style-type: none"> • lactic acid polymers (INCI: polylactic acid) <p>Currently testing formulas with:</p> <ul style="list-style-type: none"> • pumice • walnut shells • silica
Clarins	Plastic microbeads in rinse off products"	<ul style="list-style-type: none"> • Cellulose
Unilever Group	Plastic scrub beads	<ul style="list-style-type: none"> • apricot kernels • cornmeal • ground pumice • silica • walnut shells
Botica Comercial Farmacêutica	Polyethylene microspheres used in exfoliation products	Not stated, but already in use.
Oriflame Cosmetics	All solid plastic particles in rinse-off products: Synthetic, solid plastic particles used in cosmetic products for exfoliating and cleansing purposes that are nonbiodegradable in the marine environment; and plastic glitter particles	<ul style="list-style-type: none"> • poppy seeds • almond shells • silica and sugar
Shiseido	Water-insoluble synthetic plastic particles used for cleansing or exfoliating, with a particle size of 5 mm or smaller (no lower limit)	<ul style="list-style-type: none"> • cellulose
Avon Products	Intentionally added, 5 mm or less, water insoluble, solid plastic particle used to exfoliate or cleanse in rinse-off personal care products	<ul style="list-style-type: none"> • precipitated silica • hydrogenated vegetable oil • various ground seeds and shells

Source: Adapted from Greenpeace: Global Cosmetics and Personal Care companies' Microbead commitment ranking. 2016. Available at: <http://www.greenpeace.org.uk/press-releases/microbead-ranking-industry-disarray-shows-need-political-ban-says-greenpeace-20160720/>

A 2016 report¹²³ of the UK House of Commons Environmental Audit Committee identifies the following alternatives to plastic microbeads in cosmetics:

- ▶ Natural materials including cocoa beans, ground almonds, ground apricot pits, sea salt, ground pumice and oatmeal, silica, walnut shells and cornmeal.

The Swedish Ministry of the Environment and Energy, in the impact assessment on their draft ordinance to ban cleansing, exfoliating or polishing microplastics in rinse-off cosmetics (2017)¹²⁴, identified the following alternatives as being currently used:

- ▶ Microcrystalline cellulose.
- ▶ Grains, nuts or barks/shells (rice, walnut, pineapple, jojoba, corn, seville oranges, almond).
- ▶ Other organic materials (sugar, citric acid).
- ▶ Various minerals (Silica, bentonite, pumice, mica, montmorillonite, salt).

Eunomia (2016)¹²⁵ identified the following alternatives for exfoliating microbeads in rinse-off products, grouped into organic alternatives and silica:

- ▶ Organic Alternatives: Walnut shell, apricot shells and pits, cocoa beans, and pecan shells biodegrade in most environments, have been used in cosmetics products for decades and are well established in the market. Walnut shell is quoted as the most prevalent.
- ▶ Silica: used mainly for its inert, non-toxic nature; unlikely to lead to allergic reactions and product lifespans issues (which may be the case for organic alternatives).

Eunomia (2016) attempted to identify alternatives to polymers performing other functions in personal care products, i.e. beyond exfoliation in rinse-off products. However the authors note that no alternatives for these were offered in their interviews with cosmetics manufacturers, especially with regard to leave on products.

Essel R., et al. (2015)¹²⁶ reports the following alternatives for plastic microbeads in body scrubs that were presented at a trade fair for personal care ingredients, "In-Cosmetics", in Hamburg in April 2014:

- ▶ 'Artificial' sand (silica), hydrogenated palm or castor oil and cellulose.

The silica-based range mentioned above also provides an alternative to microplastics fulfilling functions other than exfoliation in rinse-off products, according to the manufacturer, which are discussed elsewhere in this section.¹²⁷ The manufacturer claims these products can act as a substitute for microplastics in personal care and toning creams, foundations, make-up, and face powder, improving sensory properties, acting as an optical blurring agent, mattifying the skin surface, and reducing visible wrinkles.

Other researchers and manufacturers are also developing cellulose-based microbeads, similar to the ones mentioned above¹²⁸.

In conclusion, the available information outlined above focuses mostly on alternatives to exfoliating/cleansing microbeads. For these a range of available alternatives are mentioned, notably silica and a range of organic materials. In the following, two alternatives are chosen as examples for a more detailed analysis of their feasibility to substitute microplastics in personal care products: walnut shell and cellulose.

¹²³ UK House of Commons Environmental Audit Committee: Environmental impact of microplastics - Fourth Report of Session 2016–17. Available at: <https://www.publications.parliament.uk/pa/cm201617/cmselect/cmenvaud/179/179.pdf>

¹²⁴ Swedish Ministry of the Environment and Energy: Draft Ordinance amending the Chemicals Products (Handling, Import and Export Prohibitions) Ordinance (1998:944). Impact assessment. Notification 2017/0284/S to the European Commission according to Directive (EU) 2015/1535.

¹²⁵ Eunomia (2016). Study to support the development of measures to combat a range of marine litter sources. Report for the European Commission DG Environment. January 2016.

¹²⁶ Essel R., et al. (2015). Sources of microplastics relevant to marine protection in Germany. Federal Environment Agency. Available at <https://www.umweltbundesamt.de/en/publikationen/sources-of-microplastics-relevant-to-marine>

¹²⁷ Evonik: New addition to Evonik's product range: an eco-friendly substitute for microplastics in cosmetics. Press release. Essen, February 15, 2017. Available at: http://corporate.evonik.com/en/media/press_releases/pages/news-details.aspx?newsid=65528

¹²⁸ See <http://www.bath.ac.uk/research/news/2017/06/02/scientists-make-biodegradable-microbeads-from-cellulose> and http://www.lessonia.com/vars/fichiers/presse/Article_HPC_Celluloscrub.pdf

Alternative 1, walnut shell was quoted as an alternative by Cosmetics Europe in their response to this study's targeted consultation, by several sources of literature, and by several personal care product manufacturers according to Greenpeace (2016)¹²⁹. Eunomia (2016)¹³⁰ identified it as the most prevalent organic material used to replace plastic microbeads, according to the personal care product manufacturers consulted in that study.

Alternative 2, cellulose based microbeads are also quoted by several sources of literature and by several personal care product manufacturers in Greenpeace (2016), and they appear to be the basis of some recently newly developed alternatives.

Note that silica, another promising alternative according several sources outlined above, will be investigated in more detail as an alternative to microplastics in detergents in Section 5.5.

Assessment of alternative 1: Walnut shell

Availability of walnut shell

Walnut is a renewable resource and global production of walnuts with shells was about 3.5 million tonnes in 2014, the main production centres in China, the Middle East, the USA and Europe¹³¹. While most of this production is likely for food, shells are mostly a bi-product. They have been used in personal care products for decades¹³² and several suppliers offer cosmetics grade walnut shell in various sizes¹³³. Given this, there appears to be no evidence that manufacturers could not supply the volumes required without undue delay.

Human health risks related to walnut shell

Data from the classification and labelling (C&L) inventory indicate the following notified classifications. There is no harmonised classification under the CLP Regulation.

Table 5.3 Classification and labelling inventory: Human health risks – Walnut

Ingredient	CAS Number	Harmonised classifications	Most common notified classifications
Walnut, <i>Juglans regia</i> , extractives	84012-43-1	None	Flam. Liq. 3 (H226) Not classified
Walnut, <i>Juglans nigra</i> , extractives	96690-56-1	None	Not classified

Source: ECHA C&L Inventory: <https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/notification-details/85/972891> and <https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/2571>

Note it is not clear if the information in the C & L Inventory are actually sold particles, given they refer to "extractives". Cross referencing this information with information on the CosIng Database indicates that *Juglans Regia* (Walnut) Wood Extract (84012-43-1) is used for skin conditioning (so we assume is not solid and *Juglans Regia* Shell Powder (with the same CAS number) is sued as an abrasive.

One type of walnut, *Juglans regia*, is commonly classified as flammable liquid and vapour. However, note that this classification relates to extractives and their physically modified derivatives (such as tinctures, concretes, absolutes, essential oils, oleoresins, terpenes, terpene-free fractions, distillates, residues, etc.) obtained from *Juglans regia*. There are no notified classifications for the other registered type of walnut, *Juglans nigra*.

¹²⁹ https://secured-static.greenpeace.org/korea/Global/korea/publications/reports/oceans/2016/EN_CorporateRankingDetails_final.pdf

¹³⁰ Eunomia (2016). Study to support the development of measures to combat a range of marine litter sources. Report for the European Commission DG Environment. January 2016.

¹³¹ <http://www.fao.org/faostat/en/#data/QC/visualize>

¹³² See <http://www.azom.com/article.aspx?ArticleID=10430> and Eunomia (2016). Study to support the development of measures to combat a range of marine litter sources. Report for the European Commission DG Environment. January 2016.

¹³³ See for instance: <https://compomat.com/cosmetic-grade-walnut-shell/>, http://www.makingcosmetics.com/Walnut-Shell-Powder_p_141.html, http://www.walnutshellpowder.com/walnut_shell/product_Cosmetic_Walnut_Shell.html, <http://raw-materials.mckinleyresources.com/category/cosmetic-walnut-shells>, <http://www.ecoshell.com/Cosmetics.htm>, <http://www.azom.com/article.aspx?ArticleID=10430>, <https://www.gracefruit.com/item/512/Gracefruit/Ground-Walnut-Shells.html>, <http://www.azom.com/article.aspx?ArticleID=10430>.

Walnut shells may pose a health risk for people who suffer from nut allergies¹³⁴. In conclusion, with the exception of possible nut allergies, no significant health risks have been identified that would be expected to affect the substitution of microplastics with this alternative. Walnut shell has been demonstrated by industry to be safe for human health in cosmetics¹³⁵.

Environment risks related to walnut shell

There are no harmonised classifications relating to environmental risks in the C&L Inventory.

As described in Section 4, the concerns resulting from microplastics in the environment relate mainly to the following three effects:

- ▶ **physical effects**, predominantly resulting from reduced nutrition as a result of fraction of microplastics in the diet;
- ▶ **translocation** of microplastics from the gut to circulatory system and/or tissues; and
- ▶ potential **toxic effects** caused by the complex mixture of chemicals that can be associated with microplastics.

No detailed information was available regarding the extent to which the use of walnut shell as alternative to microplastics would reduce the risk posed by these effects. Girard et al. 2016¹³⁶ has pointed out the lack of academic literature on the potential risks of alternatives, and that arguably a risk assessment would be required for each alternative to fully understand the potential consequences of their use in aqueous environments. However, as mentioned in Section 4, the risk of microplastics is dependent on the environmental fate of the particles, which in turn will be dependent on the behaviour of microplastics in the relevant media. Hence, a key factor for the risk of microbeads to the environment are that they are not degraded e.g. in the aquatic environment. Walnut shells biodegrade in most environments as they comprise cellulose and lignin¹³⁷. This degradability would reduce the accumulation in ecosystems associated with microplastics and thus the environmental risk of exfoliating microbeads.¹³⁸

However, potential negative impacts of adding nut shell to aquatic environments have been noted. As a natural carbon source, nut shells can aggravate oxygen depletion in water bodies which initially results from algae growth and decomposition by bacteria that use all the available oxygen in the bottom waters.¹³⁹

Technical and economic feasibility of walnut shell

Walnut shell has been used in a variety of personal care products (including body and bath products, hand soaps and scrubs) for decades¹⁴⁰ and is one of the most prevalent organic abrasives/exfoliants in personal care products¹⁴¹. Some personal care product manufacturers use ground walnut shell in scrubs for its gentle exfoliating qualities¹⁴², as well as to give a natural image to cosmetic products and explicitly marketing the fact that they do not contain microplastics.¹⁴³ However, there was no information available to suggest that

¹³⁴ Eunomia (2016). Study to support the development of measures to combat a range of marine litter sources. Report for the European Commission DG Environment. January 2016.

¹³⁵ Given its presence in the CosIng Database https://ec.europa.eu/growth/sectors/cosmetics/cosing_en

¹³⁶ Girard, N., Lester, S., Paton-Young, A., & Saner, M. (2016). Microbeads: "Tip of the Toxic Plastic-berg"? Regulation, Alternatives, and Future Implications. https://ispp.uottawa.ca/sites/ispp.uottawa.ca/files/microbeads_-_literature_review_2.pdf

¹³⁷ Eunomia (2016). Study to support the development of measures to combat a range of marine litter sources. Report for the European Commission DG Environment. January 2016.

¹³⁸ UK House of Commons Environmental Audit Committee: Environmental impact of microplastics - Fourth Report of Session 2016–17. Available at: <https://www.publications.parliament.uk/pa/cm201617/cmselect/cmenvaud/179/179.pdf>

¹³⁹ Greg Boyer, chair of the chemistry department at SUNY-College of Environmental Science and Forestry, quoted in <https://www.theguardian.com/sustainable-business/microbeads-cosmetics-gyres-plastics-pollution-makeup>.

¹⁴⁰ See <http://www.azom.com/article.aspx?ArticleID=10430> and Eunomia (2016). Study to support the development of measures to combat a range of marine litter sources. Report for the European Commission DG Environment. January 2016.

¹⁴¹ Eunomia (2016). Study to support the development of measures to combat a range of marine litter sources. Report for the European Commission DG Environment. January 2016.

¹⁴² <https://uk.lush.com/ingredients/ground-walnut-shell>

¹⁴³ http://www.lessonia.com/vars/fichiers/presse/Article_HPC_Celluloscrub.pdf and House of Commons Environmental Audit Committee: Environmental impact of microplastics - Fourth Report of Session 2016–17. Available at: <https://www.publications.parliament.uk/pa/cm201617/cmselect/cmenvaud/179/179.pdf>.

walnut shell can also be used to replace functions of microplastics in personal care products other than exfoliating/cleansing microbeads.

The use of walnut shell in cosmetics exhibits several potential disadvantages compared to plastics. As walnut shell particles are created by grinding, their size and shape may vary and can include sharp edges.¹⁴⁴ Due to their dark colour, walnut shells may affect the colour of the product they are added to.¹⁴⁵ Walnut may also affect the product expiration date¹⁴⁶ and to mitigate this (at least partially) preservatives must be added to the product and a sterilisation process needs to be applied to the walnut shell.¹⁴⁷

While some sources claim walnut shell can be cost-effective for personal care products¹⁴⁸, others claim that sustainable ingredients such as walnut shell may cost more and can have a more “problematic” supply chain.¹⁴⁹ The Swedish Ministry of the Environment and Energy (2017) notes that substituting plastics (which are considered an inexpensive material) with any of the alternative materials available may increase the raw materials costs by 0-100 Swedish Krona (€0-€10.4¹⁵⁰) per kilogram. However, the authors note that plastic microbeads in rinse-off products usually only account for some 1-10% of the total volume of the products, so for instance the cost increase for a 200 cl product containing 10% plastic particles would amount to SEK 0.2-2 (€0.02-€0.21).

Wholesale prices on the website “Alibaba.com” for walnut shell for cosmetics use from China (the world’s largest producer of walnut¹⁵¹) mostly range between \$200-\$1 000 per tonne (€180-€900¹⁵²), with most quotes roughly between \$200-\$500 per tonne (€180-€450¹⁵³). Considering the price of microplastics has been estimated to be in the order of magnitude of €1 100 per tonne, this suggests that prices of this alternative would not negatively affect the economic feasibility of substituting microplastics.

Assessment of alternative 2: Cellulose

Availability of cellulose

Cellulose based microbeads are already used as alternatives to plastic microbeads by at least six of the 30 largest global manufacturers according to a survey among personal care product manufacturers from Greenpeace (2016)¹⁵⁴ and publicly available information. This indicates that this alternative is already commercially available to some extent. The University of Bath¹⁵⁵ reports that scientists have developed a way of producing cellulose-based microbeads in a scalable, continuous manufacturing process. According to Essel R., et al. (2015)¹⁵⁶, microparticles made of cellulose are offered by at least two manufacturers. Furthermore a paper from the manufacturer of a cellulose acetate technology claims that their technology can be made available at the scale needed to replace PE microbeads, given that cellulose is an abundant natural resource.¹⁵⁷

In conclusion, the evidence suggests no problems are to be expected in producing cellulose based beads in sufficient quantities to replace plastic microbeads.

¹⁴⁴ Eunomia (2016). Study to support the development of measures to combat a range of marine litter sources. Report for the European Commission DG Environment. January 2016.

¹⁴⁵ http://www.lessonia.com/vars/fichiers/presse/Article_HPC_Celluloscrub.pdf

¹⁴⁶ According to Cosmetics Europe response to the targeted stakeholder consultation and Eunomia (2016). Study to support the development of measures to combat a range of marine litter sources. Report for the European Commission DG Environment. January 2016.

¹⁴⁷ Eunomia (2016). Study to support the development of measures to combat a range of marine litter sources. Report for the European Commission DG Environment. January 2016.

¹⁴⁸ http://www.lessonia.com/vars/fichiers/presse/Article_HPC_Celluloscrub.pdf

¹⁴⁹ Victoria Fantauzzi, co-founder of Chicago-based La Bella Figura Beauty, quoted in: <https://www.theguardian.com/sustainable-business/microbeads-cosmetics-gyres-plastics-pollution-makeup>.

¹⁵⁰ Exchange rate used: €1=SEK9.6 according to European Central Bank Euro foreign exchange reference rates, 18 July 2017.

¹⁵¹ <http://www.fao.org/faostat/en/#data/QC/visualize>

¹⁵² Exchange rate used: € = \$1.11. European Central Bank official exchange rates (01/01/2016 - 31/12/2016).

¹⁵³ Exchange rate used: € = \$1.11. European Central Bank official exchange rates (01/01/2016 - 31/12/2016).

¹⁵⁴ https://secured-static.greenpeace.org/korea/Global/korea/publications/reports/2016/EN_CorporateRankingDetails_final.pdf

¹⁵⁵ <http://www.bath.ac.uk/research/news/2017/06/02/scientists-make-biodegradable-microbeads-from-cellulose>

¹⁵⁶ Essel R., et al. (2015). Sources of microplastics relevant to marine protection in Germany. Federal Environment Agency. Available at <https://www.umweltbundesamt.de/en/publikationen/sources-of-microplastics-relevant-to-marine>

¹⁵⁷ http://www.lessonia.com/vars/fichiers/presse/Article_HPC_Celluloscrub.pdf

Human health risks related to cellulose

There are no harmonised classifications and cellulose is not classified according to the most common notifications to the classification and labelling (C&L) inventory. It should be noted that the only specific derivative that has been identified as being used to produce microbeads for personal care products (cellulose acetate) has no notified or harmonised classifications in the C&L inventory. Other derivatives of cellulose have not been investigated in this report. In conclusion, no significant health risks have been identified that would be expected to affect the substitution of microplastics with this alternative.

Table 5.4 Classification and labelling inventory: Human health risks – cellulose

Ingredient	CAS Number	Harmonised classifications	Most common notified classifications
Cellulose	409-21-2	None	Not classified
Cellulose acetate	9004-35-7	None	Not classified

Source: ECHA C&L Inventory:

<https://echa.europa.eu/substance-information/-/substanceinfo/100.029.692>

<https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/19816>

<https://echa.europa.eu/substance-information/-/substanceinfo/100.130.437>

<https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/119709>

Environment risks related to cellulose

As for the human health risk, there are no harmonised classifications and cellulose is not classified according to the most common notifications to the classification and labelling (C&L) inventory. Again, the only specific derivative that has been identified as being used to produce microbeads for personal care products (cellulose acetate) has no notified or harmonised classifications in the C&L inventory. Other derivatives of cellulose have not been investigated in this report.

As discussed in the assessment of the alternative walnut shell, biodegradability is seen as the main factor contributing to the likely lower environmental risks compared to those posed by microplastics. Several companies replacing plastic microbeads with cellulose-based microbeads 2016 state that these are biodegradable.¹⁵⁸ The University of Bath states that the cellulose-based microbeads they developed can be broken down by organisms at the sewage treatment works, or in the environment in a short period of time. A manufacturer of a cellulose acetate technology states that cellulose acetate is generally recognized as a biodegradable polymer, but no information on biodegradability in the marine environment specifically is given¹⁵⁹.

Technical and economic feasibility of cellulose

The fact that cellulose based microbeads are already used as an alternative to plastic microbeads by at least 6 of the 30 largest global manufacturers according to Greenpeace (2016)¹⁶⁰ suggests that they are technologically and economically feasible to use as alternative to plastic microbeads.

As outlined in more detail in the section on Alternative 1 (walnut shells) above, the Swedish Ministry of the Environment and Energy (2017) notes that because microbeads only account for some 1-10% of the total product volume of rinse-off products, substituting them with more expensive raw materials is estimated to lead to only a modest cost increase.

A research team, from the University of Bath's Centre for Sustainable Chemical Technologies (CSCT), has developed a way of producing an alternative to plastic microbeads in a scalable, continuous manufacturing

¹⁵⁸ Greenpeace (2016): https://secured-static.greenpeace.org/korea/Global/korea/publications/reports/oceans/2016/EN_CorporateRankingDetails_final.pdf

¹⁵⁹ http://www.lessonia.com/vars/fichiers/presse/Article_HPC_Celluloscrub.pdf

¹⁶⁰ https://secured-static.greenpeace.org/korea/Global/korea/publications/reports/oceans/2016/EN_CorporateRankingDetails_final.pdf

process.¹⁶¹ They claim their microbeads are robust enough to remain stable in a body wash and will work with industrial partners to develop materials that could be used in personal care products.

A manufacturer of a cellulose acetate technology states that their technology fulfils all requirements of an alternative to PE microbeads: white colour, colour and physical stability, similar skin feel and abrasion capacities, same suspension capacity and availability in sufficient quantity.¹⁶²

However, all of the above information focuses on alternatives to exfoliating/cleansing microbeads. There was no information available regarding whether cellulose can also be used to replace microplastics other than exfoliating/cleansing microbeads in personal care products.

No publicly available sources for a typical commercial price for cellulose-based beads was available.

Wider scope of restriction on personal care products

Overview

The sub-sections above considered alternatives for microplastics used for exfoliating and cleansing purposes in personal care products. These are essentially those already within the scope of the Cosmetics Europe recommendation and which are already being taken up by companies that are replacing microplastics in their products.

However, there are many more plastics/polymers used in personal care products, which might be affected by a restriction, depending on how microplastics are defined.

Industry (EFFCI) has provided an overview of the types of products that would be affected by a restriction depending on how microplastics are defined, including and excluding specifying the following elements as part of the definition:

- ▶ Functionality (i.e. whether or not to specify use in exfoliating/cleansing as per the Cosmetics Europe recommendation).
- ▶ Restriction on use in leave-on or rinse-off personal care products, or only on rinse-off products.
- ▶ Non-solubility in water.
- ▶ Solid plastic particles only.
- ▶ Limited to “plastic particles” or also covering “polymers”.

The information provided by EFFCI is included in Appendix F.

With each of these elements to the definition, more plastic ingredient types would be brought into scope if these aspects are not specified.

The following analysis does not examine any one potential alternative, but rather looks at the range of potential alternative types that would need to be sought in the event that a restriction is introduced at two possible levels beyond the existing Cosmetics Europe recommendation:

- ▶ Scenario 1: A restriction covering leave-on personal care products as well as not specifying the functionality of the microplastics used¹⁶³.
- ▶ Scenario 2: A restriction covering all polymers <5mm in size.

These scenarios are explored at a relatively high level in the following sections.

¹⁶¹ <http://www.bath.ac.uk/research/news/2017/06/02/scientists-make-biodegradable-microbeads-from-cellulose>

¹⁶² http://www.lessonia.com/vars/fichiers/presse/Article_HPC_Celluloscrub.pdf

¹⁶³ In this case, the restriction would not specify the function e.g. exfoliating/cleansing as is included in the Cosmetics Europe recommendation. Likewise it would not be limited to only rinse-off personal care products. Other elements of the definition would be retained e.g. solid plastic particles, <5mm in size, not soluble in water.

Availability of alternatives

Based on the analysis provided by EFFCI (Appendix F), the following product types could be affected in the event of a restriction under the two scenarios. The number of entries in the Cosing database against each of these product types is listed.

Table 5.5 Ingredient types potentially affected under each scenario and numbers of ingredients listed in Cosing database

Ingredient type	Scenario 1	Scenario 2
Abrasive	Affected – 349 entries in Cosing	Yes - 349 entries in Cosing
Rheology modifier	Some – 1 291 entries in Cosing ^[Note A]	Yes – 1 291 entries in Cosing ^[Note A]
Opacifier	Some – 203 entries in Cosing	Yes – 203 entries in Cosing
Film forming	No	Yes – 1 078 entries in Cosing
Surfactant	No	Yes – 2 840 entries in Cosing
Conditioning	No	Yes – 14 410 entries in Cosing ^[Note B]
Emulsifying	No	Yes – 2 543 entries in Cosing
Encapsulation	No	Yes - Not listed in Cosing
Dispersant	No	Yes – 120 listed in Cosing ^[Note C]
Emollient	No	Yes – 2 675 entries in Cosing
Moisturiser	No	Yes – 70 entries in Cosing
Waterproofing	No	Yes - Not listed in Cosing

Notes: [A] “Viscosity controlling” in the Cosing database, accessed 11 July 2017. [B] 2846 hair conditioning, 125 nail conditioning, 11 439 skin conditioning. There may be some duplication. [C] Not listed in Cosing – “stabilising” ingredients provided as an example here. Note that the list includes both polymer and non-polymer ingredients.

Clearly if a restriction were introduced on a wider basis there are many different functions of the microplastic ingredients that would potentially be affected and many thousands of potential alternatives. However, note that many of the entries in the Cosing database (included in the numbers in the table above) are polymers themselves.

It is not feasible within the scope of the current work to identify the most likely alternative used in the event that a restriction covers the above ingredient types. There are simply too many different combinations of possible alternatives that might be covered, depending on the product types in question. As highlighted by industry (EFFCI), a restriction with a wide definition could affect virtually all classes of cosmetic products.

The following analysis therefore focuses on the scale of the potential impacts if a restriction were introduced, in terms of numbers and volumes of products affected, and potential cost implications.

Human health and environmental risks

As indicated above, the analysis in this subsection does not focus on any specific alternatives. It is therefore not possible to comment on the change in environmental and health risks that would occur in the event of a restriction.

Technical and economic feasibility

The following analysis focuses on economic feasibility and the scale of the potential impacts if a restriction were introduced and companies were required to reformulate their products to use alternatives. It covers the two scenarios above.

Impacts of a restriction on use in leave-on products (scenario 1)

In estimating the potential scale of products that would require reformulation under the two scenarios above, the following underlying data are used.

Table 5.6 Key underlying data for estimation of leave on personal care products reformulation costs in the EU

	Best/central	Low	High
Total quantity of PCP on the market (million t) ^[A]	4	3	5
Quantity of MPs in rinse-off products (t) ^[A]	714	714	793
Quantity of MPs in leave-on products (t) ^[B]	605	537	1 112
Assumed concentration of MP in products (%) ^[C]	2.4%	2.4%	10%
Number of PCP on the market ^[D]	300 000	-	-
Reformulation cost per product (€) ^[E]	€340 000	€110 000	€820 000
Assumed amortisation period (years) ^[F]	5	-	-
Discount rate (%) ^[G]	4%	-	-
Total value of PCP market (RSP) (€ bn) ^[H]	€74 billion	-	-

Notes: [A] See Section 3.4 (market analysis). [B] See Section 3.4 (market analysis). Central is based on average of range for assumed 10% concentration in products. [C] Eunomia, 2016. [D] European Commission, 2008. [E] See analysis in Appendix E. [F] Contractors' own estimate based on knowledge of the sector. [G] Better Regulation guidelines value. [H] Cosmetics Europe statistics, data for 2015.

Clearly there is significant variability in some of the parameters affecting the estimation of the scale of products requiring reformulation and the costs of so doing. The potential impacts of a restriction have therefore been estimated by generating mean average values using a monte-carlo simulation model, with the outputs provided below, including 10% and 90% percentiles (confidence intervals).

Table 5.7 Estimated scale of impacts of a restriction on leave-on personal care products

	Mean value	10% / 90% percentiles
Quantity of products containing MPs (t) [A]	14 095	7 584 – 23 819
Average tonnes per product per formula (t) [B]	13.3	11.5 – 15.2
Total number of products [C]	1 069	563 – 1 815
Estimated reformulation cost (€m) [D]	452	183 – 821
Annualised reformulation cost (€m) [E]	102	41 – 184
Notional retail sales of products containing MP (€m) [F]	274	174 – 466
Annual reformulation cost as % of retail sales value [G]	37%	21% – 56%

Notes: [A] Quantity of microplastics in leave-on products divided by assumed concentration of MP in products. [B] Total quantity of PCP on the market divided by number of products on the market. [C] Quantity of products containing MPs divided by average tonnes per product per formula. [D] Reformulation cost per product multiplied by total number of products. [E] Calculation based on PMT function in Excel, assuming amortisation period and discount rate as per the previous table. [F] Total value of whole PCP market multiplied by ratio of quantity of products containing MPs to total quantity of PCPs on the market. [G] Annualised reformulation cost divided by notional retail sales of products containing MP.

To put the above estimates into context, these represent around 0.35% of the total personal care products market, in terms of quantity of products, total number of products and notional retail sales.

The estimated reformulation costs represent a significant proportion of retail sales value. When expressed as a percentage of manufacturers' selling prices (i.e. the revenue generated by the producers of PCP), the percentage is even higher: RSP (€74 billion for the whole EU market) is around 1.7 times MSP (€45 billion), meaning that reformulation costs above would represent around 60% of MSP.

Clearly this scale of costs is unlikely to be affordable. However, there are a number of factors that could serve to reduce the scale of reformulation costs:

- ▶ Even though the cosmetics industry's recommendation only covers rinse-off personal care products, it is possible (perhaps likely) that replacement of microplastics in certain leave-on personal care products is already being undertaken. However, no information is available on trends in use in personal care products.
- ▶ If the reformulation costs per formula are low, for example because there are already well-known alternatives that could be readily substituted for microplastics, the overall costs would be substantially lower. For example, Eunomia quote an estimate of €50 000 per product, compared to the best estimate above of €340 000 per product, though Eunomia's estimate is assumed to refer to exfoliating/cleansing microplastics in rinse-off products, where the industry acknowledges that there are available alternatives.
- ▶ It might be possible to amortise the costs over a longer time period than 5 years, reducing the annualised cost estimate. However, 5 years is considered a reasonable estimate, given that the industry is understood to reformulate around 20-30% of its products each year (though this reformulation is not necessarily to remove microplastics – the reformulated products might also include microplastics, in the absence of a regulatory or other requirement to remove them).

Impacts of a restriction on all polymers <5mm in size (scenario 2)

A restriction that does not specify parameters such as non-solubility, solid form, and specifying plastics rather than all polymers, would potentially have a much wider scope in terms of impacts. The following is intended to be broad approximation of the potential scale of the impacts. It is based on various assumptions so the estimates should be seen as indicative, order-of-magnitude values.

As shown in the table below, polyethylene beads represent a very small proportion of the total use of polymers used in personal care products in 10 member states bordering the Baltic Sea, based on 2015 data from Euromonitor.

Based on this, the 300 tonnes of polyethylene beads represented around 2% of the total polymers used in personal care products in 2015. While there are clearly other plastic beads used in personal care products, there is insufficient data to be able to estimate the total use. Nonetheless, this provides a reasonable starting point to estimate total polymer use in personal care products.

Extrapolating the above figures to the whole of the EU, it is estimated that around 980 tonnes of polyethylene beads were used in personal care products in 2015¹⁶⁴. This is concluded to be a reasonable estimate, given that the personal care industry estimate from Cosmetics Europe includes 714 tonnes of total microbeads in rinse-off personal care products and perhaps 605 tonnes in leave-on products, or around 1 300 tonnes in total. The difference between this and the approximately 980 tonnes above would be assumed to be comprised of microplastics based on other polymer types, with polyethylene being the most widely used. This is just intended to provide an approximation of the scale, not a precise estimate.

¹⁶⁴ This is based on extrapolation from the manufacturers selling price of products in the 10 member states concerned (€13.8 billion as MSP in 2015) to the total EU sales (€45 billion) based on Cosmetics Europe statistical data.

Table 5.8 Quantity of polymers used in 10 EU member states in 2015 and extrapolation to the whole EU

	10 Baltic Member States (t) ^[A]	Extrapolation to whole EU (t) ^[C]
Polyethylene Beads (Abrasives/Inorganics)	298.0	972.6
Polychlorophenols	0.5	1.7
Polyglycerol Esters	1 702.2	5 556.0
Polyoxyethylene Sorbitan Fatty Acid Esters	45.2	147.7
Polysaccharides and Oligosaccharides	3 126.3	10 204.6
Other Polysaccharides and Oligosaccharides	34.5	112.5
Alkyl Polyglucosides	4789.4	15 632.9
Ethylene Oxide/Propylene Oxide Block Copolymers	720.0	2 350.3
Copolymers ^[B]	1 543.3	5 037.6
Poly(acrylamides) ^[B]	14.9	48.7
Poly(acrylates) ^[B]	77.9	254.3
Poly(alkylene Glycols) ^[B]	1 696.3	5 536.9
Poly(vinylpyrrolidones) ^[B]	155.2	506.7
Quaternised Synthetic Polymers ^[B]	286.3	934.6
Other Synthetic Polymers ^[B]	509.0	1 661.5
Cross-linked Synthetic Polymers	338.3	1 104.1
Polyethylene Beads (Thickeners/Structurants)	2.1	6.7
Total	15 339	50 069

Notes: [A] Data relate to the following 10 member states: SE, DK, FI, DE, PL, EE, LV, LT, SK, CZ . Data are based on Euromonitor statistics provided to DG Environment by Stockholm University. [B] Together these “synthetic polymers, homopolymers and copolymers” represented 4,283 tonnes. [C] Extrapolation based on 31% of EU sales (as MSP) in the 10 Baltic Member States in 2015 (Cosmetics Europe statistics).

In order to estimate the potential scale of polymer use across personal care products in the EU, the proportion of polymers that are polyethylene beads (980 tonnes out of 50 000 tonnes, or around 2%) has been used to extrapolate the cost estimates for reformulation of the personal care products potentially affected. Taking the estimates for leave-on personal care products as a starting point, the possible scale of products affected and reformulation costs are estimated as in the table below.

Table 5.9 Estimated scale of impacts of a restriction on personal care products containing polymers

	Mean value	Estimated EU total market for comparison
Quantity of products containing MPs (t)	720 000	4 000 000 [A]
Total number of products	55 000	300 000 [B]
Estimated reformulation cost (€m)	23 000	
Annualised reformulation cost (€m)	5 200	

	Mean value	Estimated EU total market for comparison
Notional retail sales of products containing MP (€m)	14 000	74 000 [C]

Notes: Data extrapolated from figures for leave-on products (Table 5.7). Figures have been rounded to 2 s.f. [A] Based on 3-5 million tonnes estimated in the market analysis. [B] European Commission, 2008. [C] Cosmetics Europe statistics for 2015.

Based on the above, a restriction on the use of all synthetic polymers in personal care products could affect a very large proportion of the total market, or around 18% of all EU personal care products. The actual share of the market affected could be substantially higher than this, but could be lower, depending on the average concentration of polymers (number of products through which the polymers are used across the market).

The above analysis does not take into account any increase or decrease in costs resulting in differences in purchase prices of alternatives. However, it is clear that the scale of potential costs that would be imposed by a restriction with such a wide scope are potentially very significant.

Given that such a restriction would affect a major part of the personal care industry, it is likely that significant resources would need to be devoted to attempting to reformulate products, with negative effects on business performance and R&D. It is likely that there would not be available alternatives for many products: while there are many ingredients in each product category (Table 5.5) many of the potential alternatives would also be synthetic polymers. Many personal care products will contain multiple polymer types as ingredients and if reformulation were required it seems obvious that there would be major changes to the quality and performance of end products across the industry.

Given the wide diversity of polymers and products potentially affected, with variation in their health/environmental risks as well as those of potential substitutes, and unknown issues related to technical feasibility of using alternatives, it is not considered possible to demonstrate that the net benefits of a restriction to health and the environment would outweigh the net costs to the industry and consumers at the present time.

5.4 Application 2: Paints

Microspheres and microfibers are used in waterborne building paints¹⁶⁵. They ease paint application, permit application of thicker lays and enable dried paint properties like elasticity, scratch resistance, toughness and resistance against crack¹⁶⁶. Industry consultation, cross referenced with publicly available literature has suggested that a potential alternative in this application would be glass beads. Consultation also suggested that “cellulose based microspheres or fibres” would be a further alternative. The latter is discussed in Section 3.4 under the Personal Care Products (PCP) section of this report.

Assessment of glass beads

Availability of glass beads

Glass beads are widely commercially available and have been for many years. The largest application appears to be in reflective road markings, ensuring markings reflect lights in the dark although more general “industrial” applications are mentioned by several manufacturers. There is limited information in the public domain on European production, import and export volumes, however information available via the European Glass Bead Industry Association “Eurobead”¹⁶⁷, states that the association represents the three

¹⁶⁵ http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-10/pdf/amec_tors.pdf / <https://chemicalwatch.com/48495/rivm-tracks-microplastics-from-tyres-paints-and-cleaning-agents/> / <https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2016/07/11/emission-of-microplastics-and-potential-mitigation-measures/emission-of-microplastics-and-potential-mitigation-measures.pdf>.

¹⁶⁶ Source: Industry consultation carried out with several European Trade Associations, Summer 2017.

¹⁶⁷ <http://www.euroadbead.eu/>

major glass bead producing companies in Europe, with a total of 13 production sites and a production capacity of over 200 000 tonnes of glass beads per year¹⁶⁸. There is evidence of additional companies active in this market, however¹⁶⁹. Overall, whilst demand for glass beads may increase over a relatively short time period as a result of any potential restriction, it is understood that technical feasibility may limit the extent of use in paints - to some extent - this is discussed further below. Given this, existing production capacities and the other uses of glass beads, there appears to be no evidence that manufacturers could not supply the volumes required without undue delay.

Human health risks related to glass beads

Glass is exempt from registration under the REACH regulation, under specific circumstances¹⁷⁰. Safety data sheets (SDS) relating to glass beads¹⁷¹ have been reviewed from the three largest European manufacturers¹⁷². These refer to up to two ingredients: Glass oxide; Glass and Cristobalite¹⁷³. It notes that prolonged and/or massive inhalation of respirable Cristobalite may cause lung fibrosis (commonly referred to as silicosis). Cristobalite is in the registry of intentions for harmonised classification and labelling (CLH) on the basis of suspected carcinogenicity¹⁷⁴. Data from the classification and labelling (C&L) inventory indicate the following notified classifications.

Table 5.10 Classification and labelling inventory: Human health risks – glass beads

Ingredient	CAS Number	Harmonised classifications	Most common notified classifications
Glass oxide; Glass	65997-17-3	None	Carcinogen Cat 1B (H350 - May cause cancer) Eye irritation 2 (H319 - Causes serious eye irritation) Skin irritation 2 (H315 - Causes skin irritation) STOT SE 3 (H335 - May cause respiratory irritation)
Cristobalite	14464-46-1	None	Carcinogen Cat 1A (H350 - May cause cancer) STOT RE 1 (H372 - Causes damage to organs through prolonged or repeated exposure) STOT RE 2 (H373 - May cause damage to organs through prolonged or repeated exposure) STOT SE 1 (H370 - Causes damage to organs) Acute Tox 4 (H332 - Harmful if inhaled)

Source: ECHA C&L Inventory: <https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/1086> and <https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/26467>

¹⁶⁸ <http://www.euroadbead.eu/wp-content/uploads/2014/03/PCF-Report-2014.pdf>

¹⁶⁹ http://www.roadtraffic-technology.com/contractors/road_marking/weissker-gmbh/ / <http://www.weissker.com/>
<http://www.europages.co.uk/companies/glass%20beads%20manufacturers.html>

¹⁷⁰ These materials can best be defined through their starting materials and production process. EINECS has several entries for glasses as follows: Glass, nonoxide, chemicals (EC: 295-731-7), Glass, oxide, calcium magnesium potassium sodium phosphosilicate (EC: 305-415-3), Glass, oxide, calcium magnesium sodium phosphosilicate (EC: 305-416-9) and Glass, oxide, chemicals (EC: 266-046-0). Unless they meet the criteria for classification as dangerous according to Directive 67/548/EEC (Dangerous Substances Directive) and provided that they do not contain constituents meeting the criteria as dangerous in accordance with Directive 67/548/EEC present in concentrations above the lowest of the applicable concentration limits set out in Directive 1999/45/EC or concentration limits set out in Annex I to Directive 67/548/EEC, unless conclusive scientific experimental data show that these constituents are not available throughout the lifecycle of the substance and those data have been ascertained to be adequate and reliable Source:

<http://www.hse.gov.uk/reach/resources/exemptions.pdf>

¹⁷¹ Various referred to as glass beads, glass bead, glass grain and cristobalite blends.

¹⁷² Sovitec, Swarco and Potters. Source: <http://www.euroadbead.eu/>

¹⁷³ http://www.potterseurope.org/Portals/14/lit/MSDS/Glass%20Bead,%20Glass,%20and%20Cristobalite%20blend_EUSDS.PD
http://www.sovitec.com/sites/sovitec/files/2016-05/Sovitec_MSDS_En_Omicron_P0.pdf /
<https://www.swarco.com/northamerica/Products-Services/Glass-Beads/Traffic-Beads/REFLEX-BEADS>

¹⁷⁴ https://echa.europa.eu/registry-current-classification-and-labelling-intentions/-/substance-rev/13008/term?viewsubstances_WAR_echarevsubstanceportlet_SEARCH_CRITERIA_EC_NUMBER=238-455-4&viewsubstances_WAR_echarevsubstanceportlet DISS=true

Environment risks related to glass beads

The same SDS information suggests that ingredients above are persistent but inert in aquatic systems. They are not classified as persistent bioaccumulation and toxic (PBT) or very persistent and very bio-accumulative (vPvB)^{175 176}. There are no harmonised classifications relating to environmental risks in the CL Inventory for either ingredient. However, glass oxide has been notified (by one company) as being toxic to aquatic life with long lasting effects (Aquatic chronic 1 (H410)).¹⁷⁷

Glass beads have been pointed out as an alternative to mitigate the environmental risks associated with microplastics¹⁷⁸. No literature has been identified that specifically investigates the physical or translocation effects of glass beads in the environment or comparing them to those of microplastics. However, one study was identified that compared the effects of mineral products with those of microplastics, indicating that microplastics, and in particular secondary microplastics, have a greater capacity to negatively affect feeding in *Daphnia magna* compared to naturally occurring mineral particles of similar size¹⁷⁹. Further details are provided in the risk assessment section of this report.

Technical and economic feasibility of glass beads

Glass beads are currently used in several paint applications; the most common use is in reflective road - markings ensuring night time visibility. Other existing applications include various “industrial” uses, where performance characteristics noted include controlled thickness and scratch resistance¹⁸⁰. However, no evidence has been found that these could replicate certain other specific performance characteristics of microbeads (i.e. elasticity). This is supported by information from industry consultation indicating that this alternative would be appropriate only for certain product types, potentially reducing the range of paints for the DIY and professional painters, with associated loss of revenue if these could not be replaced with a further alternative(s)¹⁸¹. More generally, glass beads are noted as a theoretical alternative, which would need to be incorporated into new formulations and functionality evaluated for each application.

In terms of economic feasibility, a search of publicly available sources suggest that a typical commercial price for glass beads is in the range of between \$300 and up to \$1 000 per tonne. Taking an average of the median values at current exchange rates this is broadly equivalent to €400 per tonne. Considering the price of microplastics has been estimated to be in the order of magnitude of €1 100 per tonne, this suggests that the price of this alternative would not negatively affect the economic feasibility of substituting microplastics.

However, it should be noted that the costs associated with reformulating paints to replace microplastics (including for example product testing, R&D, etc.) could be more significant than any impact related to the price differential of the alternatives. No information was available to estimate the costs associated with this reformulation in paints.

Table 5.11 Pricing information – glass beads

	Cost per tonne (low high)	Median cost per tonne in Euro	Overall average assumed in analysis
Highway Safety Micro Reflective Glass Beads For Road Marking Paint	\$1-400	€220	

¹⁷⁵ <http://www.euroadbead.eu/wp-content/uploads/2014/03/PCF-Report-2014.pdf>

¹⁷⁶ http://www.potterseurope.org/Portals/14/lit/MSDS/Glass%20Bead,%20Glass%20Grain%20and%20Cristobalite%20blend_EUSDS.PDF

¹⁷⁷ <https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/1086>

¹⁷⁸ See for instance: A. Verschoor et al.: Quick scan and Prioritization of Microplastic Sources and Emissions RIVM Letter report 2014-0156.

¹⁷⁹ Ogonowski M., Schür C., Jarsén Å., Gorokhova E. The effects of natural and anthropogenic microparticles on individual fitness in *Daphnia magna*. PLoS ONE. 2016;11:e0155063 doi: 10.1371/journal.pone.0155063..

¹⁸⁰ <http://www.euroadbead.eu/wp-content/uploads/2014/03/Euroadbead-Brochure-2016.pdf>

¹⁸¹ Note that A. Verschoor et al.: Quick scan and Prioritization of Microplastic Sources and Emissions RIVM Letter report 2014-0156, suggest that for uses of microplastics in “Paint and adhesives (industry)” natural materials can be sought as a replacement for the microplastics, it notes, however that technical performance may be affected. It goes on to note that for paints in construction little to no alternatives are available (to microplastics).

	Cost per tonne (low high)	Median cost per tonne in Euro	Overall average assumed in analysis
High purity Glass Beads Blast cleaning Paint removal	\$500 – 1 000	€660	
Reflective road marking paint glass beads	\$350 – 600	€415	
Wholesale reflective road marking paint glass beads	\$280 - 320	€260	
High refractive index road marking paint microspheres reflective Glass Beads	\$200 – 550	€330	
Overall			€400

Source: https://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&SearchText=glass+beads+paint Search conducted July 2017. Exchange rate used 1 Eur+ 1.1412 US Dollar 7th July 2017. Source: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html
Note the overall average has been rounded to the nearest €100 to avoid spurious claims to accuracy.

5.5 Application 3: Detergents

Microplastics are used in various detergents and cleaning applications¹⁸² where (for example) polyurethane particles are used for gentle cleaning of hard surfaces, such as ceramic/glass surface cleaners. Note alternatives to microplastics used as “abrasives” more generally is also covered separately below. As above, alternatives were identified via a literature review alongside an industry consultation exercise and with further research on specific products.

A 2016 assessment of over 400 (abrasive) cleaning agents of six market-leading companies found ten products suspected of containing microplastics. In these, the microplastics serve as abrasive agents in floor cleaning products. It noted that many abrasive cleaning agents for household purposes use inorganic ingredients such as silica (or alumina, clay or calcium carbonate (calcite))^{183 184}. Silica formulations are also marketed as rheology modifiers (i.e. they adjust the flow behaviour of substances)¹⁸⁵. On balance, whilst several potential alternatives are identified, silica (silicon dioxide) is considered to be a widely applicable alternative and has been examined in more detail below.

Assessment of silica

Availability of silica

Silica is commercially available in large volumes. The European Association of Industrial Silica producers (Eurosil), indicates that there are 100 silica quarries in Europe¹⁸⁶. ECHA’s inventory notes the substance is manufactured and/or imported in the European Economic Area in the 1 000 000+ tonnes per year category¹⁸⁷. Given this, there appears to be no evidence that manufacturers could not supply the volumes required without undue delay.

¹⁸² Hard surface cleaner (glass ceramic cleaner): Scrubbing/abrasive agent for ceramic hob cleaning. Cleaning without damaging; Toilet cleaners: Block cohesion improvement, aesthetics; Stainless steel cleaner: Abrasive agent; Other (oven cleaner, laundry stain remover): Rheology modifiers used to thicken the product; and Bathroom acid cleaner: Abrasive agent. Note For the purposes of this assessment release of microfibers arising from clothes within washing machines that then appear in wastewater are not covered

¹⁸³ Verschoor et al.: Emission of microplastics and potential mitigation measures Abrasive cleaning agents, paints and tyre wear RIVM Report 2016-0026

¹⁸⁴ Verschoor et al.: Emission of microplastics and potential mitigation measures Abrasive cleaning agents, paints and tyre wear RIVM Report 2016-0026 / see also <http://www.ima-europe.eu/about-industrial-minerals/applications/industrial-minerals-detergents>

¹⁸⁵ https://www.dispersions-pigments.basf.com/portal/basf/ien/dt.jsp?setCursor=1_785993

¹⁸⁶ <http://www.eurosil.eu/members-and-industry-overview>

¹⁸⁷ <https://echa.europa.eu/substance-information/-/substanceinfo/100.028.678>

Human health risks related to silica

Whilst naturally occurring and very common, the health risk from silica depend on its form. Data from the classification and labelling (C&L) inventory indicates the following notified classifications associated largely with respiratory risks. There are no harmonised classifications. The (UK) Health and Safety Executive (HSE) carried out a risk assessment of occupational exposure to respirable crystalline silica, which can result – usually following prolonged exposure - in silicosis, chronic obstructive pulmonary disease (COPD) and lung cancer. However, when exposure to dust is controlled, the health risks are deemed to be insignificant¹⁸⁸.

Given that silica will be present in liquid form in detergents (or at least not present as respirable dust), risks to the consumer are unlikely to be of concern. Depending on the form (e.g. size distribution) of silica used, there could potentially be exposure in the workplace where silica is incorporated into detergent products.

Table 5.12 Classification and labelling inventory: Human health risks – silica (silicon dioxide)

Ingredient	CAS Number	Harmonised classifications	Most common notified classifications
Silicon dioxide	7631-86-9, 112926-00-8	None	Not classified Skin irritant 2 (H315 - Causes skin irritation) Eye irritation 2 (H319 - Causes serious eye irritation) STOT SE 3 (H335 - May cause respiratory irritation) Acute Tox 4 (H332 - Harmful if inhaled) STOT RE (H372 - Causes damage to organs through prolonged or repeated exposure) STOT SE 2 (H373 - May cause damage to organs through prolonged or repeated exposure).

Source: ECHA C&L Inventory: <https://echa.europa.eu/substance-information/-/substanceinfo/100.028.678>

Environment risks related to silica

There are no harmonised classifications relating to environmental risks in the CL Inventory. However silicon dioxide has been notified (by one company) as being toxic to aquatic life with long lasting effects (Aquatic chronic 3 (H412)).¹⁸⁹ It does not have PBT nor vPvB properties.

Studies have shown that silica particles do not exhibit the same environmental risks from physical effects as observed for microplastics. According to Ogonowski et al. (2016), microplastics have a greater capacity to negatively affect feeding in *Daphnia magna* compared to naturally occurring mineral particles of similar size¹⁹⁰. Straub et al. 2017 used silica particles as a control and observed negative effects on amphipods in terms of weight loss from microplastics exposure compared to the silica control¹⁹¹.

Technical and economic feasibility of silica

Microplastic particles are used in abrasive cleaning agents because of their mild abrasive action, useful for avoiding scratch marks, for example. Whilst softer abrasives can become less effective as the abrasive is itself worn down, plastic particles are generally softer than mineral particles but typically more expensive. For these reasons they tend to be used in products specifically designed for delicate surfaces¹⁹².

Commercially available silica formulations marketed for general use in detergents and cleaning products, focus largely on the products' absorption capacity, which facilitates more compact economical powder

¹⁸⁸ <http://www.hse.gov.uk/pubns/indg463.pdf>

¹⁸⁹ <https://www.echa.europa.eu/web/guest/information-on-chemicals/cl-inventory-database/-/discli/details/50736>

¹⁹⁰ Ogonowski, M., Schür, C., Jarsén, Á., & Gorokhova, E. (2016). The Effects of Natural and Anthropogenic Microparticles on Individual Fitness in *Daphnia magna*. *PLoS ONE*, 11(5), e0155063. <http://doi.org/10.1371/journal.pone.0155063>

¹⁹¹ Straub, S., Hirsch, P. E., & Burkhardt-Holm, P. (2017). Biodegradable and Petroleum-Based Microplastics Do Not Differ in Their Ingestion and Excretion but in Their Biological Effects in a Freshwater Invertebrate *Gammarus fossarum*. *International Journal of Environmental Research and Public Health*, 14(7), 774. <http://doi.org/10.3390/ijerph14070774>

¹⁹² Verschoor et al.: Emission of microplastics and potential mitigation measures Abrasive cleaning agents, paints and tyre wear RIVM Report 2016-0026

formulations and on their rheological modification. The latter are used in many liquid laundry detergents, automatic dishwashing liquids, or liquid household cleaners and provide useful characteristics for handling, stability, dosing and storage¹⁹³.

Overall the evidence indicates that silica formulations are technically feasible for use in several detergent applications – however with a value of between 6 and 7 on the Moh scale of relative hardness they are likely to be inappropriate for certain applications requiring softer abrasive function. “Plastics media”, for example have a rating of between 3 and 5 and calcite a rating of 3¹⁹⁴.

In terms of economic feasibility, a search of publicly available sources suggest that a typical commercial price for silicon dioxide is in the range of between c. \$500 and up to \$1 500 per tonne. Taking an average of the median values at current exchange rates this is broadly equivalent to €700 per tonne. Considering the price of microplastics has been estimated to be in the order of magnitude of €1 100 per tonne, this suggests that prices of this alternative would not negatively affect the economic feasibility of substituting microplastics. Verschoor (2016) suggests that, given alternative ingredients are available, “in abrasive cleaning agents and other products [...] it is assumed [phasing out micoplastcis] is relatively cheap”. However, it is recognised that for certain niche products the alternatives may not be suitable and that costs will be incurred in reformulation and in obtaining registration for new products¹⁹⁵.

Table 5.13 Pricing information – silica (silicon dioxide) powder

	Cost per tonne (low high)	Median cost per tonne in Euro	Overall average assumed in analysis
White Carbon Black / Precipitated Silicon SiO₂ CAS No.: 7631-86-9	\$635 – 780	€620	
Fumed Silica, precipitated silica, White Carbon Black, CAS No.7631-86-9	\$480 - 680	€510	
China high quality silicon dioxide Cas NO.7631-86-9	\$1 000-1 500	€1 095	
CAS No 7631-86-9 white powder SiO₂ silicon dioxide for sale	\$700 – 850	€680	
high quality and purity silica powder/CAS No.7631-86-	\$500 - 700	€525	
Overall			€700

Source: https://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&SearchText=silica+cas+7631-86-9

Search conducted July 2017. Exchange rate used 1 Eur+ 1.1412 US Dollar 7th July 2017. Source:

https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html

Note the overall average has been rounded to the nearest €100 to avoid spurious claims to accuracy.

¹⁹³ <https://www.aerosil.com/sites/lists/RE/DocumentsSI/II-2246-AEROSIL-and-SIPERNAT-for-detergents-and-cleaning-products-EN.pdf>

¹⁹⁴ <http://www.healthycleaning101.org/types-of-household-cleaning-products/>
http://www.armtech.pl/f/uslugi/Mohs_scale_of_relative_hardness.pdf / <http://www.reade.com/reade-resources/reference-educational/reade-reference-chart-particle-property-briefings/32-mohs-hardness-of-abrasives>

¹⁹⁵ Verschoor et al.: Emission of microplastics and potential mitigation measures Abrasive cleaning agents, paints and tyre wear RIVM Report 2016-0026

Beyond any price differential – and requirements for larger or smaller volumes, a major source of economic cost would be the need for reformulation of detergent products. No public available data has been identified on the specific costs of reformulation, per product, for detergents, but in broad terms, these may be on a similar order of magnitude to those in the personal care products sector noted earlier. However, it should be noted that the total numbers of products are likely to be lower, given the lower overall tonnage.

In those applications where silica is technically feasible/acceptable, it is likely there would be some loss of consumer satisfaction with the product, given the comparative hardness. This will like affect prices and may lead to some loss of market value.

5.6 Application 4: Abrasives

Microplastics are widely used as abrasives. In this application potential alternatives were identified via a literature review alongside industry consultation exercise and further research on specific products. A range of alternatives have been identified including coconut shell¹⁹⁶, dry ice¹⁹⁷, silicon carbide¹⁹⁸ or glass beads (see above). Given that glass beads are covered above, this sections focusses on silicon carbide.

Assessment of silicon carbide (SiC)

Availability of silicon carbide

Silicon carbide is commercially available in large volumes - it has been mass produced in powder form for use as an abrasive since the late 1800s¹⁹⁹. The ECHA inventory notes that the substance is manufactured and/or imported in the European Economic Area in the 100 000+ tonnes per year category²⁰⁰. Publicly available market data is limited but 2011 data suggests Chinese export capacity alone may be 216 000 tonnes²⁰¹. Given this, there appears to be no evidence that manufacturers could not supply the volumes required without undue delay.

Human health risks related to silicon carbide

Data from the classification and labelling (C&L) inventory indicate the following notified classifications. There are no harmonised classifications.

As with Silica, depending on the form, there could potentially be exposure via respiration in the workplace where silicon carbide is incorporated into detergent products, where it used in dust form.

Table 5.14 Classification and labelling inventory: Human health risks – silicon carbide

Ingredient	CAS Number	Harmonised classifications	Most common notified classifications
Silicon carbide	409-21-2	None	Not classified Carcinogen 1B (H350 - May cause cancer) STOT RE 1 (H372 - Causes damage to organs through prolonged or repeated exposure) Skin Irritation 2 (H315 - Causes skin irritation) Eye Irritation 2 (H319 - Causes serious eye irritation) STOT SE 3 (H335 - May cause respiratory irritation).

Source: ECHA C&L Inventory: <https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/123165>

¹⁹⁶ <http://www.reade.com/products/coconut-shell-powder-coconut-shell-flour>

¹⁹⁷ <http://www.cleansurface.co.uk/>

¹⁹⁸ <http://www.sic.saint-gobain.com/products/sika-abr/> / http://medias.im.saint-gobain.com/ebooks/Internet/Saint_Gobain_Sika_Brochure/files/assets/basic-html/page-19.html

¹⁹⁹ <https://www.digikey.com/en/articles/techzone/2016/dec/silicon-carbide-history-and-applications>

²⁰⁰ <https://echa.europa.eu/substance-information/-/substanceinfo/100.006.357>

²⁰¹ http://siliconcarbideandmore.com/index_files/SiC39final.pdf

Environment risks related to silicon carbide

There are no harmonised or notified classifications relating to environmental risks in the CL Inventory.²⁰²

As discussed for silica above, limited evidence is available but studies have shown that naturally occurring mineral particles have lower capacity to adversely affect certain biota as compared to microplastics²⁰³.

Technical and economic feasibility of silicon carbide

Silicon carbide (SiC) has been used as an abrasive in a range of loose or fixed applications for over 100 years it has high abrasion resistance and is available at relatively low cost²⁰⁴. Manufacturers state that technical grade ceramics developed with SiC exhibit properties such as: exceptional hardness; high strength; low density; high elastic modulus; high thermal shock resistance; chemical inertness; high thermal conductivity and low thermal expansion²⁰⁵. Manufacturers state that abrasive tools made out of Silicon Carbide are commonly used for grinding steel, cast iron, tungsten carbide, aluminium, non-ferrous metal, plastic and rubber.²⁰⁶ Given the hardness of SiC, as above, whilst technically feasible in certain applications, it is likely to be inappropriate where soft abrasive function is required. This would depend on the precise needs, but may include cleansing of moulds used in the manufacture of plastics or rubber, cleansing aboard ships, cleansing of turbine blades at power plants or removal of graffiti from walls.

In terms of economic feasibility, a search of publicly available sources suggests that a typical commercial price for silicon carbide is in the range of between c. \$300 and up to \$1 500 per tonne. Taking an average of the median values at current exchange rates this is broadly equivalent to €700 per tonne. Considering the price of microplastics has been estimated to be in the order of magnitude of €1 100 per tonne, this suggests that prices of this alternative would not negatively affect the economic feasibility of substituting microplastics.

Table 5.15 Pricing information – silicon carbide

	Cost per tonne (low high)	Median cost per tonne in Euro	Overall average assumed in analysis
Black/Green Silicon Carbide prices	\$400 – 600	€440	
China gold supplier powder granule Black silicon carbide	\$300 – 800	€490	
Black Silicon Carbide F1200 for polishing	\$1 050 – 1 500	€1 120	
Sandblasting black/Green silicon carbide	\$989 – 999	€870	
Silicon Carbide	\$600 – 1 000	€700	
Overall			€700

Source: <https://www.alibaba.com/showroom/silicon-carbide.html>

Search conducted July 2017. Exchange rate used 1 Eur+ 1.1412 US Dollar 7th July 2017. Source:

https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html

Note the overall average has been rounded to the nearest €100 to avoid spurious claims to accuracy.

Further costs would be incurred through product reformulation. No public available data has been identified on the specific costs of reformulating abrasives, however given the comparative hardness it appears likely

²⁰² <https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/123165>

²⁰³ See for instance: Ogonowski, M., Schür, C., Jarsén, Å., & Gorokhova, E. (2016). The Effects of Natural and Anthropogenic Microparticles on Individual Fitness in *Daphnia magna*. *PLoS ONE*, 11(5), e0155063. <http://doi.org/10.1371/journal.pone.0155063>

²⁰⁴ <https://www.digikey.com/en/articles/techzone/2016/dec/silicon-carbide-history-and-applications>

²⁰⁵ <https://www.digikey.com/en/articles/techzone/2016/dec/silicon-carbide-history-and-applications>

²⁰⁶ <http://www.sic.saint-gobain.com/markets/abrasives>

there may be some loss of consumer satisfaction with the product functionality and hence effect on prices/market size.

5.7 Application 5: Agriculture

The main use of microplastics in agricultural applications are in nutrient prills (granules)²⁰⁷. These contain a coating often composed of a polymer such as polysulfone, polyacrylonitrile or cellulose acetate, which encapsulates nutrient combinations for fertilisation. These ensure that fertiliser diffuses into the soil over predetermined time periods, typically 3 to 18 months, providing a continuous nutrient supply to the plant roots, at the optimum concentration and at controlled rates. In turn this enables a reduction of the quantity of fertiliser needed per unit area of cropland and ultimately increases yields GESAMP (2015)²⁰⁸.

In addition, applications where microplastics are potentially contained include soil conditioners, which can increase the water holding capacity of soils, increasing water use efficiency, reducing irrigation frequency and enhancing soil permeability. In irrigation systems, drag reducing polymers within a fluid reduce friction resistance in a turbulent flow, reducing the energy requirements of sprinkler irrigation systems. In soil remediation polymers aid the removal or recovery of metal ions from aqueous solutions (Ekebafé et al. (2011)²⁰⁹.

Based on a review of available literature, an alternative to polymer-coated nutrient prills would be an alternative technique - is nitrification inhibitors. These control the release of nutrients for fertilisation by controlling the rate at which ammonium is converted in nitrate²¹⁰. There are several ammonium stabilisers, the most common contain the active ingredients include dicyandiamide (DCD) – also called Cyanoguanidine (CAS No: 461-58-5); 3, 4-dimethylpyrazole phosphate DMPP (CAS No: 202842-98-6)²¹¹ or 2-chloro-6-(trichloromethyl)-pyridine (Nitrapyrin) – CAS NO: 1929-82-4²¹².

Note that information dated June 2017 suggests that cellulose beads have been developed which could potentially replace microbeads that could be used [...] impregnated with agrichemicals for use in, for example, slow release fertilisers. This information is part of a press release from the University of Bath (in the UK). At present this product does not yet appear to be commercially available, given that the source goes on to note that “they will work with industrial partners to develop materials”²¹³. Note that cellulose alternatives more generally are discussed in the “cosmetics” section. On that basis nitrification inhibitors (in general, not one specific active ingredient) are assessed below.

Assessment of nitrification inhibitors

Availability of nitrification inhibitors

No publically available information on production volumes for nitrification inhibitors in general were identified, however they are commercially available from a range of sources²¹⁴. Public and technical literature indicates there are three common active ingredients:

²⁰⁷ <http://pubs.acs.org/doi/abs/10.1021/jf00081a053?journalCode=jafcau&/>

<https://www.pioneer.com/home/site/us/agronomy/library/controlled-release-n-fertilizers/>

²⁰⁸ GESAMP (2016). Sources, fate and effects of microplastics in the marine environment: part two of a global assessment (Kershaw, P.J., and Rochman, C.M., eds). IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection. Rep. Stud. GESAMP No. 93, 220 p.

²⁰⁹ <http://www.bioline.org.br/pdf/bk11011>

²¹⁰ WBCSD (2015): Co-optimizing Solutions: water and energy for food, feed and fiber. Annex C - Possible breakthroughs smart fertilizers. <http://www.wbcd.org/Projects/Climate-Smart-Agriculture/Resources/Co-optimizing-Solutions-water-and-energy-for-food-feed-and-fiber>

²¹¹ <http://iopscience.iop.org/article/10.1088/1748-9326/9/11/115006>

²¹² [http://www.ipni.net/publication/nss.nsf/0/21B8084A341C98E085257E3C0077595B/\\$FILE/NSS-26%20Nitrification%20Inhibitors.pdf](http://www.ipni.net/publication/nss.nsf/0/21B8084A341C98E085257E3C0077595B/$FILE/NSS-26%20Nitrification%20Inhibitors.pdf)

²¹³ <http://www.bath.ac.uk/news/2017/06/08/scientists-make-biodegradable-microbeads-from-cellulose/> Further detail is available here:

<http://pubs.acs.org/doi/abs/10.1021/acssuschemeng.7b00662>

²¹⁴ See for example: <https://www.alibaba.com/showroom/nitrification-inhibitor.html/>

<http://www.sigmaldrich.com/catalog/search?term=461-58-5&interface=CAS%20No.&N=0+&mode=partialmax&lang=en®ion=GB&focus=product>

<https://www.scbt.com/scbt/product/3-4-dimethylpyrazole-phosphate-202842-98-6>

1. Dicycandiamide (DCD)/Cyanoguanidine (CAS No: 461-58-5) is manufactured and/or imported in the European Economic Area in 10 000 - 100 000 tonnes per year²¹⁵ and is commercially available²¹⁶.
2. No information was identified on 3, 4-dimethylpyrazole phosphate DMPP (CAS No: 202842-98-6) on ECHA's website; it does not appear to be registered under REACH but is commercially available²¹⁷.
3. 2-chloro-6-(trichloromethyl)-pyridine (Nitrapyrin) – CAS NO: 1929-82-4. This is registered under REACH but there is no data on ECHA's website on tonnages, but the substance is commercially available²¹⁸.

Given the above, the alternatives are available and it appears unlikely that manufacturers could not supply the volumes required without undue delay.

Human health risks related to nitrification inhibitors

Data from the classification and labelling (C&L) inventory indicate the following classifications. There are no harmonised classifications for DCD, but there are notified classifications under “acute tox 4” (associated with harm from swallowing, skin contact and inhalation). There is no information on DMPP. Nitrapyrin has a harmonised classification (Acute Tox 4 – related to harm from swallowing) as well as a notified classification for the same as well as allergic skin reactions and serious eye irritation.

Table 5.16 Classification and labelling inventory: Human health risks – nitrification inhibitors

Ingredient	CAS Number	Harmonised classifications	Most common notified classifications
Dicycandiamide (DCD)/Cyanoguanidine	461-58-5	None	Not classified Acute Tox 4 (H302 – Harmful if swallowed; H312 - Harmful in contact with skin; H332 – harmful if inhaled)
3, 4-dimethylpyrazole phosphate DMPP	202842-98-6	No information	No information
2-chloro-6-(trichloromethyl)-pyridine (Nitrapyrin)	1929-82-4	Acute Tox 4 (H302 – Harmful if swallowed)	Acute Tox 4 (H302 – Harmful if swallowed) Skin sens 1 (H317 – may cause allergic skin reaction) Eye irritant 2 (H319 – causes serious eye irritation).

Source: ECHA C&L Inventory: <https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/103607>

Environment risks related to nitrification inhibitors

3, 4-dimethylpyrazole phosphate DMPP has a harmonised classification under CLP as aquatic chronic 2 (H411 – toxic to aquatic life with long lasting effects) it also has a notified classification under the same category²¹⁹.

Nitrification inhibitors do not exhibit the same environmental risks posed by nutrient prills as source of microplastics. The environmental concern of nutrient prills results from the remaining prill not degrading when nutrients are released²²⁰. Nitrification inhibitors do not require any coating; they can be added directly

²¹⁵ <https://echa.europa.eu/substance-information/-/substanceinfo/100.006.649>

²¹⁶ <https://thechemco.com/chemical/dicyandiamide/>

²¹⁷ <https://www.scbt.com/scbt/product/3-4-dimethylpyrazole-phosphate-202842-98-6>

²¹⁸ <http://www.sigmaaldrich.com/catalog/product/aldrich/c1930?lang=en®ion=GB>

²¹⁹ <https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/103607>

²²⁰ GESAMP (2016). Sources, fate and effects of microplastics in the marine environment: part two of a global assessment (Kershaw, P.J., and Rochman, C.M., eds). IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection. Rep. Stud. GESAMP No. 93, 220 p.

to the soil or into any ammonium-containing solid, liquid or fertiliser, and they are consumed or decomposed during use²²¹.

Technical and economic feasibility of nitrification inhibitors

There is widespread evidence that nitrification inhibitors are in use in several agricultural applications and that they provide an effective method of controlling transformation of ammonium into nitrate.²²² The use of these in place of polymer coatings represents an alternative technique rather than an alternative substance to replace the polymer coating.

Manufacturers of commercially available products suggest the benefits include: adapted delivery of nitrogen; reduced washing away and shifting of nitrogen; secure supply of nitrogen whatever the weather; savings through fewer applications of fertiliser and reduced gaseous nitrogen losses²²³. Some evidence suggests in certain applications they can be more effective than controlled release fertilisers (nutrient prills)²²⁴ and that they deliver economic benefits from increased yields²²⁵.

However, the efficacy is influenced by soil temperature, soil texture and the amount of rainfall²²⁶. In general, nitrification inhibitors are more effective in sandy soils, or soil low in organic matter and exposed to low temperatures.²²⁷ Their effectiveness for one soil type and climatic region cannot necessarily be extrapolated to others, suggesting users would need to assess effectiveness for intended applications. Other evidence suggests their use can result in increased emissions of ammonia (NH₃), however²²⁸.

In terms of economic feasibility, a search of publicly available sources was conducted on “nitrification inhibitors” in general as well as the three active substances noted easier – DCD/DMPP and Nitrapyrin show a large variance in price, likely reflecting these are prices of the pure active ingredient, or differences in package sizes / scale. The price of microplastics has been estimated to be in the order of magnitude of €1,100 per tonne. However, the difference in prices has to be seen in context of potentially increased effectiveness compared to nutrient prills and the economic benefits from increased yields. Hence it was not possible to comment with certainty on economic feasibility based on prices of nitrification inhibitors.

Table 5.17 Pricing information – nitrification inhibitors

	Cost per tonne (low high)	Median cost per tonne in Euro	Overall average assumed in analysis
dicyandiamide nitrification inhibitors	\$1 650 – 2 000	€1 600	
cyanoguanidine, Dicyandiamide, 99.5% min, industry	\$1 210 – 2 200	€1 500	
on the market 99.5% min Dicyandiamide	\$1 500 – 1 700	€1 400	
3 4-dimethylpyrazol phosphate	€27 160 – 28 670 [1]	€24 500 [2]	
Chemical Intermediate CAS No. 202842-98-6 3,4-- Dimethylpyrazole phosphate	\$10 000 – 50 000	€26 000 [2]	
2-chloro-6-(trichloromethyl)-pyridine	\$10 000 – 30 000	€17 500 [2]	

²²¹ Trenkel, M. E. (2010). Slow-and controlled-release and stabilized fertilizers: An option for enhancing nutrient use efficiency in agriculture. IFA, International fertilizer industry association. Available at: http://www.fertilizer.org/imis20/images/Library_Downloads/2010_Trenkel_slow%20release%20book.pdf?WebsiteKey=411e9724-4bda-422f-abfc-8152ed74f306&=404%3bhttp%3a%2f%2fwww.fertilizer.org%3a80%2fen%2fimages%2fLibrary_Downloads%2f2010_Trenkel_slow+release+book.pdf

²²² <http://www.nature.com/articles/srep22075>

²²³ <http://www.originfertilisers.co.uk/products/nitrogen-fertilisers/entec/>

²²⁴ See for example:

<http://www.nutrientadvantage.com.au/News%20and%20Forums/Agronomic%20Insights/ENTEC%20vs%20controlled%20release>

²²⁵ <http://www.nature.com/articles/srep22075>

²²⁶ <http://iopscience.iop.org/article/10.1088/1748-9326/9/11/115006>

²²⁷ [http://www.ipni.net/publication/nss.nsf/0/21B8084A341C98E085257E3C0077595B/\\$FILE/NSS-26%20Nitrification%20Inhibitors.pdf](http://www.ipni.net/publication/nss.nsf/0/21B8084A341C98E085257E3C0077595B/$FILE/NSS-26%20Nitrification%20Inhibitors.pdf)

²²⁸

http://ec.europa.eu/environment/integration/research/newsalert/pdf/nitrification_inhibitors_climate_change_mitigation_ipcc_less_effective_than_thought_477na4_en.pdf

	Cost per tonne (low high)	Median cost per tonne in Euro	Overall average assumed in analysis
2-chloro-6-(trichloromethyl)pyridine	\$38 000 - \$45 000	€36 400 [2]	
N-SERVE;2-Chloro-6-(trichloromethyl)pyridine;1	\$1 000 - \$10 000	€4 800	
Overall			From €2 500; potentially up to € 14 000 [2].

Table Notes

[1] This is based on several sources, per kilogram all with the same price Source:

https://www.alibaba.com/trade/search?IndexArea=product_en&fsb=y&SearchText=3%2C+4-dimethylpyrazole+phosphate+&viewtype=G

[2]: These products appears to be the relevant active ingredient, hence are much more expensive than some of the others listed, however the source is not clear and no further data has been identified to cross reference. It is advised they are treated with caution, hence the average, including and excluding these figures are set out in the table.

Source: <https://www.alibaba.com/showroom/nitrification-inhibitor.html/>

https://www.alibaba.com/trade/search?IndexArea=product_en&CatId=&fsb=y&SearchText=Cyanoguanidine&viewtype=G/

https://www.alibaba.com/trade/search?IndexArea=product_en&fsb=y&SearchText=3%2C+4-dimethylpyrazole+phosphate+&viewtype=G

https://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&SearchText=nitrapyrin&isGalleryList=G

Search conducted July 2017 on "nitrification inhibitor" as well as the three specific active ingredients.

Of the active ingredients three prices were obtained for each. Exchange rate used 1 Eur+ 1.1412 US Dollar 7th July 2017. Source:

https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html Note the overall average has been rounded to the nearest €100 to avoid spurious claims to accuracy.

Note several prices were reviewed.

6 Socio-economic analysis

6.1 Introduction

This section examines the main economic impacts associated with possible restriction scenarios. Other effects, which include social, wider economic and distributional are also assessed. Notes on “other effects” associated with restriction, including the effects of taking no action is also considered. The analysis in this section relates to all of the microplastics applications covered in the report. However, given the range of applications and of possible alternatives, a quantitative assessment of the economic costs associated with reformulation has only been possible on the PCP market.

6.2 Restriction Scenarios

Several restriction scenarios may be considered, which differ in terms of the microplastics definition used and associated economic effects. The different definitions and associated effects are discussed in the RMOA, but in broad terms the more detailed the definition, the lower the economic effects are expected to be. This section, in contrast, evaluates the economic costs associated with the following:

- ▶ A Restriction on use in rinse-off PCP.
- ▶ A Restriction on use in leave-on PCP.
- ▶ Restriction with a wide definition covering other polymers in PCP.
- ▶ Restriction on use in in paints, detergents, abrasives and agricultural applications.

6.3 Economic Impacts

Rinse off Personal Care Products

Stages of substitution for each affected product line

The overall conclusion from the analysis of alternatives in the previous sections suggests that whilst there is no-one alternative in any application, potential alternatives exist in the majority of applications. Substitution appears to be largely underway, particularly for exfoliating/cleansing microbeads in rinse-off products (while less information on alternatives is available for other applications), driven by both regulatory action and voluntary initiatives, both in and outside of the EU. In any application the economic costs incurred will be significantly influenced by:

- ▶ The definition used and the extent of the market affected. This may be all uses of synthetic polymers, which in the case of personal care products would include the majority of the market, or a subset of it.
- ▶ The extent to which - in the specific application under consideration - substitution either in the EU or beyond has already begun. Where it has, it can be assumed at least some of the more challenging aspects of reformulation: testing, downstream user and consumer acceptance, marketing and regulatory approvals (where necessary) would have been overcome.
- ▶ The tonnage of microplastics used as a proportion of tonnage of products sold in that application/market sector.

Irrespective, if a product line is affected, there are two broad options available. These apply in all applications, but are presented here in the context of rinse off PCPs.

For several applications, it has not been possible to place monetary estimates on economic costs for each stage nor the extent of the market that may be lost under each option. This reflects the uncertainty over the

scope of any restriction, the range of applications potentially affected and the detail available in industry consultation and public data. It is expected, however, that a restriction in any one applications would, in practice, result in a combination of options 1 and 2.

- ▶ **Option 1: Replace microplastics with alternative substances, if a feasible alternative (or mix of alternatives) is currently available, or identified after further testing.** Survey respondents indicated that even where a suitable (combination of) alternative is identified, significant investment in R&D, alongside batch/sample production for infield testing to ensure product functionality and hence acceptability by the downstream users and final consumers would still be required. Industry estimates are not specific, due to the uncertainties involved, but suggest this would take “years”. Given the range of applications it has not been possible – outside of the PCP market sector – to identify the total number of product lines affected, but the number is likely to be substantial. Adopting these and other alternatives, requires several steps. The key stages required would be the same for all product lines, the challenges and technical implications would differ. Following testing, for each:
 - ▶ *Purchasing alternative raw materials, taking account of different prices and volumes required.* It is not clear from current evidence if greater quantities of alternatives would be required to provide a similar function. Several of the alternatives evaluated consist of natural substances, such as walnut/almond shell, waxes, jojoba seeds, clay, silica or cellulose. These are commercially available and already in use.
 - ▶ *Capital costs associated with changes in processing/machinery and operational cost changes associated with any loss of production efficiency.*
 - ▶ *Diversion of “business as usual” R&D to regulatory compliance:* The number of product lines that would need to be tested, reformulated, re-marketed, submitted for regulatory approval and produced would pose substantial challenges; financially and in terms of staff, R&D and production capacity.
 - ▶ *Assess the implications on the technical implication of the final products and hence on price downstream users / consumers are willing to pay.* This may serve to reduce the value of the market and change manufactures’ judgements on whether to continue to invest in some product lines.
- ▶ **Option 2: If the above is not technically or economically feasible, or the companies are unable to make investment decisions based on their current knowledge of alternatives, then the affected product lines, revenues and employment in the EU will cease.** It should be noted that the possibility of a relocation outside the EU was not explicitly mentioned in the industry consultation and it is unclear if this is a realistic option given Member State and non EU action. However, under this option exports to outside the EU would also be affected.

Leave on Personal Care Products

The main source of economic costs if a restriction covering leave on PCP was introduced (as well as not specifying functionality of microplastics used) would also be reformulation costs.

Using the assumptions set out in the analysis of alternatives, it is estimated that annual reformulation costs could be in the region of €100 million (€c.40 – €185 million), per year. Comparing this value to annual retail sales prices and specifically to the manufacturer’s sales prices, this appears unaffordable for many companies. Whilst there are several factors that suggest this scale of reformulation may not be required, however in a worst case the revenues associated these product lines may be lost. This is estimated to amount to approximately 1 000 product lines – less than 1% of the notional retail sales of the personal care product market as a whole.

Polymers

Assuming a restriction using a wider definition was introduced - covering all polymers <5mm in size, the range of products affected and hence the economics costs would be very much greater, estimated in the analysis of alternatives at some €5.2 billion in annual reformation costs, in the worst case. This would affect

around 18% of the European PCP market. It is noted this is an approximate, order of magnitude estimate., but this does not account for any increase or decrease in costs from changes in raw material costs, nor form any necessary changes to manufacturing processes, regulatory approvals or marketing,

Paints

As above, all affected product lines would need to be reformulated with alternatives, where these were technically feasible. Given the specific uses and alternatives considered appears unlikely that technical functionality (i.e. elasticity, anti-scratch) which may serve to limit the availability of some products, with the associated economic costs.

Detergents

The same substitution stages would be required in this sector as outlined above for PCP. As above, all affected product lines would need to be reformulated with alternatives, where these were technically feasible. The evidence suggests that applications for delicate surfaces where microplastics were used specifically because of their softer abrasive qualities may be adversely affected, with the associated loss of market value. It has not been possible to quantify what proportion of the market may be affected, however the tonnage of microplastics used in this sector is very much less than in PCP, for example.

Abrasives

All affected product lines would need to be reformulated with alternatives. The analysis of alternatives suggested that at least the more common alternatives may not be appropriate in some applications, where a “softer” abrasive function is required. This would appear to be a small proportion of the market. Equivalent prices of raw materials, on a per tonne basis, are broadly comparable.

Agriculture

This alternative considered in this application is effectively an alternative technique; replacing polymer coated nutrient prills with nitrification inhibitors. This would result in a loss of market for existing suppliers of prills which would, over time be offset by increased sales of the alternative(s). There is limited information on production volumes, beyond evidence that these are commercially available and new products are being developed.

The net effects from their use is also uncertain, with some sources stating they have positive effects on yields, hence increased revenues for the end users and others indicating these may be offset by increased emissions of ammonia. Further, the evidence indicates that their effectiveness is influenced by soil type.

Effects on downstream users and final consumers

The preceding analysis suggested that in certain applications the range of products available may decrease and/or the cost of reformulated products may increase. However it appears likely that this would affect only a small proportion of the market and the extent of price increases are likely to be small. The technical functionality of some products is expected to be inferior, noted above. The extent to which this may occur depends on the microplastics definition used, further detail is available in the analysis of alternatives.

Benefits of acting / costs of not acting

There are significant economic costs associated with plastic pollution resulting amongst other things from clean-ups; loss of fisheries and wildlife; and reductions in tourism²²⁹. For instance, the United Nations Environment Programme has estimated that plastic waste in the marine ecosystems globally costs at least

²²⁹ UK House of Commons Environmental Audit Committee: Environmental impact of microplastics inquiry - Written evidence submitted by Mr Kofi Renner, Dr Christopher Green, Dr Edwin Routledge, Dr Mark Scrimshaw and Professor Susan Jobling, Institute of Environment, Health and Societies Department of Life Sciences, Brunel University, London. April 2016. Available at: <http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/environmental-audit-committee/environmental-impact-of-microplastics/written/31834.pdf>

\$13 billion (€11 billion) in damage annually²³⁰. Costs avoided by reducing plastic pollution imply a benefit of actions mitigating the pollution, which may exceed the costs of the actions. It has been estimated that the benefits in terms of avoided damages would amount to 120-180% of the costs of controlling marine litter and microplastics pollution in the UK²³¹.

However, there is less information available on costs specifically associated with microplastics (and thus the benefits of avoiding them). To illustrate the possible scale, written evidence²³² submitted to the Environmental impact of microplastics inquiry of the UK House of Commons Environmental Audit Committee quotes a number of studies estimating some of these costs for the UK:

- ▶ Losses from reduced growth rates and mortality caused by microplastics ingestion to the shellfish industry have been projected at between 0.02 and 2.5% of the net present value of the shellfish fishery per annum.
- ▶ This can have knock on effects on tourism revenue, leading to projected losses of £1.5 million and £499 million (€1.8 million and €610 million²³³) per year in the UK.
- ▶ Further losses to tourism revenue may also occur if microplastics interfere with the bathing water quality.

Total EU production of shellfish was worth about €2.5 billion in 2014²³⁴. By extrapolation from the above estimate of damage to the shellfish industry, assuming the same percentage of shellfish production would be lost EU-wide (0.02% to 2.5%), this would imply losses of between about €0.5 million and about €60 million per year in the EU.

It is likely that microplastics pollution could also impact other economic activities, such as other types of fishing and aquaculture not mentioned above. Furthermore, these costs do not include environmental (and potentially human health) impacts that are not reflected in economic activities.

However, it is important to note that it is **not clear how much of this cost could be associated specifically with intentionally added microplastics in products** (rather than all microplastics, which include those not intentionally added to products, such as for example tyre wear). It has been recognised that the state of knowledge about the relative importance of the various types of microplastics and their differential environmental impacts is incomplete²³⁵.

6.4 Other impacts, practicability and monitorability

Addressing microplastics through WWT

A potential alternative to addressing the risks of microplastics through a restriction (i.e. at source) would be to require the waste water treatment (WWT) industry to address the presence of microplastics in the environment. Note however, that this would only address sources from which microplastics enter the environment via waste water such as personal care products, paint brushes or detergents that are rinsed-off

²³⁰ UNEP (2014) Valuing Plastics: The Business Case for Measuring, Managing and Disclosing Plastic Use in the Consumer Goods Industry. Exchange rate used: € = \$1.18. European Central Bank official exchange rates (01/01/2014 - 31/12/2014). Note this is an estimate and made in 2014, it has not been updated in line with inflation.

²³¹ UK House of Commons Environmental Audit Committee: Environmental impact of microplastics inquiry - Written evidence submitted by Mr Kofi Renner, Dr Christopher Green, Dr Edwin Routledge, Dr Mark Scrimshaw and Professor Susan Jobling, Institute of Environment, Health and Societies Department of Life Sciences, Brunel University, London. April 2016. Available at: <http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/environmental-audit-committee/environmental-impact-of-microplastics/written/31834.pdf>

²³² Written evidence submitted to the Environmental impact of microplastics inquiry of the UK House of Commons Environmental Audit Committee (see above).

²³³ Exchange rate used: € = £0.82. European Central Bank official exchange rates (01/01/2016 - 31/12/2016).

²³⁴ Total EU landings in 2014 were worth €7.32bn of which 20% were crustaceans and molluscs (by value), and total EU aquaculture production was worth €3.96bn of which 26% were crustaceans and molluscs (by value). Source: European Market Observatory for Fisheries and Aquaculture Products (2016): The EU fish market – 2016 Edition. Available at <http://www.eumofa.eu/the-eu-fish-market>. Multiplying shares of crustaceans and molluscs of total values yields €1.46bn of shellfish landings and €1.03bn of shellfish aquaculture production, in sum €2.49bn.

²³⁵ Written evidence submitted to the Environmental impact of microplastics inquiry of the UK House of Commons Environmental Audit Committee (see above).

into water supply network, but not sources with other pathways such as offshore oil drilling or nutrient spills in agriculture. This section briefly considers the potential costs that may be associated with this approach. It is recognised there are several uncertainties with the approach and these should be treated as approximate order of magnitude figures.

There are over 45 000 WWT plants in Europe, of which around 25 000 are primary and secondary treatment plants and around 20 000 tertiary²³⁶. The technology required to treat microplastics differs but includes membrane bioreactor (MBR) treating primary effluent and different tertiary treatment technologies (discfilter, rapid sand filtration and dissolved air flotation) treating secondary effluent. Evidence on its effect indicates MBR removed 99.9% of microplastics (MPs) during the treatment, rapid sand filter 97%, dissolved air flotation 95% and discfilter 40–98.5%.²³⁷

Using public cost data alongside assumptions on lifetime operation, capital and operational costs set out below suggests that this requiring microplastics to be treated via WWT plants could result in costs to the European waste water industry in the order of several billion Euro per year, possibly tens of billions depending on the filtration technique and number of plants affected²³⁸. This does not appear to be a proportionate approach to tackling the issue of microbeads, notwithstanding the fact that there would be co-benefits through removal of other substances from effluents. Similarly, such an approach would not be consistent with the principle of controlling pollution at source.

Table 6.1 WWT costs associated with MP removal (indicative)

Filtration technique	Equivalent Annualised Cost, per WWT Plant	Number of plants affected	Equivalent Annualised Cost [2]
Membrane Bioreactor (MBR)	Low €111 700 (based on typical WW flows, due to missing data this is expected to be underestimated) High: €1.7 million (based on capex and opex estimates) [1]	Low: 25 871 High: 47 090 [5]	Low €3 billion High €80 billion
Sand Filtration	Low: €60 000 (based on typical WW flows, due to missing data this is expected to be underestimated) High €1.1 million [3]		Low: €1.5 billion High: €53 billion
Nanofiltration with reverse osmosis (RO)	Low: €300 000 High: €1.4 million (based on typical WW flows, due to missing data this is expected to be underestimated) [4]		Low €8 billion High: €65 billion

Notes: [1]: Based on capex and opex per m3 and an assumption on flow per municipal WWT using data on total inflow – urban wastewater treatment from Eurostat. This is expected to underestimate actual costs given some MS data is missing.

The high figure is based on EAC capex and opex data from L. Højbye, J. Clauson-Kaas, H. Wenzel, H. F. Larsen, B. N. Jacobsen and O. Dalgaard (2008). Sustainability assessment of advanced wastewater treatment technologies. Water Science & technology - WST, 58.5-2008. IWA Publishing, 2009

[2]: based on assumed lifetime of 15 years for MBR, and 10 years for both sand and nanofiltration and a 4% discount rate. Lifetimes based on Solutions to microplastic pollution – Removal of microplastics from wastewater effluent with advanced wastewater treatment technologies. Available from: https://www.researchgate.net/publication/318106121_Solutions_to_microplastic_pollution_-_Removal_of_microplastics_from_wastewater_effluent_with_advanced_wastewater_treatment_technologies [accessed Jul 19, 2017].

[3]: Low estimate based on capex and opex per m3 and an assumption on flow per municipal WWT using data on total inflow – urban wastewater treatment from Eurostat. This is expected to underestimate actual costs given some MS data is missing. High estimate is based on capex and opex data based on L. Højbye, J. Clauson-Kaas, H. Wenzel, H. F. Larsen, B. N. Jacobsen and O. Dalgaard (2008). Sustainability assessment of advanced wastewater treatment technologies. Water Science & technology - WST, 58.5-2008. IWA Publishing, 2009 and assuming a lifetime operation of 10 years, as noted above.

[4]: Low estimate is based on estimated EAC costs per WWT, per M3 and using the estimated average flow per WWT plant noted above. As above, this is expected to underestimate actual costs given some MS data is missing. Capex per m3 data from ScorePP (2009). Feasibility of treatment options: Comparison of the approaches evaluated to maximise removal of Priority Pollutants Draft reference document on best available techniques in the common waste water and waste gas treatment/management systems in the chemical sector, October 2009. High estimate is based on average capex data from European Commission (2009): Draft reference

²³⁶ Source: Eurostat data. Extracted March 2017.

²³⁷ Source: Solutions to microplastic pollution – Removal of microplastics from wastewater effluent with advanced wastewater treatment technologies. Available from: https://www.researchgate.net/publication/318106121_Solutions_to_microplastic_pollution_-_Removal_of_microplastics_from_wastewater_effluent_with_advanced_wastewater_treatment_technologies [accessed Jul 19, 2017].

²³⁸ The MBR lifetime assumed was 15 years, sand and nanofiltration both 10 yrs. Source: L. Højbye, J. Clauson-Kaas, H. Wenzel, H. F. Larsen, B. N. Jacobsen and O. Dalgaard (2008). Sustainability assessment of advanced wastewater treatment technologies. Water Science & technology - WST, 58.5-2008. IWA Publishing, 2009

document on best available techniques in the common waste water and waste gas treatment/management systems in the chemical sector, October 2009 and estimated opex data based on an assumption on flow per municipal WWT using data on total inflow – urban wastewater treatment from Eurostat. This is expected to underestimate actual costs given some MS data is missing.

[5]: Eurostat data. Urban wastewater treatment plants. Extracted March 2017. The high number includes all primary, secondary and tertiary WWT plants are likely to include very small plants.

Insufficient data to estimate costs associated with ultrafiltration. Numbers have been rounded are order of magnitude estimates. Note these are 2013 costs, which have not been inflated to present 2016/2017 prices given the underlying uncertainties.

Regulatory consistency

The consistency of both the definition of microplastics and the timescales of regulatory action affect the costs incurred. As part of the study, consultation was undertaken with several regulatory authorities. This included consultation with Environment and Climate Change Canada. “Microbeads” were added to the toxic substances list under the Canadian Environmental protection Act 1999 (CEPA)²³⁹. Action was taken under civil and common law; a definition was proposed and consulted on. This specified the “Regulation focussed on plastic microbeads less than 5mm in size” but did not exclude biodegradable plastics and did not specify the intended use (i.e. whether it was leave on or wash off).

In the North American context, one reason for the choice of definition of microbeads covered by the restriction was the importance of consistency, in both the definition used and the timescales for action, with markets where there are strong economic linkages, in that case between Canada and the United States²⁴⁰.

Adopting a definition/scope that is very different from that within existing regulation at Member State level or outside the EU, may impose additional costs, challenges in compliance, enforcement and monitorability.

6.5 Social impacts

Any loss of the market that could not be replaced by alternatives would have implications for employment. As above, it is not clear that significant effects would be felt in downstream sectors, but significant effects within the companies that manufacture microplastics may occur, again depending on the definition used.

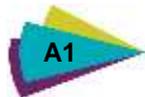
6.6 Wider impacts

The main wider economic impacts of a restriction would relate to international trade and the competitiveness of the EU. Any adverse effects would be limited by prior and ongoing non-EU regulatory action, meaning that demand outside the EU would be reduced. Current exports associated with microplastics containing products would presumably be lost.

Industry consultation highlighted the potential implications of reduced innovation within, for example, the cosmetic industry as the scale of the required reformulation effort would likely prevent R&D activities that would otherwise have occurred. This is particularly true if a wider range of functional polymers potentially fulfilling a wider range of functions are covered by the restriction. This suggests the potential for longer term losses of market share. As noted above, this effect would be limited if the scope of any regulatory action was aligned with that taken beyond the EU.

²³⁹ <http://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=26a03bfa-1>

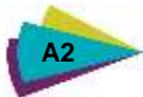
²⁴⁰ Personal Communication with E&CC Canada June 2017.



Appendix A

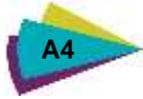
Summary of information from the literature review on product categories, (polymers, functions and size ranges)

Category	Sub-Category	Product Examples	Polymers (in bold: Microplastics according to working definition)	Functions and Size Range	Reference	Confirmed by Consultation
Cosmetics and Personal care products	Rinse off	scrubs (body, face, hands), hair care (color, conditioner, style mousse), make up remover, toothpaste, tooth whitening gels, deodorant, manicuring products (cuticle treatment), body hair removal (wax strips)	Polyethylene , Polyacrylamide, Polyvinylpyrrolidone, PMMA , Polyurethane , Polyacrylic acid, Polyamide (Nylon-6, Nylon-11) , Polypropylene , Poly(3-hydroxybutyrate) , Polyethylene terephthalate	exfoliant (< 1 mm), film forming, viscosity controlling, binder for powders, antistatic, dispersant, filler, silky feel, nanocapsules (10-1000 nm), bulking agent, slip modifier, skin conditioner	CosIng, US2010, PPG, SNF, PolygroupInc, Bugnicourt2014	Polyethylene (<315 µm to < 1 mm), Polyurethane (200-1250 µm), Nylon-11 (Polyamide-11) 150 µm, Polylactic Acid (<315 µm)
Cosmetics and Personal care products	Leave on	facial/eye cream, body lotion, decorative cosmetics (lip conditioner/stick, mascara, eye shadow, blush, make up powder, concealer stick), hair style mousse, shoe polish, facial moisturizers, anti-aging product, tanning lotions, sun creams, bleaching, styling gels	Polyethylene , Polyacrylamide, Polyvinylpyrrolidone, PMMA , Polyurethane , Polytetrafluoroethylene (PTFE) , Polyacrylic acid, Poly(lactic Acid (PLA), Acrylates crosspolymer , Polyacrylonitrile , Polycaprolactone , Styrene/Acrylate copolymer , Epoxy resin (DGEPA) , Polyvinylbutyral , Poly(3-hydroxybutyrate) , Polyethylene terephthalate , Polybutylene terephthalate	film forming, viscosity controlling, binder for powders, antistatic, dispersant, filler, silky feel, nanocapsules (10-1000 nm), bulking agent, slip modifier, skin conditioner, thickeners and suspending agents (e.g., 2-7 µm powders), stabilizers, glitter, cosmetic colors (e.g. epoxy resin coated aluminum powder), opacifying agent (particles above 170 nm)	Ooms2015, Oekotest2017, CosIng, US2010, PPG, SNF, Polygroup, Lubrizol, makingcosmetics, Lithner2011, Hu2011, Woodruff2010, Mark2007, beatthebead, SA.acrcro, SA.styac, Bugnicourt2014	



Category	Sub-Category	Product Examples	Polymers (in bold: Microplastics according to working definition)	Functions and Size Range	Reference	Confirmed by Consultation
Cosmetics and Personal care products	Superabsorbents	incontinence, sanitary napkins, diapers	Polyvinylpyrrolidone, Polyethylmethacrylate PMMA	superabsorbant polymer	Ooms2015, Fink2011, DAZ2006	
Detergents		cleaning products, laundry detergent, textile impregnation	Polyethylene, Polyamide, Polyvinylpyrrolidone, PMMA, Acrylates copolymer, PEG	Bulking agent, viscosity controlling; carrier for ingredients - > porous particles (0.1-50 µm), enzyme encapsulation (30-5000µm), binding, thickening, lubricity, water retention, and film formation, drag reduction	US2010, Oekotest2017, makingcosmetics, Sinko2011, Fink2011, DOW	Polyurethane < 600 µm, Polyester/Polyamide, Acrylic, PMMA; PET, PE 200-320µm
Paints/Coatings/Inks	Building, Road, Marine		Acrylic polymers, Polyamide, Polyacrylonitrile, Poly(ethylene vinyl acetate)	e.g.: EVA: semi flexible dispersible polymer powder with particle size: max 4% > 400 µm, for good tensile adhesion strength on inorganic surfaces (VINNAPAS 4023N/Wacker); leveling dispersible powder for smooth surfaces (VINNAPAS 5025L)	Wacker	Acrylic 5-80 µm spheres, 4-50mm x 10 µm fibres
Paints/Coatings/Inks	Paper making (drainage aid; coating)		Polyvinylpyrrolidone, PMMA, Polyacrylamide, Polyvinylamine, Melamine-formaldehyde resin	surface coating, flocculant	Fink2011, DAZ2006, SNF	
Paints/Coatings/Inks	Inks	Laserprinter inks, printer toner, packaging inks	Polyvinylpyrrolidone, Polyethylene, Polypropylene, Styrene/Acrylate copolymer, PEG	binder in toner (5-30 µm particles) -> no particles after application	Micropowders, https://de.wikipedia.org/wiki/Toner#Tonertypen	styrene/acrylate copolymer 2-10 µm

Category	Sub-Category	Product Examples	Polymers (in bold: Microplastics according to working definition)	Functions and Size Range	Reference	Confirmed by Consultation
Paints/Coatings/Inks	coatings, finishes, domestic polishing agents,	Floor finish/polish	Epoxy resin, Polyester, Polyurethane, Polytetrafluoroethylene, Polyamide, Polypropylene, Polyvinylbutyral, Polyethylene	improve chemical, mechanical, electrical, thermal and surface properties, e.g. 30-50 µm, for smooth thin films 1-30 µm, < 1 µm for clarity, gloss retention, scratch and mar resistance, slip and lubricity	Ooms2015, US2010, Essel2015, micropowders, https://en.wikipedia.org/wiki/Powder_coating	
Industrial abrasives	Abrasive media		Polycarbonate, Polyamide, Urea-formaldehyde resin	blasting abrasive: 100 µm-2.5 mm	Lithner2001, Essel2015, micropowders	
Agriculture	Controlled release fertilisers (nutrient prills), crops		Polyacrylonitrile, Polyvinylpyrrolidone	controlled release coating, binder and complexation agent for crop protection, seed treatment and coating	GESAMP2016, Akelah2013	
Agriculture	Soil enhancement (water retention)		Polyacrylamide, Polyacrylic acid, Expanded Polystyrene (EPS)	soil additives to retain moisture, increase soil tilth, aeration, porosity, stimulate root formation	Lithner2011, SNF, Akelah2013, Accepta	

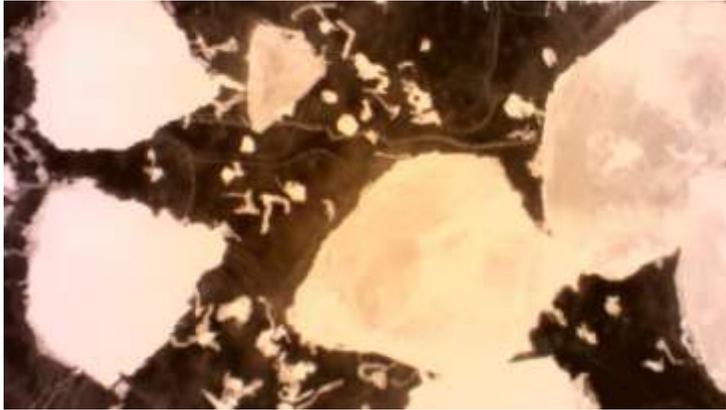


Category	Sub-Category	Product Examples	Polymers (in bold: Microplastics according to working definition)	Functions and Size Range	Reference	Confirmed by Consultation
Medical applications	Pharmaceuticals	additive in drug formulations, chewable sublingual and effervescent tablets	Polyacrylic acid, Acrylate Crosspolymer, Polycaprolactone, Polyactic acid, Polyvinylpyrrolidone, PMMA, Acrylonitrile-Butadiene-Styrene	encapsulating agents for pharmaceuticals (controlled release properties), bioadhesion, rheology modification, suspension of insoluble ingredients, emulsification of oil-in-water systems; in pharmaceutical tablets/capsules 3-30% of the finished product weight, tablet granulation, disintegrating aid in orally disintegrating tablet, sorbent for delivery of active ingredients	Lithner2011, Lubrizol, Impag, Hu2011, CosIng, US2010, Woodruff2010, Mark2007, DAZ2006, Ooms2015	
Medical applications	Abrasive in dental polish	dental polish	Acrylic resin	abrasive	Colgate2006	
Waste water treatment	flocculation agent, sewage dewatering		Polyacrylamide, Polyvinylamine	flocculant, dewatering/separation of sewage sludge	SNF, Vanotti2005	
Construction	Polymer concrete, Fibre reinforced concrete		Polyacrylonitrile, Polyacrylamide, Polypropylene, Polyamide, Polyethylene terephthalate		GESAMP2016, Lithner2011	
	Insulation (EPS)		Expanded Polystyrene (EPS)			
Others	Furniture / soft toys (e.g. expanded PS)					

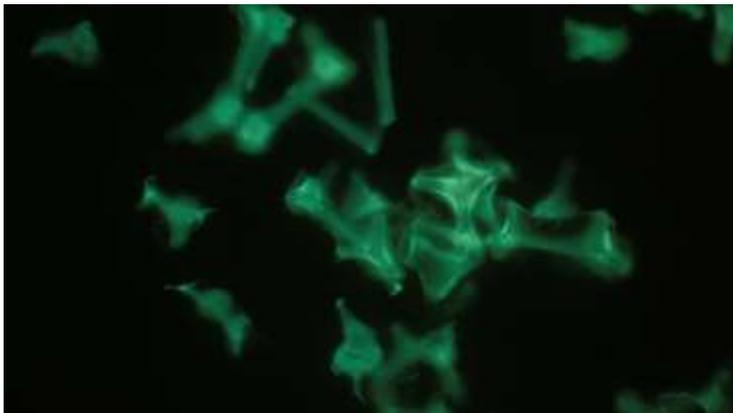


Category	Sub-Category	Product Examples	Polymers (in bold: Microplastics according to working definition)	Functions and Size Range	Reference	Confirmed by Consultation
Others	Adhesives and sealants	glue stick, hot melt adhesives, wall fillers, self-leveling compounds/screeds	Urea-formaldehyde resin, Melamine-formaldehyde resin, Polyvinylpyrrolidone, Polyurethane, Poly(ethylene vinyl acetate)		Lithner2011, Essel2015, Sinko2011, US2010, DAZ2015, Ooms2015, Wacker, polymerdatabase.com	
Others	Oil and Gas	drilling fluid, flocculant	Polyacrylamide, Polyacrylates, Vinyl copolymer, styrene copolymer , AMPS copolymer, Polytetrafluoroethylene	lubricant agent in drilling fluid, solids flocculation	Caenn2017, Ooms2015, SNF	
Others	Food	food additive, food processing aid, food packaging	Polyvinylpyrrolidone, Polyacrylic acid, PEG	food additive, clarifying of beverages (beer, wine, fruit juice), meat and fish package linings for liquid absorption	Sinko2011, US2010, DAZ2015, Ooms2015	

Examples of particles shapes in cosmetic products:



Polyethylene (PE) and Polylactic Acid (PLA) particles extracted from body scrub; ca. 0.1 – 0.7 mm particle size © Bettina Liebmann/Umweltbundesamt.



Sharp edged Polyurethane (PU) particles extracted from hand scrub, ca. 0.05 – 0,2 mm particle size © Norbert Kreuzinger/Vienna University of Technology



Variety of alternative abrasives found in facial scrub: Hydrated silica and hydrogenated Jojoba wax beads (blue), ca. 0.05-0.4 mm particle size © Bettina Liebmann/Umweltbundesamt



Appendix B

Summary of information from the consultation on product categories (tonnages, polymers, functions, size ranges and releases)

The following list of product categories containing microplastics, including the types and tonnage of microplastics added is based on questionnaire responses received in the consultation by 24 April 2017.

Product Category	Description of products	Types of microplastics added (material/substance, particle shape and size)	Total quantity of microplastics present in the product category (tonnes)	Total quantity of products containing microplastics in the product category (tonnes)	Weighted average concentration of microplastics in products containing microplastics (w/w)	Description of the specific technical function provided by microplastics – why are microplastics important?	Potential for release of microplastics to the environment
Skin Care and Cleaning Products	Hand Cleaners (professional)	Polyurethane, sphere, 200-1250 µm	440.07	unknown	unknown	Scrubbing	[1]



Product Category	Description of products	Types of microplastics added (material/substance, particle shape and size)	Total quantity of microplastics present in the product category (tonnes)	Total quantity of products containing microplastics in the product category (tonnes)	Weighted average concentration of microplastics in products containing microplastics (w/w)	Description of the specific technical function provided by microplastics – why are microplastics important?	Potential for release of microplastics to the environment
Waterborne building paints	Paints for Walls and Ceilings	Thermoplastic: - Micro spheres; Acrylic polymer; size 5 to 80 microns. - Fibres; Polyamide or Poly Acrylo Nitrile; size length 4 to 50 millimetres, diameter 10 microns	220.00	14 000	1.6%	To obtain: With microspheres: - Ease of paint application; thicker layers - Unique dried paint properties like elasticity, scratch resistance With microfibers: - Toughness; resistance against crack	Pathway: cleaning brushes and rollers under the tap. Ref. CEPE webpage: Emission Factor according to the Specific Emission Release Categories for users of waterborne building paints (DIY-er and professional painters): 1 % of Waterborne paint. With an average intentionally added micro-plastics content of 1.5 % this would equal an emission for EU 28 of 2.2 Tonnes before water treatment. Remark: the microspheres used have a very low density and will most probably float once they become highly diluted. Their removal at the water-treatment plant would be expected.
Skin Care and Cleaning Products	Body Foot Scrubs	Polyethylene, sphere/bead/irregular, <1 mm	126.10	unknown	unknown	Scrubbing, Cleansing and Exfoliating	[1]



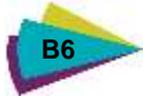
Product Category	Description of products	Types of microplastics added (material/substance, particle shape and size)	Total quantity of microplastics present in the product category (tonnes)	Total quantity of products containing microplastics in the product category (tonnes)	Weighted average concentration of microplastics in products containing microplastics (w/w)	Description of the specific technical function provided by microplastics – why are microplastics important?	Potential for release of microplastics to the environment
Hard surface cleaner (Glass ceramic cleaner)		Polyurethane CAS No. 9009-54-5 fine powder < 600 µm	126.00	2 592	4.9%	Scrubbing/abrasive agent for ceramic hob cleaning. Cleaning without damaging.	No data available
Skin Care and Cleaning Products	Face Scrubs	Polyethylene, sphere/beads/ovoid/irregular, < 1 mm	72.95	unknown	unknown	Scrubbing, Cleansing and Exfoliating	[1]
Skin Care and Cleaning Products	Face Masks	Polyethylene, ovoid/sphere, < 1 mm	42.10	unknown	unknown	Cleansing and Exfoliating	[1]
Toilet cleaners	WC blocks	Polyester/polyamide, Acrylic, PMMA, PET glitters	12.00	797	1.5%	Block cohesion improvement Aesthetic	Release to toilet water
Skin Care and Cleaning Products	Body Shower Gels	Polyethylene, sphere/bead, <450 µm	11.60	Not provided	Not provided	Cleansing and Exfoliating	[1]
Skin Care and Cleaning Products	Face Cleaning Products	Polyethylene, sphere/bead/ovoid/irregular, <1 mm	9.34	Not provided	Not provided	Scrubbing, Cleansing and Exfoliating	[1]
Hair Care Products (Wash-off)	Shampoo	Polyethylene, ovoid/hexagonal, <315 µm	7.02	Not provided	Not provided	Scrubbing, Cleansing and Exfoliating	[1]
Stainless steel cleaner		Polyurethane CAS:9009-54-5, <600µm	3.50	176	2.0%	Abrasive agent	No data available
Skin Care and Cleaning Products	Face Scrubs	Polylactic Acid, sphere/beads/irregular, < 315 µm	1.33	Not provided	Not provided	Scrubbing	[1]



Product Category	Description of products	Types of microplastics added (material/substance, particle shape and size)	Total quantity of microplastics present in the product category (tonnes)	Total quantity of products containing microplastics in the product category (tonnes)	Weighted average concentration of microplastics in products containing microplastics (w/w)	Description of the specific technical function provided by microplastics – why are microplastics important?	Potential for release of microplastics to the environment
Skin Care and Cleaning Products	Face Cleaning Products	Nylon-11, sphere, 150 µm	1.13	Not provided	Not provided	Cleansing and Exfoliating	[1]
Skin Care and Cleaning Products	Foot care products	Polyethylene, sphere, < 1 mm	1.01	Not provided	Not provided	Scrubbing	[1]
Skin Care and Cleaning Products	Body Foot Scrubs	Cellulose Acetate, irregular, 300 - 400 µm	0.70	Not provided	Not provided	Scrubbing	[1]
Skin Care and Cleaning Products	Body Foot Scrubs	Polylactic Acid, sphere/irregular, < 315 µm	0.49	Not provided	Not provided	Scrubbing	[1]
Skin Care and Cleaning Products	Face Scrubs	Cellulose Acetate, irregular, 300 - 400 µm	0.10	Not provided	Not provided	Scrubbing	[1]
Other soaps, detergents and maintenance products	Oven cleaner Laundry stain remover	rheology modifiers	0.05	7.1	0.7%	Rheology modifiers used to thicken the product	Potential route of aquatic exposure is indirect for both products through washing and subsequent waste water release to sewage treatment plants. Consequently potential for wider environmental release is considered to be minimal.
Skin Care and Cleaning Products	Soap Bars	Polyethylene, no information	0.05	Not provided	Not provided	Cleansing and Exfoliating	[1]
Drilling – cement additives		Not provided	Not provided	Not provided	Not provided	Not provided	Minimal



Product Category	Description of products	Types of microplastics added (material/substance, particle shape and size)	Total quantity of microplastics present in the product category (tonnes)	Total quantity of products containing microplastics in the product category (tonnes)	Weighted average concentration of microplastics in products containing microplastics (w/w)	Description of the specific technical function provided by microplastics – why are microplastics important?	Potential for release of microplastics to the environment
Drilling – loss circulation material		Not provided	Not provided	Not provided	Not provided	Not provided	Minimal
Oilfield production – wax inhibitors		Not provided	Not provided	Not provided	Not provided	Not provided	Dependant on K_{ow} [octanol-water partition coefficient] and partitioning in produced fluids
Pipeline – crosslinking chemicals		Not provided	Not provided	Not provided	Not provided	Not provided	Minimal
Cosmetic Ingredients - no further detail provided		Not provided	Not provided	Not provided	Not provided	Not provided	Not provided
Inorganic bonded abrasives		Microplastics (e.g. PMMA) might be used as pore forming agents (out of a range of different pore forming agents). However, these will be completely burned during the firing process (> 1000 °C).	Not available due to the very low feedback	Not provided	Not provided	In case of inorganic abrasives microplastics (e.g. PMMA) might be used as pore forming agents (out of a range of different pore forming agents).	Microplastics will be completely burned during the firing process (> 1000 °C) and thus have no potential to enter in the environment as particles. All installations are equipped with adequate waste gas treatment installations.



Organic bonded abrasives / coated abrasives

Different types of resins as bond (e.g. phenol-formaldehyde resins) or as part of the bonding system. These resins might fall under the working definition of microplastics – depending on the particle size and physical state of the used product (powder / liquid). Rubber particles are used in some products as part of the bonding system. For some cut-off and grinding wheels also polyethylene (< Ø 0.5 mm) is used as technical filler. [2]

Not available due to the very low feedback

These abrasives use different types of resins as bond (e.g. phenol-formaldehyde resins) or as part of the bonding system. Also rubber particles fulfilling the definition of microplastics are used in some products as part of the bonding system. Some of the resins have – apart from its bonding function - additional functions like increasing the hardness of the product. For some cut-off and grinding wheels also polyethylene (< Ø 0.5 mm) is used as technical filler to improve the tool performance during the use of the product.

The potential release of microplastics in the environment – and in particular into the water – during the productions process but also during the grinding process is seen very unlikely. The European Abrasive industry has implemented appropriate measures (waste gas treatment systems) to avoid a potential exposure to the environment.

Also during the use of abrasives a release of microplastics into the environment (water) is seen as unlikely. In case of wet grinding tools the cooling agents are required to be collected and disposed of by authorised disposal companies. In case of dry grinding appropriate ventilation systems have to be in place to comply with legal requirements (e.g. dust exposure limit value). The abrasive manufacturers inform their clients about the required protection measures via voluntary product information (VIP).



Product Category	Description of products	Types of microplastics added (material/substance, particle shape and size)	Total quantity of microplastics present in the product category (tonnes)	Total quantity of products containing microplastics in the product category (tonnes)	Weighted average concentration of microplastics in products containing microplastics (w/w)	Description of the specific technical function provided by microplastics – why are microplastics important?	Potential for release of microplastics to the environment
Bathroom acid cleaner		Polyethylene particles' size 200 - 320 µm	Data not available			Abrasive agent	No data available

Notes:

[1] Current scientific evidence indicates there are varying types of debris in marine litter, and shows that plastic microbeads account for a small fraction of the plastic debris found in the marine environment (between 0.1% to 1.5%) of the total microplastic entering the marine environment. Plastics microbeads are typically released during use (e.g. shower, bath) and go down the drain. However, only a small quantity of this release will reach the marine environment. Indeed, a number of studies have identified that a very significant proportion of microplastic litter can be effectively removed from water by waste water treatment plants. In studies conducted in Europe and the US, treatment facilities were found to remove more than 99% of microplastic particles. (Sources: Magnussen and Norden 2014 - Screening of microplastic particles in and downstream a waste water treatment plant; Carr et al., 2016 - Transport and fate of microplastic particles in wastewater treatment plants; Murphy et al., 2016 - Wastewater Treatment Works (WwTW) as a Source of Microplastics in the Aquatic Environment).

[2] As the resins are used as bonding system or part of the bonding systems, they are cross-linked during the production process. As a consequence in the final product only a homogenous bond is present which may not constitute “microplastics” according to the working definition.

Source:

Amec Foster Wheeler targeted stakeholder consultation February-April 2017.

Appendix C

EUSES modelling information (Supplement to Section 3)

Detailed approach to modelling exposure to microplastics

With some modification, it is possible to use the environmental modelling tool EUSES²⁴¹ to estimate the concentrations of microplastics that end up in the environment. The model works on different spatial scales, *local* (close to the point of release), *regional* (at the scale of a notional member state, within which emissions take place at one or more local sites, or diffusely) and *continental* (the background). The main output is the predicted environmental concentrations 'PEC' (of the substance) in different environmental media at different spatial scales.

The model is designed for the assessment of chemical substances (rather than specifically for particulates) but can successfully be adapted for particles. The standard outputs from the model have to be adapted however to allow the assessment of particles, such as microplastic beads, for example for local scale PECs in water and sediment it is difficult to estimate the partitioning between these two media (because the model assumes that non-soluble particles will all go to sediment, while in reality the distribution between surface water and sediment will be determined at least in part by density (this can be estimated more precisely in further work). However, the concentrations of microplastics in soil is dependent on the concentrations that are in sewage sludge (that is subsequently spread on land).

As far as possible the risk assessment has followed the Guidance on Information Requirements and Chemical Safety Assessment produced by the European Chemicals Agency (ECHA) for the EU REACH Regulation. In particular, Chapter R.16 (ECHA, 2016) of the Guidance outlines the recommended approach and methods for carrying out environmental exposure assessment and this has been used as the basis of the approach here. However, the approach has been modified and adapted to take into account the specific properties of microplastics compared with the more normal types of (pure) chemical substances to which the methodology is usually applied. This has by necessity resulted in the use of assumptions and simplifications that increases the uncertainty of the exposure assessment for microplastics.

The procedures outlined in ECHA (2016) are implemented in a number of tools including the CHESAR Tool and the EUSES model. The EUSES model (version 2.1.2) has been used for some of the calculations here as this model allows some of the default parameters within the model to be adjusted and the sensitivity of the exposure assessment to the assumptions over these parameters to be investigated.

It is important to note that there is only limited information on the amounts of microplastics released to the environment from many of the applications considered. Therefore, in most cases a worst-case approach to estimating the emissions to the environment has been used in the absence of information. This worst-case approach is based on ECHA (2016) but it should be recognised that the emission estimates obtained using this approach are uncertain and the actual emissions could in some cases be significantly lower than suggested by these estimates.

Waste-water treatment

The EUSES programme contains a waste water treatment plant model called *SimpleTreat*. This is a multi-media 'box' model of an average sized treatment plant based on aerobic degradation by activated sludge. The model contains a primary settler, an aeration tank, and a solids-liquid separator, the model calculates concentrations at a steady-state within the treatment plant. Some of the key assumptions and variables within the SimpleTreat model as summarised in Table C1.

²⁴¹<https://ec.europa.eu/jrc/en/scientific-tool/european-union-system-evaluation-substances>

In order to use the Simple Treat model, it is necessary to consider the possible implications of the assumptions in the model for microplastics (see Table C1). Most of the assumptions within the model seem to be applicable to plastics. However, the model assumes a density of between 1.3 kg/l and 1.5 kg/l for various solids within the treatment plant. As microplastics are (suspended) solids within the influent to the plant, it is necessary to consider how changing the density of the solid phase affects the predicted behaviour during waste water treatment (see Table C2).

Table C1 Key assumptions for the EUSES model

Assumption		Default values from EUSES Simpletreat model	Values assumed for microplastics	Implications for microplastics
Preliminary screening (mesh size 5 mm or lower) of influent for grit removal		None included		Particulates >5 mm will be removed prior to biological treatment
Primary treatment/settlement tank	Depth	4 m	4 m	None
	Hydraulic retention time	2 hr	2 hr	None
	Density suspended and settled solids	1.5 kg/l	Range assumed	Removal dependent upon density
	Fraction organic carbon in settled sewage sludge	0.3	0.3	None
Activated sludge tank	Depth	3 m	3 m	None
	Density solids of activated sludge	1.3 kg/l	Range assumed	Removal may be dependent upon density
	Concentration solids of activated sludge	4 kg/m ³	4 kg/m ³	None
	Steady state O ₂ concentration in activate sludge	2×10 ⁻³ kg/m ³	2×10 ⁻³ kg/m ³	None
	Mode of aeration	Surface	Surface	None
	Fraction organic carbon in activated sewage sludge	0.37 kg/kg	0.37 kg/kg	None
	Sludge loading rate	0.15 kg/kg/d	0.15 kg/kg/d	None
	Hydraulic retention time in aerator (9-box STP)	6.9 hr	6.9 hr	None
	Sludge retention time of aeration tank	9.2 d	9.2 d	None
Solids-liquids separator	Depth	3 m	3 m	None
	Density suspended and settled solids	1.3 kg/l	Range ~0.85-1.4kg/l	Removal may be dependent upon density
	Concentration solids in effluent	30 mg/l	30 mg/l	None
	Hydraulic retention time	6 hr	6 hr	None

Assumption	Default values from EUSES Simpletreat model	Values assumed for microplastics	Implications for microplastics	
	Fraction organic carbon in effluent sewage sludge	0.37 kg/kg	0.37 kg/kg	None

In order to investigate the sensitivity of the SimpleTreat model to assumptions over the solids density the model was run a number of times using different assumptions over the density. The “substance” properties listed below were assumed in all runs. These properties essentially assume that the microplastics will behave as non-soluble, non-volatile and non-degradable substances that will associate with the solid phase within the waste water treatment plant.

- ▶ Molecular weight: 10 000 g/mole.
- ▶ Melting point: 150°C.
- ▶ Vapour pressure: 1×10^{-10} Pa at 25°C.
- ▶ Water solubility: 1×10^{-10} mg/l at 25°C.
- ▶ Henry’s law constant: 1×10^{-10} Pa m³/mole at 25°C.
- ▶ log Kow: 15.
- ▶ Not biodegradable.

The results, in terms of the predicted removal during waste water treatment, are summarised in Table C2. As can be seen, varying the solids density between 0.7 kg/l and 1.7 kg/l has effectively no effect on the predicted removal.

The sensitivity of the SimpleTreat model to the assumed properties of the microplastic have also been investigated. For these estimates the default parameters for the waste water treatment plant were assumed within SimpleTreat. The results are summarised in Table C3. As can be seen from the table varying the assumed molecular weight (between 1 000 g/mole and 20 000 g/mole), the melting point (between 50 and 300°C), the vapour pressure (between 1×10^{-7} and 1×10^{-13} Pa, the water solubility (between 1×10^{-7} and 1×10^{-13} mg/l or Henry’s law constant (between 1×10^{-7} and 1×10^{-13} Pa m³/mole) had effectively no effect on the predicted removal. Similarly varying the log Kow between 12 and 16 had no effect on the predicted removal but by about a log Kow of 10 the predicted amount going to sludge begins to decrease and the predicted amount going to water effluent begins to increase.

Overall, based on this analysis, the predicted removal for microplastics during waste water treatment is around 92% to sludge and 8% to water effluent.

Sensitivity of waste water treatment plant distribution to assumed physico-chemical properties is shown in Table C3. For all estimates the default parameters for the waste-water treatment plant were assumed within EUSES.



Table C2 Predicted distribution in the waste water treatment plant as a function of assumed particle density

Assumed density of solids (kg/l)a		Predicted distribution in the waste water treatment plant (%)				
Primary treatment	Activated sludge and solids liquid separator	Air	Degraded	Sewage sludge	Water effluent (total)	Overall removal efficiency
0.7	0.7	1.1E-15	0	92	8	92
0.9	0.9	1.0E-15	0	92	8	92
1.1	1.1	1.1E-15	0	92	8	92
1.5	1.3	1.1E-15	0	92	8	92
1.5	1.5	1.1E-15	0	92	8	92
1.7	1.7	1.1E-15	0	92	8	92

Notes: a) Values in red are the recommended default values from EUSES.



Table C3 Sensitivity of waste water treatment plant distribution to assumed physico-chemical properties

Properties ^a						Predicted distribution in the waste water treatment plant (%)				
Molecular weight (g/mole)	Melting point (°C)	Vapour pressure at 25°C (Pa)	Water solubility at 25°C (mg/l)	Henry's law constant at 25°C (Pa m ³ /mole)	Log Kow	Air	Degraded	Sewage sludge	Water effluent (total)	Overall removal efficiency
10,000	150	1E-10	1E-10	1E-10	15	1.1E-15	0	92	8	92
1,000	150	1E-10	1E-10	1E-10	15	1.1E-15	0	92	8	92
20,000	150	1E-10	1E-10	1E-10	15	1.1E-15	0	92	8	92
10,000	50	1E-10	1E-10	1E-10	15	1.1E-15	0	92	8	92
10,000	300	1E-10	1E-10	1E-10	15	1.1E-15	0	92	8	92
10,000	150	1E-7	1E-10	1E-10	15	1.1E-15	0	92	8	92
10,000	150	1E-13	1E-10	1E-10	15	1.1E-15	0	92	8	92
10,000	150	1E-10	1E-7	1E-10	15	1.1E-15	0	92	8	92
10,000	150	1E-10	1E-13	1E-10	15	1.1E-15	0	92	8	92
10,000	150	1E-10	1E-10	1E-7	15	1.1E-12	0	92	8	92
10,000	150	1E-10	1E-10	1E-13	15	1.1E-16	0	92	8	92
10,000	150	1E-10	1E-10	1E-10	10	4.2E-13	0	91.6	8.4	91.6
10,000	150	1E-10	1E-10	1E-10	12	3.8E-14	0	92	8	92
10,000	150	1E-10	1E-10	1E-10	14	3.5E-15	0	92	8	92
10,000	150	1E-10	1E-10	1E-10	16	3.2E-16	0	92	8	92

Note: a) The base case is shown in red. Values varied from the base case are shown in blue.

A detailed examination of the available experimental and monitoring data, on removal during waste water treatment, has been carried out by Eunomia (2017). This found that in real existing waste water treatment plants, the retention²⁴² rates for microplastics within the plant varied depending upon the type of treatment plant/process. Thus, the range of retention rates within the plant varied between 17% and 78% for primary treatment plants, 29% and 98% for secondary treatment plants and 72% to 99.7% for tertiary treatment plants (based on Murphy *et al.* (2016), MST (2017), Ziajahromi *et al.* (2017) and Leslie *et al.* (2017)). It is concluded therefore that the use of a single value for the removal during waste water treatment may not adequately address the potential risks from microplastics in the environment.

Based on the ranges of retention rates, Eunomia (2017) developed estimates for the range of retention that would be expected in each EU member state, taking into account the known types of treatment and the population served by each treatment plant type. The range of retention rates estimated by country ranged from 22% up to 94%, with average retention rates between 33% and 86%. The EU average retention rates were between 53% and 84%. Therefore, the EUSES model estimates for the amount retained (92% to sludge) are towards the upper end of the available estimates by Member State.

In order to investigate the sensitivity of the risk assessment to assumptions on the retention within the waste water treatment plant, the upper and lower estimates for the EU retention rates from the Eunomia (2017) study were also considered in the predicted environmental concentration (PEC) calculations. These are summarised below.

Lower estimate EU average	53% to sludge 47% to water effluent
Upper estimate EU average	84% to sludge 16% to water effluent

It is important to note that for the risk assessment, the application of sewage sludge onto agricultural land is assumed (see below). Therefore, the use of different removal rates effectively results in moving some of the emission from water to sludge and vice versa. Assuming a high retention within the plant results in a higher concentration in sludge (and hence agricultural soil) and proportionately lower concentration in water than assuming a lower retention within the plant.

Local concentrations in water

In line with ECHA (2016), the local concentrations in water represent the concentrations immediately downstream from a point source of release, such as an industrial site or a waste water treatment plant. In simple terms, the local concentrations in surface water are estimated from the total concentration of the substance in the effluent from the point source assuming the following:

- ▶ Dilution of the effluent in the receiving water occurs (a standard dilution factor of 10 is assumed for freshwater, and 100 is assumed for marine water).
- ▶ Partitioning of the substance occurs between the water phase and the solid phase.
- ▶ All sources of release contribute to a “regional” background concentration that is added to the local concentration.

It is important to consider the implications of these assumptions for microplastics.

The dilution of the effluent in the receiving water is not dependent upon the type of substance being considered and so the assumptions from ECHA (2016), which are also built into the EUSES model, will be equally as applicable to microplastics as other substances.

²⁴² Removal from the aqueous phase to sludge (no loss to air).

The partitioning of the substance between the water phase and the solid phase is more problematic for microplastics. The methods used in ECHA (2016)/EUSES are based on partitioning of the substance from the water phase to the organic phase of the suspended matter based on the organic carbon-water partition coefficient (K_{oc}), which in turn can be estimated from the octanol-water partition coefficient ($\log K_{ow}$). However, such partitioning is likely to be less relevant for microplastics, and other processes such as direct sedimentation of the plastic particles are also likely to be relevant.

The effluent concentrations predicted using EUSES are “total” concentrations i.e. this makes no distinction between the substance truly dissolved and the substance in, or adsorbed to, the particulate phase. Thus, it is possible to derive a “total” concentration of microplastics in the receiving water by applying a simple dilution. Subsequently, some of these particles may remain suspended in the water column, whilst others may deposit into the sediment phase. This is likely to depend, at least in part, on the density of the particles, with particles denser than water tending to deposit, particles with densities close to that of water (i.e. 1 kg/L) tending to remain suspended, and particles with densities lower than water tending to float on the water surface (GESAMP, 2016; Duis and Coors, 2016). The total concentration in water estimated in this way, should give an indication of the maximum concentration (or number) of particles in surface water expected from a given point source.

The density of the common polymers used in microplastics was summarised in Table 4.1 (Section 4 main report). The density of the polymers is close to 1 kg/L (unity being the density of pure water), with some polymers having densities above 1 kg/L and some polymers having densities below 1 kg/L.

The issue of how many of the particles initially present in the water column will subsequently deposit into sediment is an important one, but a difficult one to address when estimating concentrations. Deposition to sediment will depend on the density, but even for particles that are initially less dense than water, the effective density can increase in the environment as a result of the formation of biolayers, and colonisation (‘fouling’) by a range of organisms (GASMP, 2016; Duis and Coors, 2016). This means that particles that would initially be expected to remain in the surface layer of water, may subsequently be deposited to sediment. Furthermore, organisms can subsequently graze on the colonising organisms, could reduce the density of the microplastic, which may subsequently transfer back from the sediment to the water column (Duis and Coors, 2016). Thus, there is no simple way to apportion the fraction of the microplastics initially present in the water column that will subsequently be deposited to sediment.

Taking into account the complexity/uncertainty described above, the predicted local concentrations (PECs) in water are presented as the total concentration in surface water immediately following discharge. This represents the maximum concentration in surface water that is likely to be reached as a result of a point source discharge (the regional background concentration is considered in more detail the last subsection of 3.3).

Local concentrations in sediment

Using the ECHA (2016)/EUSES approach, the local concentrations in sediment are estimated from the concentration in water using the following assumptions:

- ▶ The substance partitions from the water phase to the suspended matter phase (and this is dependent upon the water organic carbon partition coefficient (K_{oc})).
- ▶ The suspended matter phase settles to become freshly deposited sediment (i.e. the concentration in freshly deposited sediment is the same as in suspended matter).
- ▶ All sources of releases contribute to a ‘regional’ background concentration that is added to the local concentration.

As discussed above, predicting the partitioning between the water phase and the sediment phase is problematic for microplastics as the methods used in ECHA (2016)/EUSES are not directly applicable to microplastics, and the partitioning between the two media is complex for microplastics. If a high $\log K_{ow}$ value is assumed for the microplastic (as was done for the waste water treatment plant), this has the effect of predicting that essentially all of the microplastic in the water phase will be associated with the suspended sediment and hence sediment. Thus, the use of a high $\log K_{ow}$ value in EUSES has

the effect maximising the concentration in the sediment phase (i.e. effectively all of the substance in the effluent is then predicted to enter the sediment). Concentrations in sediment estimated in this way therefore represent the highest theoretical concentration in sediment resulting from complete deposition to the sediment immediately downstream from the source of release.

Local concentrations in soil

The following approach is used in ECHA (2016)/EUSES to estimate the local concentrations in agricultural soils.

- a) The substance can reach agricultural soil via spreading of sewage sludge and aerial deposition.
- b) The local concentration is calculated following 10 years of sewage sludge application and constant atmospheric input.
- c) Removal (biodegradation, leaching and volatilisation) is taken into account.
- d) The concentration is averaged over either 30 days or 180 days after the last application of sewage sludge.
- e) All sources of releases contribute to a “regional” background concentration in natural that is added to the local concentration.

For microplastics, atmospheric deposition onto soil is likely to be an insignificant process and can be ignored. Application to soil from sewage sludge is however relevant. The methods using in ECHA (2016)/EUSES can therefore be adapted to microplastics in the following way.

- a) The concentration in sewage sludge can be calculated using the SimpleTreat model. This can either be the estimated value or can be based on actual removal data.
- b) Setting a very high log Kow, a very low vapour pressure and assuming that the substance does not biodegrade, will result in essentially no removal once applied to soil. This would be an appropriate assumption for microplastics as a first stage.

Thus, the local concentrations in soil can be obtained directly from the EUSES model (for regional see the last subsection).

Contamination in the food chain (Secondary poisoning)

‘Secondary poisoning’ relates to predators consuming contaminated prey. The methods outlined in ECHA (2016)/EUSES relate to two different scenarios, one for the terrestrial compartment related to earthworms as prey, and the other for the aquatic compartment related to fish as prey. The way these are estimated have different implications for microplastics, and so each is considered in turn.

Terrestrial compartment - earthworms

This scenario calculates the concentration in earthworms from the local concentration in agricultural soil using a bioconcentration factor. There are two parts to the bioconcentration factor.

- a) The gut of the earthworm contains contaminated soil. A 10% soil content is assumed (based on kg dry weight/kg wet weight voided worm).
- b) Uptake from substances dissolved in soil pore water into the earthworm can occur by bioconcentration processes which are related to the log Kow.

For microplastics, the most important processes can be assumed, at least in an initial assessment, as being from substance present in the gut contents. As discussed above, the EUSES model will give a reasonable approximation to the local concentration of microplastics in soil. Therefore, the EUSES model can be adapted for microplastics if it is assumed that the uptake from pore water is limited.

The ECHA (2016)/EUSES approach assumes that the predator receives 50% of the dose from the local source and 50% of the dose from the regional background (see last subsection).

Aquatic compartment – fish (aquatic organisms)

For the possibility that accumulated substance (here microbeads) in prey species cause effects in predators (so called *secondary poisoning*) in the aquatic compartment, the approach in ECHA

(2016)/EUSES is to estimate a concentration in fish using a bioconcentration factor (BCF) and biomagnification factor (BMF) along with the dissolved concentration in water. The method can use either experimental BCF/BMF data or values estimated from the log of the octanol-water partition coefficient (log Kow).

The default methods in ECHA (2016)/EUSES are not directly applicable for microplastics, as they relate to substances dissolved in water with their uptake dependent upon their lipophilicity (i.e. propensity to dissolve in fat rather than water, which can be predicted by logKow). However, if experimental data are available that relate the total concentration (or number) of microplastics present in the exposure media (i.e. water) to the total concentration (or number) of microplastics present in an exposed aquatic organism, this could be used in a similar way to the approach outlined in ECHA (2016)/EUSES.

There is a significant and growing literature suggesting that microplastics are taken up by aquatic organisms from water and sediment (e.g. see reviews by GESAMP (2016), Duis and Coors (2016), amongst others). GESAMP (2016) postulated four main processes by which microplastics could be taken up by aquatic organisms:

- ▶ Ingestion.
- ▶ Particles adhering to the body.
- ▶ Uptake across gills through ventilation.
- ▶ Absorption through cell membranes.

Of these processes, ingestion would appear to be the most significant and most well studied (Duis and Coors, 2016), although absorption in phytoplankton (microscopic plants) has been shown to occur (GESAMP, 2016). Once in the organism, translocation (movement from one part of the body to another) from the gut to the circulatory system is possible (GESAMP, 2016; Duis and Coors, 2016), but this is thought to be dependent upon the particle size (the potential for translocation is thought to be higher for smaller particles than for larger particles).

Duis and Coors (2016) suggested that ingestion of microplastics will occur in a wide range of species and that this will depend upon properties such as particle size, shape, density and colour. Many filter feeders and deposit-feeding organisms are indiscriminate feeders, and are likely to ingest particles from the water column (filter feeders) or sediments (benthic filter and suspension feeders).

Duis and Coors (2016) reports the results of a study by Avio *et al.* (2015) where mullet (*Mugil cephalus*) were exposed for seven days to concentrations of 33.8 mg/l of either PE or PS particles. The particles had a size range of 0.1-1 mm, and the exposure concentration was equated to around 2 500 particles/l. Particles were found to be present in the gastrointestinal tract (approximately 10 particles per fish for PE and 90 particles per fish for PS) and liver (approximately 1-2 particles per fish for both PE and PS). Based on this, a tentative accumulation factor (defined on the basis of number of particles per fish / number of particles per litre in water) of around 0.036 l/fish can be estimated. This can potentially be used in place of a fish BCF in order to estimate the likely exposure of fish.²⁴³

For filter feeders, Van Cauwebergh (2015) found that the concentrations (in particles per gram of tissue) of microplastics in mussels (*Mytilus edulis*) collected in the field, were around 0.5 times the concentration (in particles per litre) in water. This is equivalent to an accumulation factor (defined on the basis of number of particles per gram in mussel/number of particles per litre in water) of around 0.5 l/g.

Microplastics within the intestinal tract of aquatic organisms are usually excreted (passed out) within hours to a few days. Excretion of microplastics that have translocated to the circulatory system and/or surrounding tissues has also been demonstrated, but at a slower rate. Transfer through the food chain

²⁴³ Ideally, the weight of the fish can be used to allow a better comparison with the BCF (this was not done for this present study).

from prey to predator has also been found to occur, but it is not known if microplastics biomagnify²⁴⁴ (Duis and Coors, 2016).

The ECHA (2016)/EUSES approach assumes that the predator receives 50% of the dose from the local source and 50% of the dose from the regional background.

Man exposed via the environment

The risk assessment approach in ECHA (2016) assumes that humans can be exposed to substances released to the environment through the food chain. A number of sources of exposure are taken into account, and the total human exposure through all sources is used in the risk characterisation²⁴⁵. In order to evaluate whether this approach is applicable for assessment of microplastics, it is necessary to briefly consider each exposure source, and how the exposure concentration is estimated in the ECHA (2016)/EUSES methodology. The basic approach is to determine the concentration of a substance in each of the intake media (i.e. food, drinking water, air) and to combine this with the intake rate of each medium using a standard consumption pattern) to assess the total human exposure (via the environment).

- ▶ **Air** - The ECHA (2016) approach uses the local concentration in air as the starting point. For microplastics, the concentration in air can be assumed to be very low when considering environmental exposure, and so this route of exposure would be expected to be negligible as a first approximation.
- ▶ **Drinking water** - The ECHA (2016) approach considers two possible sources of drinking water, surface water and ground water. The starting point is either the annual average local concentration in surface water or, for groundwater, the concentration in pore water of agricultural soil. These drinking water sources are then assumed to undergo some basic treatment prior to consumption. For microplastics, the potential for leaching from soils into groundwater, is unclear, but the leaching from soils is generally most significant for substances of relatively high water-solubility that do not adsorb strongly onto soils. Microplastics are essentially insoluble particles and are likely to be “trapped” within the soil matrix rather than pass through it with infiltrating water. Therefore, it would be expected that leaching through soils into groundwater can be neglected, at least at a screening level assessment, as human exposure through this route is likely to be low compared with other sources of exposure. Microplastics could potentially be present in surface water that is abstracted for drinking water. However, surface water would undergo treatment before entering the water supply chain. Such treatment is likely to include filtration (such as activated carbon filtration, sand beds etc.) which are assumed to remove the microplastic beads from the water. Therefore, human exposure from drinking water derived from surface water would also be expected to be negligible compared with other potential sources of exposure (e.g. food).
- ▶ **Food** - Five main food types are considered: fish (or shellfish); leaf crops, root crops, meat, and dairy products. The concentrations (of substance) in these food items are estimated using bioconcentration factors (BCFs) or biotransfer factors (BTF) which relates the concentration in these food items to the external exposure concentration in media such as air, water and soil. The BCFs and BTFs used in ECHA (2016)/EUSES are generally estimated from the log Kow of the substance; such estimation methods are not applicable to microplastics. However, it is still possible use a similar approach for microplastics if suitable data are available that can be used to replace the BCFs or BTFs in the method. The possible significance of each food type for microplastics is considered qualitatively below.

²⁴⁴ Increasing concentration (of a substance), in the tissues of organisms at successively higher levels in a food chain.

²⁴⁵ The comparison between the predicted environmental [exposure] concentration (PEC) and the predicted no effect concentration (PNEC).

- ▶ **Fish/shellfish** - The considerations here are the same as for secondary poisoning (see previous subsection). However, for microplastics, filter feeders also need to be considered.
- ▶ **Root crops** - The ECHA (2016) method assumes that the substance is accumulated into the root crop from the soil pore water. However, for microplastics the particle size will effectively limit the transfer from the soil into the plant. Although microplastics may be present in soil adhering to the root crops, the food is usually washed and/or peeled before consumption. This means that the human exposure from root crops is likely to be negligible compared with other sources.
- ▶ **Leaf crops** - The ECHA (2016) method assumes that transfer of the substance into leaf crops occurs by both internal transfer from the roots and from the air. Again, as the concentrations of microplastics in air and root crops are expected to be negligible, the concentration of microplastics in leaf crops would also be expected to be negligible. It is possible that soil contaminated by microplastics may end up on the outside of leaf crops but this would be washed off prior to consumption. Therefore, human exposure from leaf crops is likely to be negligible compared with other sources.
- ▶ **Meat** - The ECHA (2016) method is based on the internal concentration of cattle exposed via drinking water, through inhalation and ingestion of grass (or other feed) with adhering soil. As before, exposure to microplastics through inhalation can be assumed to be low compared to the other sources. The intake into cattle through both drinking water and ingestion of grass with adhering soil is possible. In the case of drinking water, for cattle the exposure concentration would be the local concentration in surface water, as (not the case for drinking water for humans) the water will not always be treated prior to consumption (e.g. drinking directly from a river). Similar to the case with leaf crops the internal concentration of microplastics within the grass will be negligible. However, soil adhering to the grass (or other feed) will generally not be washed off prior to ingestion and therefore the exposure of cattle will be related to the concentration in soil. Both intake through drinking water and ingestion of contaminated grass will result in the microplastics entering the gut of the cattle. However, this is assumed to pass through the cattle without entering into the edible parts of the cattle (i.e. meat). Little information is available on the transfer of microplastics from the guts into the internal tissues of animals, but this would be expected to be an insignificant process as the particle size should limit tissue transfer. Therefore, although microplastics can enter into the gut of cattle, the human exposure from consumption of meat can be expected to be negligible.
- ▶ **Milk** - The ECHA (2016) methodology assumes that the concentration in milk can be estimated from the internal tissue concentration in cattle using a BTF. The concentration in milk is used to represent the likely exposure from all dairy products (such as cheese and yoghurt). As discussed above, the microplastics are likely to be only present within the gut contents of cattle and so transfer into milk can be assumed to be unlikely. Therefore, exposure of humans from ingestion of milk can be assumed to be negligible compared with other sources.

Regional assessment

A key part of the ECHA (2016)/EUSES methodology is to estimate the background concentrations in the environment that result from all sources of release. In order to do this a regional assessment is undertaken. In this context, the region is assumed to be a heavily industrialised area where 10% of the wide dispersive uses (e.g. use in personal care products) also occur.

The regional concentrations are steady-state concentrations estimated using a multi-media level III fugacity model. The model contains many assumptions, including assumptions over the *advective* (physical) transport between the various environmental compartment (e.g. deposition process, run-off, erosion, burial). In addition, as the model is based on the fugacity concept, the output of the model is very dependent upon the assumed physical chemical properties (e.g. water solubility, log Kow, vapour

pressure, Henry's law constant) of the substance. As these properties are not well defined for microplastics, the validity of the model to microplastics is questionable.

In order to investigate the usefulness of the regional model to microplastics, a sensitivity analysis has been undertaken in order to understand the implications of different assumptions made. For this analysis, a standard regional release of 80 kg/day to the waste water treatment plant and 20 kg/day direct to surface water was assumed²⁴⁶. The following substance properties were considered in the analysis.

	Base case	Range investigated
Molecular weight	10 000 g/mole	1 000-20 000 g/mole
Melting point	150°C	50-300°C
Boiling point	>500°C	N/A
Vapour pressure at 25°C	1×10^{-10} Pa	1×10^{-7} - 1×10^{-19} Pa
Water solubility at 25°C	1×10^{-10} mg/l	1×10^{-7} - 1×10^{-13} mg/l
Log Kow	15	10-24
Henry's law constant at 25°C	1×10^{-10} Pa m ³ /mole	1×10^{-7} - 1×10^{-20} Pa m ³ /mole

The results of the analysis are summarised in Table C4. The analysis shows that the regional concentrations are relatively insensitive to the assumed molecular weight, melting point and Henry's law constant. The vapour pressure affects the predicted concentrations in air significantly but the concentrations in water, sediment and soil increase only slightly with decreasing vapour pressure until the value is around 1×10^{-13} Pa. Similarly, the assumed water solubility affects the predicted concentrations in air significantly but again has only a relatively small effect on the predicted concentrations in water, sediment and soil (the concentrations in these media tending to decrease with increasing assumed water solubility).

In order to provide a base-line with which to compare the outputs from the EUSES regional model, calculations for water, sediment and agricultural soil (the most important compartments in relation to microplastics) have been carried out using simple mass-balance considerations based on various parameters from the regional model. These are summarised in Table C5 (taken from ECHA, 2016).

The calculations assumed the same daily release rate of the substance as above (80 kg/day to the waste water treatment plant and 20 kg/day direct to water), a removal of 92% to sludge in the waste water treatment plant, and took into account that the sludge from the waste water treatment plant would be applied to agricultural land. These emissions were taken to be released into the regional water, sediment or soil compartments as appropriate based on the dimensions given in Table C4. A removal fraction of 0.025 d⁻¹ for surface water and 2.74×10^{-4} d⁻¹ for sediment (based on the residence times of these compartments (see Table C5) were assumed. For soil, a different approach was considered, whereby the concentration in regional soil were estimated following one application of sewage sludge with no removal assumed and then this daily tonnage was used to determine how many of these daily applications would be required to reach concentrations of the order of 1 mg/kg wet weight (the approximate order of magnitude of the concentrations obtained using the EUSES regional model is shown in Table C4).

²⁴⁶ A 80% connection rate to waste water treatment plants is the default assumption for the regional model in ECHA (2016).



Table C4 Sensitivity analysis for the regional model

Properties ^a						Regional concentrations					
Molecular weight (g/mole)	Melting point (°C)	Vapour pressure at 25°C (Pa)	Water solubility at 25°C (mg/l)	Log Kow	Henry's law constant at 25°C (Pa m ³ /mole)	Air (mg/m ³)	Surface water (total) (mg/l)	Seawater (total) (mg/l)	Freshwater sediment (mg/kg wet wt.)	Marine sediment (mg/kg wet wt.)	Agricultural soil (mg/mg wet wt.)
1.00E+04	150	1.00E-10	1.00E-10	15	1.00E-10	1.0E-06	8.3E-05	7.2E-06	2.4E+00	6.2E-01	1.5E+00
1.00E+03	150	1.00E-10	1.00E-10	15	1.00E-10	8.4E-07	9.3E-05	7.9E-06	2.7E+00	6.9E-01	2.6E+00
3.00E+03	150	1.00E-10	1.00E-10	15	1.00E-10	9.7E-07	8.6E-05	7.4E-06	2.5E+00	6.4E-01	1.8E+00
2.00E+04	150	1.00E-10	1.00E-10	15	1.00E-10	1.0E-06	8.2E-05	7.1E-06	2.4E+00	6.2E-01	1.4E+00
5.00E+03	150	1.00E-10	1.00E-10	15	1.00E-10	1.0E-06	8.4E-05	7.3E-06	2.4E+00	6.3E-01	1.6E+00
1.00E+04	50	1.00E-10	1.00E-10	15	1.00E-10	1.0E-06	8.3E-05	7.2E-06	2.4E+00	6.2E-01	1.5E+00
1.00E+04	300	1.00E-10	1.00E-10	15	1.00E-10	1.0E-06	8.3E-05	7.2E-06	2.4E+00	6.2E-01	1.5E+00
1.00E+04	150	1.00E-07	1.00E-10	15	1.00E-10	1.1E-06	7.9E-05	6.9E-06	2.3E+00	6.0E-01	1.1E+00
1.00E+04	150	1.00E-13	1.00E-10	15	1.00E-10	3.9E-08	1.4E-04	1.1E-05	3.9E+00	9.7E-01	7.9E+00
1.00E+04	150	1.00E-16	1.00E-10	15	1.00E-10	4.0E-11	1.4E-04	1.1E-05	4.0E+00	9.8E-01	8.2E+00
1.00E+04	150	1.00E-19	1.00E-10	15	1.00E-10	4.0E-14	1.4E-04	1.1E-05	4.0E+00	9.8E-01	8.2E+00
1.00E+04	150	1.00E-10	1.00E-07	15	1.00E-10	3.9E-08	1.4E-04	1.1E-05	3.9E+00	9.7E-01	7.9E+00
1.00E+04	150	1.00E-10	1.00E-09	15	1.00E-10	8.4E-07	9.3E-05	7.9E-06	2.7E+00	6.9E-01	2.6E+00
1.00E+04	150	1.00E-10	1.00E-11	15	1.00E-10	1.1E-06	8.1E-05	7.1E-06	2.4E+00	6.1E-01	1.3E+00
1.00E+04	150	1.00E-10	1.00E-13	15	1.00E-10	1.1E-06	7.9E-05	6.9E-06	2.3E+00	6.0E-01	1.1E+00
1.00E+04	150	1.00E-10	1.00E-10	10	1.00E-10	1.2E-06	9.0E-05	8.2E-06	1.9E+00	3.2E-01	1.2E+00
1.00E+04	150	1.00E-10	1.00E-10	12	1.00E-10	1.1E-06	8.2E-05	7.2E-06	2.3E+00	5.6E-01	1.3E+00
1.00E+04	150	1.00E-10	1.00E-10	14	1.00E-10	1.0E-06	8.2E-05	7.1E-06	2.4E+00	6.1E-01	1.4E+00
1.00E+04	150	1.00E-10	1.00E-10	16	1.00E-10	9.7E-07	8.6E-05	7.4E-06	2.5E+00	6.4E-01	1.8E+00
1.00E+04	150	1.00E-10	1.00E-10	18	1.00E-10	5.4E-07	1.1E-04	9.2E-06	3.2E+00	8.0E-01	4.5E+00
1.00E+04	150	1.00E-10	1.00E-10	20	1.00E-10	9.2E-08	1.3E-04	1.1E-05	3.9E+00	9.5E-01	7.5E+00
1.00E+04	150	1.00E-10	1.00E-10	22	1.00E-10	9.1E-09	1.4E-04	1.1E-05	4.0E+00	9.8E-01	8.1E+00
1.00E+04	150	1.00E-10	1.00E-10	24	1.00E-10	8.4E-10	1.4E-04	1.1E-05	4.0E+00	9.8E-01	8.2E+00
1.00E+04	150	1.00E-10	1.00E-10	15	1.00E-07	1.0E-06	8.3E-05	7.2E-06	2.4E+00	6.2E-01	1.5E+00
1.00E+04	150	1.00E-10	1.00E-10	15	1.00E-08	1.0E-06	8.3E-05	7.2E-06	2.4E+00	6.2E-01	1.5E+00
1.00E+04	150	1.00E-10	1.00E-10	15	1.00E-09	1.0E-06	8.3E-05	7.2E-06	2.4E+00	6.2E-01	1.5E+00
1.00E+04	150	1.00E-10	1.00E-10	15	1.00E-11	1.0E-06	8.3E-05	7.2E-06	2.4E+00	6.2E-01	1.5E+00
1.00E+04	150	1.00E-10	1.00E-10	15	1.00E-13	1.0E-06	8.3E-05	7.2E-06	2.4E+00	6.2E-01	1.5E+00
1.00E+04	150	1.00E-10	1.00E-10	15	1.00E-20	1.0E-06	8.3E-05	7.2E-06	2.4E+00	6.2E-01	1.5E+00

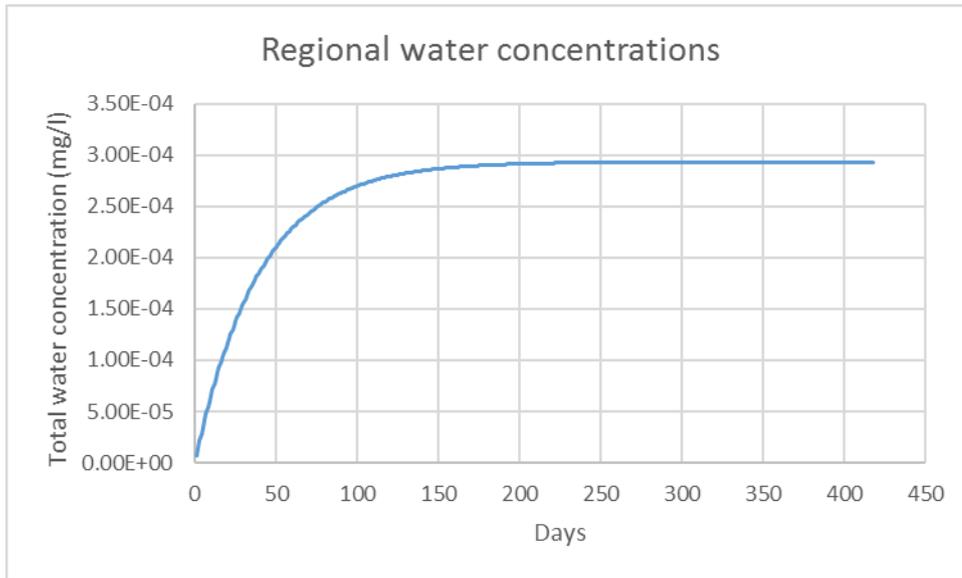
Note: a) The base case is shown in red. Values varied from the base case are shown in blue.

Table C5 Default parameters from the regional model

Parameter	Value	Comment
Total area of region	4×10 ⁴ km ²	
Connection rate to waste water treatment plant	80%	
Effluent flow rate from waste water treatment plant	4×10 ⁶ m ³ /day	
River water inflow rate	6.5×10 ⁷ m ³ /day	Effective dilution factor of effluent = 17.3
Area fraction of water	0.03	Area of water = 1.2×10 ⁹ m ²
Depth of water	3 m	Volume of water = 3.6×10 ⁹ m ³
Residence time of water	40 d	Assumed removal fraction for mass balance model = 0.025 d ⁻¹
Depth of sediment	0.03 m	Volume of sediment = 3.6×10 ⁷ m ³
Bulk density of sediment	1 300 kg wet weight/m ³	Weight of sediment = 4.68×10 ¹⁰ kg
Net sedimentation rate	3 mm/year	Effective residence time of sediment before burial = 10 years Assumed removal fraction for mass balance model = 2.74×10 ⁻⁴ d ⁻¹
Area fraction of agricultural soil	0.6	Area of agricultural soil = 2 462 000 m ²
Mixing depth of agricultural soil	0.2 m	Volume of agricultural soil = 492 500 m ³

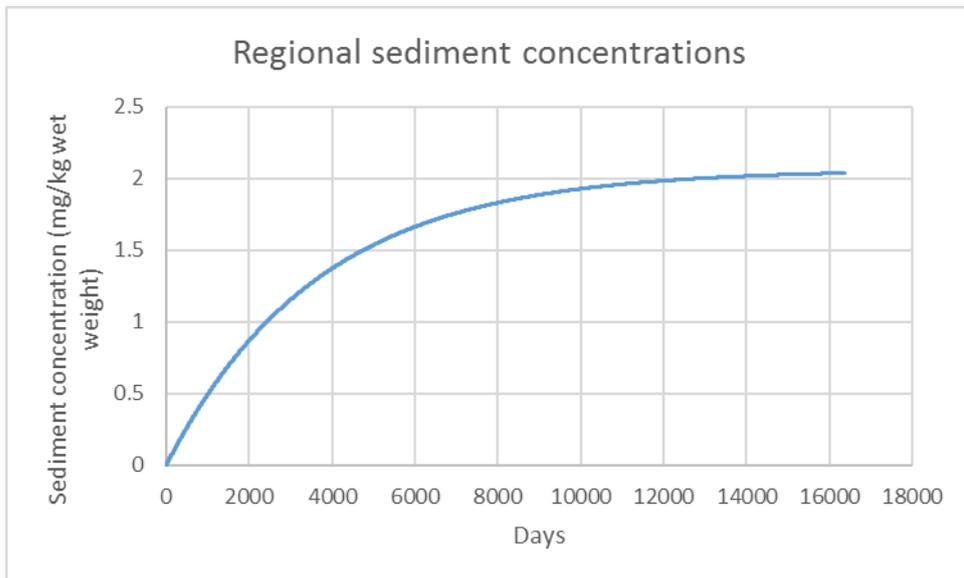
For surface water, the simple mass-balance model suggested that the fresh surface water concentrations (total) would tend towards a concentration of around 3×10⁻⁴ mg/l (see Figure C.1). This is generally in good agreement with the concentrations predicted using the EUSES regional model in Table C4 (range predicted 7.9×10⁻⁵-1.4×10⁻⁴ mg/l). The mass-balance model suggests that the steady-state in the water concentrations would be obtained after around 250 days continual emission.

Figure C1 Time trend in predicted regional water concentrations using a simple mass balance model



For sediment, the simple mass balance model suggested that the freshwater sediment concentrations would tend towards a concentration of around 2 mg/kg wet weight (see Figure C2). This is in generally good agreement with the concentrations predicted using the EUSES regional model in Table C4 (range predicted 1.9-4 mg/kg wet weight). The mass balance model suggests that the steady state in the water concentrations would be obtained after around 16 000 days continual emission.

Figure C2 Time trend in predicted regional sediment concentrations using a simple mass balance model



For predicted agricultural soil concentration following one application is around 9×10^{-6} mg/kg wet weight. On this basis, it would require around 10^5 - 10^6 applications in order to reach concentrations of a similar order of magnitude as predicted using the regional model in EUSES (of the order of 1-8 mg/kg wet weight; see Table C4).

Overall, the analysis shows that the predicted regional concentrations in water, sediment and soil are relatively insensitive to the assumptions made over the chemical properties, and the variability in the predicted concentrations for these media is in most cases $\ll 1$ order of magnitude over the property range considered. However, the predicted concentrations in air are more sensitive to the assumed properties,

indicating that this part of model may be less applicable to microplastics. This uncertainty in the air concentrations however, it considered less significant to the aims of the current project.

When considering the outputs of the regional model it is relevant to consider that the microplastics themselves will have different properties depending upon, for example, particle size distribution, densities etc. Transport processes between compartments e.g. via wind-blown dust, sedimentation, loss from turbulent water to air etc., is likely to vary with these properties (Duis and Coors, 2016) and so the modelling carried out is by necessity a simplification of the actual situation. The results should of the regional assessment should therefore be seen as indicative values.

Concentrations

The methods outlined in ECHA (2016) and the EUSES model, result in mass-based concentrations in the various environmental media considered (i.e. the concentration of microbeads in terms of the weight of plastic per weight or volume of environmental medium e.g. mg/kg or mg/L). For microplastics, it is also informative to consider the number (quantity) of particles present in the media. The mass-based concentrations can be converted to concentrations based on particle numbers, using the typical mass of a microplastic. However, this conversion is not straight forward, as the microplastics being considered show a range of particle sizes and densities, and hence masses. Examples of the size ranges of microplastics being considered are summarised in Table C6.

Table C6 Particle size of microplastics

Polymer	Size range (assumed as diameter)
Polyethylene	200 - 1 250 µm
Polyurethane	2 – 1 240 µm
Polymethylmethacrylate	200 – 320 µm
Styrene/acrylates copolymer	2 – 10 µm

Assuming a density of 1 000 kg/m³ (1×10⁻¹² g/µm³), the mass of individual particles can be estimated for various diameter sizes (this is shown in Table C7 below). The mass-based concentrations in the environment are reported in terms of mg/l or mg/kg, and so the number of particles of present in 1 mg is also given. This allows the mass-based concentrations to be converted to particle-number-based concentrations.

Table C7 Mass of microplastic particles and number of particles present in 1 mg

Particle diameter (µm)	Particle radius (µm)	Particle volume (µm ³)	Assumed density (g/µm ³)	Particle weight (g)	No of particles present in 1 mg (0.001 g)
2	1	4.19E+00	1E-12	4.19E-12	2.39E+08
10	5	5.23E+02	1E-12	5.23E-10	1.91E+06
50	25	6.54E+04	1E-12	6.54E-08	1.53E+04
100	50	5.23E+05	1E-12	5.23E-07	1.91E+03
200	100	4.19E+06	1E-12	4.19E-06	2.39E+02
500	250	6.54E+07	1E-12	6.54E-05	1.53E+01
100	500	5.23E+08	1E-12	5.23E-04	1.91E+00
1250	625	1.02E+09	1E-12	1.02E-03	9.78E-01

As can be seen from Table 3.8, the number of particles present in 1 mg ranges between around 1 particle (1 250 µm diameter) to 2×10^8 particles (2 µm diameter) over the particle size range being considered. Thus, the conversion of mass-based concentrations to particle-number-based concentrations is complicated and requires a much more detailed understanding of the release to, and subsequent behaviour in, the environment, than is currently available.

As a simplification for the purposes of this study, a particle size of 200 µm is being assumed for the conversion (this is the lower end of the range in Table C7, for polyethylene and polymethylmethacrylate, and is within the range for polyurethane). Thus, 1 mg is assumed to contain 239 particles. However, it should be noted that the actual number of particles present may be up to 1×10^6 times higher or 100 times lower than suggested by this conversion, dependent upon the actual particle sizes present.

Personal care and cosmetics and products (PCCP)

Based on the results of the industry survey, it is estimated that there are around 714 tonnes/year of microplastics used in 'rinse-off'²⁴⁷ personal care products in the EU. The total amount of rinse-off products containing microplastics is unknown.

Another source (Eunomia, 2016) reported that there was evidence for use of microplastics in some 'leave-on'²⁴⁸ products and the total amount of microplastics used in personal care products could be between 4 500 and 8 200 tonnes/year, but this estimate is subject to high uncertainty. The weighted average concentration of microplastics in personal care products calculated from Eunomia (2016) is 2.4%, with a range of 0.005% to 72%.

New information from Cosmetics Europe: 714 tonnes in wash-off PCP and 540 – 1 120 tonnes in leave-off PCP (with a best estimate of 605 tonnes).

Based on this the total EU use would be 1 254-1 834 tonnes/year, with a best estimate of 1 319 tonnes year

Formulation of PCCPs

A number of sources can be used to estimate the release from formulation of PCCPs containing microplastics.

The relevant Environmental Release Categories (ERCs) from the ECHA Guidance (ECHA, 2016) are ERC 2 – Formulation into a mixture and ERC 3 – Formulation into a solid matrix. ERC 2 applies to formulation of mixtures and ERC 3 applies to formulation of solid products. ERC 3 is probably more appropriate for formulation of plastic products than PCCPs and so the most relevant ERC is ERC 2. The default release factors from ECHA (2016) are shown below.

ERC 2	0.025 (2.5%) to air 0.02 (2%) to water (before STP) 0.0001 (0.01%) to soil
ERC 3	0.3 (30%) to air 0.002 (0.2%) to water (before STP) 0.001 (0.1%) to soil

Microplastics are assumed as non-volatile with a low potential for dust formation, and so the release to air from formulation are likely to be much lower than suggested by the above default release factors.

Cosmetics Europe has developed Specific Environmental Release Categories (SpERCs) covering formulation of PCCPs. These define the amount of substance likely to be formulated into PCCP on a site per day, and the likely release factors and estimated releases to air, water and soil from the process.

²⁴⁷ Products that the intended to be removed with water (that goes to waste water) as part of use, for example, shower gels, shampoo etc.

²⁴⁸ Products that are not intended to be removed with water as part of use, for example deodorants, hair gels, skin creams, makeup. Note that there is some contention on some products such as sun care lotions, since they may be quickly washed off, although that is not the intention.

The amount of substance in the SpERCs is based on a 20% content in the finished PCCP. This is too high for many uses of microplastics, and so estimates are shown for both a 20% content and a 2.4% content (see Table C8). The 2.4% figure represents the weighted average concentration of microplastics in personal care products calculated from Eunomia (2016). Using a 2.4% content, the highest amount of microplastics assumed to be formulated into personal care products, at a site is around 2,000 kg/d which is equivalent to around 500 tonnes/year assuming 250 days formulation. This figure is relatively consistent (in order of magnitude terms) with the available information on the total amounts of microplastic used in personal care products, given that there may be several sites formulating such products.

For the initial regional assessment, it has been assumed that a total of 500 tonnes/year of microplastics are used in PCCPs in a region and that a total of 5 000 tonnes/year are used in the EU²⁴⁹ (the fraction used in the region is therefore 0.1 (10%)). This has then been split equally between the eight exposure scenarios represented in Table C8. The total regional releases from formulation estimated using this approach is as follows:

0 kg/d to air
 18.3 kg/d to water (before STP)
 0 kg/d to soil

New information from Cosmetics Europe: 714 tonnes in wash-off PCP and 540 – 1 120 tonnes in leave-off PCP (with a best estimate of 605 tonnes).

Based on this the total EU use would be 1 254-1 834 tonnes/year, with a best estimate of 1 319 tonnes year. Using the same approach as above, the total regional releases would be

	Range	Best estimate
Air	0 kg/d	0 kg/d
Water (before STP)	4.6-6.7 kg/d	4.8 kg/d
Industrial soil	0 kg/d	0 kg/d]

Total EU releases would be as follows.

Assuming 8 200 tonnes/year total use:	300 kg/d to water (before STP)
Assuming 1 254 tonnes/year total use:	46 kg/d to water (before STP)
Assuming 1 834 tonnes/year total use:	67 kg/d to water (before STP)
Assuming 1 319 tonnes/year total use (best estimate):	48 kg/d to water (before STP)]

Professional and consumer use of PCCPs

In accordance with the ECHA Guidance on environmental exposure assessment (ECHA, 2016) both professional and consumer use of PCCPs are considered as wide dispersive uses. In both cases the “local” source is a waste water treatment plant serving a population of 10 000 people and releases from both professional and consumer uses are assumed to enter the same waste water treatment plant.

For an initial assessment, it is not necessary to distinguish between professional and consumer uses as a) the releases from use can be assumed to be similar and b) the releases enter into the same waste water treatment plant. Therefore, the approach taken is based on ECHA (2016).

Assumed total EU use = 4 500-8 200 tonnes/year

Fraction used in the region = 0.1 (10%)

Regional tonnage = 820 tonnes/year

Population served by the local waste water treatment plant = 10 000

Number of inhabitants in the region = 20 000 000

²⁴⁹ Based on figure estimated from Eunomia 2016 - Figure E-1 - European PCCP Microplastics Reduction Timeline – total microplastic use in personal care products – projection for 2016/17 (figure rounded to 5 000 tpa).

Number of days of use = 365 days/year.

Assessment factor = 4 [this is used to take into account any geographical and temporal peaks in the use].

“Local” usage = $820 \text{ t/year} \times 10\,000 \times 4 / (20\,000\,000 \times 365) = 0.0045 \text{ tonnes/day} = 4.5 \text{ kg/d}$.

The fraction released to the environment may depend upon whether the product is a wash-off or leave-on product. For wash-off products up to 100% of the substance will be released to waste water. For leave-on products the percentage lost to water will be dependent on how much substance remains on the skin during use prior to subsequent washing. As microplastics are essentially non-volatile, it can be assumed that little loss by volatilisation will occur. However, many products are removed using means other than washing to water.

As a worst case for the initial assessment it will be assumed that 100% of both wash-off and stay-on products will be released to waste water. This approach gives an indication of the maximum likely concentrations in the environment; the actual concentrations will be lower than this.

For the assessment, the local and regional releases are assumed to be as follows:

Assumed release factor = 1 (100%) to water (before STP)
 Local release = 4.5 kg/d
 Regional release = $2.25 \times 10^3 \text{ kg/day}$

As the use in personal care products is an important use, in terms of the potential for release to the environment, it is also relevant to consider that there is some uncertainty over the amounts currently used within the EU. The above local release estimate is based on the total amount of microplastics used in the EU being as high as 8 200 tonnes/year. However, the survey of industry carried out for this project (see Section 3) suggested a lower figure of 714 tonnes/year in rinse-off personal care products and a similar amount for leave-on personal care products (best estimate value of 605 tonnes). If this lower figure for the total EU use is assumed, using the same method as above, the local release from use of personal care products would reduce from 4.5 kg/day to 0.39 kg/day. Both of these local release figures are considered in the PEC calculations.

New information from Cosmetics Europe: 714 tonnes in wash-off PCP and 540 – 1 120 tonnes in leave-off PCP (with a best estimate of 605 tonnes).

Based on this the total EU use would be 1 254-1 834 tonnes/year, with a best estimate of 1 319 tonnes year. Using the same approach as above, the local and regional releases to water (before STP) would be:

	Range	Best estimate
Local release to water (before STP)	0.69-1.0 kg/d	0.72 kg/d
Regional release to water (before STP)	344-502 kg/d	361 kg/d

Total EU releases would be as follows.

Assuming 8 200 tonnes/year total use: $2.25 \times 10^4 \text{ kg/d}$ to water (before STP)
 Assuming 1 254 tonnes/year total use: $3.44 \times 10^3 \text{ kg/d}$ to water (before STP)
 Assuming 1 834 tonnes/year total use: $5.02 \times 10^3 \text{ kg/d}$ to water (before STP)
 Assuming 1 319 tonnes/year total use (best estimate): $3.61 \times 10^3 \text{ kg/d}$ to water (before STP)]

Paints and coatings

Around 220 tonnes of microplastics are used in the EU in water-based building paints. The total amount of such paint/coating produced in the EU containing microplastics is of the order of 14 000 tonnes/year. The weighted average concentration of microplastics in the paint/coating is 1.6% with a range of 1-2%.

Other estimates suggest that the total usage in paints/coatings within the EU could be significantly higher, at up to 22 000-38 000 tonnes/year, but this estimate is subject to a high uncertainty and has not been verified by any available data.

Formulation

The relevant ERC from the ECHA Guidance (ECHA, 2016) is ERC 2 – Formulation into a mixture. The default release factors from ECHA (2016) are shown below.

ERC 2	0.025 (2.5%) to air
	0.02 (2%) to water (before STP)
	0.0001 (0.01%) to industrial soil

Microplastics are essentially non-volatile and so the release to air from formulation are likely to be much lower than suggested by the above default release factors.

SpERCs are available from covering the formulation and use of water-based coatings. The SpERCs have been developed by CEPE and in many cases, are based on information given in the OECD Emission Scenario Document (ESD) for coatings (OECD, 2009). The CEPE SpERC 2.2c.v1(CEPE, 2010a) covers the formulation of solids into water-based coatings and inks. The SpERC suggests that the maximum amount of an additive used at a formulating site would be around 1 000 kg/day and that formulation would occur over 225 days per year. This would suggest that a large formulation site would use around 225 tonnes/year of an additive, which is similar to the above estimate for the total amount of microplastics used in water-based building paints in the EU. **For the local scale assessment in this present study, it is assumed that 1 000 kg/day of microplastics are used on a formulation site over 220 days (this assumes that all of the 220 tonnes identified in the survey are formulated at one site).**

For the **regional assessment**, it is necessary to consider that the total EU use in paints/coatings could be higher than 220 tonnes/year. Therefore, the higher (but more uncertain) estimate of 22 000-38 000 tonnes/year is taken into account.

The SpERC gives the following emission factors to air, water and soil for solids during the formulation:

Emission factor to air	Maximum of 0.000097 (0.0097%)
Emission factor to water (before STP)	Maximum of 0.00005 (0.005%)
Emission factor to industrial soil	0

According to the SpERC, no direct dust emissions to air expected. Any initial loss from handling of solid substances, would be captured by air extraction devices, but this could lead to indirect emission to air. Similarly, for water, no direct emission to water is thought to occur during the process, but indirect emissions via dust deposition and subsequent wet-cleaning of surfaces may occur. No direct emission to industrial soil occurs.

The dustiness of microplastics is unknown, but the potential for dust generation may be expected to increase as the particle size decreases.

Based on the above information, the following worst-case releases can be estimated for microplastics from paint formulation sites.

Assumed total EU use	= 22 000-38 000 tonnes/year
Fraction used in the region	= 0.1 (10%)
Regional tonnage	= 2 200-3 800 tonnes/year
Local tonnage	= 220 t/year
Number of days of use	= 220 days/year
Local emission	= 0.097 kg/day to air
	= 0.05 kg/day to water (before STP)
	= 0 kg/day to industrial soil
Regional emission	= 0.58-1.0 kg/day to air
	= 0.30-0.52 kg/day to water (before STP)

[Total EU emission would be as follows.

Total EU emission to air:	5.8-10 kg/d
Total EU emission to water (before STP):	3.0-5.2 kg/d]

Use of paints

Paints and coatings can potentially be used in industrial settings by professionals, and by consumers. The main uses of water-based paints and coatings containing microplastics, appears to be in building applications (coating walls and ceilings). Such uses are mainly carried out by professionals and consumers, but use in an industrial setting could also potentially be possible.

The relevant ERCs from the ECHA Guidance (ECHA, 2016) are shown below.

For **industrial** use, we used ERC 5 - Use at industrial site leading to inclusion into/onto article.

ERC 5	0.5 (50%) to air 0.5 (50%) to water (before STP) 0.01 (1%) to industrial soil.
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For **professional and consumer use**, two ERCs apply depending on whether the paint is applied indoors or outdoors. ERC 8C - Widespread use leading to inclusion into/onto article (indoor). ERC 8F – Widespread use leading to inclusion into/onto article (outdoor).

ERC 8C	0.15 (15%) to air 0.05 (5%) to water (before STP) industrial soil – not applicable.
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ERC8F	0.15 (15%) to air 0.05 (5%) to water (before STP) 0.005 (0.5%) to industrial soil
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The default release factors to air and water are the same for both indoor and outdoor uses and the same factors apply for professional use and consumer uses.

Given that microplastics are essentially non-volatile, the above default release factors may overestimate the release to air from the use of paints containing microplastics.

CEPE has developed SpERCs covering industrial, professional and consumer use of coatings. The relevant information is considered in the following Sections.

Industrial use

Industrial application of coatings and inks by spraying – solids. CEPE SpERC 5.1a.v1 (CEPE, 2010b). Based on this SpERC the typical amount of paint consumed at a large industrial use site would be around 1 000 kg paint/day over 225 days. Assuming that the concentration of microplastics in the paint is up to 2%, this would equate to a total of 20 kg microplastic/day formulated into the paint. The emission factors are given based on the OECD ESD for coatings (OECD, 2009) and assumed that in industrial uses the paint is applied by spray and that a proportion of the solid phase will be contained in overspray resulting in a potential emission to air. No emission to water would be expected.

Emission factor to air	0.02 (2%)
Emission factor to water	0
Emission factor to industrial soil	0

The emission factor for air may be reduced by 95% if air treatment (wet scrubber or filtration) is in place.

The local releases from industrial use of coatings can therefore be estimated as follows.

$$\begin{aligned} \text{Local release} &= 20 \text{ kg/d} \times 0.02 = 0.4 \text{ kg/d to air} \\ &= 0 \text{ kg/d to water} \\ &= 0 \text{ kg/d to industrial soil} \end{aligned}$$

In order to estimate the regional release from industrial use it is necessary to know the total amount of paint that is used in industrial applications. This is not known specifically. Therefore, the regional emissions are estimated assuming that most of the use is in professional and consumer use (see below). In practical terms, this simplification will have only a limited impact on the total regional emissions from all uses as use of paints/coatings only makes a relatively small contribution to the total regional emissions (see Appendix C Section on total regional emissions).

Professional and consumer use

There are several SpERCs covering professional use of coatings. Application by spraying by professionals is covered in CEPE SpERC 8c.3a.v1 (indoor use) and CEPE SpERC 8f.3a.v1 (outdoor use) (CEPE, 2010c and 2010d). Both of these SpERCs assume that the typical amount of paint consumed by professionals at a local site would be up to 100 kg/day and that professional use would occur on 225 days per year. Assuming that the concentration of microplastics in the paint is up to 2%, this would equate to a total of 2 kg microplastic/day used in the paint. The emission factors assume that a proportion of the solid phase will be contained in overspray resulting in a potential emission to air, and that during outdoor application a proportion of the applied coating can be deposited into water. Similarly, deposition to industrial soil is possible from outdoor application but the SpERC indicates that there is currently no information on which to base a reliable emission factor. The emission factors are summarised below.

	Indoor (SpERC 8c.3a.v1)	Outdoor (SpERC 8f.3a.v1)
Emission factor to air	0.022 (2.2%)	0.022 (2.2%)
Emission factor to water	0	0.02 (2%)
Emission factor to industrial soil	0	unknown

Professional application of coatings by brush or roller is covered in CEPE SpERC 8c.2a.v1 (indoor use) and CEPE SpERC 8f.2a.v1 (outdoor use) (CEPE, 2010e and 2010f). The amount of paint consumed at a local site would be up to 25 kg/day and that professional use may occur over 225 days. Assuming that the concentration of microplastics in the paint is up to 2%, this would equate to a total of 0.5 kg microplastic/day used in the paint. For this scenario, there is no emission to air of the solid phase, but around 1% could be lost to waste-water from cleaning of equipment etc., and 0.5% may be lost to soil (deposited below the area being painted; outdoor application only). The emission factors are summarised below:

	Indoor (SpERC 8c.2a.v1)	Outdoor (SpERC 8f.2a.v1)
Emission factor to air	0	0
Emission factor to water	0.01 (1%)	0.01 (1%)
Emission factor to soil	0	0.005 (0.5%)

For consumer use of paints/coating most application will be via brush or roller, rather than spray. CEPE SpERC 8c.1a.v1 and SpERC 8f.1a.v1 cover application by brush/roller indoors and outdoors respectively (CEPE, 2010g and 2010h). The amount of paint used by a consumer would typically be <5 kg paint/day, and use can be considered to occur over 365 days/year. Assuming that the concentration of microplastics in the paint is up to 2%, this would equate to a total of <0.1 kg microplastic/day used in the paint. The relevant emission factors are summarised below. The solid phase is not emitted to air, and around 1% is assumed to be released to water from washing of equipment. Again, deposition to soil below the area being painted is also possible from outdoor application

	Indoor (SpERC 8c.1a.v1)	Outdoor (SpERC 8f.1a.v1)
Emission factor to air	0	0
Emission factor to water	0.01 (1%)	0.01 (1%)
Emission factor to soil	0	0.005 (0.5%)

Although the CEPE SpERCs give an indication of the amount of paint used by a professional or a consumer on any given day, the use will occur at many different sites (e.g. professionals will move from construction site to construction site and any given consumer is unlikely to apply the paint continually over the year). This means that the point source for the local release estimate will vary from day to day. In order, to take this into account ECHA (2016) assumes that both professional use and consumer uses are considered as wide dispersive uses (i.e. many small-scale users relatively evenly distributed throughout the EU). For such uses, the local point source becomes a waste water treatment plant serving a population of 10 000 people and releases from both professional and consumer users within that population are assumed to enter the same waste water treatment plant, averaged over a year. For an initial assessment, it is therefore not necessary to distinguish between professional and consumer uses as a) the releases from use can be assumed to be similar and b) the releases enter into the same waste water treatment plant. Therefore, the approach taken to define the local usage for professional use is based on ECHA (2016).

Assumed total EU use = 22 000-38 000 tonnes/year
 Fraction used in the region = 0.1 (10%)
 Regional tonnage = 2 200-3 800 tonnes/year
 Population served by the local waste water treatment plant = 10 000
 Number of inhabitants in the region = 20 000 000
 Number of days of use = 365 days/year
 Assessment factor = 4 [this is used to take into account any geographical and temporal peaks in the use]
 "Local" usage = $2\ 200\ [to\ 3\ 800]\ t/year \times 10\ 000 \times 4 / (20\ 000\ 000 \times 365) = 0.012\ to\ 0.021\ tonnes/day = 12 - 21\ kg/d.$

These local usage figures are slightly higher than those given in the CEPE SpERCs. However, they are used for the initial screening assessment in preference to the SpERC usage rates as they have been obtained using the recommended approach in ECHA (2016) and take into account the uncertainty in the overall EU consumption in this application.

In order to estimate the local and regional emission from professional and consumer use of coatings, the emission factors from the CEPE SpERCs are used. These emission factors are dependent upon whether the application is by brush or spray (in the case of professional use) and whether the paint is applied indoors or outdoors. There is insufficient information to split the total tonnage between these various possibilities. For the assessment, it is assumed that the emission factor to waste water is 1%²⁵⁰, the emission factor to soil is taken to be 0.25%²⁵¹ and the emission factor to air is taken to be around 1.1%²⁵². Thus the local and regional emissions for professional and consumer use can be estimated as follows.

Local release	= 0.12-0.21 kg/d to water (before STP)
	= 0.13-0.23 kg/d to air
	= 0.030-0.053 kg/d to soil
Regional release	= 60.3-104 kg/d to water (before STP)
	= 66.3-115 kg/d to air
	= 15.1-26.0 kg/d to soil

²⁵⁰ This is the emission factor from the SpERCs for application by brush/roller by both professionals and consumers, and it is also the average emission factor for professional spray application if it is assumed that 50% of the application occurs indoors (0% to water) and 50% of the application occurs outdoors (2% to water).

²⁵¹ This assumes that around 50% of the total application occurs indoors (0% to soil) and 50% occurs outdoors (0.5% to soil).

²⁵² This assumes that around 50% of the total application is by spray application (2.2% to air) and 50% is by brush/roller application (0% to air).

[Total EU emissions would be as follows:

Water (before STP)	603-1.04×10 ³ kg/d
Air	663-1.15×10 ³ kg/d
Soil	151-260 kg/d]

Painted articles during their service life

For the purposes of this study, and in the light of not finding information to the contrary, we assume that once the paint has been applied and has dried, the microplastic will become an integral part of the coating and will not be available for subsequent release. Although loss of paint to the environment may occur during the service life of the article (e.g. by weathering, chipping and flaking) and at the end of the service life (e.g. during disposal), this will be as particles of paint rather than as the microplastics themselves. Therefore, these sources are not considered further. They are however considered in the parallel study on microplastics other than those intentionally added to products.

Soaps, detergents and maintenance products

Around 190-200 tonnes/year of microplastics are thought to be used in soaps, detergents and maintenance products. The weighted average concentration of microplastics in such products is around 4%, with a range of 0.7-4.9%. In tonnage terms, the highest usage of microplastics in this area is in hard surface cleaners (glass ceramic cleaners) but other products (e.g. toilet cleaners (WC blocks), stainless steel cleaners, oven cleaners and laundry stain removers) may also contain microplastics.

Formulation of soaps, detergents and maintenance products

The relevant Environmental Release Categories (ERCs) from the ECHA Guidance (ECHA, 2016) are ERC 2 – *Formulation into a mixture* and ERC 3 – *Formulation into a solid matrix*. ERC 2 applies to formulation of mixtures and ERC 3 applies to formulation of solid products. ERC 3 is probably more appropriate for formulation of plastic products than soaps, detergents and maintenance products and so the most relevant ERC is ERC 2. The default release factors from ECHA (2016) are shown below.

ERC 2	0.025 (2.5%) to air 0.02 (2%) to water (before STP) 0.0001 (0.01%) to industrial soil
ERC 3	0.3 (30%) to air 0.002 (0.2%) to water (before STP) 0.001 (0.1%) to industrial soil

Microplastics are assumed to be non-volatile and so the release to air from formulation are likely to be much lower than suggested by the above default release factors.

SpERCs for formulation of cleaning products have been developed by AISE (2012a and 2012b). AISE (2012a) covers the formulation of granular products and so is not relevant to the main applications of microplastics. AISE (2012b) covers the formulation of liquid cleaning and maintenance products. Both low viscosity products (e.g. liquid cleaners) and high viscosity products (e.g. gels, pastes etc) are considered in the SpERC, and formulation is considered in terms of small scale (up to 1 000 tonnes/year of cleaning product), medium scale (up to 10 000 tonnes/year of cleaning product and large scale (over 10 000 tonnes/year of cleaning product).

For microplastics, a total of 200 tonnes/year of microplastics would result in a total of around 5 000 tonnes/year of formulated cleaning products (assuming an average content of 4%). The number of formulating sites in the EU is not known but based on a total of 5 000 tonnes/year of formulated product, a site formulating up to 1 000 tonnes/year would appear to be a realistic assumption. The relevant SpERC from AISE (2012b) is therefore AISE SpERC 2.1.i.v2 for low viscosity products (small scale) and AISE SpERC 2.1.i.v2 for high viscosity products (small scale).

For a site formulating 1 000 tonnes/year of cleaning product, the amount of microplastic used would be around 40 tonnes/year (at a 4% content). The SpERCs give the number of days of release as 250 days/year. The relevant emission factors are shown below.

	Low viscosity products SpERC 2.1.i.v2	High viscosity products SpERC 2.1.l.v2
Emission factor to air	0	0
Emission factor to water (before STP)	0.002 (0.2%)	0.004 (0.4%)
Emission factor to industrial soil	0	0

Based on this the local release can be estimated as follows:

For a site formulating low viscosity products:

Local emission = 40 t/year × 0.002 = 0.08 t/year = 0.32 kg/day to water (before STP)
 = 0 kg/day to air
 = 0 kg/day to industrial soil

For a site formulating high viscosity products:

Local emission = 40 t/year × 0.004 = 0.16 t/year = 0.64 kg/day to water (before STP)
 = 0 kg/day to air
 = 0 kg/day to industrial soil

For the regional assessment, it is assumed that 40% of the total formulation occurs in the region (i.e. 80 tonnes of microplastics). This corresponds to two small formulation sites; in the absence of further information it is assumed that one site formulates low viscosity products and one site formulates high viscosity products, and so the average emission factor is 0.003 (0.3%). Thus, the regional emissions are estimated as follows.

Total EU tonnage of microplastics = 200 tonnes/year
 Percentage formulated in the region = 40%
 Regional tonnage = 80 tonnes/year
 Average emission factor to water (before STP) = 0.003
 Regional emission = 0.24 t/year = 0.66 kg/day to water (before STP)
 = 0 kg/day to air
 = 0 kg/day to industrial soil

[The total EU emissions would be as follows.

Total EU emission to water (before STP) = 1.64 kg/d
 Total EU emission to air = 0 kg/d
 Total EU emission to industrial soil = 0 kg/d]

Professional and consumer use of cleaning products

Cleaning products can be used by professionals and consumers. Industrial use of cleaning products is also theoretically possible, but there is insufficient information on whether this actually occurs for products containing microplastics.

Professional and consumer uses of cleaning products are both considered as wide dispersive uses in the ECHA Guidance (ECHA, 2016) and both lead to essentially complete release to waste water. Therefore, it is possible to consider professional and consumer use together. The relevant ERC from the ECHA Guidance is ERC 8a - Widespread use of non-reactive processing aid (no inclusion into or onto article, indoor). The default emission factors for ERC 8a are shown below.

Emission factor to air	100%
Emission factor to water (before STP)	100%
Emission factor to soil	Not applicable

The default emission factors for ERC 8a take into account that both volatile and non-volatile substances could be used in cleaning products, and hence up to 100% could be released by either air or water. For microplastics, releases to air can be expected to be negligible during cleaning, as they are not volatile, and so release would be 100% to water.

Using the approach outlined in ECHA (2016), the local point source for professional and consumer use of cleaning products is a waste water treatment plant serving a population of 10,000 people, and releases from both professional and consumer users within that population are assumed to enter the same waste water treatment plant, averaged over a year. The amount used in the region is set to 10% of the total EU amount as a default²⁵³.

Assumed total EU use = 200 tonnes/year
 Fraction used in the region = 0.1 (10%)
 Regional tonnage = 20 tonnes/year
 Population served by the local waste water treatment plant = 10 000
 Number of inhabitants in the region = 20 000 000
 Number of days of use = 365 days/year
 Assessment factor = 4 [this is used to take into account any geographical and temporal peaks in the use]
 "Local" usage = 20 t/year × 10 000 × 4 / (20 000 000 × 365) = 0.00011 tonnes/day = 0.11 kg/d.

Assuming 100% release to water (before STP) during use the following local and regional releases can be estimated.

Local release to water (before STP) 0.11 kg/day
 Regional release to water (before STP) 54.8 kg/day

[The total EU release would be 548 kg/d to water (before STP)]

Abrasives

Microplastics are used in the industrial abrasives industry, but the actual amounts used, and their exact functions, are unclear. It has been suggested that microplastics are used in sandblasting in amounts up to 1 000-5 000 tonnes/year in the EU. However, information provided by the industry does not confirm this use, but instead suggests that their main application is in the manufacture of abrasives and that they are either cross-linked or destroyed (combusted) during the manufacture process, and so are not present in the final abrasive.

As there is little information (and therefore considerable uncertainty) over the use of microplastics in abrasives, a worst case generic approach is taken in the exposure assessment. Two scenarios are considered, the first assumes that the microplastics are used in the manufacture (formulation) of abrasives, and the second assumes that microplastics are used as an industrial abrasive in sandblasting. Both exposure estimates use the default approach from the ECHA Guidance R.16 (ECHA, 2016) and the resulting exposure estimates are therefore conservative and highly uncertain. Again, in the absence of further information it is assumed that the total tonnage for each of these applications is 2 500 tonnes/year (giving 5 000 tonnes in total).

Manufacture (formulation) of abrasives

The relevant ERC from ECHA (2016) is ERC 3 (formulation into a solid matrix). The relevant worst-case release factors are summarised below.

Release factor to air 0.3 (30%)
 Release factor to water (before STP) 0.002 (0.2%)

²⁵³ AISE SpERC 8a.1.a.v2 (AISE,) suggests that a lower region fraction of 0.04 (4%) is appropriate for cleaning products in general. However, as the range of cleaning products containing microplastics and the total amount of microplastics used is relatively low, the default approach from ECHA (2016) is used here in order to take into account that temporal and/or geographical peaks in use may occur.

Release factor to industrial soil 0.001 (0.1%)

The default release factor to air of 30% appears to be unrealistically high for microplastics. The microplastics are essentially non-volatile and, based on the limited available information, are destroyed during the process. The release to air is more likely to be of a similar order to the release to water or industrial soil (0.1-0.2%) rather than 30% and so, in the absence of other information, the release factor to air will be set to 0.2%²⁵⁴.

There is no reliable information available on the total amounts of microplastics that might be used in this application, or the concentration of microplastic that might be added to the abrasive. For the assessment, the following values are assumed in the absence of other information.

Amount of microplastics used at a local site	1 000 t/year
Number of days of formulation (default)	100 days
Daily amount of microplastics used	10 t/day
Local emission to air	20 kg/day
Local emission to water (before STP)	20 kg/day
Local emission to industrial soil	10 kg/day
Regional amount of microplastics used (this assumes all the formulation sites are in the region in line with ECHA (2016))	2 500 t/year
Regional release to air	0 t/year = 13.7 kg/day
Regional release to waster (before STP)	5 t/year = 13.7 kg/day
Regional emission to industrial soil	2.5 t/year = 6.8 kg/day

[As it is assumed that all of the formulation sites are in the region, the total EU release would be the same as the regional release for this scenario].

Industrial and professional use of abrasives ('sandblasting')

Sandblasting can be carried out in industrial locations (industrial use) and also by professionals (professional use). The relevant ERCs from ECHA (2016) are ERC 4 (use of non-reactive processing aid at industrial site (no inclusion into or onto article)) for industrial uses and ERC 8a (widespread use of non-reactive processing aid (no inclusion into or onto article, indoor)) or ERC 8d (widespread use of non-reactive processing aid (no inclusion into or onto article, outdoor)) for professional use. The default release factors from ECHA (2016) are summarised below.

	ERC 4	ERC 8a	ERC 8d
Release factor to air	1 (100%)	1 (100%)	1 (100%)
Release factor to water (before STP)	1 (100%)	1 (100%)	1 (100%)
Release factor to industrial soil	0.05 (5%)	not applicable	0.2 (20%)

The default release factors for all three ERCs assume that the release is effectively 100% to water or air. For microplastics used in sandblasting it can be envisaged that the main source of release will be to air, with potential release also occurring to soil (particularly for outdoor use). Therefore, for the generic release estimates, it has been assumed that the release is initially 100% to air, from both industrial and professional use with 5% (industrial use) and 20% (professional use) also being released to soil²⁵⁵.

For industrial use, the size of a local site is not known. Therefore, for an initial assessment, it is assumed that a local site uses 1 tonne/day of microplastics for sandblasting. Assuming that the processes is carried out

²⁵⁴ This is a similar order to the default release factor to air of 0.1% for ERC 6b (Use of reactive processing aids at industrial site (no inclusion into or onto article)).

²⁵⁵ This approach leads to a total release of 105% from industrial use and 120% from professional use. This thus will overestimate the total release but this needs to be seen in relation to the uncertainty over the actual amounts of microplastics used in this application. There is currently insufficient information available with which to carry out a more realistic exposure assessment.



over 300 days per year this would equate to a total microplastics tonnage used at the site of 300 tonnes/year. Thus, the local releases from industrial use can be estimated as follows.

Local tonnage	1 t/day
Local emission to air	1 000 kg/day
Local emission to waste water (before STP)	0 kg/day
Local emission to industrial soil	50 kg/day

Professional use is considered as a wide dispersive use (ECHA, 2016). For such uses, the local source is a waste water treatment plant serving a population of 10 000, and releases from all professional within that population are assumed to enter the same waste water treatment plant, averaged over a year. The amount used in the region is set to 2 500 t/year as a default.

Assumed total EU use = 2 500 tonnes/year

Fraction used in the region = 1 (100%)

Regional tonnage = 2 500 tonnes/year

Population served by the local waste water treatment plant = 10 000

Number of inhabitants in the region = 20 000 000

Number of days of use = 365 days/year

Assessment factor = 4 [this is used to take into account any geographical and temporal peaks in the use]

“Local” usage = $2500 \text{ t/year} \times 10\,000 \times 4 / (20\,000\,000 \times 365) = 0.0137 \text{ tonnes/day} = 13.7 \text{ kg/d}$.

The local release from professional use is therefore as follows.

Local release to air	13.7 kg/day
Local release to water (before STP)	0 kg/day
Local release to industrial soil	2.7 kg/day

For the total regional release from industrial and professional use it is assumed that all of the 2 500 tonnes/year is used in the region and the releases are 100% to air and 20% to industrial soil as a worst case. Thus, the regional release is as follows.

Regional release to air	6 850 kg/day
Regional release to water (before STP)	0 kg/day
Regional release to industrial soil	1 370 kg/day

[As it is assumed as a worst case that all of the use occurs in the region, the total EU release would be the same as the regional release for this scenario].

Other uses where microplastics are used

There are other potential areas of use of microplastics in the EU, but insufficient information is available on which to carry out a reliable exposure estimate. For these industries, a purely default assessment is undertaken assuming that a total of 1 000 tonnes of microplastics is used in each industry.

Oil and gas industry

Microplastics are used in drilling fluids in oil and gas exploration, and other kinds of rock drilling. The amounts of microplastics or the concentrations used are not known, and so a nominal amount of 1 000 tonnes/year is assumed for a default worst case assessment based on ECHA (2016). The approach assumes that the microplastics are formulated into products before use. As noted in the market analysis, further work on use of microplastics in the oil and gas industry is ongoing under the auspices of OSPAR, and this is expected to yield better information on their use.

(a) Formulation

The relevant ERC from ECHA (2016) is ERC 2 (formulation into a mixture). The relevant default release factors are summarised below.

Release factor to air	0.025 (2.5%)
Release factor to water (before STP)	0.02 (2%)
Release factor to industrial soil	0.0001 (0.01%)

Assuming that a total of 1000 tonnes/year are formulated in to drilling fluids at a local site, the following local releases can be estimated.

Local tonnage of microplastics	1 000 t/year
Number of days of formulation (default) ²⁵⁶	300 days
Daily tonnage of microplastics	3.33 t/day
Local release to air	83.5 kg/day
Local release to water (before STP)	66.7 kg/day
Local release to industrial soil	0.33 kg/day

For the regional release, it is assumed that the regional tonnage is 1 000 t/year (i.e. all of EU the tonnage is formulated at one site in the region). The regional release is therefore as follows.

Regional release to air	68.5 kg/day
Regional release to water (before STP)	54.8 kg/day
Regional release to industrial soil	0.27 kg/day

[As it is assumed as a worst case that all of the use occurs in the region, the total EU release would be the same as the regional release for this scenario].

(b) Industrial use in oil and gas industry

There is a specific exposure scenario for off-shore used of chemicals in the oil and gas industry fluids that have been within the CHARM model (CIN, 2005). However, in order to use this model, it is necessary to know the concentration/dosage of microplastics within the fluid. This is currently unknown (to the authors of this present study), and so it is not possible to use this model meaningfully for microplastics. Therefore, a default assessment using the methods from ECHA (2016) is carried out.

The relevant ERC from ECHA (2016) is ERC7 (use of functional fluid at industrial site). The default release factors for ERC7 are shown below. It is not known how relevant or reliable these release factors are for use in the oil and gas industry.

Release factor to air	0.05 (5%)
Release factor to water (before STP)	0.05 (5%)
Release factor to industrial soil	0.05 (5%)

The actual tonnages involved are unknown. For a default assessment, it is assumed that 1 tonne/day of microplastics are used at a local site, over 300 days. The local release is shown below. These are highly uncertain.

Local tonnage	1 t/day
Local release to air	50 kg/day
Local release to water (before STP)	50 kg/day
Local release to industrial soil	50 kg/day

²⁵⁶ Assumes that the amount of fluid formulated will be >>1,000 t/year.



For the regional release, it is assumed that 1 000 tonnes/year is used in the region. The regional releases are therefore as follows.

Regional release to air	137 kg/day
Regional release to water (before STP)	137 kg/day
Regional release to industrial soil	137 kg/day

[As it is assumed as a worst case that all of the use occurs in the region, the total EU release would be the same as the regional release for this scenario].

Agriculture

Microplastics could potentially be used in nutrient prills²⁵⁷ for controlled-release fertilisers and other applications. These applications are similar in that they result in direct application to agricultural soil, and potentially surface water by overspray etc. The amounts of microplastics or the concentrations used are not known and so a nominal amount of 1 000 tonnes/year is assumed for a default worst case assessment based on ECHA (2016). The approach assumes that the microplastics are formulated into products before use.

(c) Formulation

The relevant ERC from ECHA (2016) is ERC 2 (formulation into a mixture). The relevant default release factors are summarised below.

Release factor to air	0.025 (2.5%)
Release factor to water (before STP)	0.02 (2%)
Release factor to industrial soil	0.0001 (0.01%)

Assuming that a total of 1 000 tonnes/year are formulated in to agricultural products at a local site, the following local releases can be estimated.

Local tonnage of microplastics	1 000 t/year
Number of days of formulation (default) ²⁵⁸	300 days
Daily tonnage of microplastics	3.33 t/day
Local release to air	83.3 kg/day
Local release to water (before STP)	66.7 kg/day
Local release to industrial soil	0.33 kg/day

For the regional release, it is assumed that the regional tonnage is 1 000 t/year (i.e. all of EU the tonnage is formulated at one site in the region). The regional release is therefore as follows.

Regional release to air	68.5 kg/day
Regional release to water (before STP)	54.8 kg/day
Regional release to industrial soil	0.27 kg/day

[As it is assumed as a worst case that all of the use occurs in the region, the total EU release would be the same as the regional release for this scenario].

(d) Professional and consumer use of agrochemical products

Most agrochemical products are used by professionals although consumer use is also possible. Both of these are considered as use is considered as a wide dispersive use in ECHA (2016). For such uses, the local source is a waste water treatment plant serving a population of 10 000, and releases from all

²⁵⁷ Pellets for the application of fertilisers to land.

²⁵⁸ Assumes that the amount of fluid formulated will be >>1 000 t/year.

professional and consumer within that population are assumed to enter the same waste water treatment plant, averaged over a year.

For the default assessment, it is assumed that 1 000 tonnes/year of microplastics are used in agricultural products. As agriculture is widespread throughout the EU, the regional tonnage is taken to be 10% of the total tonnage in line with ECHA (2016).

Assumed total EU use = 1 000 tonnes/year

Fraction used in the region = 0.1 (10%)

Regional tonnage = 100 tonnes/year

Population served by the local waste water treatment plant = 10 000

Number of inhabitants in the region = 20 000 000

Number of days of use = 365 days/year

Assessment factor = 4 [this is used to take into account any geographical and temporal peaks in the use]

“Local” usage = $100 \text{ t/year} \times 10\,000 \times 4 / (20\,000\,000 \times 365) = 0.00055 \text{ tonnes/day} = 0.55 \text{ kg/d}$.

The relevant ERCs from ECHA (2016) is ERC 8d (widespread use of non-reactive processing aid (no inclusion into or onto article). The relevant default release factors from ERC 8d are shown below.

Release factor to air	100%
Release factor to water (before STP)	100%
Release factor to industrial soil	20%

The default release factors above assume that the substance is mainly released to air or water, with a smaller release to industrial soil. However, in the case of agrichemical use, the release will be mainly to agricultural soil, with a small release to surface water (from drift etc). Therefore, for the **default assessment here it is assumed that the release is 95% to agricultural soil and 5% direct to surface water (no waste water treatment is assumed in order to take into account direct releases into water courses are possible in this scenario)**

Thus, the local and regional releases from agricultural use is as follows.

Local release to air	0 kg/day
Local release direct to water (no STP)	0.028 kg/day
Local release to agricultural soil ²⁵⁹	0.52 kg/day
Regional release to air	0 kg/day
Regional release direct to water (no STP)	13.7 kg/day
Regional release to agricultural soil	260 kg/day

[The total EU release from agricultural use would be as follows:

Total EU release to air	0 kg/day
Total EU release to water (no STP)	137 kg/day
Total EU release to agricultural soil	2.60×10 ³ kg/day

Other uses where no significant amounts of microplastics are claimed

During the consultation (for the present study (see Section 3) industry claimed that there were no significant amounts of microplastics currently used within the EU in the pharmaceutical industry or the water treatment industry. Therefore, no exposure assessment is carried out for these areas.

²⁵⁹ Within EUSES it is not possible to enter release direct to agricultural soil at a local level. Therefore, for the PEC calculation this is modelled as a release via sewage sludge which is subsequently applied to agricultural soil.



Total regional emission

The total regional emission of microplastics is estimated as follows based on the preceding sections (above).

Air	7,253 kg/day
Water (before STP)	2,697 kg/day
Water (direct)	14 kg/day
Agricultural soil (direct)	260 kg/day
Industrial soil	1,540 kg/day

The emissions to the waste water treatment plant will partition between sludge and water resulting in indirect emissions to surface water and agricultural soil (via spreading of sewage sludge).

Estimates for local releases - Personal Care Products

Table C8 Estimates for the local release from formulation of PCCPs

Description	Number of days of release (d/year)	Amount of microplastic used on a local site (kg/d)		Release factor			Estimated local release based on a 2.4% content (kg/d)		
		Based on a 20% content	Based on a 2.4% content	Air	Water (before STP)	Soil	Air	Waste water (before STP)	Soil
CE 1 - Formulation of low viscosity liquids (Shampoo, hair conditioner, shower gel, foam bath) - large scale site	250	16 700	2 004	0	0.001 (0.1%)	0	0	2.0	0
CE 2 - Formulation of low viscosity liquids (Shampoo, hair conditioner, shower gel, foam bath) - medium scale site	250	4 500	540	0	0.002 (0.2%)	0	0	1.1	0
CE 3 - Formulation of low viscosity liquids (Shampoo, hair conditioner, shower gel, foam bath) - small scale site	250	450	54	0	0.004 (0.4%)	0	0	0.22	0
CE 6 - Formulation of high viscosity body care products (body lotion, anti-perspirants (roll-on, stick), soap formulation “saponification”, hair dyes, hair gels) - medium scale site	250	4 500	540	0	0.01 (1%)	0	0	5.4	0
CE 7 - Formulation of high viscosity body care products (body lotion, anti-perspirants (roll-on, stick), soap formulation “saponification”, hair dyes, hair gels) - small scale site	250	10	1.2	0	0.02 (2%)	0	0	0.024	0

Description	Number of days of release (d/year)	Amount of microplastic used on a local site (kg/d)		Release factor		Estimated local release based on a 2.4% content (kg/d)			
		Based on a 20% content	Based on a 2.4% content	Air	Water (before STP)	Soil	Air	Waste water (before STP)	Soil
CE 8 - Formulation of non-liquid creams (skin care, body care, make-up foundation) - large scale site	250	16 700	2 004	0	0.01 (1%)	0	0	20	0
CE 9 - Formulation of non-liquid creams (skin care, body care, mascara, make-up foundation) - medium scale site	250	4 500	540	0	0.02 (2%)	0	0	10.8	0
CE 10 - Formulation of non-liquid creams (skin care, body care, mascara, make-up foundation) - small scale	250	450	54	0	0.04 (4%)	0	0	2.2	0

EUSES modelling - Predicted Environmental Concentrations in water, sludge, sediment and soil

The local and regional PECs obtained using EUSES are shown in Tables C9 to C20. As discussed in Section 3.2, three different removal rates during waste water treatment have been assumed. The following substance properties were used in each case.

The PECs calculated include the relevant contributions from the predicted regional concentration. In many cases the predicted regional contribution is significant, particularly for soil and to a lesser extent for sediment. As explored in Section 3.3, there is some uncertainty over the suitability of the regional model for predicting concentrations of microplastics. In addition, the regional model is a steady-state model and it may take many of 100s or 1 000s of years before such steady state concentrations are reached. Therefore, local concentrations are also presented without the regional contributions (termed C_{local} Tables 3.6 to 3.17, below). These reflect the likely concentration resulting solely from the local, point source, release.

As discussed in Section 3.3, the predicted concentrations are presented on both a mass-concentration basis and a particle-number-concentration basis. The conversion used was 1 mg is equivalent to 239 particles (noting that there is a large uncertainty associated with this conversion).

Calculations assuming 53% removal in the waste water treatment plant:

- Mass-based PEC calculations – Table C9
- Mass-based C_{local} calculations – Table C12
- Particle-based PEC calculations – Table C15
- Particle-based PEC C_{local} - Table C18

Calculations assuming 84% removal in the waste water treatment plant:

- Mass-based PEC calculations – Table C10
- Mass-based C_{local} calculations -Table C13
- Particle-based PEC calculations – Table C16
- Particle-based C_{local} calculations – Table C19

Calculations assuming 92% removal in the waste water treatment plant:

- Mass-based PEC calculations – Table C11
- Mass-based C_{local} calculations -Table C14
- Particle-based PEC calculations -Table C17
- Particle-based C_{local} calculations – Table C20

Table C9 Mass-based PEC calculations – 53% removal in waste water treatment plant

Scenario		STP effluent (total) – mg/l	Sewage sludge - mg/kg dry wt.	PEC Surface water (total) – mg/l	PEC Marine water (total) – mg/l	PEC Freshwater sediment – mg/kg dry wt.	PEC Marine sediment – mg/kg dry wt.	PEC Agricultural soil – mg/kg dry wt.	PEC Grassland – mg/kg dry wt.
Personal care products	Formulation - low viscosity - large scale	4.7E-01	1.3E+03	5.2E-02	5.2E-03	3.5E+03	4.1E+02	6.2E+01	4.9E+01
	Formulation - low viscosity - medium scale	2.5E-01	7.3E+02	3.1E-02	3.0E-03	2.0E+03	2.7E+02	5.2E+01	4.4E+01
	Formulation - low viscosity - small scale	5.1E-02	1.5E+02	1.0E-02	1.0E-03	6.9E+02	1.3E+02	4.2E+01	4.1E+01
	Formulation - high viscosity - medium scale	1.3E+00	3.6E+03	1.3E-01	1.3E-02	8.8E+03	9.4E+02	1.0E+02	6.4E+01
	Formulation - high viscosity - small scale	5.6E-03	1.6E+01	5.8E-03	5.5E-04	3.9E+02	1.0E+02	4.0E+01	4.0E+01
	Formulation - creams - large scale	4.7E+00	1.3E+04	4.8E-01	4.7E-02	3.2E+04	3.2E+03	2.6E+02	1.3E+02
	Formulation - creams - medium scale	2.5E+00	7.3E+03	2.6E-01	2.6E-02	1.7E+04	1.8E+03	1.6E+02	8.8E+01
	Formulation - creams - small scale	5.1E-01	1.5E+03	5.6E-02	5.6E-03	3.7E+03	4.4E+02	6.4E+01	4.9E+01
	Professional and consumer use - 4.5 kg/d	1.1E+00	3.0E+03	1.1E-01	1.1E-02	7.4E+03	8.0E+02	9.0E+01	6.0E+01



Scenario		STP effluent (total) – mg/l	Sewage sludge - mg/kg dry wt.	PEC Surface water (total) – mg/l	PEC Marine water (total) – mg/l	PEC Freshwater sediment – mg/kg dry wt.	PEC Marine sediment – mg/kg dry wt.	PEC Agricultural soil – mg/kg dry wt.	PEC Grassland – mg/kg dry wt.
	Professional and consumer use - 0.39 kg/day	9.2E-02	2.6E+02	1.4E-02	1.4E-03	9.6E+02	1.6E+02	4.4E+01	4.1E+01
Paints and coatings	Formulation	1.2E-02	3.4E+01	6.4E-03	6.1E-04	4.3E+02	1.1E+02	4.0E+01	4.0E+01
	Industrial use	0.0E+00	0.0E+00	5.3E-03	4.9E-04	3.5E+02	9.8E+01	4.0E+01	4.0E+01
	Professional and consumer use	4.9E-02	1.4E+02	1.0E-02	9.8E-04	6.8E+02	1.3E+02	4.2E+01	4.1E+01
Detergents	Formulation - low viscosity products	7.5E-02	2.2E+02	1.3E-02	1.2E-03	8.5E+02	1.5E+02	4.3E+01	4.1E+01
	Formulation - high viscosity products	1.5E-01	4.3E+02	2.0E-02	2.0E-03	1.4E+03	2.0E+02	4.7E+01	4.3E+01
	Professional and consumer use	2.6E-02	7.4E+01	7.8E-03	7.5E-04	5.2E+02	1.2E+02	4.1E+01	4.0E+01
Abrasives	Formulation	4.7E+00	1.3E+04	4.8E-01	4.7E-02	3.2E+04	3.2E+03	2.6E+02	1.3E+02
	Industrial use (sandblasting)	0.0E+00	0.0E+00	5.3E-03	4.9E-04	3.5E+02	9.8E+01	1.4E+02	2.4E+02
	Professional use (sandblasting)	0.0E+00	0.0E+00	5.3E-03	4.9E-04	3.5E+02	9.8E+01	4.1E+01	4.3E+01
Oil and gas	Formulation	1.6E+01	4.5E+04	1.6E+00	1.6E-01	1.0E+05	1.1E+04	7.9E+02	3.5E+02
	Industrial use	1.2E+01	3.4E+04	1.2E+00	1.2E-01	7.9E+04	7.9E+03	6.0E+02	2.7E+02
Agriculture	Formulation	1.6E+01	4.5E+04	1.6E+00	1.6E-01	1.0E+05	1.1E+04	7.9E+02	3.5E+02
	Professional and consumer use	1.4E-02 ^a	n/a	6.6E-03	6.3E-04	4.4E+02	1.1E+02	5.1E+01	4.4E+01



Scenario		STP effluent (total) – mg/l	Sewage sludge - mg/kg dry wt.	PEC Surface water (total) – mg/l	PEC Marine water (total) – mg/l	PEC Freshwater sediment – mg/kg dry wt.	PEC Marine sediment – mg/kg dry wt.	PEC Agricultural soil – mg/kg dry wt.	PEC Grassland – mg/kg dry wt.
Regional	Regional concentrations			5.3E-03	4.9E-04	7.0E+02	2.0E+02	6.4E+01	4.0E+01 ^b

Note: a) Represents the concentration in surface water prior to dilution.
b) Concentration in natural soil.

Table C10 Mass-based PEC calculations – 84% removal in waste water treatment plant

Scenario		STP effluent (total) – mg/l	Sewage sludge - mg/kg dry wt.	PEC Surface water (total) – mg/l	PEC Marine water (total) – mg/l	PEC Freshwater sediment – mg/kg dry wt.	PEC Marine sediment – mg/kg dry wt.	PEC Agricultural soil – mg/kg dry wt.	PEC Grassland – mg/kg dry wt.
Personal care products	Formulation - low viscosity - large scale	1.6E-01	2.1E+03	2.0E-02	2.0E-03	1.3E+03	1.8E+02	7.8E+01	5.6E+01
	Formulation - low viscosity - medium scale	8.6E-02	1.2E+03	1.2E-02	1.2E-03	8.2E+02	1.3E+02	6.1E+01	5.0E+01
	Formulation - low viscosity - small scale	1.7E-02	2.3E+02	5.4E-03	5.4E-04	3.6E+02	8.6E+01	4.6E+01	4.4E+01
	Formulation - high viscosity - medium scale	4.3E-01	5.7E+03	4.7E-02	4.7E-03	3.1E+03	3.6E+02	1.4E+02	8.1E+01
	Formulation - high viscosity - small scale	1.9E-03	2.6E+01	3.8E-03	3.9E-04	2.6E+02	7.5E+01	4.3E+01	4.2E+01
	Formulation - creams - large scale	1.6E+00	2.1E+04	1.6E-01	1.6E-02	1.1E+04	1.1E+03	4.0E+02	1.8E+02
	Formulation - creams - medium scale	8.6E-01	1.2E+04	9.0E-02	9.0E-03	6.0E+03	6.6E+02	2.3E+02	1.2E+02
	Formulation - creams - small scale	1.7E-01	2.3E+03	2.1E-02	2.1E-03	1.4E+03	1.9E+02	8.1E+01	5.8E+01
	Professional and consumer use - 4.5 kg/d	5.4E-01	4.8E+03	5.8E-02	5.8E-03	2.6E+03	3.1E+02	1.2E+02	7.4E+01



Scenario		STP effluent (total) – mg/l	Sewage sludge - mg/kg dry wt.	PEC Surface water (total) – mg/l	PEC Marine water (total) – mg/l	PEC Freshwater sediment – mg/kg dry wt.	PEC Marine sediment – mg/kg dry wt.	PEC Agricultural soil – mg/kg dry wt.	PEC Grassland – mg/kg dry wt.
	Professional and consumer use - 0.39 kg/day	3.1E-02	4.2E+02	6.8E-03	6.8E-04	4.5E+02	9.5E+01	4.9E+01	4.5E+01
Paints and coatings	Formulation	4.0E-03	5.3E+01	4.1E-03	4.1E-04	2.7E+02	7.7E+01	4.3E+01	4.3E+01
	Industrial use	0.0E+00	0.0E+00	3.7E-03	3.7E-04	2.4E+02	7.4E+01	4.2E+01	4.2E+01
	Professional and consumer use	1.7E-02	2.2E+02	5.3E-03	5.4E-04	3.5E+02	8.5E+01	4.6E+01	4.4E+01
Detergents	Formulation - low viscosity products	2.6E-02	3.4E+02	6.2E-03	6.3E-04	4.1E+02	9.1E+01	4.8E+01	4.5E+01
	Formulation - high viscosity products	5.1E-02	6.8E+02	8.8E-03	8.8E-04	5.8E+02	1.1E+02	5.4E+01	4.7E+01
	Professional and consumer use	8.0E-03	1.2E+02	4.5E-03	4.5E-04	3.0E+02	8.0E+01	4.4E+01	4.3E+01
Abrasives	Formulation	1.6E+00	2.1E+03	1.6E-01	1.6E-02	1.1E+04	1.1E+03	4.0E+02	1.8E+02
	Industrial use (sandblasting)	0.0E+00	0.0E+00	3.7E-03	3.7E-04	2.4E+02	7.4E+01	1.4E+02	2.5E+02
	Professional use (sandblasting)	0.0E+00	0.0E+00	3.7E-03	3.7E-04	2.4E+02	7.4E+01	4.4E+01	4.6E+01
Oil and gas	Formulation	5.3E+00	7.1E+04	5.4E-01	5.4E-02	3.6E+04	3.6E+03	1.2E+03	5.3E+02
	Industrial use	4.0E+00	5.3E+04	4.0E-01	4.0E-02	2.7E+04	2.7E+03	9.3E+02	4.1E+02
Agriculture	Formulation	5.3E+00	7.1E+04	5.4E-01	5.4E-02	3.6E+04	3.6E+03	1.2E+03	5.3E+02
	Professional and consumer use	1.4E-02 ^a	n/a	5.0E-03	5.1E-04	3.3E+02	8.3E+01	5.3E+01	4.7E+01



Scenario		STP effluent (total) – mg/l	Sewage sludge - mg/kg dry wt.	PEC Surface water (total) – mg/l	PEC Marine water (total) – mg/l	PEC Freshwater sediment – mg/kg dry wt.	PEC Marine sediment – mg/kg dry wt.	PEC Agricultural soil – mg/kg dry wt.	PEC Grassland – mg/kg dry wt.
Regional	Regional concentrations			3.7E-03	3.7E-04	4.9E+02	1.5E+02	8.0E+01	4.2E+01 ^b

Note: a) Represents the concentration in surface water prior to dilution.
b) Concentration in natural soil.



Table C11 Mass-based PEC calculations – 92% removal in waste water treatment plant

Scenario		STP effluent (total) – mg/l	Sewage sludge - mg/kg dry wt.	PEC Surface water (total) – mg/l	PEC Marine water (total) – mg/l	PEC Freshwater sediment – mg/kg dry wt.	PEC Marine sediment – mg/kg dry wt.	PEC Agricultural soil – mg/kg dry wt.	PEC Grassland – mg/kg dry wt.
Personal care products	Formulation - low viscosity - large scale	8.0E-02	2.3E+03	1.1E-02	1.1E-03	7.5E+02	1.2E+02	8.2E+01	5.9E+01
	Formulation - low viscosity - medium scale	4.3E-02	1.3E+03	7.6E-03	7.7E-04	5.0E+02	9.7E+01	6.4E+01	5.1E+01
	Formulation - low viscosity - small scale	8.6E-03	2.5E+02	4.1E-03	4.3E-04	2.7E+02	7.4E+01	4.7E+01	4.5E+01
	Formulation - high viscosity - medium scale	2.2E-01	6.3E+03	2.5E-02	2.5E-03	1.7E+03	2.1E+02	1.5E+02	8.5E+01
	Formulation - high viscosity - small scale	9.6E-04	2.8E+01	3.3E-03	3.5E-04	2.2E+02	6.9E+01	4.3E+01	4.3E+01
	Formulation - creams - large scale	8.0E-01	2.3E+04	8.3E-02	8.3E-03	5.6E+03	6.0E+02	4.3E+02	2.0E+02
	Formulation - creams - medium scale	4.3E-01	1.3E+04	4.6E-02	4.7E-03	3.1E+03	3.6E+02	2.5E+02	1.3E+02
	Formulation - creams - small scale	8.6E-02	2.5E+03	1.2E-02	1.2E-03	7.9E+02	1.3E+02	8.5E+01	6.0E+01
	Professional and consumer use - 4.5 kg/d	1.8E-01	5.2E+03	2.1E-02	2.1E-03	1.4E+03	1.9E+02	1.3E+02	7.8E+01



Scenario		STP effluent (total) – mg/l	Sewage sludge - mg/kg dry wt.	PEC Surface water (total) – mg/l	PEC Marine water (total) – mg/l	PEC Freshwater sediment – mg/kg dry wt.	PEC Marine sediment – mg/kg dry wt.	PEC Agricultural soil – mg/kg dry wt.	PEC Grassland – mg/kg dry wt.
	Professional and consumer use - 0.39 kg/day	1.6E-02	4.5E+02	4.8E-03	5.0E-04	3.2E+02	7.8E+01	5.0E+01	
Paints and coatings	Formulation	2.0E-03	5.8E+01	3.4E-03	3.6E-04	2.3E+02	6.9E+01	4.4E+01	4.3E+01
	Industrial use	0.0E+00	0.0E+00	3.2E-03	3.4E-04	2.2E+02	6.8E+01	4.3E+01	4.3E+01
	Professional and consumer use	8.3E-03	2.4E+02	4.1E-03	4.2E-04	2.7E+02	7.4E+01	4.7E+01	4.5E+01
Detergents	Formulation - low viscosity products	1.3E-02	3.7E+02	4.5E-03	4.7E-04	3.0E+02	7.6E+01	4.9E+01	4.5E+01
	Formulation - high viscosity products	2.6E-02	7.5E+02	5.8E-03	6.0E-04	3.9E+02	8.5E+01	5.5E+01	4.8E+01
	Professional and consumer use	4.4E-03	1.3E+02	3.7E-03	3.8E-04	2.5E+02	7.1E+01	4.5E+01	4.4E+01
Abrasives	Formulation	8.0E-01	2.3E+04	8.3E-02	8.3E-03	5.6E+03	6.0E+02	4.3E+02	2.0E+02
	Industrial use (sandblasting)	0.0E+00	0.0E+00	3.2E-03	3.4E-04	2.2E+02	6.8E+01	1.4E+02	2.5E+02
	Professional use (sandblasting)	0.0E+00	0.0E+00	3.2E-03	3.4E-04	2.2E+02	6.8E+01	4.5E+01	4.6E+01
Oil and gas	Formulation	2.7E+00	7.8E+04	2.7E-01	2.7E-02	1.8E+04	1.8E+03	1.3E+03	5.8E+02
	Industrial use	2.0E+00	5.3E+04	2.0E-01	2.0E-02	1.4E+04	1.4E+03	1.0E+03	4.4E+02
Agriculture	Formulation	2.7E+00	7.8E+04	2.7E-01	2.7E-02	1.8E+04	1.8E+03	1.3E+03	5.8E+02
	Professional and consumer use	1.4E-02 ^a	n/a	4.6E-03	4.8E-04	3.1E+02	7.7E+01	5.4E+01	4.7E+01
Regional	Regional concentrations			3.2E-03	3.4E-04	4.3E+02	1.4E+02	8.4E+01	4.3E+01 ^b



Note: a) Represents the concentration in surface water prior to dilution.
b) Concentration in natural soil.

Table C12 Mass-based Clocal calculations – 53% removal in waste water treatment plant

Scenario		C _{local} Surface water (total) – mg/l	C _{local} Marine water (total) – mg/l	C _{local} Freshwater sediment – mg/kg dry wt.	C _{local} Marine sediment – mg/kg dry wt.	C _{local} Agricultural soil – mg/kg dry wt.	C _{local} Grassland – mg/kg dry wt.
Personal care products	Formulation - low viscosity - large scale	4.7E-02	4.7E-03	3.1E+03	3.1E+02	2.2E+01	8.9E+00
	Formulation - low viscosity - medium scale	2.5E-02	2.5E-03	1.7E+03	1.7E+02	1.2E+01	4.8E+00
	Formulation - low viscosity - small scale	5.1E-03	5.1E-04	3.4E+02	3.4E+01	2.4E+00	9.7E-01
	Formulation - high viscosity - medium scale	1.3E-01	1.3E-02	8.4E+03	8.5E+02	6.0E+01	2.4E+01
	Formulation - high viscosity - small scale	5.6E-04	5.6E-05	3.8E+01	3.7E+00	2.7E-01	1.1E-01
	Formulation - creams - large scale	4.7E-01	4.7E-02	3.1E+04	3.1E+03	2.2E+02	8.9E+01
	Formulation - creams - medium scale	2.5E-01	2.5E-02	1.7E+04	1.7E+03	1.2E+02	4.8E+01
	Formulation - creams - small scale	5.1E-02	5.1E-03	3.4E+03	3.4E+02	2.4E+01	9.7E+00
	Professional and consumer use - 4.5 kg/d	1.1E-01	1.1E-02	7.0E+03	7.0E+02	5.0E+01	2.0E+01
	Professional and consumer use - 0.39 kg/day	9.2E-03	9.2E-04	6.1E+02	6.1E+01	4.4E+00	1.7E+00
Paints and coatings	Formulation	1.2E-03	1.2E-04	7.8E+01	7.8E+00	5.7E-01	2.4E-01
	Industrial use	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.0E-02	6.1E-02
	Professional and consumer use	4.9E-03	4.9E-04	3.3E+02	3.3E+01	2.3E+00	9.9E-01
Detergents	Formulation - low viscosity products	7.5E-03	7.5E-04	5.0E+02	5.0E+01	3.6E+00	1.4E+00



Scenario		C _{local} Surface water (total) – mg/l	C _{local} Marine water (total) – mg/l	C _{local} Freshwater sediment – mg/kg dry wt.	C _{local} Marine sediment – mg/kg dry wt.	C _{local} Agricultural soil – mg/kg dry wt.	C _{local} Grassland – mg/kg dry wt.
	Formulation - high viscosity products	1.5E-02	1.5E-03	1.0E+03	1.0E+02	7.2E+00	2.9E+00
	Professional and consumer use	2.6E-03	2.6E-04	1.7E+02	1.7E+01	1.2E+00	1.2E+00
Abrasives	Formulation	4.7E-01	4.7E-02	3.1E+04	3.1E+03	2.2E+02	9.1E+01
	Industrial use (sandblasting)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.0E+02	2.1E+02
	Professional use (sandblasting)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.7E+00	3.4E+00
Oil and gas	Formulation	1.6E+00	1.6E-01	1.0E+05	1.0E+04	7.5E+02	3.2E+02
	Industrial use	1.2E+00	1.2E-01	7.8E+04	7.8E+03	5.6E+02	2.3E+02
Agriculture	Formulation	1.6E+00	1.6E-01	1.0E+05	1.0E+04	7.5E+02	3.2E+02
	Professional and consumer use	1.4E-03	1.4E-04	9.2E+01	9.2E+00	1.1E+01	4.4E+00



Table C13 Mass-based Clocal calculations – 84% removal in waste water treatment plant

Scenario		C _{local} Surface water (total) – mg/l	C _{local} Marine water (total) – mg/l	C _{local} Freshwater sediment – mg/kg dry wt.	C _{local} Marine sediment – mg/kg dry wt.	C _{local} Agricultural soil – mg/kg dry wt.	C _{local} Grassland – mg/kg dry wt.
Personal care products	Formulation - low viscosity - large scale	1.6E-02	1.6E-03	1.1E+03	1.1E+02	3.5E+01	1.4E+01
	Formulation - low viscosity - medium scale	8.6E-03	8.6E-04	5.8E+02	5.8E+01	1.9E+01	7.7E+00
	Formulation - low viscosity - small scale	1.7E-03	1.7E-04	1.2E+02	1.2E+01	3.8E+00	1.5E+00
	Formulation - high viscosity - medium scale	4.3E-02	4.3E-03	2.9E+03	2.9E+02	9.6E+01	3.8E+01
	Formulation - high viscosity - small scale	1.9E-04	1.9E-05	1.3E+01	1.4E+00	4.3E-01	1.7E-01
	Formulation - creams - large scale	1.6E-01	1.6E-02	1.1E+04	1.1E+03	3.5E+02	1.4E+02
	Formulation - creams - medium scale	8.6E-02	8.6E-03	5.7E+03	5.9E+02	1.9E+02	7.7E+01
	Formulation - creams - small scale	1.7E-02	1.7E-03	1.2E+03	1.2E+02	3.8E+01	1.5E+01
	Professional and consumer use - 4.5 kg/d	5.4E-02	5.4E-03	2.4E+03	2.4E+02	7.9E+01	3.2E+01
	Professional and consumer use - 0.39 kg/day	3.1E-03	3.1E-04	2.1E+02	2.1E+01	6.9E+00	2.8E+00
Paints and coatings	Formulation	4.0E-04	4.0E-05	2.7E+01	2.8E+00	8.9E-01	3.7E-01
	Industrial use	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.0E-02	6.1E-02
	Professional and consumer use	1.7E-03	1.7E-04	1.1E+02	1.1E+01	3.7E+00	1.5E+00
Detergents	Formulation - low viscosity products	2.6E-03	2.6E-04	1.7E+02	1.7E+01	5.7E+00	2.3E+00

Scenario		C _{local} Surface water (total) – mg/l	C _{local} Marine water (total) – mg/l	C _{local} Freshwater sediment – mg/kg dry wt.	C _{local} Marine sediment – mg/kg dry wt.	C _{local} Agricultural soil – mg/kg dry wt.	C _{local} Grassland – mg/kg dry wt.
	Formulation - high viscosity products	5.1E-03	5.1E-04	3.4E+02	3.4E+01	1.1E+01	4.5E+00
	Professional and consumer use	8.0E-04	8.0E-05	5.8E+01	6.0E+00	2.0E+00	7.8E-01
Abrasives	Formulation	1.6E-01	1.6E-02	1.1E+04	1.1E+03	3.5E+02	1.4E+02
	Industrial use (sandblasting)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.0E+02	2.1E+02
	Professional use (sandblasting)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.7E+00	3.4E+00
Oil and gas	Formulation	5.3E-01	5.3E-02	3.6E+04	3.6E+03	1.2E+03	4.9E+02
	Industrial use	4.0E-01	4.0E-02	2.7E+04	2.7E+03	8.9E+02	3.6E+02
Agriculture	Formulation	5.3E-01	5.3E-02	3.6E+04	3.6E+03	1.2E+03	4.9E+02
	Professional and consumer use	1.4E-03	1.4E-04	9.1E+01	9.2E+00	1.1E+01	4.4E+00

Table C14 Mass-based Clocal calculations – 92% removal in waste water treatment plant

Scenario		C _{local} Surface water (total) – mg/l	C _{local} Marine water (total) – mg/l	C _{local} Freshwater sediment – mg/kg dry wt.	C _{local} Marine sediment – mg/kg dry wt.	C _{local} Agricultural soil – mg/kg dry wt.	C _{local} Grassland – mg/kg dry wt.
Personal care products	Formulation - low viscosity - large scale	8.0E-03	8.0E-04	5.3E+02	5.3E+01	3.9E+01	1.6E+01
	Formulation - low viscosity - medium scale	4.3E-03	4.3E-04	2.9E+02	2.9E+01	2.1E+01	8.4E+00
	Formulation - low viscosity - small scale	8.6E-04	8.6E-05	5.8E+01	5.5E+00	4.2E+00	1.7E+00
	Formulation - high viscosity - medium scale	2.2E-02	2.2E-03	1.4E+03	1.4E+02	1.0E+02	4.2E+01
	Formulation - high viscosity - small scale	9.6E-05	9.6E-06	6.4E+00	4.6E-01	4.6E-01	1.9E-01
	Formulation - creams - large scale	8.0E-02	8.0E-03	5.4E+03	5.3E+02	3.9E+02	1.6E+02
	Formulation - creams - medium scale	4.3E-02	4.3E-03	2.9E+03	2.9E+02	2.1E+02	8.4E+01
	Formulation - creams - small scale	8.6E-03	8.6E-04	5.8E+02	5.8E+01	4.2E+01	1.7E+01
	Professional and consumer use - 4.5 kg/d	1.8E-02	1.8E-03	1.2E+03	1.2E+02	8.7E+01	3.5E+01
	Professional and consumer use - 0.39 kg/day	1.6E-03	1.6E-04	1.0E+02	1.0E+01	7.6E+00	3.0E+00
Paints and coatings	Formulation	2.0E-04	2.0E-05	1.3E+01	9.2E-01	9.8E-01	4.0E-01
	Industrial use	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.0E-02	6.1E-02
	Professional and consumer use	8.3E-04	8.3E-05	5.6E+01	5.5E+00	4.1E+00	1.7E+00
Detergents	Formulation - low viscosity products	1.3E-03	1.3E-04	8.6E+01	8.3E+00	6.2E+00	2.5E+00



Scenario		C _{local} Surface water (total) – mg/l	C _{local} Marine water (total) – mg/l	C _{local} Freshwater sediment – mg/kg dry wt.	C _{local} Marine sediment – mg/kg dry wt.	C _{local} Agricultural soil – mg/kg dry wt.	C _{local} Grassland – mg/kg dry wt.
	Formulation - high viscosity products	2.6E-03	2.6E-04	1.7E+02	1.7E+01	1.2E+01	5.0E+00
	Professional and consumer use	4.4E-04	4.4E-05	2.9E+01	2.8E+00	2.1E+00	8.5E-01
Abrasives	Formulation	8.0E-02	8.0E-03	5.4E+03	5.3E+02	3.9E+02	1.6E+02
	Industrial use (sandblasting)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.0E+02	2.1E+02
	Professional use (sandblasting)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.7E+00	3.4E+00
Oil and gas	Formulation	2.7E-01	2.7E-02	1.8E+04	1.8E+03	1.3E+03	5.3E+02
	Industrial use	2.0E-01	2.0E-02	1.3E+04	1.3E+03	9.8E+02	4.0E+02
Agriculture	Formulation	2.7E-01	2.7E-02	1.8E+04	1.8E+03	1.3E+03	5.3E+02
	Professional and consumer use	1.4E-03	1.4E-04	9.2E+01	8.7E+00	1.1E+01	4.4E+00



Table C15 Particle-based PEC calculations – 53% removal in waste water treatment plant

Scenario		STP effluent (total) – particles/l	Sewage sludge - particles/kg dry wt.	PEC Surface water (total) – particles/l	PEC Marine water (total) – particles/l	PEC Freshwater sediment – particles/kg dry wt.	PEC Marine sediment – particles/kg dry wt.	PEC Agricultural soil – particles/kg dry wt.	PEC Grassland – particles/kg dry wt.
Personal care products	Formulation - low viscosity - large scale	1.1E+02	3.2E+05	1.2E+01	1.2E+00	8.3E+05	9.8E+04	1.5E+04	1.2E+04
	Formulation - low viscosity - medium scale	6.1E+01	1.7E+05	7.3E+00	7.2E-01	4.9E+05	6.4E+04	1.2E+04	1.1E+04
	Formulation - low viscosity - small scale	1.2E+01	3.5E+04	2.5E+00	2.4E-01	1.6E+05	3.2E+04	1.0E+04	9.7E+03
	Formulation - high viscosity - medium scale	3.0E+02	8.7E+05	3.2E+01	3.2E+00	2.1E+06	2.3E+05	2.4E+04	1.5E+04
	Formulation - high viscosity - small scale	1.3E+00	3.8E+03	1.4E+00	1.3E-01	9.3E+04	2.4E+04	9.5E+03	9.5E+03
	Formulation - creams - large scale	1.1E+03	3.2E+06	1.1E+02	1.1E+01	7.6E+06	7.7E+05	6.3E+04	3.1E+04
	Formulation - creams - medium scale	6.1E+02	1.7E+06	6.2E+01	6.2E+00	4.1E+06	4.3E+05	3.8E+04	2.1E+04
	Formulation - creams - small scale	1.2E+02	3.5E+05	1.3E+01	1.3E+00	8.9E+05	1.0E+05	1.5E+04	1.2E+04
	Professional and consumer use - 4.5 kg/d	2.5E+02	7.2E+05	2.7E+01	2.7E+00	1.8E+06	1.9E+05	2.1E+04	1.4E+04

Scenario		STP effluent (total) – particles/l	Sewage sludge - particles/kg dry wt.	PEC Surface water (total) – particles/l	PEC Marine water (total) – particles/l	PEC Freshwater sediment – particles/kg dry wt.	PEC Marine sediment – particles/kg dry wt.	PEC Agricultural soil – particles/kg dry wt.	PEC Grassland – particles/kg dry wt.
	Professional and consumer use - 0.39 kg/day	2.2E+01	6.3E+04	3.4E+00	3.4E-01	2.3E+05	3.8E+04	1.1E+04	9.9E+03
Paints and coatings	Formulation	2.8E+00	8.0E+03	1.5E+00	1.5E-01	1.0E+05	2.5E+04	9.6E+03	9.5E+03
	Industrial use	0.0E+00	0.0E+00	1.3E+00	1.2E-01	8.4E+04	2.3E+04	9.5E+03	9.5E+03
	Professional and consumer use	1.2E+01	3.3E+04	2.4E+00	2.3E-01	1.6E+05	3.1E+04	1.0E+04	9.7E+03
Detergents	Formulation - low viscosity products	1.8E+01	5.1E+04	3.1E+00	3.0E-01	2.0E+05	3.5E+04	1.0E+04	9.8E+03
	Formulation - high viscosity products	3.6E+01	1.0E+05	4.8E+00	4.8E-01	3.2E+05	4.7E+04	1.1E+04	1.0E+04
	Professional and consumer use	6.2E+00	1.8E+04	1.9E+00	1.8E-01	1.2E+05	2.8E+04	9.8E+03	9.6E+03
Abrasives	Formulation	1.1E+03	3.2E+06	1.1E+02	1.1E+01	7.6E+06	7.7E+05	6.3E+04	3.1E+04
	Industrial use (sandblasting)	0.0E+00	0.0E+00	1.3E+00	1.2E-01	8.4E+04	2.3E+04	3.3E+04	5.9E+04
	Professional use (sandblasting)	0.0E+00	0.0E+00	1.3E+00	1.2E-01	8.4E+04	2.3E+04	9.9E+03	1.0E+04
Oil and gas	Formulation	3.8E+03	1.1E+07	3.8E+02	3.8E+01	2.5E+07	2.5E+06	1.9E+05	8.5E+04
	Industrial use	2.8E+03	8.0E+06	2.8E+02	2.8E+01	1.9E+07	1.9E+06	1.4E+05	6.5E+04
Agriculture	Formulation	3.8E+03	1.1E+07	3.8E+02	3.8E+01	2.5E+07	2.5E+06	1.9E+05	8.5E+04
	Professional and consumer use	3.3E+00 ^a	n/a	1.6E+00	1.5E-01	1.1E+05	2.6E+04	1.2E+04	1.1E+04



Scenario	STP effluent (total) – particles/l	Sewage sludge - particles/kg dry wt.	PEC Surface water (total) – particles/l	PEC Marine water (total) – particles/l	PEC Freshwater sediment – particles/kg dry wt.	PEC Marine sediment – particles/kg dry wt.	PEC Agricultural soil – particles/kg dry wt.	PEC Grassland – particles/kg dry wt.
Regional	Regional concentrations		1.3E+00	1.2E-01	1.7E+05	4.7E+04	1.5E+04	9.5E+03 ^b

Note: a) Represents the concentration in surface water prior to dilution.
b) Concentration in natural soil.

Table C16 Particle-based PEC calculations – 84% removal in waste water treatment plant

Scenario		STP effluent (total) – particles/l	Sewage sludge - particles/kg dry wt.	PEC Surface water (total) – particles/l	PEC Marine water (total) – particles/l	PEC Freshwater sediment – particles/kg dry wt.	PEC Marine sediment – particles/kg dry wt.	PEC Agricultural soil – particles/kg dry wt.	PEC Grassland – particles/kg dry wt.
Personal care products	Formulation - low viscosity - large scale	3.8E+01	5.1E+05	4.7E+00	4.7E-01	3.1E+05	4.3E+04	1.9E+04	1.3E+04
	Formulation - low viscosity - medium scale	2.1E+01	2.7E+05	2.9E+00	3.0E-01	2.0E+05	3.1E+04	1.5E+04	1.2E+04
	Formulation - low viscosity - small scale	4.1E+00	5.5E+04	1.3E+00	1.3E-01	8.6E+04	2.0E+04	1.1E+04	1.0E+04
	Formulation - high viscosity - medium scale	1.0E+02	1.4E+06	1.1E+01	1.1E+00	7.5E+05	8.6E+04	3.3E+04	1.9E+04
	Formulation - high viscosity - small scale	4.6E-01	6.1E+03	9.2E-01	9.3E-02	6.1E+04	1.8E+04	1.0E+04	1.0E+04
	Formulation - creams - large scale	3.8E+02	5.1E+06	3.9E+01	3.9E+00	2.6E+06	2.7E+05	9.5E+04	4.4E+04
	Formulation - creams - medium scale	2.1E+02	2.7E+06	2.2E+01	2.2E+00	1.4E+06	1.6E+05	5.6E+04	2.8E+04
	Formulation - creams - small scale	4.1E+01	5.5E+05	5.0E+00	5.0E-01	3.3E+05	4.5E+04	1.9E+04	1.4E+04
	Professional and consumer use - 4.5 kg/d	1.3E+02	1.1E+06	1.4E+01	1.4E+00	6.3E+05	7.5E+04	2.9E+04	1.8E+04
Professional and consumer use - 0.39 kg/day	7.5E+00	9.9E+04	1.6E+00	1.6E-01	1.1E+05	2.3E+04	1.2E+04	1.1E+04	



Scenario		STP effluent (total) – particles/l	Sewage sludge - particles/kg dry wt.	PEC Surface water (total) – particles/l	PEC Marine water (total) – particles/l	PEC Freshwater sediment – particles/kg dry wt.	PEC Marine sediment – particles/kg dry wt.	PEC Agricultural soil – particles/kg dry wt.	PEC Grassland – particles/kg dry wt.
Paints and coatings	Formulation	9.6E-01	1.3E+04	9.7E-01	9.8E-02	6.5E+04	1.8E+04	1.0E+04	1.0E+04
	Industrial use	0.0E+00	0.0E+00	8.7E-01	8.9E-02	5.8E+04	1.8E+04	1.0E+04	1.0E+04
	Professional and consumer use	4.0E+00	5.3E+04	1.3E+00	1.3E-01	8.5E+04	2.0E+04	1.1E+04	1.0E+04
Detergents	Formulation - low viscosity products	6.1E+00	8.1E+04	1.5E+00	1.5E-01	9.9E+04	2.2E+04	1.1E+04	1.1E+04
	Formulation - high viscosity products	1.2E+01	1.6E+05	2.1E+00	2.1E-01	1.4E+05	2.6E+04	1.3E+04	1.1E+04
	Professional and consumer use	1.9E+00	2.8E+04	1.1E+00	1.1E-01	7.2E+04	1.9E+04	1.1E+04	1.0E+04
Abrasives	Formulation	3.8E+02	5.1E+05	3.9E+01	3.9E+00	2.6E+06	2.7E+05	9.5E+04	4.4E+04
	Industrial use (sandblasting)	0.0E+00	0.0E+00	8.7E-01	8.9E-02	5.8E+04	1.8E+04	3.4E+04	5.9E+04
	Professional use (sandblasting)	0.0E+00	0.0E+00	8.7E-01	8.9E-02	5.8E+04	1.8E+04	1.1E+04	1.1E+04
Oil and gas	Formulation	1.3E+03	1.7E+07	1.3E+02	1.3E+01	8.6E+06	8.7E+05	3.0E+05	1.3E+05
	Industrial use	9.6E+02	1.3E+07	9.6E+01	9.6E+00	6.4E+06	6.5E+05	2.2E+05	9.7E+04
Agriculture	Formulation	1.3E+03	1.7E+07	1.3E+02	1.3E+01	8.6E+06	8.7E+05	3.0E+05	1.3E+05
	Professional and consumer use	3.3E+00 ^a	n/a	1.2E+00	1.2E-01	8.0E+04	2.0E+04	1.3E+04	1.1E+04
Regional	Regional concentrations			8.7E-01	8.9E-02	1.2E+05	3.5E+04	1.9E+04	1.0E+04 ^b

Note: a) Represents the concentration in surface water prior to dilution.
 b) Concentration in natural soil.

Table C17 Particle-based PEC calculations – 92% removal in waste water treatment plant

Scenario	STP effluent (total) – particles/l	Sewage sludge - particles/kg dry wt.	PEC Surface water (total) – particles/l	PEC Marine water (total) – particles/l	PEC Freshwater sediment – particles/kg dry wt.	PEC Marine sediment – particles/kg dry wt.	PEC Agricultural soil – particles/kg dry wt.	PEC Grassland – particles/kg dry wt.	
Personal care products	Formulation - low viscosity - large scale	1.91E+01	5.57E+05	2.69E+00	2.72E-01	1.79E+05	2.89E+04	1.95E+04	1.40E+04
	Formulation - low viscosity - medium scale	1.03E+01	3.01E+05	1.81E+00	1.85E-01	1.20E+05	2.31E+04	1.53E+04	1.23E+04
	Formulation - low viscosity - small scale	2.06E+00	6.02E+04	9.81E-01	1.02E-01	6.53E+04	1.76E+04	1.13E+04	1.07E+04
	Formulation - high viscosity - medium scale	5.16E+01	1.50E+06	5.94E+00	5.98E-01	3.96E+05	5.06E+04	3.52E+04	2.03E+04
	Formulation - high viscosity - small scale	2.29E-01	6.67E+03	7.97E-01	8.36E-02	5.31E+04	1.64E+04	1.04E+04	1.03E+04
	Formulation - creams - large scale	1.91E+02	5.57E+06	1.99E+01	1.99E+00	1.33E+06	1.44E+05	1.03E+05	4.74E+04
	Formulation - creams - medium scale	1.03E+02	3.01E+06	1.11E+01	1.11E+00	7.40E+05	8.50E+04	6.04E+04	3.04E+04
	Formulation - creams - small scale	2.06E+01	6.02E+05	2.84E+00	2.88E-01	1.89E+05	3.00E+04	2.03E+04	1.43E+04
	Professional and consumer use - 4.5 kg/d	4.30E+01	1.25E+06	5.08E+00	5.11E-01	3.38E+05	4.49E+04	3.12E+04	1.86E+04
	Professional and consumer use - 0.39 kg/day	3.73E+00	1.09E+05	1.15E+00	1.19E-01	7.64E+04	1.87E+04	1.21E+04	1.10E+04



Scenario		STP effluent (total) – particles/l	Sewage sludge - particles/kg dry wt.	PEC Surface water (total) – particles/l	PEC Marine water (total) – particles/l	PEC Freshwater sediment – particles/kg dry wt.	PEC Marine sediment – particles/kg dry wt.	PEC Agricultural soil – particles/kg dry wt.	PEC Grassland – particles/kg dry wt.
Paints and coatings	Formulation	4.78E-01	1.39E+04	8.22E-01	8.60E-02	5.48E+04	1.65E+04	1.05E+04	1.04E+04
	Industrial use	0.00E+00	0.00E+00	7.74E-01	8.13E-02	5.16E+04	1.63E+04	1.03E+04	1.03E+04
	Professional and consumer use	1.99E+00	5.78E+04	9.73E-01	1.01E-01	6.49E+04	1.76E+04	1.12E+04	1.07E+04
Detergents	Formulation - low viscosity products	3.06E+00	8.91E+04	1.08E+00	1.12E-01	7.20E+04	1.83E+04	1.17E+04	1.09E+04
	Formulation - high viscosity products	6.12E+00	1.78E+05	1.39E+00	1.42E-01	9.23E+04	2.03E+04	1.32E+04	1.14E+04
	Professional and consumer use	1.05E+00	3.06E+04	8.80E-01	9.18E-02	5.86E+04	1.69E+04	1.08E+04	1.05E+04
Abrasives	Formulation	1.91E+02	5.57E+06	1.99E+01	1.99E+00	1.33E+06	1.44E+05	1.03E+05	4.77E+04
	Industrial use (sandblasting)	0.00E+00	0.00E+00	7.74E-01	8.13E-02	5.16E+04	1.63E+04	3.41E+04	5.91E+04
	Professional use (sandblasting)	0.00E+00	0.00E+00	7.74E-01	8.13E-02	5.16E+04	1.63E+04	1.07E+04	1.11E+04
Oil and gas	Formulation	6.38E+02	1.86E+07	6.46E+01	6.46E+00	4.30E+06	4.41E+05	3.23E+05	1.38E+05
	Industrial use	4.78E+02	1.26E+07	4.86E+01	4.86E+00	3.23E+06	3.34E+05	2.43E+05	1.05E+05
Agriculture	Formulation	6.38E+02	1.86E+07	6.46E+01	6.46E+00	4.30E+06	4.41E+05	3.23E+05	1.38E+05
	Professional and consumer use	3.27E+00 ^a	n/a	1.10E+00	1.14E-01	7.34E+04	1.84E+04	1.29E+04	1.13E+04
Regional	Regional concentrations			7.74E-01	8.13E-02	1.03E+05	3.24E+04	2.00E+04	1.03E+04 ^b

Note: a) Represents the concentration in surface water prior to dilution.
 b) Concentration in natural soil.

Table C18 Particles-based C_{local} calculations – 53% removal in waste water treatment plant

Scenario		C _{local} Surface water (total) – particles/l	C _{local} Marine water (total) – particles/l	C _{local} Freshwater sediment – particles/kg dry wt.	C _{local} Marine sediment – particles/kg dry wt.	C _{local} Agricultural soil – particles/kg dry wt.	C _{local} Grassland – particles/kg dry wt.
Personal care products	Formulation - low viscosity - large scale	1.1E+01	1.1E+00	7.5E+05	7.5E+04	5.3E+03	2.1E+03
	Formulation - low viscosity - medium scale	6.1E+00	6.1E-01	4.0E+05	4.0E+04	2.9E+03	1.2E+03
	Formulation - low viscosity - small scale	1.2E+00	1.2E-01	8.1E+04	8.1E+03	5.8E+02	2.3E+02
	Formulation - high viscosity - medium scale	3.0E+01	3.0E+00	2.0E+06	2.0E+05	1.4E+04	5.8E+03
	Formulation - high viscosity - small scale	1.3E-01	1.3E-02	9.0E+03	8.8E+02	6.4E+01	2.6E+01
	Formulation - creams - large scale	1.1E+02	1.1E+01	7.5E+06	7.5E+05	5.3E+04	2.1E+04
	Formulation - creams - medium scale	6.1E+01	6.1E+00	4.0E+06	4.0E+05	2.9E+04	1.2E+04
	Formulation - creams - small scale	1.2E+01	1.2E+00	8.1E+05	8.1E+04	5.8E+03	2.3E+03
	Professional and consumer use - 4.5 kg/d	2.5E+01	2.5E+00	1.7E+06	1.7E+05	1.2E+04	4.8E+03
	Professional and consumer use - 0.39 kg/day	2.2E+00	2.2E-01	1.5E+05	1.5E+04	1.0E+03	4.2E+02
Paints and coatings	Formulation	2.8E-01	2.8E-02	1.9E+04	1.9E+03	1.4E+02	5.7E+01
	Industrial use	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.2E+00	1.5E+01
	Professional and consumer use	1.2E+00	1.2E-01	7.8E+04	7.8E+03	5.6E+02	2.4E+02
Detergents	Formulation - low viscosity products	1.8E+00	1.8E-01	1.2E+05	1.2E+04	8.5E+02	3.4E+02



Scenario		C _{local} Surface water (total) – particles/l	C _{local} Marine water (total) – particles/l	C _{local} Freshwater sediment – particles/kg dry wt.	C _{local} Marine sediment – particles/kg dry wt.	C _{local} Agricultural soil – particles/kg dry wt.	C _{local} Grassland – particles/kg dry wt.
Abrasives	Formulation - high viscosity products	3.6E+00	3.6E-01	2.4E+05	2.4E+04	1.7E+03	6.8E+02
	Professional and consumer use	6.2E-01	6.2E-02	4.1E+04	4.2E+03	2.9E+02	2.9E+02
	Formulation	1.1E+02	1.1E+01	7.5E+06	7.5E+05	5.4E+04	2.2E+04
	Industrial use (sandblasting)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.4E+04	4.9E+04
	Professional use (sandblasting)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.0E+02	8.2E+02
Oil and gas	Formulation	3.8E+02	3.8E+01	2.5E+07	2.5E+06	1.8E+05	7.5E+04
	Industrial use	2.8E+02	2.8E+01	1.9E+07	1.9E+06	1.3E+05	5.6E+04
Agriculture	Formulation	3.8E+02	3.8E+01	2.5E+07	2.5E+06	1.8E+05	7.5E+04
	Professional and consumer use	3.3E-01	3.3E-02	2.2E+04	2.2E+03	2.6E+03	1.0E+03



Table C19 Particles-based C_{local} calculations – 84% removal in waste water treatment plant

Scenario		C _{local} Surface water (total) – particles/l	C _{local} Marine water (total) – particles/l	C _{local} Freshwater sediment – particles/kg dry wt.	C _{local} Marine sediment – particles/kg dry wt.	C _{local} Agricultural soil – particles/kg dry wt.	C _{local} Grassland – particles/kg dry wt.
Personal care products	Formulation - low viscosity - large scale	3.8E+00	3.8E-01	2.6E+05	2.6E+04	8.5E+03	3.4E+03
	Formulation - low viscosity - medium scale	2.1E+00	2.1E-01	1.4E+05	1.4E+04	4.6E+03	1.8E+03
	Formulation - low viscosity - small scale	4.1E-01	4.1E-02	2.7E+04	2.7E+03	9.1E+02	3.7E+02
	Formulation - high viscosity - medium scale	1.0E+01	1.0E+00	6.9E+05	6.9E+04	2.3E+04	9.1E+03
	Formulation - high viscosity - small scale	4.6E-02	4.6E-03	3.1E+03	3.3E+02	1.0E+02	4.1E+01
	Formulation - creams - large scale	3.8E+01	3.8E+00	2.5E+06	2.5E+05	8.5E+04	3.4E+04
	Formulation - creams - medium scale	2.1E+01	2.1E+00	1.4E+06	1.4E+05	4.6E+04	1.8E+04
	Formulation - creams - small scale	4.1E+00	4.1E-01	2.7E+05	2.7E+04	9.1E+03	3.7E+03
	Professional and consumer use - 4.5 kg/d	1.3E+01	1.3E+00	5.7E+05	5.7E+04	1.9E+04	7.6E+03
	Professional and consumer use - 0.39 kg/day	7.5E-01	7.5E-02	5.0E+04	4.9E+03	1.7E+03	6.6E+02
Paints and coatings	Formulation	9.6E-02	9.6E-03	6.4E+03	6.6E+02	2.1E+02	8.8E+01
	Industrial use	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.2E+00	1.5E+01
	Professional and consumer use	4.0E-01	4.0E-02	2.6E+04	2.6E+03	8.9E+02	3.7E+02
Detergents	Formulation - low viscosity products	6.1E-01	6.1E-02	4.1E+04	4.1E+03	1.4E+03	5.4E+02



Scenario		C _{local} Surface water (total) – particles/l	C _{local} Marine water (total) – particles/l	C _{local} Freshwater sediment – particles/kg dry wt.	C _{local} Marine sediment – particles/kg dry wt.	C _{local} Agricultural soil – particles/kg dry wt.	C _{local} Grassland – particles/kg dry wt.
Abrasives	Formulation - high viscosity products	1.2E+00	1.2E-01	8.1E+04	8.1E+03	2.7E+03	1.1E+03
	Professional and consumer use	1.9E-01	1.9E-02	1.4E+04	1.4E+03	4.7E+02	1.9E+02
	Formulation	3.8E+01	3.8E+00	2.5E+06	2.5E+05	8.5E+04	3.4E+04
	Industrial use (sandblasting)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.4E+04	4.9E+04
	Professional use (sandblasting)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.0E+02	8.2E+02
Oil and gas	Formulation	1.3E+02	1.3E+01	8.5E+06	8.5E+05	2.8E+05	1.2E+05
	Industrial use	9.6E+01	9.6E+00	6.4E+06	6.4E+05	2.1E+05	8.7E+04
Agriculture	Formulation	1.3E+02	1.3E+01	8.5E+06	8.5E+05	2.8E+05	1.2E+05
	Professional and consumer use	3.3E-01	3.3E-02	2.2E+04	2.2E+03	2.6E+03	1.0E+03



Table C20 Particles-based Clocal calculations – 92% removal in waste water treatment plant

Scenario		C _{local} Surface water (total) – particles/l	C _{local} Marine water (total) – particles/l	C _{local} Freshwater sediment – particles/kg dry wt.	C _{local} Marine sediment – particles/kg dry wt.	C _{local} Agricultural soil – particles/kg dry wt.	C _{local} Grassland – particles/kg dry wt.
Personal care products	Formulation - low viscosity - large scale	1.9E+00	1.9E-01	1.3E+05	1.3E+04	9.3E+03	3.7E+03
	Formulation - low viscosity - medium scale	1.0E+00	1.0E-01	6.8E+04	6.8E+03	5.0E+03	2.0E+03
	Formulation - low viscosity - small scale	2.1E-01	2.1E-02	1.4E+04	1.3E+03	1.0E+03	4.0E+02
	Formulation - high viscosity - medium scale	5.2E+00	5.2E-01	3.4E+05	3.4E+04	2.5E+04	1.0E+04
	Formulation - high viscosity - small scale	2.3E-02	2.3E-03	1.5E+03	1.1E+02	1.1E+02	4.4E+01
	Formulation - creams - large scale	1.9E+01	1.9E+00	1.3E+06	1.3E+05	9.3E+04	3.7E+04
	Formulation - creams - medium scale	1.0E+01	1.0E+00	6.9E+05	6.9E+04	5.0E+04	2.0E+04
	Formulation - creams - small scale	2.1E+00	2.1E-01	1.4E+05	1.4E+04	1.0E+04	4.0E+03
	Professional and consumer use - 4.5 kg/d	4.3E+00	4.3E-01	2.9E+05	2.9E+04	2.1E+04	8.3E+03
	Professional and consumer use - 0.39 kg/day	3.7E-01	3.7E-02	2.5E+04	2.4E+03	1.8E+03	7.2E+02
Paints and coatings	Formulation	4.8E-02	4.8E-03	3.2E+03	2.2E+02	2.3E+02	9.6E+01
	Industrial use	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.2E+00	1.5E+01
	Professional and consumer use	2.0E-01	2.0E-02	1.3E+04	1.3E+03	9.7E+02	4.0E+02
Detergents	Formulation - low viscosity products	3.1E-01	3.1E-02	2.0E+04	2.0E+03	1.5E+03	5.9E+02



Scenario		C _{local} Surface water (total) – particles/l	C _{local} Marine water (total) – particles/l	C _{local} Freshwater sediment – particles/kg dry wt.	C _{local} Marine sediment – particles/kg dry wt.	C _{local} Agricultural soil – particles/kg dry wt.	C _{local} Grassland – particles/kg dry wt.
Abrasives	Formulation - high viscosity products	6.1E-01	6.1E-02	4.1E+04	4.1E+03	3.0E+03	1.2E+03
	Professional and consumer use	1.1E-01	1.1E-02	7.0E+03	6.6E+02	5.1E+02	2.0E+02
	Formulation	1.9E+01	1.9E+00	1.3E+06	1.3E+05	9.3E+04	3.7E+04
	Industrial use (sandblasting)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.4E+04	4.9E+04
	Professional use (sandblasting)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.0E+02	8.2E+02
Oil and gas	Formulation	6.4E+01	6.4E+00	4.2E+06	4.2E+05	3.1E+05	1.3E+05
	Industrial use	4.8E+01	4.8E+00	3.2E+06	3.2E+05	2.3E+05	9.5E+04
Agriculture	Formulation	6.4E+01	6.4E+00	4.2E+06	4.2E+05	3.1E+05	1.3E+05
	Professional and consumer use	3.3E-01	3.3E-02	2.2E+04	2.1E+03	2.6E+03	1.0E+03

EUSES modelling - Predicted Environmental Concentrations - Food chain exposure

As detailed in Appendix C exposure via the food chain for microplastics can occur through fish, filter-feeders (e.g. mussels and oysters) and by direct ingestion of soil (e.g. by earthworms). In order to assess the potential concentrations of microparticles that may be present in such food items the following “accumulation” factors have been considered.

Fish	0.036 l/fish based on particle number
Mussels	0.5 l/g based on particle number
Earthworm	0.1 – fraction of worm that is soil.

Predicted concentrations in each food item have been estimated from the relevant PECs for freshwater, marine water or soil. Calculations are presented assuming that 50% of the exposure results from local sources and 50% of the exposure results from regional sources (as assumed in ECHA (2016) and EUSES, for secondary poisoning of wildlife) and also assuming that all of the exposure results from local sources. In addition, the potential human exposure from consuming mussels from local sources has also been investigated. This assumes that a human consumes 115 g of fish/seafood per day and a human body weight of 70 kg (again based on the assumptions in ECHA (2016) and the EUSES model). The results are summarised in Appendix C (Table C21 Particles-based food chain calculations – 53% removal in waste water treatment plant Tables C21, C22 and C23).



Table C21 Particles-based food chain calculations – 53% removal in waste water treatment plant

Scenario		Concentrations assuming 50% from local sources and 50% from regional sources					Assuming 100% from local sources						
		Fish – freshwater – particles/ fish	Mussels – freshwater - particles/g	Fish – marine – particles / fish	Mussels – marine – particles/g	Earthworms – particles/ kg	Fish – freshwater – particles/ fish	Mussels – freshwater - particles/g	Fish – marine – particles/ fish	Mussels – marine – particles/g	Earthworms – particles/ kg	Human intake from freshwater mussels – particles/ kg bw/day	Human intake from marine mussels – particles/ kg bw/day
Personal care products	Formulation - low viscosity - large scale	2.5E-01	3.4E+00	2.4E-02	3.4E-01	1.5E+03	4.5E-01	6.2E+00	4.5E-02	6.2E-01	1.5E+03	5.6E-01	1.0E+00
	Formulation - low viscosity - medium scale	1.5E-01	2.1E+00	1.5E-02	2.1E-01	1.4E+03	2.6E-01	3.7E+00	2.6E-02	3.6E-01	1.2E+03	3.5E-01	6.0E-01
	Formulation - low viscosity - small scale	6.7E-02	9.3E-01	6.4E-03	8.9E-02	1.3E+03	8.9E-02	1.2E+00	8.6E-03	1.2E-01	1.0E+03	1.5E-01	2.0E-01
	Formulation - high viscosity - medium scale	5.9E-01	8.2E+00	5.9E-02	8.2E-01	2.0E+03	1.1E+00	1.6E+01	1.1E-01	1.6E+00	2.4E+03	1.3E+00	2.6E+00
	Formulation - high viscosity - small scale	4.8E-02	6.6E-01	4.5E-03	6.2E-02	1.2E+03	5.0E-02	6.9E-01	4.7E-03	6.6E-02	9.5E+02	1.0E-01	1.1E-01
	Formulation - creams - large scale	2.1E+00	2.9E+01	2.1E-01	2.9E+00	3.9E+03	4.1E+00	5.7E+01	4.1E-01	5.7E+00	6.3E+03	4.7E+00	9.3E+00
	Formulation - creams - medium scale	1.1E+00	1.6E+01	1.1E-01	1.6E+00	2.7E+03	2.2E+00	3.1E+01	2.2E-01	3.1E+00	3.8E+03	2.6E+00	5.1E+00
	Formulation - creams - small scale	2.6E-01	3.7E+00	2.6E-02	3.6E-01	1.5E+03	4.8E-01	6.7E+00	4.8E-02	6.7E-01	1.5E+03	6.0E-01	1.1E+00



Scenario		Concentrations assuming 50% from local sources and 50% from regional sources					Assuming 100% from local sources						
		Fish – freshwater – particles/fish	Mussels – freshwater - particles/g	Fish – marine – particles / fish	Mussels – marine – particles/g	Earthworms – particles/kg	Fish – freshwater – particles/fish	Mussels – freshwater - particles/g	Fish – marine – particles/fish	Mussels – marine – particles/g	Earthworms – particles/kg	Human intake from freshwater mussels – particles/ kg bw/day	Human intake from marine mussels – particles/ kg bw/day
	Professional and consumer use - 4.5 kg/d	5.0E-01	7.0E+00	5.0E-02	6.9E-01	1.8E+03	9.6E-01	1.3E+01	9.5E-02	1.3E+00	2.1E+03	1.1E+00	2.2E+00
	Professional and consumer use - 0.39 kg/day	8.5E-02	1.2E+00	8.2E-03	1.1E-01	1.3E+03	1.2E-01	1.7E+00	1.2E-02	1.7E-01	1.1E+03	1.9E-01	2.8E-01
Paints and coatings	Formulation	5.0E-02	7.0E-01	4.7E-03	6.6E-02	1.2E+03	5.5E-02	7.7E-01	5.2E-03	7.3E-02	9.6E+02	1.1E-01	1.2E-01
	Industrial use	4.5E-02	6.3E-01	4.2E-03	5.9E-02	1.2E+03	4.5E-02	6.3E-01	4.2E-03	5.9E-02	9.5E+02	9.7E-02	9.7E-02
	Professional and consumer use	6.6E-02	9.2E-01	6.3E-03	8.8E-02	1.3E+03	8.7E-02	1.2E+00	8.4E-03	1.2E-01	1.0E+03	1.4E-01	1.9E-01
Detergents	Formulation - low viscosity products	7.8E-02	1.1E+00	7.5E-03	1.0E-01	1.3E+03	1.1E-01	1.5E+00	1.1E-02	1.5E-01	1.0E+03	1.7E-01	2.4E-01
	Formulation - high viscosity products	1.1E-01	1.5E+00	1.1E-02	1.5E-01	1.3E+03	1.7E-01	2.4E+00	1.7E-02	2.4E-01	1.1E+03	2.4E-01	3.9E-01
	Professional and consumer use	5.6E-02	7.8E-01	5.3E-03	7.4E-02	1.3E+03	6.7E-02	9.4E-01	6.5E-03	9.0E-02	9.8E+02	1.2E-01	1.5E-01
Abrasives	Formulation	2.1E+00	2.9E+01	2.1E-01	2.9E+00	3.9E+03	4.1E+00	5.7E+01	4.1E-01	5.7E+00	6.3E+03	4.7E+00	9.3E+00
	Industrial use (sandblasting)	4.5E-02	6.3E-01	4.2E-03	5.9E-02	2.4E+03	4.5E-02	6.3E-01	4.2E-03	5.9E-02	3.3E+03	9.7E-02	9.7E-02



Scenario		Concentrations assuming 50% from local sources and 50% from regional sources					Assuming 100% from local sources						
		Fish – freshwater – particles/ fish	Mussels – freshwater - particles/g	Fish – marine – particles / fish	Mussels – marine – particles/g	Earthworms – particles/ kg	Fish – freshwater – particles/ fish	Mussels – freshwater - particles/g	Fish – marine – particles/ fish	Mussels – marine – particles/g	Earthworms – particles/ kg	Human intake from freshwater mussels – particles/ kg bw/day	Human intake from marine mussels – particles/ kg bw/day
	Professional use (sandblasting)	4.5E-02	6.3E-01	4.2E-03	5.9E-02	1.3E+03	4.5E-02	6.3E-01	4.2E-03	5.9E-02	9.9E+02	9.7E-02	9.7E-02
Oil and gas	Formulation	6.8E+00	9.4E+01	6.8E-01	9.4E+00	1.0E+04	1.4E+01	1.9E+02	1.4E+00	1.9E+01	1.9E+04	1.6E+01	3.1E+01
	Industrial use	5.1E+00	7.1E+01	5.1E-01	7.1E+00	8.0E+03	1.0E+01	1.4E+02	1.0E+00	1.4E+01	1.4E+04	1.2E+01	2.3E+01
Agriculture	Formulation	6.8E+00	9.4E+01	6.8E-01	9.4E+00	1.0E+04	1.4E+01	1.9E+02	1.4E+00	1.9E+01	1.9E+04	1.6E+01	3.1E+01
	Professional and consumer use	5.1E-02	7.1E-01	4.8E-03	6.7E-02	1.4E+03	5.7E-02	7.9E-01	5.4E-03	7.5E-02	1.2E+03	1.1E-01	1.2E-01



Table C22 Particles-based food chain calculations – 84% removal in waste water treatment plant

Scenario		Concentrations assuming 50% from local sources and 50% from regional sources					Assuming 100% from local sources						
		Fish – freshwater – particles/ fish	Mussels – freshwater - particles/g	Fish – marine – particles / fish	Mussels – marine – particles/g	Earthworms – particles/ kg	Fish – freshwater – particles/ fish	Mussels – freshwater - particles/g	Fish – marine – particles/ fish	Mussels – marine – particles/g	Earthworms – particles/ kg	Human intake from freshwater mussels – particles/ kg bw/day	Human intake from marine mussels – particles/ kg bw/day
Personal care products	Formulation - low viscosity - large scale	1.0E-01	1.4E+00	1.0E-02	1.4E-01	1.9E+03	1.7E-01	2.3E+00	1.7E-02	2.4E-01	1.9E+03	2.3E-01	3.9E-01
	Formulation - low viscosity - medium scale	6.9E-02	9.5E-01	6.9E-03	9.6E-02	1.7E+03	1.1E-01	1.5E+00	1.1E-02	1.5E-01	1.5E+03	1.6E-01	2.4E-01
	Formulation - low viscosity - small scale	3.9E-02	5.4E-01	3.9E-03	5.5E-02	1.5E+03	4.6E-02	6.4E-01	4.7E-03	6.5E-02	1.1E+03	9.0E-02	1.1E-01
	Formulation - high viscosity - medium scale	2.2E-01	3.0E+00	2.2E-02	3.0E-01	2.6E+03	4.0E-01	5.6E+00	4.0E-02	5.6E-01	3.3E+03	5.0E-01	9.2E-01
	Formulation - high viscosity - small scale	3.2E-02	4.5E-01	3.3E-03	4.5E-02	1.5E+03	3.3E-02	4.6E-01	3.4E-03	4.7E-02	1.0E+03	7.5E-02	7.7E-02
	Formulation - creams - large scale	7.2E-01	1.0E+01	7.2E-02	1.0E+00	5.7E+03	1.4E+00	2.0E+01	1.4E-01	2.0E+00	9.5E+03	1.6E+00	3.2E+00
	Formulation - creams - medium scale	4.0E-01	5.6E+00	4.0E-02	5.6E-01	3.7E+03	7.7E-01	1.1E+01	7.8E-02	1.1E+00	5.6E+03	9.2E-01	1.8E+00
	Formulation - creams - small scale	1.1E-01	1.5E+00	1.1E-02	1.5E-01	1.9E+03	1.8E-01	2.5E+00	1.8E-02	2.5E-01	1.9E+03	2.4E-01	4.1E-01



Scenario		Concentrations assuming 50% from local sources and 50% from regional sources					Assuming 100% from local sources						
		Fish – freshwater – particles/fish	Mussels – freshwater - particles/g	Fish – marine – particles / fish	Mussels – marine – particles/g	Earthworms – particles/kg	Fish – freshwater – particles/fish	Mussels – freshwater - particles/g	Fish – marine – particles/fish	Mussels – marine – particles/g	Earthworms – particles/ kg	Human intake from freshwater mussels – particles/kg bw/day	Human intake from marine mussels – particles/kg bw/day
	Professional and consumer use - 4.5 kg/d	2.6E-01	3.7E+00	2.6E-02	3.7E-01	2.4E+03	5.0E-01	6.9E+00	5.0E-02	6.9E-01	2.9E+03	6.0E-01	1.1E+00
	Professional and consumer use - 0.39 kg/day	4.5E-02	6.2E-01	4.5E-03	6.3E-02	1.5E+03	5.8E-02	8.1E-01	5.9E-03	8.2E-02	1.2E+03	1.0E-01	1.3E-01
Paints and coatings	Formulation	3.3E-02	4.6E-01	3.4E-03	4.7E-02	1.5E+03	3.5E-02	4.8E-01	3.5E-03	4.9E-02	1.0E+03	7.7E-02	8.1E-02
	Industrial use	3.1E-02	4.4E-01	3.2E-03	4.4E-02	1.5E+03	3.1E-02	4.4E-01	3.2E-03	4.4E-02	1.0E+03	7.3E-02	7.3E-02
	Professional and consumer use	3.9E-02	5.4E-01	3.9E-03	5.4E-02	1.5E+03	4.6E-02	6.3E-01	4.6E-03	6.4E-02	1.1E+03	8.9E-02	1.1E-01
Detergents	Formulation - low viscosity products	4.2E-02	5.9E-01	4.3E-03	6.0E-02	1.5E+03	5.3E-02	7.4E-01	5.4E-03	7.5E-02	1.1E+03	9.8E-02	1.2E-01
	Formulation - high viscosity products	5.3E-02	7.4E-01	5.4E-03	7.5E-02	1.6E+03	7.5E-02	1.0E+00	7.6E-03	1.1E-01	1.3E+03	1.2E-01	1.7E-01
	Professional and consumer use	3.5E-02	4.8E-01	3.5E-03	4.9E-02	1.5E+03	3.8E-02	5.3E-01	3.9E-03	5.4E-02	1.1E+03	8.1E-02	8.9E-02
Abrasives	Formulation	7.2E-01	1.0E+01	7.2E-02	1.0E+00	5.7E+03	1.4E+00	2.0E+01	1.4E-01	2.0E+00	9.5E+03	1.6E+00	3.2E+00
	Industrial use (sandblasting)	3.1E-02	4.4E-01	3.2E-03	4.4E-02	2.7E+03	3.1E-02	4.4E-01	3.2E-03	4.4E-02	3.4E+03	7.3E-02	7.3E-02



Scenario		Concentrations assuming 50% from local sources and 50% from regional sources					Assuming 100% from local sources						
		Fish – freshwater – particles/fish	Mussels – freshwater - particles/g	Fish – marine – particles / fish	Mussels – marine – particles/g	Earthworms – particles/ kg	Fish – freshwater – particles/fish	Mussels – freshwater - particles/g	Fish – marine – particles/fish	Mussels – marine – particles/g	Earthworms – particles/ kg	Human intake from freshwater mussels – particles/ kg bw/day	Human intake from marine mussels – particles/ kg bw/day
	Professional use (sandblasting)	3.1E-02	4.4E-01	3.2E-03	4.4E-02	1.5E+03	3.1E-02	4.4E-01	3.2E-03	4.4E-02	1.1E+03	7.3E-02	7.3E-02
Oil and gas	Formulation	2.3E+00	3.2E+01	2.3E-01	3.2E+00	1.6E+04	4.6E+00	6.4E+01	4.6E-01	6.4E+00	3.0E+04	5.3E+00	1.1E+01
	Industrial use	1.8E+00	2.4E+01	1.8E-01	2.4E+00	1.2E+04	3.5E+00	4.8E+01	3.5E-01	4.8E+00	2.2E+04	4.0E+00	7.9E+00
Agriculture	Formulation	2.3E+00	3.2E+01	2.3E-01	3.2E+00	1.6E+04	4.6E+00	6.4E+01	4.6E-01	6.4E+00	3.0E+04	5.3E+00	1.1E+01
	Professional and consumer use	3.7E-02	5.2E-01	3.8E-03	5.3E-02	1.6E+03	4.3E-02	6.0E-01	4.4E-03	6.1E-02	1.3E+03	8.6E-02	1.0E-01



Table C23 Particles-based food chain calculations – 92% removal in waste water treatment plant

Scenario	Concentrations assuming 50% from local sources and 50% from regional sources						Assuming 100% from local sources						
	Fish – freshwater – particles/ fish	Mussels – freshwater - particles/g	Fish – marine – particles / fish	Mussels – marine – particles/g	Earthworms – particles/ kg	Fish – freshwater – particles/ fish	Mussels – freshwater - particles/g	Fish – marine – particles/ fish	Mussels – marine – particles/g	Earthworms – particles/ kg	Human intake from freshwater mussels – particles/ kg bw/day	Human intake from marine mussels – particles/ kg bw/day	
Personal care products	Formulation - low viscosity - large scale	6.2E-02	8.7E-01	6.4E-03	8.8E-02	2.0E+03	9.7E-02	1.3E+00	9.8E-03	1.4E-01	2.0E+03	1.5E-01	2.2E-01
	Formulation - low viscosity - medium scale	4.6E-02	6.5E-01	4.8E-03	6.6E-02	1.8E+03	6.5E-02	9.0E-01	6.6E-03	9.2E-02	1.5E+03	1.1E-01	1.5E-01
	Formulation - low viscosity - small scale	3.2E-02	4.4E-01	3.3E-03	4.6E-02	1.6E+03	3.5E-02	4.9E-01	3.7E-03	5.1E-02	1.1E+03	7.5E-02	8.4E-02
	Formulation - high viscosity - medium scale	1.2E-01	1.7E+00	1.2E-02	1.7E-01	2.8E+03	2.1E-01	3.0E+00	2.2E-02	3.0E-01	3.5E+03	2.8E-01	4.9E-01
	Formulation - high viscosity - small scale	2.8E-02	3.9E-01	3.0E-03	4.1E-02	1.5E+03	2.9E-02	4.0E-01	3.0E-03	4.2E-02	1.0E+03	6.8E-02	6.9E-02
	Formulation - creams - large scale	3.7E-01	5.2E+00	3.7E-02	5.2E-01	6.2E+03	7.2E-01	9.9E+00	7.2E-02	1.0E+00	1.0E+04	8.5E-01	1.6E+00
	Formulation - creams - medium scale	2.1E-01	3.0E+00	2.2E-02	3.0E-01	4.0E+03	4.0E-01	5.5E+00	4.0E-02	5.6E-01	6.0E+03	4.9E-01	9.1E-01
	Formulation - creams - small scale	6.5E-02	9.0E-01	6.6E-03	9.2E-02	2.0E+03	1.0E-01	1.4E+00	1.0E-02	1.4E-01	2.0E+03	1.5E-01	2.4E-01



Scenario		Concentrations assuming 50% from local sources and 50% from regional sources					Assuming 100% from local sources						
		Fish – freshwater – particles/ fish	Mussels – freshwater - particles/g	Fish – marine – particles / fish	Mussels – marine – particles/g	Earthworms – particles/ kg	Fish – freshwater – particles/ fish	Mussels – freshwater - particles/g	Fish – marine – particles/ fish	Mussels – marine – particles/g	Earthworms – particles/ kg	Human intake from freshwater mussels – particles/ kg bw/day	Human intake from marine mussels – particles/ kg bw/day
	Professional and consumer use - 4.5 kg/d	1.1E-01	1.5E+00	1.1E-02	1.5E-01	2.6E+03	1.8E-01	2.5E+00	1.8E-02	2.6E-01	3.1E+03	2.4E-01	4.2E-01
	Professional and consumer use - 0.39 kg/day	3.5E-02	4.8E-01	3.6E-03	5.0E-02	1.6E+03	4.1E-02	5.7E-01	4.3E-03	5.9E-02	1.2E+03	8.2E-02	9.7E-02
Paints and coatings	Formulation												
	Industrial use	2.9E-02	4.0E-01	3.0E-03	4.2E-02	1.5E+03	3.0E-02	4.1E-01	3.1E-03	4.3E-02	1.0E+03	6.9E-02	7.1E-02
	Professional and consumer use	2.8E-02	3.9E-01	2.9E-03	4.1E-02	1.5E+03	2.8E-02	3.9E-01	2.9E-03	4.1E-02	1.0E+03	6.7E-02	6.7E-02
Detergents	Formulation - low viscosity products	3.1E-02	4.4E-01	3.3E-03	4.6E-02	1.6E+03	3.5E-02	4.9E-01	3.6E-03	5.1E-02	1.1E+03	7.5E-02	8.3E-02
	Formulation - high viscosity products	3.3E-02	4.6E-01	3.5E-03	4.8E-02	1.6E+03	3.9E-02	5.4E-01	4.0E-03	5.6E-02	1.2E+03	7.9E-02	9.2E-02
	Professional and consumer use	3.9E-02	5.4E-01	4.0E-03	5.6E-02	1.7E+03	5.0E-02	6.9E-01	5.1E-03	7.1E-02	1.3E+03	9.2E-02	1.2E-01
Abrasives	Formulation	3.0E-02	4.1E-01	3.1E-03	4.3E-02	1.5E+03	3.2E-02	4.4E-01	3.3E-03	4.6E-02	1.1E+03	7.1E-02	7.5E-02
	Industrial use (sandblasting)	3.7E-01	5.2E+00	3.7E-02	5.2E-01	6.2E+03	7.2E-01	9.9E+00	7.2E-02	1.0E+00	1.0E+04	8.5E-01	1.6E+00



Scenario		Concentrations assuming 50% from local sources and 50% from regional sources					Assuming 100% from local sources						
		Fish – freshwater – particles/ fish	Mussels – freshwater - particles/g	Fish – marine – particles / fish	Mussels – marine – particles/g	Earthworms – particles/ kg	Fish – freshwater – particles/ fish	Mussels – freshwater - particles/g	Fish – marine – particles/ fish	Mussels – marine – particles/g	Earthworms – particles/ kg	Human intake from freshwater mussels – particles/ kg bw/day	Human intake from marine mussels – particles/ kg bw/day
	Professional use (sandblasting)	2.8E-02	3.9E-01	2.9E-03	4.1E-02	2.7E+03	2.8E-02	3.9E-01	2.9E-03	4.1E-02	3.4E+03	6.7E-02	6.7E-02
Oil and gas	Formulation	2.8E-02	3.9E-01	2.9E-03	4.1E-02	1.5E+03	2.8E-02	3.9E-01	2.9E-03	4.1E-02	1.1E+03	6.7E-02	6.7E-02
	Industrial use	1.2E+00	1.6E+01	1.2E-01	1.6E+00	1.7E+04	2.3E+00	3.2E+01	2.3E-01	3.2E+00	3.2E+04	2.7E+00	5.3E+00
Agriculture	Formulation	8.9E-01	1.2E+01	8.9E-02	1.2E+00	1.3E+04	1.7E+00	2.4E+01	1.8E-01	2.4E+00	2.4E+04	2.0E+00	4.0E+00
	Professional and consumer use	1.2E+00	1.6E+01	1.2E-01	1.6E+00	1.7E+04	2.3E+00	3.2E+01	2.3E-01	3.2E+00	3.2E+04	2.7E+00	5.3E+00

References

The following are references relevant to the risk/exposure assessment. Other references are included throughout the report as footnotes.

AISE (2012a). AISE SpERC Fact Sheet – Industrial use in formulation of granular cleaning and maintenance products. AISE SpERC 2.1.a.v2, AISE SpERC 2.1.b.v2 and AISE SpERC 2.1.c.v2, October 2012. Available from <https://echa.europa.eu/csr-es-roadmap/use-maps/use-maps-library>

AISE (2012b). AISE SpERC Fact Sheet – Industrial use in formulation of liquid cleaning and maintenance products. AISE SpERC 2.1.g.v2, AISE SpERC 2.1.h.v2, AISE SpERC 2.1.i.v2, AISE SpERC 2.1.j.v2, AISE SpERC 2.1.k.v2 and AISE SpERC 2.1.l.v2, October 2012. Available from <https://echa.europa.eu/csr-es-roadmap/use-maps/use-maps-library>

AISE (2012c). AISE SpERC Fact Sheet – Wide dispersive use of cleaning and maintenance products. AISE SpERC 8a.1.a.v2, AISE SpERC 8a.1.b.v2 and AISE SpERC 8a.1.c.v2, October 2012. Available from <https://echa.europa.eu/csr-es-roadmap/use-maps/use-maps-library>

Avio CG, Gorbi S, Regoli F (2015). Experimental development of a new protocol for extraction and characterization of microplastics in fish tissues: first observations in commercial species from Adriatic Sea. *Mar Environ Res*. doi:10.1016/j.marenvres.2015.06.014

CEPE (2010a). Manufacture of water borne liquid coatings and inks. Formulation – waterborne coatings and inks – solids. CEPE SpERC 2.2c.v1. Available from http://www.cepe.org/EPUB/easnet.dll/ExecReg/Page?eas:template_im=100087&eas:dat_im=101AED

CEPE (2010b). Industrial application of coatings and inks by spraying. Application – industrial – spraying – indoor use – solids. CEPE SpERC 5.1a.v1. Available from http://www.cepe.org/EPUB/easnet.dll/ExecReg/Page?eas:template_im=100087&eas:dat_im=101AED

CEPE (2010c). Professional application of coatings and inks by spraying. Application – professional – spraying – indoor use – solids. CEPE SpERC 8c.3a.v1. Available from http://www.cepe.org/EPUB/easnet.dll/ExecReg/Page?eas:template_im=100087&eas:dat_im=101AED

CEPE (2010d). Professional application of coatings and inks by spraying. Application – professional – spraying – outdoor use – solids. CEPE SpERC 8f.3a.v1. Available from http://www.cepe.org/EPUB/easnet.dll/ExecReg/Page?eas:template_im=100087&eas:dat_im=101AED

CEPE (2010e). Professional application of coatings and inks by brush or roller. Application – professional – brush/roller – indoor use – solids. CEPE SpERC 8c.2a.v1. Available from http://www.cepe.org/EPUB/easnet.dll/ExecReg/Page?eas:template_im=100087&eas:dat_im=101AED

CEPE (2010f). Professional application of coatings and inks by brush or roller. Application – professional – brush/roller – outdoor use – solids. CEPE SpERC 8f.2a.v1. Available from http://www.cepe.org/EPUB/easnet.dll/ExecReg/Page?eas:template_im=100087&eas:dat_im=101AED

CIN (2005). CHARM Chemical Hazard Assessment and Risk Management for the use and discharge of chemicals used offshore. User Guide Version 1.4. Charm Implementation Network (CIN), February 2015. Available from <http://www.eosca.eu/wp-content/uploads/CHARM-User-Guide-Version-1.4.pdf>

Cosmetics Europe. Cosmetics Europe SpERCs Version 2. Available from <https://echa.europa.eu/csr-es-roadmap/use-maps/use-maps-library>

Danish Environmental Protection Agency (2017). Microplastic in Danish wastewater Sources, occurrences and fate. March 2017.

Duis Karen and Coors Anja (2016). Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects. *Environ. Sci. Eur.*, 2016, 28(2), 25pp. (Funded by the German Cosmetic, Toiletry, Perfumery and Detergent Association (IKW)).

ECHA (2016). Guidance on information requirements and chemical safety assessment. Chapter R.16: Environmental exposure assessment. Version 3.0, European Chemicals Agency, February 2016.

Eunomia (2016). Study to support the development of measures to combat a range of marine litter sources. Report for European Commission DG Environment. Eunomia Research & Consulting Ltd, 29th January 2016.

Eunomia (2017). Personal communication. WWT Model v1_20170609.

GESAMP (2016). Sources, fate and effects of microplastics in the marine environment: part two of a global assessment (Kershaw, P.J., and Rochman, C.M., eds). IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection. Rep. Stud. GESAMP No. 93, 220 p.

Leslie H A, Brandsma S H, van Velzen M J M and Vethaak A D (2017). Microplastics en route: Field measurements in the Dutch river delta and Amsterdam canals, wastewater treatment plants, North Sea sediments and biota. *Environment International*, Vol.101, pp.133–142.

Murphy F, Ewins C, Carbonnier F, and Quinn B (2016). Wastewater Treatment Works (WwTW) as a Source of Microplastics in the Aquatic Environment. *Environmental Science & Technology*, Vol.50, No.11, pp.5800–5808.

OECD (2009). Emission Scenario Document on Coating Industry (Paints, Laquers and Varnishes) OECD Series on Emission Scenario Documents Number 22. Organisation for Economic Co-operation and Development, ENV/JM/MONO(2009)24, 8th July 2009. Available from <http://www.oecd.org/env/ehs/risk-assessment/emissionscenariodocuments.htm>

Van Cauwenberghe L (2015). Occurrence, effects and risks of marine microplastics. Thesis submitted in fulfilment of the requirements for the degree of Doctor (PhD) in Applied Biological Sciences. Ghent University.

Ziajahromi S, Neale P A, Rintoul L and Leusch F D L (2017). Wastewater treatment plants as a pathway for microplastics: Development of a new approach to sample wastewater-based microplastics. *Water Research*, Vol.112, pp.93–99.



Appendix D

Exposure assessment - migration of additives from microbeads

Method

In accordance with the diffusion model is set out in Appendix IV to the OECD ESD for plastics additives (OECD, 2009a citing Fisk *et al.*, 2006), the key assumptions are:

1. The substrate is a continuous matrix.
2. At the beginning of the modelled time period the additive is uniformly dispersed throughout the particle, but may diffuse freely so that a concentration gradient is established.
3. Additives are not chemically bound to the polymer, the only interactions being weak.
4. The concentration of the additive in the receiving compartment is assumed to be negligible / not influential.

Fick's second law of diffusion²⁶⁰ deals with diffusion which is time-dependent, i.e. during the period between time zero and the establishment, if it occurs, of a steady state.

Consider a piece of polymer containing evenly-distributed additive at concentration C_0 . If the area of surface exposed to a sink for the substance is A , then Fick's second Law can be solved such that, for small amounts of loss (up to approx. 20%), the mass loss N_{add} (in kg) is given by:

$$N_{add} = 2A_{polymer}C_0 \left(\frac{D_{add}t}{\pi} \right)^{0.5} \text{ (Eqn 1)}$$

Where:

D_{add} is the self-diffusion coefficient for additive in the polymer in m^2/s ;

$A_{polymer}$ is the surface area of polymer in m^2 ;

C_0 is the initial concentration of additive in polymer in kg/m^3 (= g/l).

D_{add} can be estimated using the following equation developed by Reynier *et al.*:

$$D_{add} = \frac{10^{(-7.83 - 0.0062 \times MW_{add})}}{10000} \text{ (Eqn 2)}$$

MW_{add} is the molecular weight of the additive.

Equation 1 predicts that the rate of diffusion will slow with time, which is a consequence of the physical fact that the molecules near the surface will escape first, and then it takes more time for the deeper ones to reach the surface and escape. It also shows that the rate of loss is proportional to area and concentration.

After approximately 20% mass loss, Fick's first Law²⁶¹ (steady state diffusion) can be used to give the rate, i.e.

$$N_{add} = \frac{A_{polymer}D_{add}C_0t}{r} \text{ (Eqn 3)}$$

Where r is the radius of the polymer bead (in m) and other symbols are as defined above.

²⁶⁰ J. Crank, "The mathematics of diffusion", Clarendon Press, 1975.

²⁶¹ Fick, A. (1855). "On liquid diffusion". *Poggendorffs Annalen*. **94**: 59. – reprinted in "On liquid diffusion". *Journal of Membrane Science*. **100**: 33–38. 1995.

The time for a specified fraction (x) of the initial mass to be lost, can be calculated by rearranging equations 1 and 3 and substituting the following equations:

$$C_0 = \frac{M_0}{V_{polymer}} \quad (\text{Eqn 4})$$

$$N_{add} = xM_0 \quad (\text{Eqn 5})$$

$$\frac{V_{polymer}}{A_{polymer}} = \frac{\frac{4}{3}\pi r^3}{4\pi r^2} = \frac{r}{3} \quad (\text{Eqn 6; for a spherical bead})$$

Where:

M_0 is the initial mass of the additive;

$V_{polymer}$ is the volume of the polymer.

For the initial loss (Fick's second law):

$$t = \frac{\pi x^2 r^2}{36D_{add}}$$

And for steady state diffusion (Fick's first law):

$$t = \frac{xr^2}{3D_{add}}$$

Therefore, in both cases, the time to lose a specified portion of the additive is dependent on the square of the polymer particle radius and inversely proportional to the diffusion coefficient.

The following should be noted:

- ▶ As levels of additive within the bead get very low, there is no longer a concentration gradient between the inside and the outside of the bead and the mathematics above does not apply. Therefore, it is not recommended to predict time to 100% loss using the above model.
- ▶ The model assumes negligible concentration in the receiving compartment. Therefore, it will not apply as the concentrations in the receiving compartment and the bead approach their equilibrium values.

Results

Table D1 shows loss of additive per kg of beads over one day. A concentration of additive/monomer in beads of 1% and a maximum loss of 95% of the additive are assumed. The plastic types are based on the most common plastics used for microbeads and the limits of their typical size ranges. Particles with a diameter of 5000 μm (5 mm) are also illustrated because this is the limit for definition as a microplastic. The only property of the additive that influences the calculations is the molecular weight; therefore, a range of molecular weights are assessed.

Table D1 also shows the time taken to lose 20%, 50% and 95% of the additive. Loss of 100% of the additive is not calculated because as complete loss is approached, a concentration gradient between the inside and outside of the bead no longer exists and the maths is no longer valid.

The time to reach a specified percentage loss is proportional to the square of the particle radius and inversely proportional to the diffusion coefficient. The diffusion coefficient depends only on the molecular weight (larger MW = larger diffusion coefficient) using the current model. In reality, the diffusion coefficient will depend on the combination of additive and polymer.²⁶²

The predicted times to 95% loss vary from less than 1 hour for a low molecular weight additive in a small particle to several years for a high molecular weight additive in a large particle.

²⁶² From Teuton 2009 Transport and release of chemicals from plastics. HOC diffusivities in plastics were higher in HDPE ($D = 1\text{E-}14 \text{ m}^2/\text{s}$) and lower in PVC ($1\text{E-}17$ to $1\text{E-}18 \text{ m}^2/\text{s}$).



Table D1 Calculated diffusion coefficients, mass of additive lost over 1 day and time to 20%, 50% and 95% loss for a range of polymer types and additives.

Polymer type	Additive name	Diameter of polymer	Density of polymer	Molecular weight of additive	Diffusion coefficient of additive at 12°C	Mass of additive lost over 1 day per kg of beads	Time to 20% loss	Time to 50% loss	Time to 95% loss
		DIA	RHO _{polymer}	MW _{add}	D _{add}	Naddbeads	T _{td}	T _{fd}	T _{nd}
		µm	kg/m ³	g/mol	m ² /s	kg/kg	days	days	days
Polyethylene	Ethylene monomer	200	920	28.05	9.5E-13	9.5E-03	4.3E-04	1.3E-02	3.1E-02
Polyethylene	Ethylene monomer	1250	920	28.05	9.5E-13	9.5E-03	1.7E-02	4.9E-01	1.2E+00
Polyethylene	High MW additive	200	920	500	1.1E-15	3.3E-03	3.6E-01	1.1E+01	2.6E+01
Polyethylene	High MW additive	1250	920	500	1.1E-15	5.3E-04	1.4E+01	4.2E+02	1.0E+03
Polyethylene	High MW additive	5000	920	500	1.1E-15	1.3E-04	2.2E+02	6.7E+03	1.6E+04
Polyethylene	Additive - MW 100	200	920	100	3.4E-13	9.5E-03	1.2E-03	3.5E-02	8.6E-02
Polyethylene	Additive - MW 100	1250	920	100	3.4E-13	9.3E-03	4.7E-02	1.4E+00	3.4E+00
Polyethylene	Additive - MW 300	200	920	300	2.0E-14	9.5E-03	2.1E-02	6.1E-01	1.5E+00
Polyethylene	Additive - MW 300	1250	920	300	2.0E-14	2.2E-03	8.1E-01	2.4E+01	5.9E+01
Polyurethane	Methylene diphenyl diisocyanate, MDI	2	1200	250.26	4.0E-14	9.5E-03	1.0E-06	3.0E-05	7.4E-05
Polyurethane	Methylene diphenyl diisocyanate, MDI	1240	1200	250.26	4.0E-14	3.2E-03	3.9E-01	1.2E+01	2.8E+01
Polyurethane	Ethylene glycol	2	1200	62.07	5.8E-13	9.5E-03	6.9E-08	2.1E-06	5.0E-06
Polyurethane	Ethylene glycol	1240	1200	62.07	5.8E-13	9.5E-03	2.7E-02	7.9E-01	1.9E+00



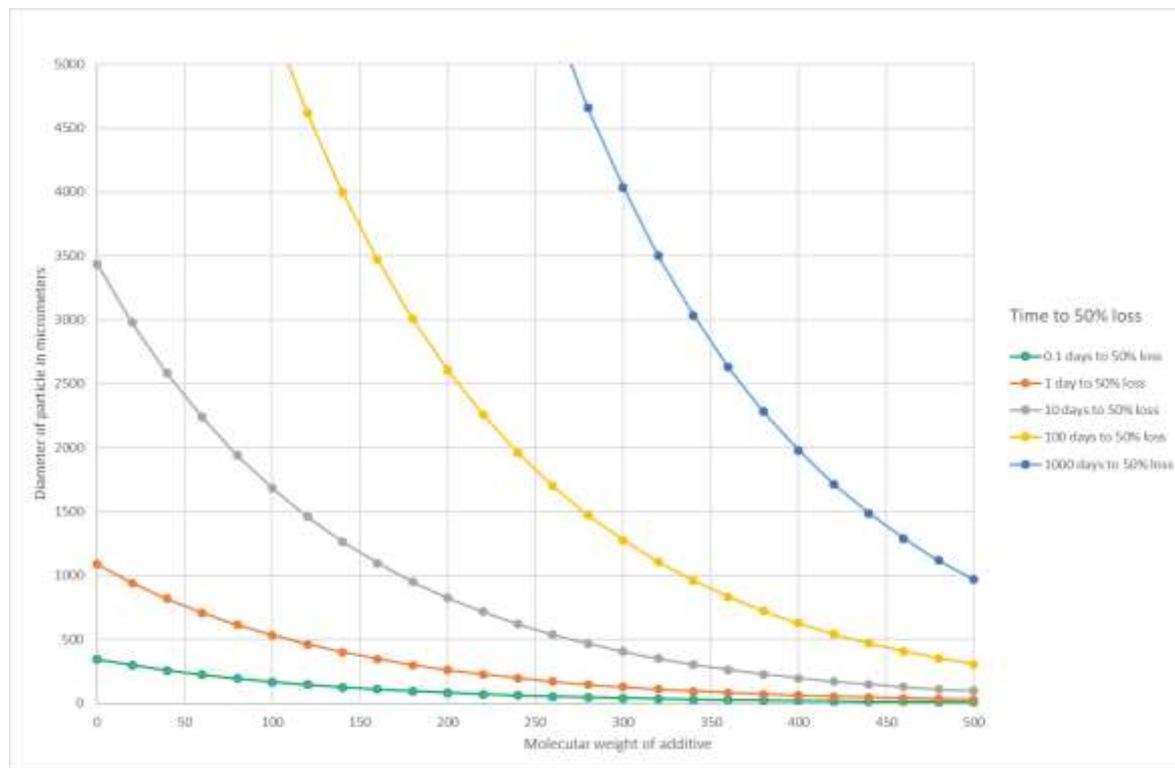
Polymer type	Additive name	Diameter of polymer	Density of polymer	Molecular weight of additive	Diffusion coefficient of additive at 12°C	Mass of additive lost over 1 day per kg of beads	Time to 20% loss	Time to 50% loss	Time to 95% loss
Polyurethane	High MW additive	1240	1200	500	1.1E-15	5.4E-04	1.4E+01	4.1E+02	1.0E+03
Polyurethane	High MW additive	5000	1200	500	1.1E-15	1.3E-04	2.2E+02	6.7E+03	1.6E+04
Polyurethane	Additive - MW 100	2	1200	100	3.4E-13	9.5E-03	1.2E-07	3.5E-06	8.6E-06
Polyurethane	Additive - MW 100	1240	1200	100	3.4E-13	9.3E-03	4.6E-02	1.4E+00	3.3E+00
Polyurethane	Additive - MW 300	2	1200	300	2.0E-14	9.5E-03	2.1E-06	6.1E-05	1.5E-04
Polyurethane	Additive - MW 300	1240	1200	300	2.0E-14	2.2E-03	8.0E-01	2.4E+01	5.8E+01
Polymethylmethacrylate	Methyl methacrylate	200	1200	100.12	3.4E-13	9.5E-03	1.2E-03	3.5E-02	8.7E-02
Polymethylmethacrylate	Methyl methacrylate	320	1200	100.12	3.4E-13	9.5E-03	3.1E-03	9.1E-02	2.2E-01
Polymethylmethacrylate	Additive - MW 300	200	1200	300	2.0E-14	9.5E-03	2.1E-02	6.1E-01	1.5E+00
Polymethylmethacrylate	Additive - MW 500	200	1200	500	1.1E-15	3.3E-03	3.6E-01	1.1E+01	2.6E+01
Polymethylmethacrylate	Additive - MW 300	320	1200	300	2.0E-14	8.7E-03	5.3E-02	1.6E+00	3.8E+00
Polymethylmethacrylate	Additive - MW 500	320	1200	500	1.1E-15	2.1E-03	9.2E-01	2.7E+01	6.7E+01
Styrene/Acrylate s copolymer	Styrene	2	1100	104.15	3.2E-13	9.5E-03	1.3E-07	3.7E-06	9.2E-06
Styrene/Acrylate s copolymer	Styrene	10	1100	104.15	3.2E-13	9.5E-03	3.2E-06	9.4E-05	2.3E-04
Styrene/Acrylate s copolymer	Methyl methacrylate	2	1100	100.12	3.4E-13	9.5E-03	1.2E-07	3.5E-06	8.7E-06



Polymer type	Additive name	Diameter of polymer	Density of polymer	Molecular weight of additive	Diffusion coefficient of additive at 12°C	Mass of additive lost over 1 day per kg of beads	Time to 20% loss	Time to 50% loss	Time to 95% loss
Styrene/Acrylates copolymer	Methyl methacrylate	10	1100	100.12	3.4E-13	9.5E-03	3.0E-06	8.8E-05	2.2E-04
Styrene/Acrylates copolymer	Additive - MW 300	2	1100	300	2.0E-14	9.5E-03	2.1E-06	6.1E-05	1.5E-04
Styrene/Acrylates copolymer	Additive - MW 300	10	1100	300	2.0E-14	9.5E-03	5.2E-05	1.5E-03	3.8E-03
Styrene/Acrylates copolymer	Additive - MW 500	2	1100	500	1.1E-15	9.5E-03	3.6E-05	1.1E-03	2.6E-03
Styrene/Acrylates copolymer	Additive - MW 500	10	1100	500	1.1E-15	9.5E-03	9.0E-04	2.7E-02	6.5E-02

Figure D1 shows the molecular weight of the additive versus the diameter of the particle with contour lines representing times to 50% loss of additive from the particle.

Figure D1 Impact of molecular weight of the additive and diameter of the microbead on the time to 50% loss



It should be noted that more hydrophobic particles may have a higher affinity for the plastic microbeads than the water phase. Depending on the concentration of microbeads and the partition coefficient between water and microbeads, the equilibrium concentration of an additive associated with the microbeads could be significant. For example, if the microbead-water partition coefficient is equal to the octanol-water partition coefficient (see above) and a concentration of 1 mg/l or 0.01 mg/l microbeads is present, the fractions in water and absorbed to microbeads are shown in Table 2.2.²⁶³ Therefore, for high log K_{ow} substances at high concentrations of microbeads, not all of the additive content of the beads will be released. In these cases, the calculated times to release additive can be considered as an indication of how fast equilibrium between beads and water will be reached.

²⁶³ This ignores the presence of other absorbing materials such as natural sediment.



Table D.2 Fractions in water, and absorbed to microbeads

log Kow	Concentration 1 mg/l		Concentration 0.01 mg/l	
	Fraction in water	Fraction in beads	Fraction in water	Fraction in beads
0	1.00	0.00	1.00	0.00
1	1.00	0.00	1.00	0.00
2	1.00	0.00	1.00	0.00
3	1.00	0.00	1.00	0.00
4	0.99	0.01	1.00	0.00
5	0.91	0.09	1.00	0.00
6	0.50	0.50	0.99	0.01
7	0.09	0.91	0.91	0.09
8	0.01	0.99	0.50	0.50
9	0.00	1.00	0.09	0.91

Table D3 Predicted environmental concentrations in environmental compartments for additives in microplastic beads at 1%

		Mass of additive present at 0.01 kg/kg (1%)							
Scenario		STP effluent (total) – mg/l	Sewage sludge - mg/kg dry wt.	PEC Surface water (total) – mg/l	PEC Marine water (total) – mg/l	PEC Freshwater sediment – mg/kg dry wt.	PEC Marine sediment – mg/kg dry wt.	PEC Agricultural soil – mg/kg dry wt.	PEC Grassland – mg/kg dry wt.
Personal care products	Formulation - low viscosity - large scale	4.70E-03	1.30E+01	5.20E-04	5.20E-05	3.50E+01	4.10E+00	6.20E-01	4.90E-01
	Formulation - low viscosity - medium scale	2.50E-03	7.30E+00	3.10E-04	3.00E-05	2.00E+01	2.70E+00	5.20E-01	4.40E-01
	Formulation - low viscosity - small scale	5.10E-04	1.50E+00	1.00E-04	1.00E-05	6.90E+00	1.30E+00	4.20E-01	4.10E-01
	Formulation - high viscosity - medium scale	1.30E-02	3.60E+01	1.30E-03	1.30E-04	8.80E+01	9.40E+00	1.00E+00	6.40E-01
	Formulation - high viscosity - small scale	5.60E-05	1.60E-01	5.80E-05	5.50E-06	3.90E+00	1.00E+00	4.00E-01	4.00E-01
	Formulation - creams - large scale	4.70E-02	1.30E+02	4.80E-03	4.70E-04	3.20E+02	3.20E+01	2.60E+00	1.30E+00
	Formulation - creams - medium scale	2.50E-02	7.30E+01	2.60E-03	2.60E-04	1.70E+02	1.80E+01	1.60E+00	8.80E-01
	Formulation - creams - small scale	5.10E-03	1.50E+01	5.60E-04	5.60E-05	3.70E+01	4.40E+00	6.40E-01	4.90E-01
	Professional and consumer use - 4.5 kg/d	1.10E-02	3.00E+01	1.10E-03	1.10E-04	7.40E+01	8.00E+00	9.00E-01	6.00E-01
	Professional and consumer use - 0.39 kg/day	9.20E-04 0.00E+00	2.60E+00 0.00E+00	1.40E-04 0.00E+00	1.40E-05 0.00E+00	9.60E+00 0.00E+00	1.60E+00 0.00E+00	4.40E-01 0.00E+00	4.10E-01 0.00E+00
Paints and coatings	Formulation	1.20E-04	3.40E-01	6.40E-05	6.10E-06	4.30E+00	1.10E+00	4.00E-01	4.00E-01
	Industrial use	0.00E+00	0.00E+00	5.30E-05	4.90E-06	3.50E+00	9.80E-01	4.00E-01	4.00E-01
	Professional and consumer use	4.90E-04	1.40E+00	1.00E-04	9.80E-06	6.80E+00	1.30E+00	4.20E-01	4.10E-01



Mass of additive present at 0.01 kg/kg (1%)

Scenario		STP effluent (total) – mg/l	Sewage sludge - mg/kg dry wt.	PEC Surface water (total) – mg/l	PEC Marine water (total) – mg/l	PEC Freshwater sediment – mg/kg dry wt.	PEC Marine sediment – mg/kg dry wt.	PEC Agricultural soil – mg/kg dry wt.	PEC Grassland – mg/kg dry wt.
Detergents	Formulation - low viscosity products	7.50E-04	2.20E+00	1.30E-04	1.20E-05	8.50E+00	1.50E+00	4.30E-01	4.10E-01
	Formulation - high viscosity products	1.50E-03	4.30E+00	2.00E-04	2.00E-05	1.40E+01	2.00E+00	4.70E-01	4.30E-01
	Professional and consumer use	2.60E-04	7.40E-01	7.80E-05	7.50E-06	5.20E+00	1.20E+00	4.10E-01	4.00E-01
Abrasives	Formulation	4.70E-02	1.30E+02	4.80E-03	4.70E-04	3.20E+02	3.20E+01	2.60E+00	1.30E+00
	Industrial use (sandblasting)	0.00E+00	0.00E+00	5.30E-05	4.90E-06	3.50E+00	9.80E-01	1.40E+00	2.40E+00
	Professional use (sandblasting)	0.00E+00	0.00E+00	5.30E-05	4.90E-06	3.50E+00	9.80E-01	4.10E-01	4.30E-01
Oil and gas	Formulation	1.60E-01	4.50E+02	1.60E-02	1.60E-03	1.00E+03	1.10E+02	7.90E+00	3.50E+00
	Industrial use	1.20E-01	3.40E+02	1.20E-02	1.20E-03	7.90E+02	7.90E+01	6.00E+00	2.70E+00
Agriculture	Formulation	1.60E-01	4.50E+02	1.60E-02	1.60E-03	1.00E+03	1.10E+02	7.90E+00	3.50E+00
	Professional and consumer use	1.40E-04	0.00E+00	6.60E-05	6.30E-06	4.40E+00	1.10E+00	5.10E-01	4.40E-01
Regional	Regional concentrations	0.00E+00	0.00E+00	5.30E-05	4.90E-06	7.00E+00	2.00E+00	6.40E-01	4.00E-01
Maximum		1.60E-01	4.50E+02	1.60E-02	1.60E-03	1.00E+03	1.10E+02	7.90E+00	3.50E+00



Table D4 Predicted environmental concentrations in environmental compartments for additives in microplastic beads at 0.1%

Scenario		Mass of additive present at 0.001 kg/kg (0.1%)							
		STP effluent (total) – mg/l	Sewage sludge - mg/kg dry wt.	PEC Surface water (total) – mg/l	PEC Marine water (total) – mg/l	PEC Freshwater sediment – mg/kg dry wt.	PEC Marine sediment – mg/kg dry wt.	PEC Agricultural soil – mg/kg dry wt.	PEC Grassland – mg/kg dry wt.
Personal care products	Formulation - low viscosity - large scale	4.70E-04	1.30E+00	5.20E-05	5.20E-06	3.50E+00	4.10E-01	6.20E-02	4.90E-02
	Formulation - low viscosity - medium scale	2.50E-04	7.30E-01	3.10E-05	3.00E-06	2.00E+00	2.70E-01	5.20E-02	4.40E-02
	Formulation - low viscosity - small scale	5.10E-05	1.50E-01	1.00E-05	1.00E-06	6.90E-01	1.30E-01	4.20E-02	4.10E-02
	Formulation - high viscosity - medium scale	1.30E-03	3.60E+00	1.30E-04	1.30E-05	8.80E+00	9.40E-01	1.00E-01	6.40E-02
	Formulation - high viscosity - small scale	5.60E-06	1.60E-02	5.80E-06	5.50E-07	3.90E-01	1.00E-01	4.00E-02	4.00E-02
	Formulation - creams - large scale	4.70E-03	1.30E+01	4.80E-04	4.70E-05	3.20E+01	3.20E+00	2.60E-01	1.30E-01
	Formulation - creams - medium scale	2.50E-03	7.30E+00	2.60E-04	2.60E-05	1.70E+01	1.80E+00	1.60E-01	8.80E-02
	Formulation - creams - small scale	5.10E-04	1.50E+00	5.60E-05	5.60E-06	3.70E+00	4.40E-01	6.40E-02	4.90E-02
	Professional and consumer use - 4.5 kg/d	1.10E-03	3.00E+00	1.10E-04	1.10E-05	7.40E+00	8.00E-01	9.00E-02	6.00E-02
	Professional and consumer use - 0.39 kg/day	9.20E-05	2.60E-01	1.40E-05	1.40E-06	9.60E-01	1.60E-01	4.40E-02	4.10E-02
		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Paints and coatings	Formulation	1.20E-05	3.40E-02	6.40E-06	6.10E-07	4.30E-01	1.10E-01	4.00E-02	4.00E-02
	Industrial use	0.00E+00	0.00E+00	5.30E-06	4.90E-07	3.50E-01	9.80E-02	4.00E-02	4.00E-02
	Professional and consumer use	4.90E-05	1.40E-01	1.00E-05	9.80E-07	6.80E-01	1.30E-01	4.20E-02	4.10E-02



Mass of additive present at 0.001 kg/kg (0.1%)

Scenario		STP effluent (total) – mg/l	Sewage sludge - mg/kg dry wt.	PEC Surface water (total) – mg/l	PEC Marine water (total) – mg/l	PEC Freshwater sediment – mg/kg dry wt.	PEC Marine sediment – mg/kg dry wt.	PEC Agricultural soil – mg/kg dry wt.	PEC Grassland – mg/kg dry wt.
Detergents	Formulation - low viscosity products	7.50E-05	2.20E-01	1.30E-05	1.20E-06	8.50E-01	1.50E-01	4.30E-02	4.10E-02
	Formulation - high viscosity products	1.50E-04	4.30E-01	2.00E-05	2.00E-06	1.40E+00	2.00E-01	4.70E-02	4.30E-02
	Professional and consumer use	2.60E-05	7.40E-02	7.80E-06	7.50E-07	5.20E-01	1.20E-01	4.10E-02	4.00E-02
Abrasives	Formulation	4.70E-03	1.30E+01	4.80E-04	4.70E-05	3.20E+01	3.20E+00	2.60E-01	1.30E-01
	Industrial use (sandblasting)	0.00E+00	0.00E+00	5.30E-06	4.90E-07	3.50E-01	9.80E-02	1.40E-01	2.40E-01
	Professional use (sandblasting)	0.00E+00	0.00E+00	5.30E-06	4.90E-07	3.50E-01	9.80E-02	4.10E-02	4.30E-02
Oil and gas	Formulation	1.60E-02	4.50E+01	1.60E-03	1.60E-04	1.00E+02	1.10E+01	7.90E-01	3.50E-01
	Industrial use	1.20E-02	3.40E+01	1.20E-03	1.20E-04	7.90E+01	7.90E+00	6.00E-01	2.70E-01
Agriculture	Formulation	1.60E-02	4.50E+01	1.60E-03	1.60E-04	1.00E+02	1.10E+01	7.90E-01	3.50E-01
	Professional and consumer use	1.40E-05	0.00E+00	6.60E-06	6.30E-07	4.40E-01	1.10E-01	5.10E-02	4.40E-02
Regional	Regional concentrations	0.00E+00	0.00E+00	5.30E-06	4.90E-07	7.00E-01	2.00E-01	6.40E-02	4.00E-02
Maximum		1.60E-02	4.50E+01	1.60E-03	1.60E-04	1.00E+02	1.10E+01	7.90E-01	3.50E-01

Partitioning of PBTs in the environment to microbeads

Theory

In order to investigate whether partition of PBT substances already present in the environment to microbeads could be important, a thermodynamic modelling approach has been applied. It is essentially a Level I model, as described by Mackay (ref). Thermodynamic equilibrium between media is assumed, and there are no advective losses.

The mass fractions of the chemical in each medium (F) can be described as:

$$F_w = \frac{V_{WW}K_{WW}}{K_{WW}V_w + K_{polymer-water}V_{polymer} + M_{OC}K_{OC}} \quad (\text{Eqn 4.1})$$

$$F_{polymer} = \frac{V_{polymer}K_{polymer-water}}{K_{WW}V_w + K_{polymer-water}V_{polymer} + M_{OC}K_{OC}} \quad (\text{Eqn 4.2})$$

$$F_{OC} = \frac{M_{OC}K_{OC}}{K_{WW}V_w + K_{polymer-water}V_{polymer} + M_{OC}K_{OC}} \quad (\text{Eqn 4.3})$$

Where $K_{WW} = 1$ and W, polymer and OC refer to water, microbead and organic carbon (Gouin et al. 2011²⁶⁴).

$V_{polymer}$, the volume of microbeads has been taken from the predicted environmental concentrations of microbeads from the local scale EUSES modelling.

M_{OC} , the mass of organic carbon has been calculated using default assumptions for concentration of suspended sediment and fraction of organic carbon in the sediment from the REACH guidance (ref to R16, table 16-9). The concentration of suspended sediment is 15 mg/l and the fraction of organic carbon is 0.1, giving a concentration of organic carbon of 1.5 mg/l. This is similar to the highest PECs for microbeads at a local scale.

K_{OC} , the organic carbon-water partition coefficient, can be calculated from the log K_{OW} (ref to TGD guidance).

$K_{polymer-water}$, the partition coefficient between water and the microbeads has been estimated in three different ways. Gouin et al. (2011) (footnote 102) suggest that $K_{polymer-water} = K_{OW}$ could be a reasonable worst-case assumption. $K_{polymer-water}$ has also been estimated as $K_{polymer-water} = 0.1 * K_{OW}$ and as $K_{polymer-water} = K_{OC}$.

Results

Figure D2 shows the fraction of a contaminant predicted to partition to microbeads for contaminants of varying K_{OW} at different environmental concentrations of microbeads, when $K_{polymer-water}$ is calculated in different ways.

²⁶⁴ dx.doi.org/10.1021/es1032025 | Environ. Sci. Technol. 2011, 45, 1466–1472

Figure D2 Fraction of a contaminant predicted to partition to microbeads for contaminants of varying KOW. (a) $K_{\text{polymer-water}} = K_{\text{ow}}$; (b) $K_{\text{polymer-water}} = 0.1 * K_{\text{ow}}$; (c) $K_{\text{polymer-water}} = K_{\text{oc}}$. Blue dots = 1 mg microbeads / l water; orange dots = 0.1 mg microbeads / l water; grey dots = 0.01 mg microbeads / l water; yellow dots = 0.001 mg microbeads / l water.

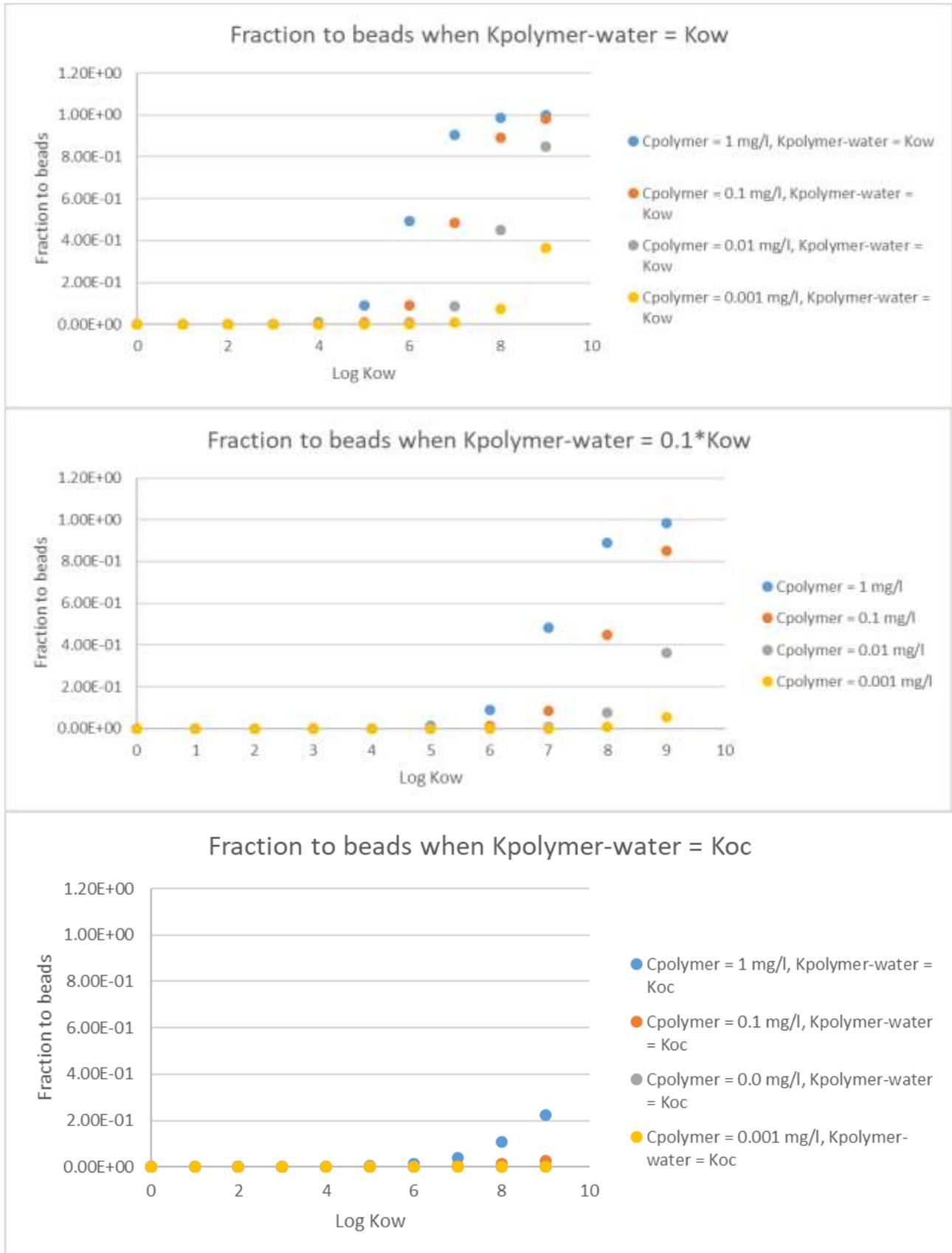
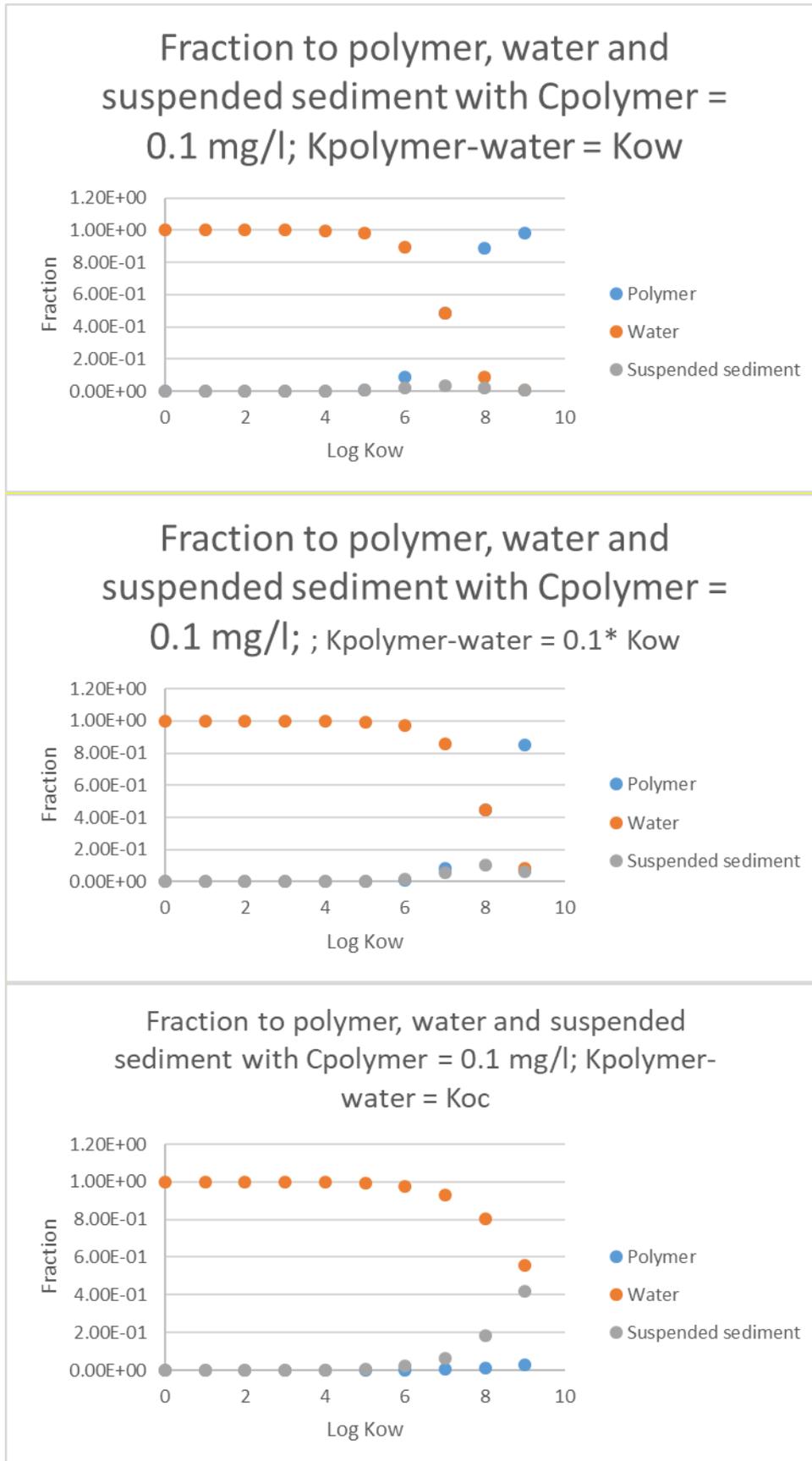




Figure D3 shows the fraction of a contaminant predicted to partition to microbeads for contaminants of varying K_{OW} , suspended sediment and water at a concentration of microbeads of 0.1 mg/l, when $K_{polymer-water}$ is calculated in different ways.

Figure D3 Fraction of a contaminant predicted to partition to microbeads for contaminants of varying KOW. (a) $K_{\text{polymer-water}} = K_{\text{ow}}$; (b) $K_{\text{polymer-water}} = 0.1 * K_{\text{ow}}$; (c) $K_{\text{polymer-water}} = K_{\text{oc}}$. Orange dots = water; blue dots = polymer; grey dots = suspended sediment.



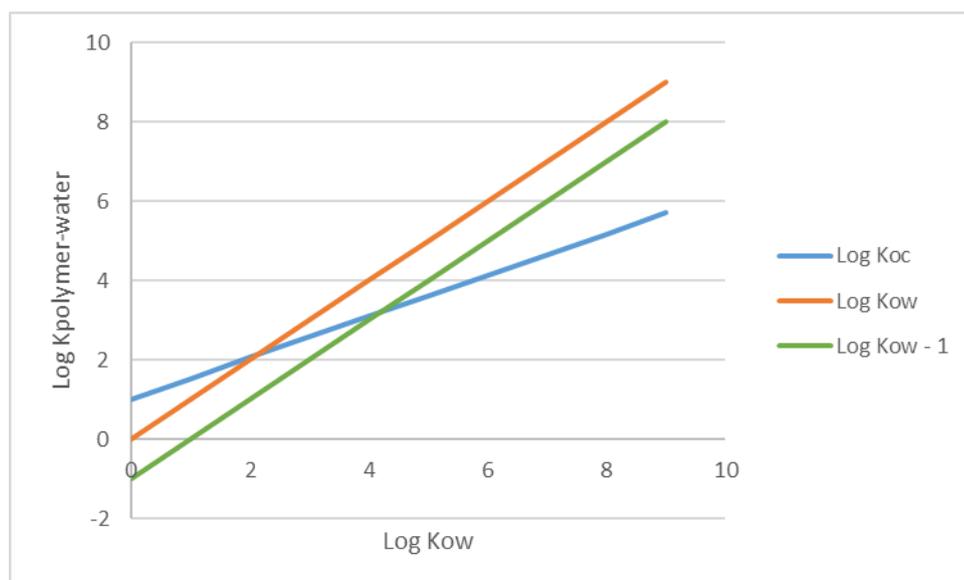
It can be seen that, due to the high PECs for microbeads at local scale, uptake by beads could be significant. The concentration associated with microbeads and suspended sediment increases with increasing $\log K_{ow}$ of the contaminant. The degree of partitioning to microbeads depends heavily on:

- ▶ How the microbead-water partition coefficient, $K_{\text{polymer-water}}$, is calculated.
- ▶ The concentration of microbeads in the environment.

Table D2 shows the variation of $\log K_{\text{polymer-water}}$ (using different calculation methods) and $\log K_{oc}$ with $\log K_{ow}$. Where $\log K_{\text{polymer-water}}$ is proportional to $\log K_{ow}$, $K_{\text{polymer-water}}$ becomes much greater than $\log K_{oc}$ for more hydrophobic substances. Therefore, partitioning to microbeads is more important than partitioning to natural organic carbon for hydrophobic substances when the concentration of microbeads is similar to the concentration of organic carbon.

The default concentration of suspended sediment is 15 mg/l and the fraction of organic carbon is 0.1, giving a concentration of organic carbon of 1.5 mg/l. This is similar to the highest PECs for microbeads at a local scale. A lower concentration of microbeads results in preferential absorption to natural sediment even when the partition coefficient of microbeads is higher than that to organic carbon.

Figure D4 Variation of $\log K_{\text{polymer-water}}$ with $\log K$ when calculated in various ways. Blue line: $\log K_{\text{polymer-water}} = \log K_{oc}$; orange line: $\log K_{\text{polymer-water}} = \log K_{ow}$; green line: $\log K_{\text{polymer-water}} = 0.1 * \log K_{ow}$.



Note on limitations of this assessment - This assessment could also be done for the sediment and soil compartment (this has not been) – it would most likely show that beads are less important than for water as the mass of sediment is higher relative to that of beads, but it could still be important. The maximum PEC freshwater sediment for beads is $1E+05$ mg/kg = 0.1 kg/kg and not all of the sediment is organic carbon, so if $K_{\text{polymer-water}}$ is higher than K_{oc} , adsorption to beads rather than sediment could be important/significant. Soil would not be so significant since the highest PEC is $1.2E+03$ mg/kg (0.0012 kg/kg).

Uncertainties

The model assumes a closed system at equilibrium with no losses by degradation, volatilisation, advection or any other mechanism.

There are uncertainties associated with the calculations of the prediction environmental concentrations of microbeads.

The results of the calculations presented in this section are highly dependent on the method used to calculate $K_{\text{polymer-water}}$. No definitive information is available on values of $K_{\text{polymer-water}}$ for relevant contaminant and polymer combinations.



References

The following are references relevant to the risk/exposure assessment. Other references are included throughout the report as footnotes.

P. Fisk, L. McLaughlin and R. Wildey, "A new assessment of the release of flame retardants from polyurethane foam", Report v3, Peter Fisk Associates, under contract to the Environment Agency, 2006.

OECD ESD for plastics additives

Reynier, Dole P., Humbel S. and Feigenbaum A., "Diffusion coefficients of additives in polymers. I. Correlation with geometric parameters", J. Appl. Polymer Sci., 82, 2422-2433.

Todd Gouin, Nicola Roche, Rainer Lohmann, and Geoff Hodges (2011). A Thermodynamic Approach for Assessing the Environmental Exposure of Chemicals Absorbed to Microplastic. Environ. Sci. Technol. 2011, 45, 1466–1472

Appendix E

Estimation of reformulation costs for leave on PCP and polymers in other PCP

If companies were required to reformulate their personal care products to remove microplastics, all of the products that contain them would need to be replaced with alternatives. While alternatives seem to be readily available for products within the scope of the Cosmetics Europe recommendation (microplastics for exfoliating/cleansing in rinse-off personal care products), for other products and particularly for the wide range of polymers used in personal care products, the industry has not identified alternatives, as evidenced through the responses provided for this study. Indeed, there are many thousands of different polymers used in personal care products, so there will be many thousands of potential alternatives that would need to be investigated.

Products within the personal care industry are regularly reformulated and, on average, large companies reportedly reformulate 30% of their products each year and SMEs 20% (European Commission, 2008). However, these figures include minor reformulations, as well as other more significant ones (around 75% of reformulations are 'minor', relating to change of supplier or to a slight change of matrix, texture or a specific ingredient). While some products are replaced with new formulations fairly frequently, others retain the same formulation for much longer (decades). Many products currently containing polymers/plastics would be reformulated to other products that also contain polymers/plastics.

Reformulation of personal care products is a time-consuming process, when the various stages in getting a product to market are taken into account. Key steps in reformulating a product include identification of alternative substance and reformulation into products, possible claim re-substantiation, potential additional toxicity testing, marketing and customer acceptance. These may take several years for any given product.

Eunomia (2016) quoted an estimated cost of €50 000 per formulation to remove microplastics. However, this is understood to relate to products within the scope of Cosmetics Europe's recommendation, where alternatives are largely already identified. For other products (e.g. leave-on products and products containing polymers more widely), it is assumed that there would be substantially more effort needed to reformulate.

Costs of reformulating products are reported in the literature, though recent data do not appear to be readily available. For example, RTI (2002) estimated total costs of reformulating relevant products as shown in the table below. The report provides a low, medium and high estimate of costs for 'minor' and 'major' ingredients. It is assumed that microplastics/polymers are major rather than minor ingredients²⁶⁵.

Table E.1 Estimated costs of reformulating a personal care product based on RTI, 2002 (in €)

Cost element	Low	Medium	High
Idea generation	2 065	10 325	24 779
Product research	6 389	63 885	127 770
Process development	17 424	49 367	107 121
Co-ordinating activities (purchasing, legal, marketing, QC)	11 136	33 409	55 682
Safety studies (US)	2 452	6 989	25 750
Shelf-life studies	3 151	10 853	26 246

²⁶⁵ Minor reformulations are those relating to change of supplier or to a slight change of matrix, texture or a specific ingredient. Replacement of polymers within personal care products would be a more substantial reformulation. The cost of reformulating to replace a minor ingredient are in any case similar to the 'low' estimate above (around €105 109 compared to €111 772 for the low estimate used here).

Cost element	Low	Medium	High
Packaging development	7 615	20 263	38 074
Market testing	49 048	85 834	141 013
Change process	2 898	9 584	21 172
Plant trial	4 130	15 059	128 214
Start-up and verification	5 464	27 321	133 807
Total	111 772	332 889	829 626

Costs have been converted from USD to Euro based on a 2002 exchange rate (from ECB) and uplifted to 2016 prices based on the HICP (Eurostat). Figures have not been rounded within this table for reasons of transparency of calculations but rounded figures are used in the subsequent analysis.

In estimating costs associated with replacement of microplastics, the element related to safety studies in the above table has not been included in the estimates as the regulatory regime differs (the figures were based on the US situation, rather than the EU). The extent of any toxicological testing required would vary significantly by product, but all products are expected to have a product safety assessment under the Cosmetic Products Regulation and the European Commission (2008) estimates these to cost €15 000 (€17 000 in 2016 prices) for a new product and €1 800 (€2 000 in 2016 prices) for a reformulated product.

Applying the data from the table above, and replacing the estimates for safety studies with the cost of EU product safety assessment, the estimated costs of reformulation are as shown in the table below, including a central, low and high estimate.

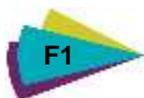
Table E.2 Estimated costs of reformulating a personal care product used in the analysis (in €)

	Low	Medium	High
Total cost to replace microplastics/polymers per product	110 000	340 000	820 000

Costs based on data from RTI (2002) in the table above, excluding costs of US safety studies but adding costs of EU product safety assessment. The cost of safety assessment for a new product is included in the high estimate and the costs for a (minor) reformulated product in the low estimate, with the central estimate including an average of these values.

The underlying data used here are obviously now rather old. However, the central estimate value is in reasonable agreement with the value quoted in a recent restriction proposal under REACH for the substances D4 and D5, which included an estimated €350 000 cost per product, based on a more recent survey/analysis involving the EU personal care products industry²⁶⁶.

²⁶⁶ <https://echa.europa.eu/documents/10162/23cd6eda-688d-44ea-99b0-a254a8f83ba5>.

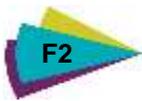


Appendix F

Coverage of functional polymers and the potential impact on cosmetic products depending on the definition of microplastics

The following table has been provided by the European Federation for Cosmetic Ingredients (EFFCI) and is reproduced in this report with kind permission from EFFCI. Note that the table, particularly the impact on cosmetic products, reflects the views of EFFCI. Conclusions of the authors of this study are presented in the main body of the report.

Variations of Microplastic Definition	Functional Polymers Covered	Impact on Cosmetic Products (according to EFFCI)
Synthetic polymer < 5mm in size.	Plastic microbeads, rheology modifiers, opacifiers, film-formers, surfactants, conditioners, emulsifiers, encapsulation technology, dispersants, emollients, moisturisers, glass	Most severe impact on virtually all classes of cosmetic products. Most formulations would no longer be feasible. Alternative technologies are not available and would take years/decades to develop (if at all possible).
Any intentionally added, 5 mm or less, plastic* particle used in personal care products.	Plastic microbeads, rheology modifiers, opacifiers, film formers, surfactants, conditioners, emulsifiers, encapsulation technology, dispersants, emollients, moisturisers, waterproofers	<p>Very severe impact on all classes of cosmetic products.</p> <p>Rinse-off products: virtually all shampoos and shower gels contain water-soluble polymers. Basic functionalities would no longer be feasible. Loss of efficacy and performance.</p> <p>Leave-on products: virtually all products affected as they contain one or more of the covered "functional polymers". No alternatives available. Would effect the feasibility of preparing state-of-the-art emulsions, which are the vast majority of skin care products.</p> <p>Examples of products affected: hair settings products (sprays, gels, mousses), gels, cremes, lotions, decorative cosmetics, opacified toiletries, shampoos, hair conditioning, suncare (especially where waterproof effect is required), toothpastes, mouthwashes.</p>
Any intentionally added, 5 mm or less, solid plastic* particle used in personal care products.	Plastic microbeads, rheology modifiers, opacifiers, film formers	<p>Very severe impact on all classes of cosmetic products.</p> <p>Rinse-off products: virtually all shampoos and shower gels contain water-soluble polymers. Basic functionalities would no longer be feasible.</p> <p>Leave-on cosmetics: over 90% of products contain one of the covered "functional polymers". Preparation and expected performance would not longer be feasible.</p> <p>Examples of products affected: hair settings products (sprays, gels, mousses), gels, cremes, lotions, decorative cosmetics, opacified toiletries, shampoos, hair conditioning, suncare (especially where waterproof effect is required), toothpastes, mouthwashes.</p>
Any intentionally added, 5 mm or less, water insoluble, solid plastic* particle used in personal care products.	Plastic microbeads**, some rheology modifiers & opacifiers	<p>Partial to major impact on some classes of cosmetic products.</p> <p>Rinse-off products: impact depends on the definition of the solubility parameters. The impact could reach from mainly on the appearance to having a strong impact on the performance of conditioning products.</p> <p>Examples of products affected: shampoos, shower gels, cremes, lotions, decorative cosmetics, suncare.</p>



Variations of Microplastic Definition	Functional Polymers Covered	Impact on Cosmetic Products (according to EFfCI)
Any intentionally added, 5 mm or less, water insoluble, solid plastic* particle used to exfoliate or cleanse in rinse-off personal care products.	Plastic** microbeads	Impact limited to microbeads capable to contribute to marine litter.

Source: EFfCI, provided June 2017

Notes

* no definition of a plastic included in definition, thus term has been ignored

** using the definition of plastic adopted by the Global Microplastics Task Force: Plastic: Synthetic water insoluble polymers that are repeatedly molded, extruded or physically manipulated into various, solid forms which retain their defined shapes in their intended applications during their use and disposal.

