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

Paints and microplastics

Exploring recent developments to minimise the use and release of microplastics in the Dutch paint value chain

RIVM report 2021-0037

M. Faber et al.

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Synopsis

Paints and microplastics
Exploring the possibilities to reduce the use and release of microplastics from paints. Feedback from the paint sector.

Microplastics are small plastic particles that consist of polymers. These particles end up in the environment where they can harm animals and plants. Paints also contain microplastics. By adding solid polymers (primary microplastics) to paints, paint layers are formed that can cover and protect surfaces. They are released when dried paint layers break down or are sanded. Then we call these secondary microplastics.

RIVM asked a large group of stakeholders in the paint sector what they do to limit the release of microplastics from paints. The paint sector is aware that microplastics can cause problems in the environment, but they do not actively try to reduce the emissions. They believe that the emission cannot be avoided and that the polymers are needed to create a paint layer that can cover and protect surfaces for a long time. There are still only a few paint products available without polymers. These are not (yet) suitable for all paint applications.

The paint sector has taken indirect measures to lower the emission. They have, for example, developed paints that last much longer; almost twice as long. The sector also indicates that professional painters are taking measures to reduce the release of paint particles and dust during work. They normally use a device that collects particles during sanding.

It is unknown whether do-it-yourself handymen also take these measures and whether this is possible. Also, they rinse brushes with water-based paints in the sink. This is not advisable.

Currently it is unclear how many microplastics are released during the production, use and disposal of paints. More data on this is needed in order to be able to take measures, for example via measurements in the environment. It is also important that the entire paint sector thinks about measures to lower emissions.

Keywords: paint, microplastics, emission, measures, developments

Publiekssamenvatting

Verf en microplastics

Verkenning van mogelijkheden om het gebruik en de uitstoot van microplastics uit verf te minimaliseren. In gesprek met de verfsector.

Microplastics zijn kleine kunststofdeeltjes die bestaan uit polymeren. Deze deeltjes komen in het milieu terecht, waar ze schadelijk kunnen zijn voor dieren en planten. Microplastics zitten onder andere in verf. Door vaste polymeren (primaire microplastics) aan verf toe te voegen ontstaan verflagen die oppervlakten kunnen bedekken en beschermen. Ze komen eruit vrij als gedroogde verflagen verweren of worden geschuurd. Dan noemen we ze secundaire microplastics.

Het RIVM heeft een brede groep van belanghebbenden uit de verfsector gevraagd wat zij doen om de uitstoot van microplastics uit verf te beperken. De verfsector blijkt zich ervan bewust te zijn dat microplastics problemen kunnen geven in het milieu. Maar ze zijn er niet actief mee bezig om de uitstoot te verkleinen. Volgens hen is de uitstoot niet te voorkomen. De polymeren zijn nodig om een verflaag aan te brengen die oppervlakten langdurig bedekt en beschermt. Er bestaan nog weinig verfproducten zonder polymeren. Deze zijn (nog) niet geschikt voor alle toepassingen van verf.

De verfsector heeft wel indirect maatregelen genomen die de uitstoot verkleinen. Zo hebben ze verf ontwikkeld die veel langer goed blijft en blijft zitten; bijna twee keer zo lang. Ook geeft de sector aan dat professionele schilders maatregelen nemen om de uitstoot van verfdeeltjes en stof tijdens het werk te verminderen. Zo gebruiken zij standaard een apparaat dat schuursel opvangt tijdens het schuren.

Voor doe-het-zelf klussers is onbekend of zij ook zulke maatregelen nemen en of dat mogelijk is. Ook spoelen doe-het-zelf klussers kwasten met verf op waterbasis af onder de kraan. Dit is niet wenselijk.

Het is nu niet duidelijk hoeveel microplastics worden uitgestoten tijdens de productie, het gebruik en de afvalverwerking van verf. Het is wenselijk dat hierover meer gegevens beschikbaar komen om maatregelen te kunnen nemen. Bijvoorbeeld door metingen in het milieu. Daarnaast is het belangrijk dat de hele keten nadenkt over maatregelen om de uitstoot te verminderen.

Kernwoorden: verf, microplastics, uitstoot, maatregelen, ontwikkelingen

Contents

1 Introduction

1.1 Research context

In the last decade, increased attention has been paid to microplastics by policymakers, scientific researchers, and the broader public (Koelmans et al., 2019, EC, 2019). The presence of microplastics has been demonstrated in water, soil, sediment, air, and organisms (Horton and Dixon, 2018). Due to their persistence they are likely to remain in the environment long after their initial release (ECHA, 2020b). Microplastics can be easily ingested by organisms and can potentially be transferred within food chains. While the effects of microplastics on the environment can currently not be assessed with a conventional quantitative risk characterisation, a case by case assessment has demonstrated the adverse effects of microplastics on biota and their persistence in the environment (ECHA, 2020b). This has led to the conclusion that releases of microplastics should be minimised, as any release will result in wide spread distribution and environmental stock build up (ECHA, 2020b).

Earlier research by the National Institute for Public Health and the Environment (RVIM) focused on identifying microplastic sources. Studies were performed to prioritise and estimate the total microplastic emissions released from different sources in the Dutch aquatic environment (Verschoor et al., 2014, Verschoor et al., 2016). More recently, research was conducted to identify potential measures for the reduction of microplastic from car tires, abrasive cleaning agents, paints, and textiles (Verschoor and de Valk, 2017, Zwart and de Valk, 2019).

For paints, it was estimated that 690 tonnes of microplastics are released to the Dutch environment annually (Verschoor and de Valk, 2017). Figure 1-1 lists the potential measures proposed to address these emissions. It was estimated that around 220 tonnes of microplastic emissions could be reduced by implementing these measures (Verschoor and de Valk, 2017).

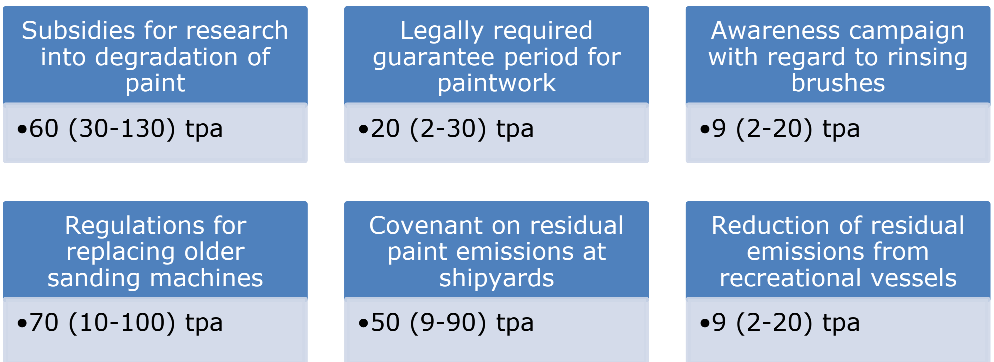

Figure 1-1: Proposed measures to reduce paint particle emissions and the estimated emission reductions in tonnes per annum (tpa) with uncertainty margins (Verschoor and de Valk, 2017).

1.2 Goal and methods

On behalf of the Dutch Ministry of Infrastructure and Water Management, the RIVM identified recent developments and measures taken in the Dutch paint value chain that can lead to a reduction in microplastic emissions. The goal of this report is to give an overview of these findings without recommending or prioritising the developments or measures identified. This report serves as a starting point for discussions between policymakers and stakeholders in the Dutch paint value chain on how to move forward on the issue of microplastics release from paints.

Research methods
To gain insights in the developments and measures taken in the Dutch paint value chain that could lead to a reduction in microplastic emissions, information was gathered through two methods; semi-structured interviews and a literature research. These are described in more detail:

1. Semi-structured interviews: Stakeholders in the Dutch paint value chain were selected to gain a broad view on their perspectives regarding microplastic emissions and possibilities to reduce these. Semi-structured interviews, where a list of questions was prepared and sent in advance of the interviews (see appendix 1), were conducted with paint producers, trade organizations, raw material suppliers, and research institutes (see Table 1-1). It should be noted that, while the focus was on the Dutch paint value chain, most of the upstream stakeholders operate at a European or even global level. Furthermore, while this explorative study initially focused on developments and measures in the design and use phases, the interviews also yielded information on the waste management phase. Therefore, this phase was included, however, stakeholders at the end-of-life phase of paints were not explicitly consulted. Each interview was attended by two RIVM staff. A total of 13 interviews were held.
2. Literature research: A literature search was performed to supplement and crosscheck the information gathered from the semi-structured interviews. Firstly, the Scopus and Embase scientific repositories were searched for peer-reviewed scientific literature using a combination of the following keywords: microplastic, nanoplastic, paint, release, weathering, aging, degradation and waste. The abstracts of the publications were scanned to determine their content and assess their relevance. This resulted in a total of 112 publications from the year 1999 onwards, of which only 3 were considered relevant for this report. Secondly, a more general search was conducted using the Google and Google Scholar search engines applying the above terms, supplemented with a broader terminology, including terms such as dispersion, emulsion and specific polymer types (e.g. alkyd, acryl and epoxy). Finally, websites from key organisations (e.g. ECHA, UBA, CEPE, EC[1]) were searched for relevant reports on microplastic emissions from paints.

[1] ECHA – European Chemicals Agency; UBA – German Federal Environmental Agency; CEPE – European Council of the Paint, Printing Ink, and Artist's Colours Industry; EC – European Commission.

Table 1-1 List of stakeholders interviewed between June 2020 and October 2020.

Stakeholder	Type of organization	Step in paint value chain
AkzoNobel	Paint producer	Development and production
Baril Coatings	Paint producer	Development and production
CEPE[1]	Trade organization	Development and production
D+F Coatings	Representing paint producer	Development and production
DSM	Raw material supplier	Development and supply
HISWA[2]	Trade organization	Application and maintenance
NMT[2]	Trade organization	Application and maintenance
OnderhoudNL[a]	Trade organization	Application and maintenance
PPG Architectural Coatings	Paint producer	Development and production
PPG Protective and Marine Coatings	Paint producer	Development and production
VVVF[2]	Trade organization	Development and production
VVVH[2]	Trade organization	Distribution
WUR[2]	Research institute	Research & development

a: Written reply to questions.

1.3 Reading guide

Chapter 2 presents information on paints and on microplastics use and release from paints.

Chapter 3 reviews legal aspects related to paints and the use and release of microplastics from paints.

Chapters 4, 5 and 6 give an overview of the findings from the interviews and literature research, describing developments and measures to reduce microplastic emissions. The chapters discuss the research and development, application and maintenance, and waste management phase of paint products, respectively.

Chapter 7 gives a brief discussion on the research findings and presents the conclusions of this report.

[2] HISWA - Nederlandse Vereniging voor Handel en Industrie op het gebied van Scheepsbouw en Watersport; NMT – Netherlands Maritime Technology; VVVF - Vereniging van Verf- en Drukinktfabrikanten; VVVH - Vereniging van Verfgroothandelaren in Nederland; WUR – Wageningen University and Research.

2 Paints, microplastics use and release

The background information presented by Verschoor et al. (2016) in the RIVM report "*Emission of microplastics and potential mitigation measures - Abrasive cleaning agents, paints and tyre wear*" has been updated in this report. The original report provided a comprehensive overview of paints, their applications, and the definition and sources of microplastics. It also provided estimations of microplastic emissions to Dutch surface waters for the most relevant paint applications, and identified reduction measures. This chapter serves as the context for the findings on development and for the measures taken to reduce microplastic emissions reported in chapters 4, 5 and 6. While some information is repeated, it mainly elaborates on recent developments on the aforementioned topics and provides an overview of the current Dutch paint value chain and potential emissions per activity (phase).

2.1 Paint and its applications

Paints are pigmented liquids applied to surfaces of objects for protection or for aesthetic purposes. These surfaces, often referred to as substrates, can be made of various materials, including wood, metal, concrete, stone and plastics. Paint products are used for a variety of consumer applications such as for the decoration of houses and furniture, as well as for professional applications in sectors such as construction, automotive industries, and shipping (VVVF, 2012). In the latter, a special category of paints is used, i.e. antifouling paints, that prevent the growth of algae and shellfish on ship hulls. Certain types of antifouling paints are meant to gradually wear over the years to release biocides such as copper and zinc (Miller et al., 2020). Depending on the function, paints differ in composition, i.e. due to differences in the technical requirements related to the substrate or location (indoor/outdoor).

The main components of paints are pigments, binders, additives and solvents (VVVF, 2020b). Pigments give colour and opacity to paints, but can also be used to create decorative effects (e.g. gloss) or to enhance product performance (e.g. anticorrosive properties) (Talbert, 2007). Binders used in paints are generally based on carbon-chain polymers such as alkyds, acrylics, polyurethane and epoxies, which are added to create a solid film layer after application. The polymers create a matrix that retains the additives and pigments embedded in the paint (Talbert, 2007). These carbon-chain polymers are often synthesized from petrochemicals, but bio-based alternatives are upcoming. In addition, inorganic polymers such as silicones can be used in combination with organic polymers (Augustinho et al., 2016). There are also paints on the market without polymeric binders, where lime is applied as binder (PCC Group, 2018). Additives, which can be a variety of organic as well as inorganic compounds, can have different functions acting, amongst others, as thickening agents, fillers, dispersing agents, biocides, UV-blockers, silicones and driers, while solvents are used to reduce viscosity of paints (Talbert, 2007, Lambourne and Strivens, 1999). Paints can be divided in solvent-based and water-based paints, utilizing organic compounds and water as solvents, respectively. Whereas most paints used to be solvent-based, a clear shift to water-based paints occurred after the emission of volatile organic compounds (VOC) from paints was regulated in 2004; this is further discussed in chapter 3. When compared to water-based paints, solvent-based paints have some advantages, such as faster drying times and the ability to contain higher contents of solids, therefore they are still used for certain applications, e.g. application in humid conditions. It should be noted that while polymers are dissolved in solvent-based paints, water-based paints are basically emulsions in which polymer particles are dispersed. The size of the polymer particles affects different aspects of water-based paints, with fine particles enhancing film formation and pigment-binding but also increasing the viscosity. The polymer particles in water-based paints are reported to be in the range 80 to 1000 nm (Overbeek, 2010, SpecialChem, 2020).

Paints can be applied to substrates by numerous methods including brushing, rolling, dipping, spraying, airless spraying, vacuum impregnation, and full immersion (Talbert, 2007, TECI, 2013). Metal objects can also be powder coated, where dry paint powder is sprayed using an electrostatic gun. In the latter case, curing at high temperatures is needed. Liquid paints applied to a surface undergo a drying process yielding a solid film layer. Drying occurs physically due to the evaporation of liquids, or chemically by oxidation or reactive paint ingredients (Talbert, 2007). The resulting solid polymer matrix holds the different components together in the dried paint layer.

The use of polymers in paint products leads to microplastic emissions, for example as a result of inadequate disposal of non-applied water-based paints leading to discharge of polymer particles, as well as the weathering of dried paint layers where particles with a polymer backbone are formed. These emission routes are further detailed in section 2.3, while section 2.2 describes the type of microplastics that can be formed, i.e. primary and secondary microplastics.

Update on paint sales in the Netherlands
In the Netherlands, the total amount of paint sold was 106,100 tonnes in the year 2019 (VVVF, 2020a). Based on sales volume, the sectors 'Construction' and 'Do It Yourself (DIY)' are the most important markets for paints, with 46% and 23% of total sales, respectively (Figure 2-2). These sectors have been in decline since 2011[3], with the sectors 'Industry' and 'Shipping' becoming more important. A shift in paint sales represents a shift in the type of paints used and where they are applied, which may influence the release of microplastics and its environmental pathways; a relative increase in the shipping segment can be indicative of more direct emissions to aquatic environments. Note that this report does not focus on the quantification of microplastic emissions. In addition, no information was available to quantify the number of paints sold that cause less microplastic emissions compared to conventional paints. Data on paint sales could only be used to distinguish between indoor & outdoor paint, as well as solvent or water-based paints.

[3] As of 2016, the VVVF uses a different method to calculate the total sales of paints. A decline is visible from 2016 onwards, sale volumes between 2011 and 2019 are therefore difficult to compare. It is expected that the new calculation method will have limited effects on the relative distribution of paints over the different sectors.

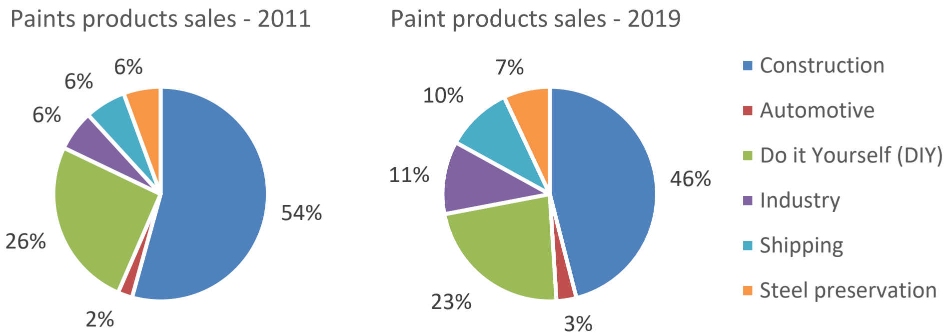

Figure 2-1 Sales of paint products in the Netherlands for 2011 and 2019. Numbers are presented as the relative amount of sales in tonnes (data derived from (VVVF, 2012, VVVF, 2020a).

2.2 Defining microplastics

The definition of microplastics has changed over time, as is reflected by the definitions used in literature. In Verschoor et al. (2016) the following working definition was used: microplastics are solid, synthetic polymer particles with a size smaller than 5 mm, with a low solubility in water (<1 mg/L), and a low degradation rate (based on REACH persistence criteria). They also indicated that microplastics may contain non-polymeric additives, oils, fillers, or other product aids.

In this report, the working definition of microplastics has been replaced by the definition given by ECHA's Committee for Risk Assessment (RAC) in their opinion on the proposed restriction on intentionally added microplastics submitted by the European Chemicals Agency (ECHA) (ECHA, 2020b, ECHA, 2020a). In the RAC opinion, microplastics are defined as particles containing solid polymer[4], to which additives or other substances may have been added, and where ≥ 1% w/w of particles have: (i) all dimensions ≤ 5 mm, or (ii) a length of ≤ 15 mm and a length to diameter ratio of >3. Furthermore, it is stated that this definition shall not apply to: (i) natural polymers that have not been chemically modified, (ii) biodegradable polymers[5], and (iii) water soluble polymers[6] (solubility >2 g/L). This updated microplastics definition can be regarded as a further refinement of the earlier applied working definition, with the only substantial change being that fibres are now

[4] Solid is defined as substance or a mixture which does not meet the definitions of liquid or gas, where 'gas' means a substance which (i) at 50 °C has a vapour pressure greater than 300 kPa (absolute); or (ii) is completely gaseous at 20 °C at a standard pressure of 101.3 kPa, and where 'liquid' means a substance or mixture which (i) at 50 °C has a vapour pressure of not more than 300 kPa (3 bar); (ii) is not completely gaseous at 20 °C and at a standard pressure of 101.3 kPa; and (iii) which has a melting point or initial melting point of 20 °C or less at a standard pressure of 101.3 kPa; or (b) fulfilling the criteria in ASTM D 4359-90; or (c) the fluidity test (penetrometer test) in section 2.3.4 of Annex A of the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR).
[5] A tiered approach is followed to determine biodegradability, which includes screening level tests to determine ready biodegradation, enhanced/modified ready biodegradation, inherent biodegradation, bio(degradation) relative to a reference material, and degradation simulation test to derive half-life values under relevant environmental conditions. For more information, see (ECHA, 2020a).
[6] Quantification can be done either via the procedure described in OECD guideline 120 or in OECD guideline 105. For more information see (ECHA, 2020a).

defined as having a maximal length of 15 mm[7]. Adapting the microplastics definition does not affect the outcome of the previous work on microplastics and paints, as the use of fibres in paints appears to be limited (see section 2.3). It is, however, important to realise that the term microplastics does not differentiate between the composition of the particles nor the source of these particles.

Microplastics can be separated into primary and secondary microplastics. Primary microplastics are particles that have been added to products to fulfil a certain function in the product; microbeads used in personal care products and scrubbing materials in cleaning agents are examples. Certain paint products also contain microspheres, i.e. microbeads or microfibres, to enhance their properties (see section 2.3). Water-based paints additionally contain a potentially much larger source of primary microplastics including dispersed polymer particles. They act as a binder in cured paint layers, but remain primary microplastics when paints are disposed inadequately, for example when fluid is poured down the drain. The dissolved polymers in solvent-based paints are, however, not considered microplastics as they are not solid polymer particles.

Secondary microplastics are formed by the fragmentation of macroplastics (>5 mm) by processes such as weathering of plastic litter and paint layers, as well as wear of car tyres. Secondary microplastics consist of the entire paint matrix, including the binder polymers, but also the other components described in section 2.1. The microplastics definition does not have a lower size limit and, as such, plastics in the nanosize range (<100 nm) are included in the microplastics definition.

2.3 Microplastic emissions from paints

Microplastics derived from paints have been detected in the aquatic environment as well as in aquatic species. Herrera et al. (2019) reported that 16.7% of the sampled fish contained paint particles in the form of microplastics in the gastrointestinal tract. Cardozo et al. (2018) demonstrated that 63% of the found plastic fragments in sampled fish species derived from fishing, of which 55% derived from paint fragments of vessels. No detailed information was given by Cardozo et al. (2018) on the size of these fragments, i.e. whether the fragments were macro or microplastics. Lima et al. (2014) identified 14,724 microplastic items in 216 samples from a river estuary, of which almost 30% were paint chips. From these studies, it is evident that microplastics derived from paint end up in the aquatic environment. However, they cannot be used to draw quantitative conclusions as the sampling and analytical methodologies are not standardized and thus difficult to compare. To obtain a more robust dataset for the Dutch surface waters, in 2019, Rijkswaterstaat started the ‘Microplastic Monitoring’ programme. Its goal is to develop reliable methods to measure microplastics in surface waters in the Netherlands as of 2023. Once reliable methods are available, measuring microplastics will be implemented in the Monitoring Waterstaatkundige Toestand des Lands’ (MWTL-programme). This will

[7] In general all microplastics, including microfibres, were previously defined as particles smaller than 5 mm. Note that CEPE indicates that fibres up to 50 mm are used as intentionally added microplastics in paints and therefore the restriction does not apply to all microfibres used (CEPE, 2018).

then allow Rijkswaterstaat to continuously monitor water quality in Dutch surface waters (RWS, 2020a).

Microplastics can be emitted at various phases in the paint value chain and include both primary and secondary microplastics. Figure 2-2 presents an overview of the different phases of the paint value chain.

Figure 2-2 Different phases in the paint value chain.

In this report, we focus on three phases of the paint value chain: (i) research and development, (ii) application and maintenance, and (iii) waste management. The phases and their relationship to microplastics are presented below. The production and distribution phases are not discussed any further as no information was found regarding microplastic emissions or developments in these phases.

Research and development phase
During the research and development phase, paint formulations are developed to meet different criteria, including functionality, durability, and legislative requirements. The choices made in this phase can affect the emissions of microplastics at subsequent phases in the paint value chain.

Primary microplastics can be added to paint products to fulfil functions like weight reduction, scratch and wear resistance, and elasticity (ECHA, 2019). The European Council of the Paint, Printing Ink and Artists' Colours Industry (CEPE), reported that (hollow) microspheres (5-80 µm) as well as microfibres (0.5-50 mm) can be added to paints (CEPE, 2018). These microspheres cause a weight reduction of the paint contents, improve paint application, allow thicker layers, and provide unique dried paint properties like elasticity and scratch resistance. The microfibres improve toughness of the applied coating, bridge cracks and seams in walls or ceilings, and increase the thixotropy[8] of wet paints. CEPE report that less than 1% of water-based decorative paints contain microspheres/microfibres. This aligns with a previous comment that the majority of paint formulations do not contain microspheres as an ingredient (Verschoor et al., 2016). Note that in the research and development phase neither primary nor secondary microplastics are emitted, but decisions taken in this phase determine to what extent microplastics will be emitted in subsequent phases of the paint value chain.

Application and maintenance phase
A range of sectors are involved at this phase including the building sector (both professionals and consumers (DIY)), as well as the shipping sector. Activities performed at this phase are considered the major sources of microplastics. Emissions are mostly related to secondary

[8] Thixotropy is defined as the progressive decrease in viscosity with time for a constant applied shear stress, followed by a gradual recovery when the stress is removed (Cullen et al., 2011).

microplastics, but primary microplastics are also released. Several emission routes are discussed in detail below.
In the building sector, primary microplastics are emitted by disposing water-based paints down the drain and by rinsing brushes and rollers under the tap. This release of non-applied polymer particles and intentionally added microspheres/microfibres from liquid paints is thought to occur primarily in the DIY sector and not as much in the professional sector due to its stricter standard operating procedures. In the restriction proposal on intentionally added microplastics, ECHA estimated that annually, around 5,200 tonnes of polymers are discharged from paint brushes and rollers into the environment of the European Economic Area (EEA) (ECHA, 2019). This comprises all polymers, including the polymers used as binders in water-based paints. CEPE estimated an annual emission of 2,000-3,000 tonnes for intentionally added microspheres/microfibres, which is 40-60% less than the ECHA estimate (CEPE, 2018). The numbers provided by CEPE do not include polymer dispersions but only represent additive microplastics. CEPE noted that this concerns less than 1% of the waterborne decorative paints. Previously, Verschoor et al. (2016) estimated for the Netherlands that approximately 16 tonnes of microplastics are released annually to the environment from cleaning paint brushes. It should be noted that microplastics end up in the sewage system and thereafter in communal wastewater treatment plants (WWTPs). A large fraction is trapped in sludge at WWTPs. In the Netherlands, most of the sludge is incinerated, and none is applied to soil as fertilizer. WWTP can reduce microplastic emissions by up to 99.9% when using membrane bioreactors (Ngo et al., 2019), however these systems are not applied at WWTPs in the Netherlands. Conventional WWTP reduce more than 90% of the emissions (Ngo et al., 2019), however, as treatment steps differ at each Dutch WWTP, removal efficiencies will differ as well. Occasionally, wastewaters are discharged directly to surface water without treatment, e.g. due to inactivation, bypass in case of storm events, or malfunctions; this can result in short-term releases of microplastics into the surface water.

Secondary microplastics are formed during maintenance and weathering. Verschoor et al. (2016) estimated that 490 tonnes of secondary microplastics from paints are released annually by professional building and DIY activities in the Netherlands, and 200 tonnes by shipping activities. Sources of building and DIY activities were mainly wear of paint layers (260 tonnes) and removal of old paint layers (210 tonnes). Of the latter, 35% results from DIY activities with the other 65% from building activities. The higher amount of emissions from building activities was explained by a higher paint consumption as well as a higher fraction of exterior paints applied, of which emissions were higher than interior paints.

The expected annual release of microplastic emissions from paints in Europe to OSPAR catchments (the North-East Atlantic and upstream European catchments) is between 10,000 and 90,000 tonnes (OSPAR Commission, 2017). These emissions are the result of paint application, and removal and wear of paint layers from shipyards, marinas, buildings, and roads, and include both primary and secondary microplastic emissions. When compared to ECHA’s estimate of primary

microplastic emissions in Europe, secondary microplastics are the main contributor of microplastics to the environment. These particles enter the environment if they are not fully collected, e.g. during sanding of substrates in the open air.
For shipping activities, Verschoor et al. (2016) identified maintenance and wear of paint layers as sources of microplastic emissions, in line with OSPAR (OSPAR Commission, 2017). Verschoor et al. (2016) focused on paints applied to ship hulls, i.e. primers, and antifouling paints for under water parts of the hull, and coatings for those parts above the waterline. No differentiation was made between the emissions and type of paints, however, emissions from antifouling paints may be higher, as some of the paints applied wear over time and antifouling paint particles have been identified in the aquatic environment (Muller-Karanassos et al., 2019).

Antifouling paints are used on marine vessel hulls and other submerged marine applications to reduce biofouling (Yebra et al., 2004). There are three types of conventional antifouling paints: (i) hard, (ii) soft and (iii) self-polishing antifoulings. Hard antifoulings do not wear substantially and are applied every 2-3 years without removing previously applied antifouling layers. After 6-7 years the hard antifouling layer is removed and renewed completely. Soft and self-polishing antifoulings wear over time from wear through movement in water and by gradually dissolving, respectively. For recreational ships, self-polishing paints have to be renewed every year (HISWA, 2020). For marine vessels, antifouling paints are renewed every three to five years, often before the paint layer is worn out, as renewing antifouling paints reduces fuel costs and therefore is economically beneficial. All aforementioned antifouling paints contain biocides, although similar non-biocidal types products are also available (Wezenbeek et al., 2018). These biocides, often copper and zinc compounds, end up in the water along with paint particles containing a polymer backbone (Muller-Karanassos et al., 2019). Most of the application and maintenance takes place at shipyards or marinas. Regulations and monitoring, for example by harbour masters, should prevent the release of waste to the environment. In cases where maintenance is performed while at sea, monitoring waste management practices is more complex. These maintenance activities are, however, limited.

Waste management phase
There are different end-of-life scenarios for paints. In the Netherlands, unused paints can be returned to waste collection stations where they are separately collected. The collected paints are currently incinerated as chemical waste, and not recycled (Milieucentraal, 2020). There are also some initiatives to re-use paint residues (see chapter 6). If disposed in household waste, paints will be treated as ordinary waste and incinerated. Empty paint cans and used DIY paint tools are generally also discarded as household waste. The emissions of microplastics to the environment from unused paints in household waste and waste collection stations are thus assumed to be limited.

As mentioned, paint residues enter the environment even when non-applied (e.g. during the rinsing of brushes) as well as after application (e.g. during removal of old paint layers). Both types of residues should be discarded with the household waste. Paint particles from old paint layers should especially be collected correctly, as outdoors, the dispersion of paint particles is promoted by wind and rain. Collection can be executed by using, for example, dust extraction systems but also by sweeping. Painted objects discarded in the open air or sea, either as waste or as a resource for later use (e.g. old cars, machinery, boats), may lead to secondary microplastics release over time, as the paint layers will weather over time (Lassen et al., 2015). All objects that are still maintained and painted over time, are considered in the maintenance and application phase.

3 Legal aspects of paints and microplastics

There is no specific legislation that deals with microplastics from paints. However, there are Dutch and EU legislations in place that act on the composition, application, and disposal of paint products, as well as on substances in general. Currently, EU legislation is being developed to restrict the use of intentionally added microplastics. All these legislations will directly or indirectly affect the composition of paints and subsequently, the emission of microplastics from paints. In this chapter the relevant legislation is briefly described, as well as how each will affect microplastics from paints.

3.1 The Paint Directive

Directive 2004/42/EC came in force in 2004 to limit the emissions of volatile organic compounds (VOC) from decorative paints and vehicle refinishing products (EP and CE, 2004). Since then, a clear shift to water-based paints has taken place. Moreover, solvent-based paints have also been developed that have a higher solid content and thus less solvent. Overall, the directive has led to lower VOC emissions from paints.

Inadvertently, the compositional changes also resulted to changes in the other characteristics of paint products. As noted in section 2.2, water-based paints contain microplastics (emulsions with dispersed solid polymer particles), whereas solvent-based paints do not (dissolved polymers). The shift from solvent-based to water-based paints may lead to increased release of primary microplastics through disposal of unused water-based paints through the drain.

3.2 REACH

The European Union’s Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) (EC 1907/2006) is intended to protect human health and the environment from hazardous chemicals (EC, 2006). Producers and importers are required to demonstrate safe use of their substances.

REACH regulation in general
The REACH regulation plays an important role in the paint value chain, as it can limit the use of hazardous substances in paint products. Under REACH, hazardous substances can be identified as substances of very high concern (SVHC) based on their effect on human health or the environment. These substances can be further regulated by either prohibiting all their uses, except those authorised, or by restricting certain uses. Authorisations and restrictions directly affect paint composition as they are legally binding; Annex XVII to REACH includes all the adopted restrictions. Several compounds previously used in paints can also be found on the restricted substances list, i.e. dibutyltin (DBT), lead sulphates and lead carbonates (EC, 2009). Substances that are currently used in paint products may also become regulated when it becomes apparent that they are hazardous. Paint producers and raw material suppliers need to adapt their paint formulations accordingly, which can be a driver for the innovation of paints products by

substituting or mitigating hazardous substances. Currently, polymers are exempted from registration and evaluation under REACH, although they may still be subject to authorisation and restriction (ECHA, 2012). The Chemicals Strategy for Sustainability recently released by the European Commission opts for the registration of polymers of concern under REACH (EC, 2020a).

Restriction on intentionally added microplastics
In 2019, ECHA filed a proposal to restrict the use of intentionally added (primary) microplastics in products intended for the EAA market. Scope of the proposal is to achieve an estimated reduction of 90% of intentionally added microplastics to the environment from 2022 onwards. The paint value chain is subject to this restriction proposal as paint products contain intentionally added microplastics, either as dispersed polymer particles in water-based paints for film formation, or as microbeads/microfibres for enhancing paint traits in water and solvent based paints. However, two of the proposed derogations directly affect paint products.

Derogation 5b derogates *"substances or mixtures containing microplastic where the physical properties of the microplastic are permanently modified during end use, such that the polymers no longer fulfil the meaning of a microplastic as given in the microplastics definition"*. This derogates thus the film-forming polymer particles in paints, as on drying the dispersed polymers become chemically bound in a solid matrix.

Derogation 5c derogates *"substances or mixtures containing microplastics where microplastics are permanently incorporated into a solid matrix during end use"*. This derogates the microbeads/microfibres that are added to paints as they get permanently incorporated in the solid polymer matrix of the film layer.

While the proposed restriction will prohibit the use of intentionally added microplastics in many products, this will not be the case for paint products. The Risk Assessment Committee (RAC) of ECHA does recognize in its opinion on the proposed restriction that there could be some releases of 'uncontained' microplastics under reasonably foreseeable conditions of use, and that these releases should be minimised (ECHA, 2020b). Therefore, to benefit from these derogations, paint producers and importers will be required to communicate appropriate use instructions to minimise releases to the environment and report the quantities released to ECHA. In the initial proposal, the paint sector was also required to provide more detailed information on polymer identity and use quantities, but this was removed by ECHA in the process as it was considered a significant administrative burden, could lead to double counting, and would require the disclosure of confidential business information. Two other derogations, i.e. derogations 3a and 3b derogate the use of respectively natural and biodegradable polymers, and do not include reporting requirements. CEPE indicates that particles made of natural polymers such as cellulose or coconut fibres could be used in paints, although the application of these materials has not yet been tested and evaluated (CEPE, 2018).

In addition, it is important to realise that the proposed restriction only targets primary microplastics and not the secondary microplastics that might be formed from paints, therefore the effects of the restriction on microplastic emissions from paints could be limited.

3.3 CLP regulation

The CLP regulation (1272/2008/EG) applies to all substances regardless of their use. CLP stands for Classification, Labelling and Packaging. Paint producers and importers are required to classify their hazardous substances and clearly indicate on their paint products if they are hazardous to human health or the environment. Although this regulation does not directly affect the use of microplastics, it can be a driver to substitute hazardous substances in paint products.

3.4 Environmental legislation

Waste management

The Dutch 'Wet Milieubeheer' defines legislation on environmental topics, including waste management. Chapter 10 of this law is dedicated to waste streams. In the Netherlands, every person has to manage waste in such a manner that it does not negatively affect the environment (IenW, 2021). Non-applied paint residues are considered chemical waste in the Netherlands. Consumers, professional painters and companies need to ensure that the residues are disposed correctly, for example by bringing these paint residues to municipal waste centres or authorized waste companies (Milieucentraal, 2020). If dried non-applied and applied paint residues are disposed as household waste, microplastic emissions are not expected to occur.

Shipyards and marinas

Professional ships are primarily maintained in shipyards. Activities at a shipyard are considered environmentally harmful and are regulated in the 'Besluiten Activiteiten Leefomgeving (BAL)' in the Netherlands. To prevent and reduce the impact of these activities on the aquatic environment, the 'Modelregeling dok-en hellingvloerdiscipline' was developed. The 'Nederlandse Richtlijn Bodembescherming (NRB)' is a directive to prevent the release of contaminants to soils, applicable to shipyards as well as other industries (IenM, 2012). Although the BAL and NRB do not mention microplastics explicitly, several measures inhibit the release of microplastics to the environment. Examples of measures are good housekeeping, covering of unpaved soil, and the collection and treatment of waste waters and residues. The 'Activiteitenbesluit (AB)' regulates the standards for the application of paints and maintenance at marinas. Painting companies in general also have to comply to the BAL. Various activities are regulated, including mechanically altering, e.g. sanding, and painting of substrates.

Ecolabels
Ecolabels are voluntary environmental labels established by sectors or governments. In the paint value chain, they are assigned to products or services that have less impact on the environment than conventional alternatives. In the Netherlands, OnderhoudNL and the VVVF have developed an ecolabel for paint jobs, the 'Milieulabel Schilderproject'. This label scores the complete paint job based on certain sustainability criteria like CO_2-footprint, VOC content, expected life span and amount of paint per m^2 of surface area (VVVH, 2020). However, the ecolabel does not explicitly account for the presence of primary microplastics and emissions of microplastics.

The EU Ecolabel is an initiative of the European Union solely for indoor and outdoor paints and varnishes. As of September 2020, more than 28,500 paints and varnishes have been assigned an ecolabel (EC, 2020d). In the Netherlands, nine paint products have been awarded the ecolabel (EC, 2020b). The criteria include requirements on composition, efficiency in use, and customer information (EC, 2020c). Composition criteria regarding use of microplastics and their emissions are not present. It should however be noted that both can be reduced indirectly by other ecolabel criteria, e.g. efficient use of paints. Another European initiative is the Product Environmental Footprint (PEF), which aims to develop a common measure for environmental performance (EC, 2020e). This has been done for the decorative paints segment by a broad range of European stakeholders in the PEF pilot phase. Here again, microplastics are not included in the assessment criteria.

3.5 Labour legislation

The Working Conditions Act (Dutch: Arbeidsomstandighedenwet) provides rules for employers to ensure that employees work in a safe and healthy environment. The law applies to professional painters but also to paint jobs performed by foundations and associations. Threshold limit values are derived for different types of dust particles in the Working Conditions Regulation (Dutch: Arbeidsomstandighedenregeling) to limit potential effects of these particles. The Working Conditions Act states that measures should primarily be taken at the source of the dust to limit the potential effects for employees (SZW, 2020). Exposure of employees to dust particles lower than the threshold limit values is, however, often not achievable without tools and these are therefore necessary (TNO, 2021). Firstly, collective protection measures, i.e. measures able to protect a group of workers, should be taken. A collective measure introduced to reduce paint particles in work environments is a dust extraction system. Professional painters generally use these types of systems during maintenance of paint layers to comply to the legislation[9]. Collective measures are preferred above individual measures (SZW, 2020). In cases where neither collective nor individual measures can be taken, personal protective equipment should be made available to an employee.

[9] Personal Communication OnderhoudNL (2020).

4 Research and Development

This chapter focuses on the research and development phase of the paint value chain in relation to microplastic emissions. The stakeholders interviewed included a raw material supplier, paint producers, the paint producer's trade organization, and a research institute. First, stakeholder perspectives on microplastics are described (4.1), then an overview of identified developments in paints is given (4.2), and finally, alternatives for conventional paints are discussed (4.3).

4.1 Perspectives on microplastics

The stakeholders indicated that they were aware that microplastics are formed and released from weathered paint layers, as well as during maintenance activities. Generally, this was considered as inevitable as polymers are used as binder, and weathering can be slowed down but not prevented. Durability was considered one of the most promising paint characteristics to reduce microplastic emissions. Most of the stakeholders also noted that great progress has already been made on improving the durability of paint layers, and while further developments are still being made, they do not expect radical improvements in the near future, as discussed in section 4.2.

There was some discussion regarding what the term microplastics comprises. This was especially the case regarding particles from antifouling paints that are developed to weather with time thereby releasing biocides, but also for small paint particles. As no lower limit has been set for microplastics, it was questioned whether low nanosized (very small) degradation products should be considered as single molecules and no longer as particles.

Several stakeholders perceived the amount of microplastic emissions from paints as a minor source compared to that from other sources, e.g. fragmentation of plastic litter and tyres. Based on estimates by the OSPAR Commission (2017), on average the microplastic emissions from paints to water (~50,000 tonnes/year) are indeed lower than emissions from tyre wear (~120,000 tonnes/year) and land-based litter (~110,000 tonnes/year) but higher than, for example, cosmetics, laundry fibres and detergents (each <20,000 tonnes/year). These estimates, however, are highly uncertain due to variations in local and regional habits, weather and other factors. To substantially reduce emissions, it was noted that it might be more beneficial to target these other sources. Other stakeholders were not aware that the polymer particles in water-based paints are considered as primary microplastics. One of the interviewees noted that while the proposed restriction for intentionally added microplastics (see section 3.2) exempts paints based on the incorporation of the polymer particles in the film layer, the extensive reporting on the amount and type of microplastics used is a serious administrative burden that can negatively impact the paint value chain. The interviewed stakeholders stated having a preference for voluntary measures above the currently proposed restrictions on intentionally added microplastics.

A recurring topic in most interviews was that microplastics are just one of the groups of substances used in paints that need to be addressed. Other substance and/or groups of substances mentioned were poly and perfluorinated compounds (PFAS), titanium dioxide (TiO_2), and isocyanates, which can also affect human health.

All stakeholders indicated that they account for sustainability in relation to the above noted substances including microplastics, but also for other parameters such as switching from fossil to bio-based raw materials and reducing CO_2 emissions. Regarding sustainability and microplastics usage, reference was made to the potential of biodegradable polymers and paint products based on minerals, e.g. lime and graphene, which can replace conventional polymers as binders. They considered current use of these products to be limited, mainly because paint products gain their beneficial characteristics thanks to the polymers currently in use.

4.2 Development of paint products

Improved durability
The durability of paint products is often mentioned as a key driver for clients to select a paint product. Increased quality and lifespan of the paint layer is especially important for professional painters. Durability limits the emission of secondary microplastics, however, this is not the primary motivation for professionals to purchase these paint products. Several stakeholders indicated that great steps have already been taken in recent decades regarding durability. For example, the lifespan of DIY and construction paint products has increased from 3-4 years to 10-12 years, while steel conservation paints can last up to 25 years. Optimizing durability to extend the lifespan of paints is a continuous process, as is maintaining the current lifespan. Paint compositions are continuously subject to changes, these changes can also adversely affect durability. Changes in composition can be a result of regulations, e.g. water-based paints to reduce VOC emissions (see section 3.1), but also when incorporating new raw materials or other developments. To retain the long lifespans, paint producers keep on innovating.

Although for certain applications a further extension in lifespan may be achievable, it is not necessarily feasible in practice. Consumers and professional painters may remove old paint layers and repaint objects for aesthetic reasons, irrespective of paint layer quality. Moreover, the lifespan of steel conservation paints may be longer than the lifespan of the steel objects they protect. Another example are the self-polishing antifouling paints. Their average lifespan is 3 to 5 years which coincides with the maintenance intervals of commercial shipping. Extending the lifespan might not be effective, as it is common practice in the sector to replace or renew the antifouling layer once ships are in the dry dock for maintenance. Given the current maintenance interval, there is no direct driver to invest in antifouling with longer lifespans, especially as it is common to replace or renew the antifouling layer before end-of-life, as a sub-optimally functioning antifouling layer increases fuel costs. Furthermore, self-polishing and soft antifouling are designed for wear which makes particle release inherent to these paints. This is not the case for hard antifouling paint.

Bio-based polymers and ingredients in paints
Several stakeholders, including raw material producers and paint producers, indicate that extensive research effort is being made to substituting petroleum-based polymers and ingredients for bio-based alternatives. For example, binders that contain substantial amounts of bio-based resources are available (Nabuurs and Kastelijn, 2018, Stahl, 2020), while coconut flakes, cellulose, and other natural materials (e.g. glass beads) were mentioned as alternatives for microplastics in paints.

Bio-based alternatives can reduce the environmental footprint of paint products. However, as these are still synthetic polymers, they do not contribute to the reduction of microplastics. Discussions were raised on increased biodegradability of bio-based polymers in comparison to petroleum-based polymers. There is, however, no link between the source of polymers and their biodegradability (EEA, 2020). Bio-based substances are not necessarily biodegradable, these terms are often confused or used incorrectly. Research on the application of biodegradable polymers is discussed in more detail below.

Paints using biodegradable polymers
Biodegradability of paints is recognized by many production companies and research organizations as a method to reduce the effects of released paint particles on the environment. Biodegradability is considered a conflicting property to durability, one of the current strategies in paint developments. Optimally, paints should not degrade when present on a substrate but only when released into the environment. Due to weathering, a paint layer might degrade on the substrate, undesirably losing the initial function of surface protection. One of the interviewees stated that although these desired biodegradability properties are currently unachievable, it is expected that in the future this will be the case.

Research is also being conducted on the addition of enzymes to plastics which accelerate degradation of the plastics in the environment. Development of a full-scale application of plastics containing enzymes could still take 5-10 years according to one interviewed stakeholder. Another stakeholder mentioned research on biodegradation by enzymes in soils, with great potential for reducing potential effects of microplastics in the environment. Biodegradation by fungi is also promising (Sánchez, 2020). An incomplete breakdown of particles could, however, be a negative side-effect of degradation, leading to the conversion of microparticles into smaller nanosized microplastics.

Although the effect of the upcoming restriction on intentionally added microplastics (see section 3.2) on paint products is limited, it is expected that research on biodegradable polymers will intensify. One should keep in mind that biodegradability is often demonstrated in laboratory studies, while biodegradability in the environment depends on specific environmental conditions. Certain polymers such as polyhydroxyalkanoates do degrade under certain environmental conditions, however, degradation could take up to a few years while it cannot be guaranteed that the microplastics end up in environments similar to those of the test conditions (Essel et al., 2015). It is unclear whether such polymers fulfil the ECHA biodegradation criteria (ECHA, 2020a). In addition, not all of the polymers considered to be biodegradable may be suitable for paint products.

Mineral-based paints
Substitution of polymers would inevitably lead to a reduction in secondary microplastics. The polymers are, however, considered essential by most interviewees for the process of film formation and creating a protective layer. Currently, decorative paints are available that contain no polymers as binder; the binders have been replaced by lime ($CaCO_3$), and graphene is added to increase wear resistance. These paints are promoted as a more sustainable alternative to conventional paints as their CO_2-footprint is negative, i.e. the paints bind CO_2 (EKOTEX, 2020). Graphene is also used in anticorrosion paints due to its specific properties including chemical inertness, flexibility, and impermeability (Ollik and Lieder, 2020). Graphene and its potential related emissions or effects on environmental and human health was not part of the scope of this study. As with any product and any alternative, this should be addressed to avoid any regrettable substitution (den Braver-Sewradj et al., 2020).

Thanks to the use of additives, polymers can still end up in mineral paints. The life span of mineral-based paints is similar to that of conventional paints, though they are not suitable for all applications. Most mineral paints sold are intended for interior use and on exterior walls. According to one interviewee, application on wooden surfaces is less suitable as the paints creates a rigid film, and due to wood shrinking and expanding, this leads to paint film cracking.

Powder paints
Powder paints are those that do not contain water. They are based on mineral raw materials and have to be mixed with water at the site where the product is used, e.g. at home. The paints are regarded as being more sustainable as less weight has to be transported, lowering the CO_2-footprint. Paints are available for different substrates such as concrete, stone, and bitumen (Rawpaints, 2020). Powder paints generally do not contain polymers as binders, however one of the paints applied to exterior surfaces and moisty facades, does (Rawpaints, 2021). In this case, mixing at non-dedicated facilities might lead to higher emissions of primary microplastics compared to 'ready-to-use' mineral-based paints due to drifting.

Self-healing paints
The idea of self-healing paints is based on the reparability of applied paint layers. Liquified paint is incorporated in the initially applied film layer and after the paint layer is damaged, the liquified paint diffuses, dries, and polymerizes. Repair of the paint layer is currently only possible once for each crack and this technique is still under development. The expected full-scale application could still take 10 years according to one of the interviewees. Self-healing paints have been developed to extend the lifetime of paint layers. To what extent they can reduce microplastic emissions is unclear. On one hand this technique can reduce the need for maintenance and reapplication of paint, which indirectly reduces microplastic emissions. On the other, the

incorporated liquified paint may be an additional source of microplastics through processes such as leaching.

Improved paint adhesion
In order for paints to optimally adhere to substrates, it is advised to roughen the substrates, remove old paint layers, and use primers before painting. New paints are being developed to better adhere to smooth surfaces by applying specific resins, removing the necessity of pre-treatment of substrates. Application of these paints thus indirectly reduces emissions of microplastics and particulate matter. Currently only a small number of paints has these traits, and their range of application is limited. These paints are primarily useful for "unpainted" substrates which need multiple layers of paint.

Silicone antifouling paints
Biocide-free antifouling paints containing silicone, smoothen surfaces of ships, thus preventing organisms from attaching to hulls (HEMPEL, 2020). These paints can last up to 10 years (Wezenbeek et al., 2018); however after approximately 5 years, small reparations are necessary according to one of the interviewees. Their increased longevity compared to conventional antifouling paints will result in less particles in the aquatic environment, however, the particles released can still be considered microplastics. Although silicone antifoulings are used by some ferries and cruise ships, according to one of the paint producers, conventional antifouling paints are primarily used in the transport sector. There was no apparent reason given why. According to Wezenbeek et al. (2018) one of the drawbacks of silicone antifouling paints could be difficulties with their application. On the other hand, one stakeholder indicated that the demand for biocide-free products is increasing, which could lead to an increase in use of these and other alternative products (see section 4.3), with subsequently a decrease in microplastic emissions from antifouling paints.

4.3 Alternative products for paints

Paint products are applied to cover substrates for protective or aesthetic reasons. In addition to conventional paints, alternative products are available with similar functionalities. Several products are described below.

Wrappings
Wrappings are an alternative for paints to cover surfaces. For ships and other submerged applications, wrappings can replace antifouling paints. They can be used in both fresh and salt water and can last up to 20 years (Finsulate, 2020). Wrappings can also be used to cover facades and window frames of buildings during construction or maintenance. Similarly, they are applied to vehicles. Like paints, wrappings are made of plastics. Ship wrappings are partially made of acrylic and polyester, while car wrappings are made of vinyl. Ship wrappings can also contain silicone tops (Wezenbeek et al., 2018). For facades, fluoropolymers can be used (NOWOFOL, 2020). Weathering of these wrappings will also result in the release of microplastics. The durability of wrappings is not compared to paint layers in this report; it is uncertain if the use of

wrappings as alternative to paints will reduce the emission of microplastics.

Ultrasound waves
As alternative for conventional antifouling paints, ultrasound sound wave systems can be used. Ultrasonic waves cause cavitation near ship hulls preventing biofilm adherence and removing the settlement surface for larger organisms (Wezenbeek et al., 2018). A reduction in use of antifoulings can lead to a reduction in microplastic emissions. However, there is still a need for protective coatings to prevent corrosion. Both types of paints can be applied in a multi-layered system, while hard antifoulings can also provide corrosion protection (Wezenbeek et al., 2018).

5 Application and Maintenance

This chapter focuses on the application and maintenance phase of the paint value chain in relation to microplastic emissions. The stakeholders interviewed were primarily trade organizations. These represent multiple sectors such as recreational shipping, professional shipping, and professional painters and maintenance companies in, amongst others, the building sector. Their perspectives on microplastics are first presented (5.1) before discussing the innovations and measures which potentially reduce microplastic emissions during application (5.2) and maintenance (5.3).

5.1 Perspectives on microplastics

The emissions of microplastics are not addressed directly by the stakeholders interviewed or by their clients. The trade organizations indicate that clients of professional painters (e.g. housing associations, individuals) increasingly request more environmental-friendly and sustainable products, but the presence or release of microplastics does not seem to be explicitly considered. One of the interviewees indicated that younger generations particularly take sustainability into account when selecting a paint product and its application and maintenance. However, it was questioned whether there is any awareness regarding the link between paints and microplastic emissions. Indirectly, the microplastics theme is included, as measures are being taken to limit the impact of paint practices on environmental and human health. Waste management schemes, guidelines, legislation and sustainability indicators, such as CO_2 performance ladders, all lead to more awareness on sustainability issues and the implementation of measures to resolve these issues. But as long as microplastic impacts are not considered in the underlying impact assessment models, this is not immediately true for microplastics. Professional painters working in the building sector take training courses which focus on the health and environmental aspects of application and maintenance. Professional painters also receive safety datasheets containing information on hazardous substances when buying paint products. However, neither the training courses nor the safety data sheets disseminate information on microplastic content and emissions. These training courses and safety datasheets are only given to professional painters and not to DIY painters.

5.2 Application

Paints can be applied using different methods. DIY painters and professional painters primarily use paint brushes and paint rollers. These are used for painting interior and exterior surfaces as well as ships at marinas and shipyards. Paints can also be applied by spraying the liquid onto a surface area. Spray painting is used for different applications such as ships, furniture, cars, and prefabricated products such as doors and window frames.

Reducing overspray

During spray painting, paint particles can disperse in the air and attach to unintended surfaces, so-called overspray. Depending on the provisions taken, these particles can end up in the environment. Semi-closed or open locations, such as shipyards, are therefore potential sources of microplastic emissions. One innovation mentioned during the interviews can help to reduce overspray at shipyards. Automatic spray painters are being developed which should prevent overspray, even in strong breezes (SQD, 2020). The current status of these automatic spray painters is, however, unclear.

Prefabrication
Prefabrication generally takes place in factories where parts or complete products are assembled. Prefabrication can be used to manufacture trains, ships, cars, and houses. Painting these objects takes place under controlled factory conditions, for example the application of anticorrosive paints on prefab construction elements, however, this does not apply to ships. It is therefore assumed that the release of paint particles to the environment is limited.

Canopies
When painting steel constructions like bridges, canopies (tents) are used to cover the work area. These protect employees and objects against weather influences, however they are also used to collect blasting grit after maintenance (RWS, 2020b). In this way, paint particles can also be collected, however the efficiency of preventing leaking or spreading of particles during such applications is unknown.

Cleaning of brushes
A substantial source of primary microplastic emissions are paint residues from brushes and rollers cleaned in sinks and discharged into the sewage system. Various stakeholders indicate the possibilities to reduce emissions by further raising awareness in the DIY segment. Professional painters do not commonly rinse their paint tools as they use brush pots (in Dutch: kwastenpotten) to clean and store brushes or air-tight casings for paint rollers. Some painting companies use wastewater treatment installations to rinse their paint tools (OMNIAL, 2020). Dried paint residues are disposed with other residual waste while liquids with paint particles can be disposed as chemical waste. Currently, painters in the DIY segment are informed by different means, e.g. label information on paint cans, brochures, and consumer websites.

5.3 Maintenance

During maintenance old paint layers are removed in order to restore or renew the film layer. Maintenance can be performed to apply a new protective cover or to change properties, such as colour or structure, of the film layer. Although paint products are available that do not require the removal of old paint layers (section 4.2), the substrate is usually sanded. Sanding old paint layers is a large source of secondary microplastic emissions and these are dispersed into the environment via air, water and soil. Especially when this occurs outdoors, these particles are subject to environmental factors such as wind and rain that increase their distribution.

Dust extraction systems
Removing paint layers during maintenance releases wood, paint and other types of paint particles. Dust extraction systems are capable of reducing the number of particles entering the environment as they are captured and disposed as waste. These systems are used by professional painters during sanding substrates. Although exact numbers on efficiency are not available, correct use of these systems is expected to reduce the emissions of dust particles close to or up to 100% according to one of the interviewees. Such a high efficiency seems unlikely, especially for very small (nanosized) microplastics whose retention will strongly depend on the pore size of the applied filters. Microplastics in dust are also captured, reducing emissions from professional painters. Thick paint layers are often scraped off with a wire brush or paint scraper, after which the paint particles fall on the ground. These particles can be collected and disposed, although outdoors the particles may be more difficult to fully collect and can be dispersed due to e.g. wind and rain. For industrial steel surfaces and marine coatings, dust-free abrasive vacuum blasting systems have been developed that state they capture 100% of the removed paint, including all microplastics (Pinovo, 2020). Although the Working Conditions Act sets requirements to work safely, i.e. use of dust extraction systems, this legislation does not apply to DIY, therefore the use of dust extraction systems by consumers is not mandatory. According to the interviewees, these systems are not regularly used by DIY consumers, therefore secondary microplastic emissions could potentially be reduced by addressing this sector and consumers.

Robots
Another development is the use of robots to remove old paint layers e.g. for storage tanks, drilling platforms and ship hulls (Reza Energy, 2020). These use ultra-high-pressure water to remove the old paint layers and are said to capture all waste, reducing the potential release of secondary microplastics. The water is collected and filtered to remove solids and to recycle the water. Robot development was mainly stimulated to reduce labour costs rather than paint particle emissions according to one of the interviewees. In addition, the remark was made that robots might not be suitable for all maintenance work as their use removes all paint layers while in some cases only the top layer needs to be removed. This would then result in higher costs for the application of new paint layers.

Peelable paints
According to one interviewee, in the future, removal of paint layers in one piece might be possible. These ‘peelable’ paints have already been developed for cars and may also become available for other applications. Such paint layers may also weather and release microplastics as they are made of plastics. However, releases as a result of sanding will then be lower.

6 Waste Management

This chapter focuses on the waste management phase of the Dutch paint value chain in relation to microplastic emissions. None of the interviewed stakeholders were directly involved with the processes of this phase, such as waste companies or recyclers. However, developments in paints can influence waste management strategies and vice versa; the relevant developments are discussed below. This chapter presents information gained from stakeholders involved in other phases of the Dutch paint value chain and from literature research.

6.1 Re-use and recycling of leftover paints

Leftover paints can be re-used or mechanically recycled to produce new paint products. In mechanical recycling, residues are filtered and refined. In England, walls paints can contain up to 35% of refined paint residues (Akzonobel, 2019); in the Netherlands, these are available with 97-99% paint residues (RIGO Verffabriek, 2020). However, these latter products are only a small fraction of available paint products. According to the information sheets, the quality of the products is high. Collected wall paints with more than 40% of the paint left are also distributed to thrift stores and civil organizations to be re-used, without any mechanical refinement (VVVF, 2017).

Not all paint residues can, however, be recycled according to some of the paint producers. In the Netherlands, leftover paint products have different compositions and are intended for a range of substrates with a variety of paint properties. Mixing paints with different traits does not result in products with a consistent quality, and in addition. safe products cannot be guaranteed if the content of leftover paints is uncertain. Water-based paints are more difficult to re-use than solvent based paints, as they can contain different polymer dispersions. Combining differing paints may not create the desired film layer after application, according to one of the stakeholders. In England, most paints collected are wall paints with a limited number of colours and producers. The content of most of these paints is known by the recyclers, creating more opportunities to produce safe and legally approved paint products. It is not expected that many leftover paints end up in the environment, therefore re-use and recycling of leftover paints has limited effects on the reduction of microplastic emissions, although it could lead to a reduction in the quantity of new paint production.

6.2 Recycling of end-of-life paint residues

Chemical and mechanical recycling are potential applications for end-of-life paint residues from paint layers. In chemical recycling the polymers are either purified or broken down to monomers, which can then be used to create new polymers. Different techniques are being investigated to recycle plastics, including solvent-based purification, solvent-based depolymerization, pyrolysis and gasification (Rollinson and Oladejo, 2020). Chemical recycling is an expensive energy-demanding process (Rollinson and Oladejo, 2020). It is unclear whether chemical recycling of end-of-life paint residues will be a viable option as a future waste management option. Research is being conducted on the mechanical recycling of powder coatings from appliances like bicycle frames and fridges. After coating removal and grinding, the materials may be adequate for re-use as filler in new paint products. The development of recycled paints as filler is expected to take approximately 4-5 years, according to one stakeholder.

7 Identified measures, developments and conclusions

The goal of this report is to give an overview of potential measures and developments in the Dutch paint value chain that may lead to reductions in microplastic emissions. Semi-structured interviews were held with a broad range of stakeholders involved in the paint value chain. A literature study was conducted to provide additional insights into possible measures and developments. This final chapter discusses the main measures and developments related to reducing microplastic emissions from paint, and presents the conclusions.

7.1 Identified measures and developments

Stakeholder perspectives on microplastics
The stakeholders in the Dutch paint value chain are aware of the issues related to microplastics. Reducing or preventing microplastic emissions, however, is currently not targeted in any of the phases of the Dutch paint value chain. The stakeholders noted that developments and measures taken to tackle other issues may indirectly lead to a reduction of microplastic emissions. If measures were to be taken, the interviewed stakeholders of the Dutch paint value chain would, in general, prefer this to be on a voluntary basis, rather than e.g. the proposed restriction on intentionally added microplastics.

Research and development
Paint durability is a key feature for professional and DIY painters and their clients when selecting a product. This feature is actively targeted by all paint producers. Alongside the reduction of the carbon footprint and the substitution of hazardous substances, it is one of the features that is promoted in the context of a more sustainable paint product value chain. Although not primarily targeted, most stakeholders in the value chain consider durability as the most promising way to limit microplastic emissions. Other product developments such as paints using biodegradable[10] polymers or mineral-based polymer-free paints are currently in different stages of development and not yet applicable on a large scale. Application of paints with biodegradable polymers or polymer-free paints could, however, lead to a substantial reduction in microplastic emissions from paints. To what extent these new paints will eventually be applicable to different substrates (e.g. wood) and under what conditions (in and outdoor) remains uncertain. Other developments such as the application of bio-based polymers are not expected to greatly reduce microplastic emissions, as these paints will still contain polymers.

Application and maintenance
Stakeholders stated that emissions during application and maintenance are limited due to different measures already taken in the sector. Emissions to the environment primarily occur as a result of sanding substrates. The use of dust extraction leads to a substantial decrease in

[10] A tiered approach is followed to determine biodegradability, which includes screening level tests to determine ready biodegradation, enhanced/modified ready biodegradation, inherent biodegradation, bio(degradation) relative to a reference material, and degradation simulation test to derive half-life values under relevant environmental conditions. For more information, see (ECHA, 2020a).

emissions. Stakeholders indicated that innovation has led to improved dust extraction systems, however we found no published studies to support this. Additionally, there is a need to review what happens to the very small microplastics (nanoplastics) that may be smaller than the pore size of applied filters. Dust extraction systems are used by professional painters, the main objective being to comply with legislation to reduce health risks for workers. Opportunities for a further reduction of sanded paint particles are identified for the DIY segment, where the use of dust extraction systems is not as prevalent as with professionals. Another emission route of microplastics from paint in the DIY segment is the improper rinsing of brushes and rollers in the sink. Raising awareness and facilitating DIY painters could substantially reduce microplastic emissions from paint. However, no quantitative studies were found reporting the emissions of microplastics during professional or DIY application and/or maintenance.

Waste management
During the waste phase, microplastic emissions from paints are expected to be lower than in earlier stages of the life cycle. No quantitative studies were found that report microplastic emissions from waste management of paints. Collection systems for unused paints are in place in the Netherlands, while empty cans, paint tools and paint residues are discarded with other residual waste that is incinerated. In the professional sector, collection of paint residues could be further optimized, but large improvements are not expected. In the DIY sector, however, rinsing of brushes and disposal of water-based paints down the drain is still common practice; this can be classed as improper waste management. Wastewater treatment plants are able to remove many discharged microplastics, though not completely (Ngo et al., 2019). This is also the case for paint residues from old paint layers that are not collected properly during maintenance by consumers. In this phase of the paint value chain, developments focus on the re-use of leftover paints and the recycling of paint residues from old paint layers. While it is expected that the first will have limited or no effects on reducing microplastic emissions, the latter may result in an improved drive to collect paint residues.

Measures previously identified
A previous RIVM report identified six measures that could reduce microplastic emissions from paints (Figure 1-1) (Verschoor and de Valk, 2017). Although a comprehensive comparison and analysis was not the aim of this study, half of the measures were not specifically mentioned during the interviews: 1) replacement scheme for old sanding machines, 2) covenant on residual paint emissions and 3) reduction of residual emissions from recreational vessels. The interviewees did present information on the other three measures. Research into (bio)degradation of paints is being conducted by different stakeholders with an expected development period of years before full-scale applition. With respect to a guarantee period for paint, paint durability is a main driver of paint producers, contributing to longer lifespans of applied paint layers. Furthermore, the trade organization OnderhoudNL provides a platform to ensure enlisted professionals work according to the set quality norms. Lastly, raising awareness on proper rinsing of brushes in

the DIY sector occurs in various ways, including label information on paint cans, brochures, and consumer websites.

ECHA restriction
Paints are the source of both primary and secondary microplastic emissions, with most arising from the latter. As the proposed ECHA restriction on intentionally added microplastics will derogate the use of solid polymers particles[11] in paints and as it does not target secondary microplastics, it will not significantly affect microplastic emissions from paints. The release of microplastics is and will therefore be prevalent when using current conventional paint products.

It should be noted that while the restriction proposal initially obliged stakeholders in the (Dutch) paint value chain to communicate the quantities and types of polymers used in their products, it now only requires the released quantities to be reported to ECHA. These data will be published annually by ECHA in a summary, but as the exact polymer identity is no longer mandatory information and the quantities will not be specified, insights in the use of solid polymers (primary microplastics) in paints will be limited. Sufficient information on the polymers will only be available to downstream users or suppliers so that they can comply with the ECHA reporting requirement. The proposed restriction will also not yield insights in dissolved polymers used in solvent-based paints, as these are not considered microplastics by the restriction. Note that both end up as secondary microplastics in the environment after film formation and breakdown.

7.2 Conclusions

The use of polymers and subsequently potential emissions of microplastics is viewed as an inevitability by the Dutch paint value chain. The use of polymers as binders is seen as being essential to obtain functional product characteristics needed to cover and provide long lasting protection of surfaces, especially for wood. Currently, only a limited range of paint products or alternatives are available that do not contain polymers in binders or cause microplastic emissions. In addition to functionality, the environmental and health impacts, including potential microplastic emissions, of (alternative) paints and products should be researched further to avoid any regrettable substitution.

Paint durability has been optimized over the last years and has led to reduced microplastic emissions. There are, however, no studies that quantify the effects of this and other product optimizations on (potential) microplastic emissions (primary and /or secondary) from paints. No quick wins regarding durability are expected by the stakeholders in the near future. During application and maintenance, (legal) measures are largely in place to ensure good housekeeping practice in the workplace which help limit the emission of paint particles. For application and maintenance, opportunities for improvement were indicated by stakeholders, mostly directed towards the DIY sector. For both the professional and DIY sectors, hardly any data is available on (potential) microplastic emissions to support this hypothesis. In the

[11] This includes the primary (intentionally) added microbeads that are physically bound in the final (dried) paint structure.

waste management phase, developments are in place to re-use leftover paints and to recycle paint residues from paint layers, however, these are not directly considered as being effective to reduce microplastic emissions. Moreover, no quantitative studies were found that report the emissions of microplastics from waste management of paints.

Studies modelling or measuring emissions (secondary and primary microplastics), but also data on the use of primary microplastics, are necessary to gain a better understanding of mitigation options. The proposed ECHA restriction will lead to publicly available information on microplastic emissions, however information on the types and amounts of microplastics used in paint products will not be available. Monitoring data, such as through the Dutch MWTL-programme, can give more insights in the types of paint particles that end up in the environment. Depending on the final ECHA restriction data requirements, this may be a valuable source to be able to quantitatively assess microplastic emissions from paints and to prioritize measures that can lead to a reduction in emissions. Finally, stakeholder dialogue is important as the emission of microplastics from paints is a topic which involves the whole paint value chain, from research and design to correct application, maintenance and disposal.

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Appendix 1 Interview questions

Dutch

1. Zijn microplastics een thema waar rekening mee wordt gehouden tijdens de ontwikkeling, productie, toepassing, slijtage of einde gebruiksfase van een verfproduct?
2. Wat voor maatregelen worden getroffen om microplastics te voorkomen of te verminderen (binnen uw bedrijf en in de keten)? Of zijn er andere strategieën om de uitstoot van microplastics naar het milieu te verkleinen?
3. Zijn deze maatregelen ook toepasbaar voor andere soorten verf of coatings (ondergrond (muur/hout/metaal, binnen/buiten gebruik, consumenten/professioneel)?
4. Waar liggen de grootste kansen voor het (verder) terugdringen van microplastic emissies uit verf? Zijn er innovaties die u kansrijk acht? Zijn de producenten hiervoor aan zet, of (ook) andere partijen? Wat is hiervoor nodig (kennisontwikkeling, subsidie, wetgeving, etc?)
5. Wie zouden we volgens u verder nog moeten spreken?

English

1. Are microplastics a theme in the development, production, application, wear, maintenance or end-of-life of paints?
2. Which measures can be taken to prevent or reduce the release of microplastics into the environment (within your organization and other stakeholders)? Or are other strategies available to reduce the release of microplastics to the environment?
3. Are measures available for all types of paints and coatings (based on applied surface (wood/metal/wall paints), paints for indoor/outdoor use, consumer/professional painters)?
4. Are other measures available to reduce the emissions of microplastics from paints? Are (promising) innovations available (in the near future)? Is it up to paint producers to take measures or should other parties be involved? What is needed to achieve a reduction in microplastic emissions from paints (knowledge, communication, subsidies, legislation, other)?
5. Can you recommend other stakeholders to talk to for more information concerning the topic?

RIVM

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