Research Report on Classification of Plastic Pellets

Safe Transport of Plastic Pellets at Sea

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Colophon

This document has been established in co-operation with a Steering Committee with members from the Dutch National Institute for Public Health and the Environment (RIVM), and the Dutch Ministry of Infrastructure and Water Management – Directorate-General for Civil Aviation and Maritime Affairs (DGLM) and Directorate-General for the Environment and International Affairs (DGMI).

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Summary

There are many studies showing the toxicological effects of plastic pellets. Plastic pellets consist of several substances that are classified as hazardous (toxic) on their own. In addition, plastic pellets can adsorb and leach a large range of substances that may also be toxic. Plastic pellets therefore pose a danger to the environment and human health when they end up in the (marine) environment.

Despite of this, plastic pellets are still transported by sea in containers as a non-hazardous substance. The current classification system for sea transport of packaged hazardous substances (International Maritime Dangerous Goods Code, IMDG Code) does not naturally recognize and classify this type of substance as ‘hazardous’ because it is a cocktail of substances. Therefore, mandatory regulations for sea transport of plastic pellets do not exist yet. Currently, too many pellets still end up in the marine environment during their transport by sea. Commonly known causes of this are containers falling overboard from containerships due to improper securing and stowage, and ship casualties.

This research report provides a scientifically solid basis for the fact that plastic pellets are harmful to the marine environment and indirectly to human health, and, for that reason, it is necessary to set legal requirements for its sea transport. This basis is provided in **Chapter 2 (Hazardous properties of plastic pellets)**. From the research it is concluded that the plastic pellet pollution has adverse effects on the environment, from biochemical and molecular to population and ecosystem levels (Landrigan et al., 2023). Plastic pellets can have a variety of negative effects on the environment and organisms through various ways. Although direct human exposure is yet still limited, accumulation in the food chain and other effects of plastic pollution on ecosystems upon which all humanity depends for food, oxygen, well-being and livelihood are all becoming increasingly negatively impacted (Landrigan et al., 2023). The growing number of produced plastics and increasing number of plastic pellets present in the environment by leakage during transport only further increases this problem.

In **Chapter 3 (Risk assessment of plastic pellets)** is established that, although the effects of (virgin) plastic pellets are quite well described and studied, the quantities of toxic substances in the environment from plastic pellets and subsequent chances and effects of exposure to humans and other organisms remain hard to identify. During this study, very limited information was found about the exact chemical composition of plastic pellets and their quantities. Nevertheless, it is clear that there is a large quantity and variation of toxic and non-toxic chemicals available, used, present and released from plastic pellets as has been described by Wagner et al., 2024. To further quantify the risk of plastic pellet pollution, additional information about the quantities and types of chemicals present in (virgin) pellets must be obtained. By doing so, the effects of plastic pellets on organisms and the environment can be further quantified. It is further established that reliable data on the quantity of pellets lost at sea from ships is lacking, since there is no reporting obligation.

In **Chapter 4 (Options for regulating sea transport of plastic pellets)**, an assessment of the hazardous properties of plastic pellets is made, based on the criteria for the identification of hazardous substances as laid down in international (sea) transport legislation: MARPOL, the IMDG Code (IMO) and the UN Globally Harmonized System. It is concluded that, despite the convincing number of arguments why plastic pellets pose a threat to the environment and human life, insufficient scientific proof has been found available to confirm that plastic pellets meet the specific criteria.
Following that conclusion, other options for regulating the transport are considered. It is concluded that assigning plastic pellets to class 9 of the IMDG Code in the category *‘Other substances and articles presenting a danger during transport, but not meeting the definitions of another class’* is the best option in terms of certainty and effectiveness of the process towards regulations. Therefore, the report further elaborates on this option. This does not mean that the other options that have been considered are completely wrong; the assessment that was made in this chapter is subject to assumptions on how the options would be handled in IMO, which is not set in stone.

In **Chapter 5 (Risk preventive and reactive measures)**, the necessary risk mitigating measures are identified and assessed on their effectiveness from a pragmatic point of view. It is concluded that apart from generic measures to prevent containers from falling overboard, *mandatory* stowage of containers with plastic pellets

under deck, or inboard in sheltered areas of exposed decks only is the most effective mitigating measure, supplemented by good quality packaging inside the container to prevent loss of pellets under normal transport conditions. Once plastic pellets end up in the sea, their loss with all its harmful effects is very difficult to prevent.

In **Chapter 6 (Classification of plastic pellets)**, insight is provided into the process to achieve the entry of a new UN number for plastic pellets in the IMDG Code with the effective transport conditions as considered in chapter 5. This process consists of 2 steps, namely (1) the entry of plastic pellets in the Dangerous Goods List of the UN Model Regulations, and (2) the subsequent implementation in the IMDG Code.
The possible complications encountered during this process are discussed, and it is concluded that these can be overcome by showing examples of classification of other complex substances or goods. The complete classification process would take 4 years as a minimum, if started in 2025. Lastly, it is mentioned that the industry would have to accept higher transport costs if plastic pellets were to be classified.

In **Chapter 7 (Conclusions)** the main conclusions following from the research in the previous chapters have been captured.

1. Introduction

1.1 Context and relevance

1.1.1 Plastic pellets

There are 32.000 different types of plastics used in various plastic applications. 7000 of these are classified as substances of very high concern. The semi-finished products for plastic applications consist of so-called 'plastic pellets'.

There are several studies showing the toxicological effect of plastic pellets. These plastics consist of several substances that are classified as hazardous (toxic) on their own. In addition, plastic pellets can adsorb and leach a large range of substances (NIAS, non-intentionally added substances) that may also be toxic (Audrezet, 2022). Plastic pellets therefore pose a danger to the environment and human health when they end up in the (marine) environment which is further described in Chapter 2 and 3.

Plastic pellets do not biodegrade or biodegrade very little in the environment. The micro and nano particles are toxic in nature and very harmful to the marine environment in various ways (Chapter 2). For humans, the particles are especially dangerous for pregnant women and unborn babies. Thus, if released into the environment, they pose not only an environmental problem but also a health and safety problem.

The 2023 Cedre report gives an overview of the production sites and capacities associated with the main plastic pellet polymers in France. Hann et al., 2018 states that only in Europe, 10 million tons (Mt) of plastic pellets are shipped annually via sea transport. Cedre, 2023 stated that their work from 2021 shows in that the intra-Asian market alone already represents transport of more than 30 million containers with plastic pellets per year across the sea. The global production of plastics was approximately 2 Mt per year in the 1950's and has shown exponential growth since the second world war reaching 367 Mt in 2020 (Cedre, 2023).

1.1.2 Transport risks

Plastic pellets, packed in big bags, are transported by sea in containers as a non-hazardous substance. Transportation in bulk is not permitted. The current classification system for packaged hazardous substances (International Maritime Dangerous Goods Code, IMDG Code) does not recognize and classify this type of substance as "hazardous" because it is a cocktail of substances for which no hazardous classification is available. Therefore, there are no binding rules for the packaging of pellets and for the stowing of containers on the ship. The risk of containers containing pellets going overboard and the pellets ending up in the environment is therefore present.

There are several known incidents where large quantities of pellets ended up in the sea and on beaches (MSC Zoë Netherlands (2019), X-Press Pearl Sri Lanka (2021)). Large quantities of pellets also "disappear" in the chain every year (annual loss of 445.000 tons in the transport chain). Currently, many pellets still end up in the marine environment during their transport by sea. Therefore, transporting pellets by sea is risky and dangerous to the marine environment. To better facilitate this from a preventive and sustainability point of view, regulation is needed.

1.1.3 Legislation on transport of plastics

Marine plastic litter has been regulated for a long time under MARPOL Annex V, which prohibits the discharge of all forms of garbage, including plastics, into the sea. The regulations aim to address marine pollution from ships, recognizing the harmful effects of plastics on marine ecosystems. The Annex establishes a complete ban on the release of plastics and other waste materials into the sea from ships. Additionally, the MEPC adopted an

Action Plan to Address Marine Plastic Litter from Ships (resolution MEPC.310(73)) in 2018 to contribute to the global solution for preventing marine plastic litter from entering the oceans through ship-based activities. This was followed by the adoption in 2021 of the Strategy to address marine plastic litter from ships (resolution MEPC.341(77)), which includes, inter alia, a prioritization of the actions in the Action Plan into short-term, mid-term and long-term measures, as well as an associated timeline.

All of these efforts on trying to ban plastic litter from ships are based on the knowledge that plastics have to be treated as a specific category of waste, because they have specific harmful effects on marine ecosystems. However, while these regulations address the disposal of plastic litter, they do not address the unintended loss of plastics into the marine ecosystems when transported in the form of cargo. The logical next step is to ban the loss of these plastics resulting from cargo losses.

International Maritime Organization (IMO) began addressing the issue of the transport of plastic pellets following the X-Press Pearl incident off the coast of Sri Lanka in February 2021. In March 2024, the Marine Environment Protection Committee (MEPC 81) approved MEPC.1/Circ.909 Recommendations for the carriage of plastic pellets by sea in freight containers. The recommendations address packaging, transport information and stowage of plastic pellets. These are non-binding recommendations and do not provide the necessary regulatory framework to ensure proper handling and accountability.

At its tenth session (2023), the Sub-Committee on Pollution Prevention and Response (PPR) agreed there was also a need for the development of amendments to appropriate mandatory instruments, subject to proposals by Member States and international organizations to the Marine Environment Protection Committee (MEPC), which could be informed by the experience gained from the implementation of the voluntary measures under the circular. Since then, several potential 'instruments' that could form a legal basis for regulation are being considered.

1.2 Research objective

The overarching goal of this research report is to create a scientifically sound and solid basis for the fact that plastic pellets are harmful to the marine environment and indirectly to human health (via the food chain), and for that reason, it is necessary to consider plastic pellets as hazardous substances. For this purpose, it is important to have a solid rationale for the toxicological properties of plastic pellets, or the intrinsic hazards of plastic pellets, the rate of their release into the marine environment and a risk assessment for the marine environment. The impact on human health if these substances enter humans through the food chain (marine animals) are also considered.

Further, this report considers the IMO International Maritime Dangerous Goods Code (IMDG Code) as potential instrument that could form a legal basis for regulating the sea transport of plastic pellets. It can support IMO in defining the necessary measures to make sea transport of plastic pellets safe.

1.3 Research questions

Main Question
What is the harmfulness of plastic pellets to the (marine) environment and indirectly to human health and how can regulations be adjusted accordingly?

Sub-questions
1. What toxicological effect do plastic pellets have on the (marine) environment and human health (risk assessment)?
2. What is the practice of the IMDG Code in designating substances as 'dangerous goods' and, from that perspective, is it logical to classify plastic pellets as such?

These questions have been answered by performing extensive desktop research, complemented by brief interviews with experts in the field of IMO and UN procedures, environmental issues and properties of plastics. A Steering Committee guided the research work and provided feedback on the text. The Steering Committee consisted of members from the Dutch National Institute for Public Health and the Environment (RIVM), and the Dutch Ministry of Infrastructure and Water Management – Directorate-General for Civil Aviation and Maritime Affairs (DGLM) and Directorate-General for the Environment and International Affairs (DGMI).

2. Hazardous properties of plastic pellets

2.1 Definition of plastic pellets

The term "plastic pellets" commonly refers to plastic particles or granules with a size between 0.01 mm and 1 cm. These pellets are generally granules but can also be transported in the form of powders or flakes and are pre-formed moulding material for the production of plastic end products (OSPAR, 2018; Karlsson et al., 2021; Cedre, 2023). The granules can vary in shape, e.g. (partially) round or square cubes but in general have relatively uniform dimensions (IMO, 2024). Plastic pellets are created from a mixture of starting substances (i.e., monomers, catalysts, and processing aids) which are typically used in polymerization reactions. To produce plastic materials, other chemicals such as stabilizers, are then added (Wagner et al., 2024).

2.2 Chemical properties of plastic pellets

2.2.1 General properties of plastic pellets

A plastic pellet generally consists of 93% plastic polymers and 7% additives (Cedre, 2023). 94% of the plastic polymers in plastic pellets are composed of either PP, LDPE, HDPE, PVC, PET or PS+EPS (Lithner et al., 2011, Cedre, 2023). These plastics are all thermoplastic, which means that these materials are pliable and adaptable at increased temperature, allowing for the production of a wide diversity of shapes and structures. Furthermore, all these types of plastic pellets have several well-known and similar physicochemical properties, based on the monomers itself, such as solid, persistent, durable, lightweight, low-processing-cost, non-soluble, non-emulsifiable, non-evaporative and non-adherent (Audrezet, 2022; Cedre, 2023). Virgin plastic pellets (the polymers, without additives) generally have a homogeneous smooth surface and are hydrophobic (have no acid-base behaviour), which results in the pellets generally having less interaction with their environment than other types of solid wastes.

Differences between the different types of plastics are found in e.g. the density of the material (e.g. pellets composed of PVC and PET are generally heavier than water), the thickness of the material, its strength or flexibility and the amount and types of chemicals (i.e. the additives) it may leach.

A wide range of chemicals can be added to plastic pallets in order to confer specific properties to the end-product, e.g. colour, UV-resistance, flexibility. These additives may be plasticizers, flame retardants, metals, UV-stabilizers, pigments and antioxidants (Cedre, 2023). These same additives may also leach from the plastic (sometimes under certain conditions, such as heat) (Wagner et al., 2024).

2.2.2 Chemicals in plastic pellets

Recently, Wagner et al. (2024) provided a thorough and comprehensive overview of the current scientific understanding of the chemical dimension of plastics, including the hazards, functionalities, uses, production volumes, and regulatory status of plastic chemicals. This review mainly involves chemicals that are related to plastics due to the production process, such as processing aids and additives (so-called plastic chemicals). These chemicals are present in both the (end-)products, as well as in the plastic (pre-production) pellets.

Plastic pellets may carry hazardous chemicals
The research utilizes a database (PlastChem database) compiling 16325 individual plastic-related chemicals. They classified all chemicals in the database, based on their hazardous properties (persistence, bioaccumulation, mobility and toxicity. Of these chemicals, 26% are of concern due to their hazardous properties (Figure 1). These hazardous chemicals include well-known pollutants, such as phthalates, flame retardants and organochlorines, but also new or lesser-known substances of concern such as PFAS's and alkylphenols. These chemicals may either be added to the pellets pre-production or added later in the production and subsequent processes. Wagner et al., 2024 state that the available studies show that virgin polymers (i.e., preproduction pellets) are almost always less toxic than their compounded, additive-containing

counterparts. Though it is known that the pre-production pellets that are ready for transport may already have undergone several production steps in which chemicals are added (Cedre, 2023).

Importantly, from the analysis in the review by Wagner and colleagues 2024, it is clear that the largest category of chemicals cannot be considered for their hazardous properties, because of the lack of data. The lack of information does not imply that the chemical is not hazardous. This highlights the large knowledge gap that hampers a comprehensive assessment of all chemicals that may be present in plastics and plastic pellets.

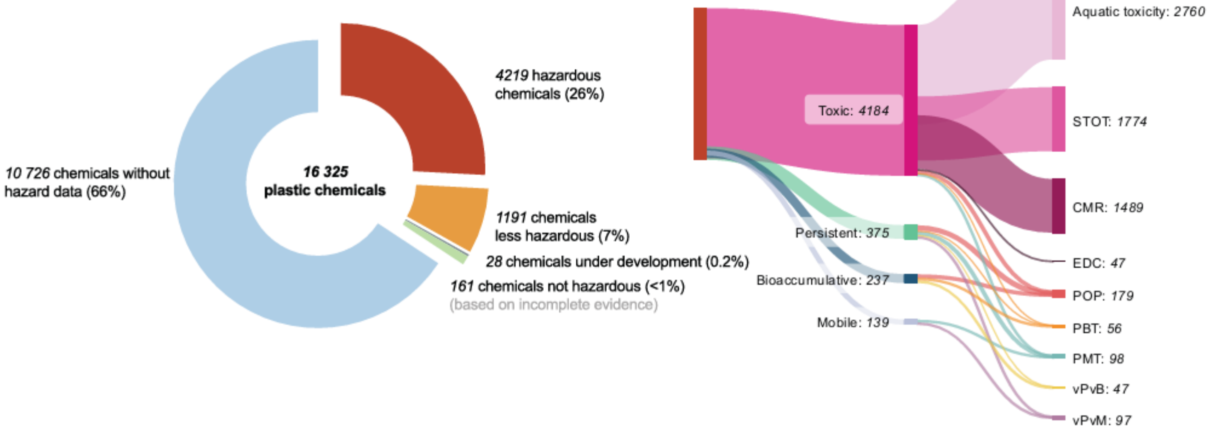


Figure 1. Classifications of chemicals that are found in plastics. Source: Wagner et al., 2024.

There is good evidence for the presence of numerous chemicals of concern in the most frequently used polymer types. These polymers (PET, HD-/LDPE, PP, PVC, PS) may contain > 400 hazardous plastic chemicals. Of the known hazardous plastic-related chemicals, more than half are classified as toxic to aquatic life (Wagner, 2024). These chemicals have all been classified under the CLP regulation[1] with either one of the following:

- Aq. Toxicity 1: H410: Very toxic to aquatic life with long lasting effects
- Aq. Toxicity 2: H411: Toxic to aquatic life with long lasting effects
- Aq. Toxicity 3: H412: Harmful to aquatic life with long lasting effects
- Aq. Toxicity 4: H413: May cause long lasting harmful effects to aquatic life

Polymers PET and PE generally contain the most chemicals of concern as is depicted in Figure 2 (Wagner et al., 2024). There is strong evidence that many of these plastic chemicals can be released into their environment and thus have a high exposure potential.

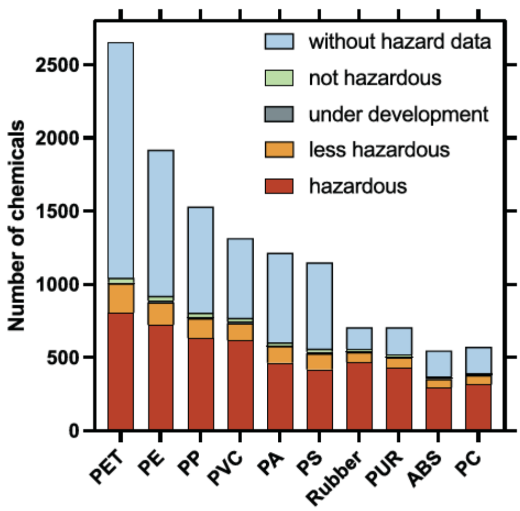


Figure 2. Hazard information for chemicals used or detected in plastics according to polymer type. Source: Wagner et al., 2024.

[1] Classification, Labelling and Packaging Regulation ((EC) No 1272/2008)

Table 1. Overview of a selection of polymer types with the highest amount of chemicals used or detected. Source: Wagner et al., 2024.

Polymer	Use	Number of plastic chemicals...					Thereof...		
		analyzed	used	present	released	Sum [a]	not hazardous	without hazard data	hazardous
PET	Packaging, food/household, textiles	2914	757 (26%)	1573 (54%)	236 (8%)	2566 (88%)	31 (1%)	1609 (63%)	806 (31%)
PE	Packaging, consumer goods, textiles	2529	809 (32%)	539 (21%)	571 (23%)	1919 (76%)	31 (2%)	999 (52%)	722 (38%)
PP	Packaging, consumer goods, transport	1835	528 (29%)	259 (14%)	606 (33%)	1393 (76%)	29 (2%)	725 (52%)	633 (45%)
PVC	Construction, health care, electronics, transport	1370	736 (54%)	418 (31%)	136 (10%)	1290 (94%)	25 (2%)	546 (42%)	618 (48%)
PS	Packaging, food/household, construction	1347	327 (24%)	465 (35%)	358 (27%)	1150 (85%)	20 (2%)	591 (51%)	418 (36%)

Pellets may release hazardous chemicals
Table 1 shows that a significant number of used and present chemicals in plastics may be released into their environment (see column 'released'). The hazardous chemicals in plastics and pellets may thus present a hazard when they are leached into their environment, such as when beached or ingested by animals. Investigations on the joint effects of all chemicals that leach from the materials show that plastic leachates may be toxic to humans and the environment, including cytotoxicity, endocrine disruption, growth, survival, reproduction, genotoxicity (e.g., mutagenic, carcinogenic) and developmental effects. Besides, as will be explained in paragraph 2.3.2, pellets may, under influence of environmental factors, sorb chemicals and other pollutants from its environment and leach them later.

2.3 Fate of plastic pellets in the environment

2.3.1 Behaviour of plastic pellets in the environment

2.3.1.1 Behaviour in water

Plastic pellets show typical behaviour when they end up in the water column. Most plastic pellets, around 80% of the worldwide production, are lighter than water and will stay afloat (Cedre, 2023).

Plastic pellets' fate after a marine spill is influenced by polymer type, polymer density and environmental factors like wind and currents. Sinking pellets behave more like sand and will accumulate in wave-breaking areas, while floating ones spread along the coast, accumulating in macro litter hotspots (Forsberg et al., 2020; Kystverket/NCA, 2020). Once in the environment, the floating pellets can get stuck on beaches close to the point of release, but the pellets and their associated chemicals can also travel far from their point of release (Karlsson, 2021). Pellets can travel long distances, potentially causing widespread contamination of the environment and require large-scale cleanup operations.

Floating plastics may eventually sink. This can be either due to the material density, or because the plastics get weathered and have things (e.g. biofilms) grow on them (Rummel et al., 2017), or because they get entangled with other debris (Karlsson et al., 2021).

2.3.1.2 Behaviour on land and the coastline

Plastic pellets, being light, can be easily remobilized by winds, tides, and runoff after land-based spills or coastal arrivals. Without rapid recovery, they can spread to waterways and vegetated areas. For instance, after an 8-ton pellet spill on the road between Boulogne-Sur-Mer and Marquise (France) in February 2016, plastic pellets were found within a 50 km radius (Surfrider, 2020). Waterways facilitate the spread of floating pellets, potentially leading to shoreline arrivals, while vegetated areas trap pellets, preventing remobilization (Kystverket/NCA, 2020). Assessing contamination in vegetated areas is challenging due to reduced visibility. Pellets can also bury in soft soil and sediment due to sediment transport, winds, waves, or trampling. For example, weeks after the MV X-Press Pearl spill, pellets were found buried up to several tens of centimetres deep on Sri Lankan beaches.

Buoyant plastic particles can travel hundreds of kilometres or more (Yamashita, 2018). However, there are indications that most plastic particles in de millimetre-range are generally contained within ~5 km from the coast due to nearshore trapping caused by stokes drift, as demonstrated by Isobe et al. (2014). However, some pellets can escape from nearshore trapping and can make a long travel through the marine environment, as evidenced by findings of pellets on beaches even on remote islands (Yamashita, 2018).

2.3.1.3 Plastic pellet degradation

Virgin plastic pellets are generally described as persistent, meaning that they are not easily biodegraded once exposed to the environment. However, plastic pellets may still over time be degraded by the environment, leading to altered physicochemical properties of the pellets. Mainly photo-oxidation and physical abrasion attribute to the degradation of pellets, leading to the formation of “secondary plastic pellets” and smaller plastic particles, i.e. micro- and nano plastics, all with more irregular shapes and sizes (Rodriguez-Seijo & Pereira, 2017).

The general buoyancy of plastic pellets in the marine environment leads to continuous exposure to solar radiation. This results in erosion, such as cracks and cavities in the surface (Fotopoulou, 2012; Song, 2017; Tang, 2019; Zhang, 2019). The results of this erosion are not solely physical (as seen by electron microscope, Figure 3) but also chemical. New polar groups appear on the surface of the plastic pellets due to the photochemical processes (Tang, 2019). Besides photo-oxidation, mechanical abrasion occurs due to repeated contact with other materials e.g. sand and rocks. These effects occur over a period of several weeks to a few years (Song, 2017; Tang, 2019).

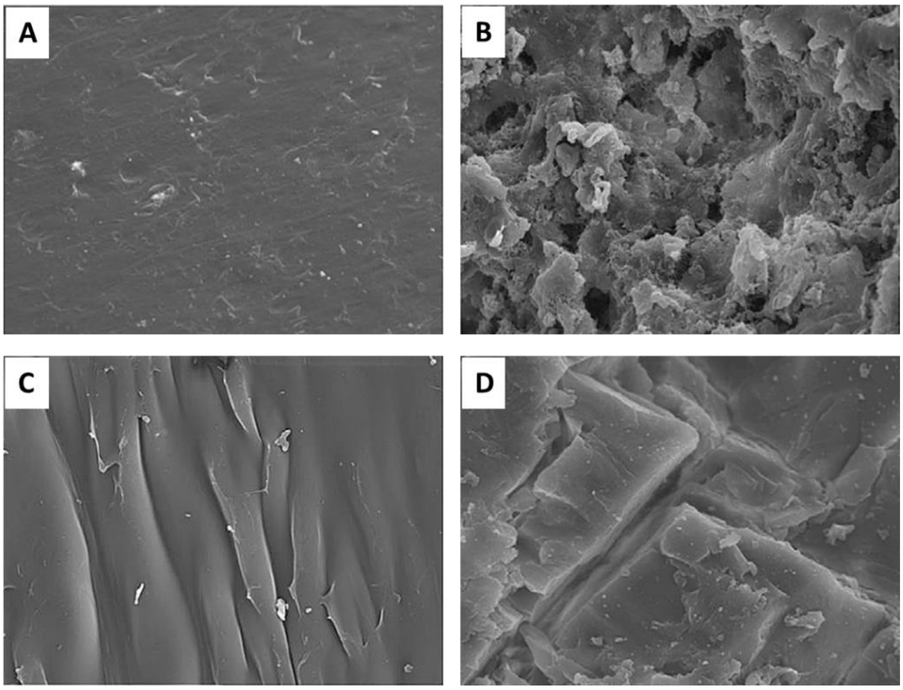


Figure 3. The surface topography of virgin plastic pellets enlarged 1000 times. A = virgin PE pellets, B = eroded PE pellets, C = virgin PP pellets, D = eroded PP pellets (Source: Fotopoulou, 2012).

Several researchers have shown that plastic pellets and microplastics can be carriers of a wide range of organic and inorganic compounds that adsorb to the pellets. There are several mechanisms through which the adsorption and the possible eventual leaching occurs, e.g. electrostatic or hydrophobic interactions, hydrogen bonding and coulombic interactions. These interactions are dependent on both the polymer type, the environment and the contaminant.

The changing surface morphology, functional groups, pore volume and other specific changes due to exposure to the environment all influence the possible mechanisms through which the pellet can adsorb or carry chemical and biological pollutants. Indeed, it has been shown that the physical and chemical alteration of the plastic pellet, mainly of its surface, leads to altered affinity to other chemicals or contaminants that would otherwise not adhere/adsorb to the virgin pellets. This has been shown, both in laboratory settings, field studies and from beached plastic pellets:

- The longer PE stays in the marine environment, the more polar it becomes. This means that the pellet is no longer solely a hydrophobic medium, but a material that interacts with more compounds than before (Fotopoulou, 2012; Zhang, 2019).
- The more the plastic is eroded, the more it will be enriched with pollutants from the environment. These may now be both hydrophobic and polar pollutants e.g. metals and organic pollutants (also: microbes and aquatic plants, animals) (Fotopoulou, 2012; Zhang, 2019; Tang, 2019). The attachment of microbes in a biofilm may in turn alter the properties and behaviour of the particles. E.g. the biofilm layer may retard the photo-degradation of pellets (Tang, 2019) or decrease the buoyancy, causing the particle to sink (Audrezet, 2022).
- Once beached, photo-radiation continues the erosion of pellets, and might even increase (Tang, 2019).

The different types of plastics react differently to the named environmental factors. E.g. photo-oxidation has a greater impact on PP and high- and low-density PE than on PVC (Tang, 2018). And polystyrene (EPS) pellets are more susceptible to mechanical abrasion than high- and low-density PE.

2.3.2 Uptake and consequent leaching of chemicals into the environment

It is widely recognized that once in the (marine) environment, plastics sorb a wide range of pollutants including toxic, hydrophobic, persistent, and bio-accumulative substances such as PAHs, PCBs, DDTs, heavy metals, antibiotics etc. (Yamashita et al., 2018; Zhang et al., 2019). This potential is increased in eroded plastic pellets, because of its physicochemical changes and expanded surface area. Erosion also allows for microbes and biofilms to latch onto the pellets, and thus changing the plastic particle into a transportation vehicle of both chemical and biological pollutants (Audrezet, 2022), see also paragraph 2.3.4.

The chemicals are sorbed to the plastic pellets in their (marine) environment (Yamashita, 2018) and may thus transport the chemicals over long distances. Alike, the plastics can leach these chemicals into the environment and studies have confirmed the presence of chemicals typically associated with plastics in beach sand, in seabirds, and in several species of fish (Karlsson et al., 2021). Pesticides and organic pollutants are consistently found in plastic waste in marine environments at harmful concentrations 100 times those found in sediments and 1 million times those occurring in sea water (Teuten, 2009).

Plastic particles in marine environments become a cocktail of chemicals of both pre-production added chemicals and those adsorbed from polluted water, including phthalates, PBDEs, BPA, PCBs, styrenes, PAHs, pesticides and metals (Landrigan et al., 2023). According to Karlsson and colleagues two groups of these environmental sorbed chemicals are to be specifically highlighted because of their frequency and toxicity:

- Benzotriazole ultraviolet stabilizers (BUV's). These chemicals are generally classified as very toxic to aquatic life with long lasting effects.
- Polychlorinated biphenyls (PCBs). These chemicals are toxic to life and classified as carcinogenic. Though since the ban on PCBs in the 1980's, these compounds are still often found in the environment.

BUV's are frequently found in the terrestrial and marine environments (including beaches), in animals (e.g. seafood) and wastewaters. Their hydrophobicity also gives them an affinity for sorbing to plastic litter in the environment, thus it is likely that the found BUVs in marine plastic pellets is likely to be a combination of additives and sorbed BUVs. Of PCB's it is known that these chemicals are not intentionally added to the pellets, since they are no longer in use. But they can very efficiently sorb to the plastics in the environment and leach them later and elsewhere (Yamashita, 2018; Landrigan, 2023). Also, because hydrophobic chemicals are still retained in eroded pellets and/or their micro- and nano plastic particles, the plastic fragments ingested by seabirds act as internal exposure sources of such chemicals. Indeed, there are clear indications that pellets with e.g. high concentrations of PCBs spread PCBs to organisms and so to areas that are less polluted (Yamashita, 2018; Karlsson, 2021). Also, seabirds that have consumed plastic waste have PBCs in their tissues at 300% greater concentrations than in those that have not eaten plastic (Teuten, 2009), thus the pollutants also leach into the intestines of organisms.

2.3.3 Release of micro- and nano plastics

All plastic materials and products release plastic particles in the nano- and millimetre size range. Micro and nano plastics (MNPs) are already found in natural and human environments with most particles originating from abrasion, due to UV-radiation, heat and physical impacts, during plastic use or presence of plastics in the environment (Yamashita, 2018; Landrigan, 2023; Wagner et al., 2024). Some polymers have a higher propensity to release MNPs, but a systematic assessment is lacking. Generally, amorphous polymers (e.g., PS, PVC) are more prone to degradation than crystalline ones (e.g., PE, PET) and thus may generate more MNPs. Comparative studies on virgin and processed plastic materials and their propensity to generate MNPs is currently lacking (Wagner et al., 2024). The research group from TNO (Boersma et al., 2023) has recently introduced the Microplastic index which could be a good system to predict microplastics formation and could help to further investigate the propensity to generate MNP's.

MNPs are currently of general concern since they are widespread present in the environment and in organisms. They are found in all layers of the food webs, inside tissues, lipid storages and cells in both terrestrial and aquatic organisms (Rochman, 2013; Landrigan et al., 2023; Wagner et al., 2024. The adverse effects of the widespread presence of MNPs occur from the molecular level to the ecosystem and are seen in both the environment and in humans. Meta-analyses consistently show that MNPs have adverse impacts on reproduction, homeostasis and other effects such as endocrine disruption (Ospar, 2014; Landrigan et al., 2023; Wagner et al., 2024), further described in chapter 3.4. Furthermore, as stated in paragraph 3.3.2 also the MNPs release plastic-related chemicals including additives and residual monomers into the environment and into organisms including humans, causing a wide range of toxic effects. These include neurodevelopmental effects, reproductive birth defects and cancers (Landrigan, 2023).

2.3.4 Pellets as carriers of organisms

Plastic debris (e.g. from plastic pellets) generally floats and exists longer in the environment than most natural debris which makes it an ideal vessel for micro- and macro-organisms. Plastic debris mostly has a hard and hydrophobic surface. These characteristics makes plastic debris an ideal surface for a number of opportunistic colonizers. Floating debris is the most common transport system for aquatic life and plays a major role in the distribution of colonizing species across the world (Barnes & Milner, 2005; Carlton et al., 2017; Audrezet, 2022). Colonization of habitats by alien species is one of the greatest threats to global biodiversity, and the explosive increase of anthropogenic debris in the oceans only adds to this problem.

Many types of animals use marine debris as a way to spread across the water, particularly bryozoans, barnacles, tube and polychaete worms, hydroids foraminifera, coralline algae and (bivalve) molluscs (Barnes, 2002; Gregory, 2009). Zettler et al., 2013 found diverse microbial communities on plastic debris, consisting of heterotrophs, autotrophs, predators and symbionts in what they dubbed, the 'Plastisphere'. These microbial communities were different from surrounding surface water, which indicates that the plastic debris presents novel habitats for microbial life in the world's seas and oceans. Some of these organisms residing in the 'plastisphere' were opportunistic pathogens, for example E. Coli and species of Vibrio which adds additional risks to plastic debris in the environment (Rodrigues et al., 2019). Other detected inhabitants of the 'plastisphere' on plastic debris were harmful algal bloom (HAB) species proving that plastic debris can also be a potential factor in the dispersal of microalgae (Garcés & Camp, 2003).

The dispersal of aggressive alien and invasive species can threaten sensitive and/or endangered marine and terrestrial coastal environments (Gregory, 2009) by harming biodiversity, changing how ecosystems function, and affecting local economies through mitigation measures and the depletion of aquaculture resources (i.e., loss of fish and shellfish stocks) (Audrezet, 2022). With the increasing quantities of these non-biodegradable and synthetic materials in the environment over the last five decades, the spread of potentially aggressive and invasive species to new habitats would likely become a more serious issue (Gregory 1978, 2004; Winston et al., 1997; Barnes, 2002-a, 2002-b).

2.3.5 Differences between polymer types

In the preceding paragraphs, no specific attention was given to the differences between the polymers (main polymers studied are LD/HD-PE, PP, PET, PS+EPS and PVC), but rather the group of plastic pellets as a whole. However, both the physicochemical properties and their behaviour in the environment may differ, leading to different hazard characteristics.

The differences between plastic pellets, their behaviour and their hazard characteristics are influenced by several factors. These factors include the polymer types (monomers such as PP, PE etc.), the additives and processing aids and other chemicals that are present due to the production process, and the sorption of contaminants from the environment. Such properties lead to a difference in the environmental fate when spilled into the marine environment.

Table 2. Environmental fate of polymers when spilled into the environment.

Polymer	Hazard classification of the monomer (Lithner, 2011)	Amount and relative amount of related and known hazardous plastic chemicals (Wagner, 2024)	Found pollutants bound to marine plastics (Zhang, 2019)	Environmental fate biodegradation (Lithner, 2011)	Environmental fate in water column	Endpoint in marine environment (Audrezet, 2022)
LDPE	May cause drowsiness or dizziness Extremely flammable gas	722 (38%)	PCBs, DDTs, PAHs, metals, antibiotics, PFAS	Very resistant to biodegradation	Float	Surface water, deep-sea sediments, mangrove
HDPE				Very resistant to biodegradation	Float	
PP	Extremely flammable gas	633 (45%)	PCBs, DDE, DDTs, NP, PAHs, metals, antibiotics	Very resistant to biodegradation	Float	Surface water, deep-sea sediments, mangrove
PET	Acute toxic through oral route	806 (31%)	Metals	Resistant to biodegradation	Float or sink, depending on density	Sediments
PS	Acute toxic through inhalation Causes serious eye irritation	418 (36%)	PAHs, PCBs, DDTs, Hg, antibiotics, PFAS	Resistant to biodegradation	Sink	Surface water, beaches, estuarine and subtidal sediments, water column
EPS	Causes skin irritation			Resistant to biodegradation	Float	Surface water, beaches, and mangrove sediments
PVC	May cause cancer Extremely flammable gas	618 (48%)	Metals, antibiotics	Resistant to biodegradation	Sink	Sediments, mangrove

Table 2 shows that the monomers PET and PS may be toxic to humans and/or the environment because of their intrinsic hazard properties. Also, the plastics are all known to harbour hazardous plastic chemicals which may be added to the pellets during pre-production. Furthermore, of all plastics it is known that they may sorb possible hazardous pollutants from the environment, during exposure to the marine environment. As stated before, all of the 6 studied polymer types sorb environmental pollutants such as PCBs into the polymer matrix. However, it is not clear which polymer types have a higher sorption capacity and available literature is contradictory on this topic (Rochman et al., 2013; Yamashita, 2018).

Besides the general hazard and behaviour properties, the chemicals related to the plastics and their environmental fate, there may be more properties that influence the hazard properties of different types of plastics (related to the monomers). The pellets and resulting plastic debris, once in the marine environment, may cause toxicity in the eventual end-point due to their leachate toxicity. The toxicity of leached chemicals is investigated and summarized in Figure 4, derived from Wagner et al., 2024). The colour of the heatmap represents the proportion of datapoints that indicate an adverse effect.

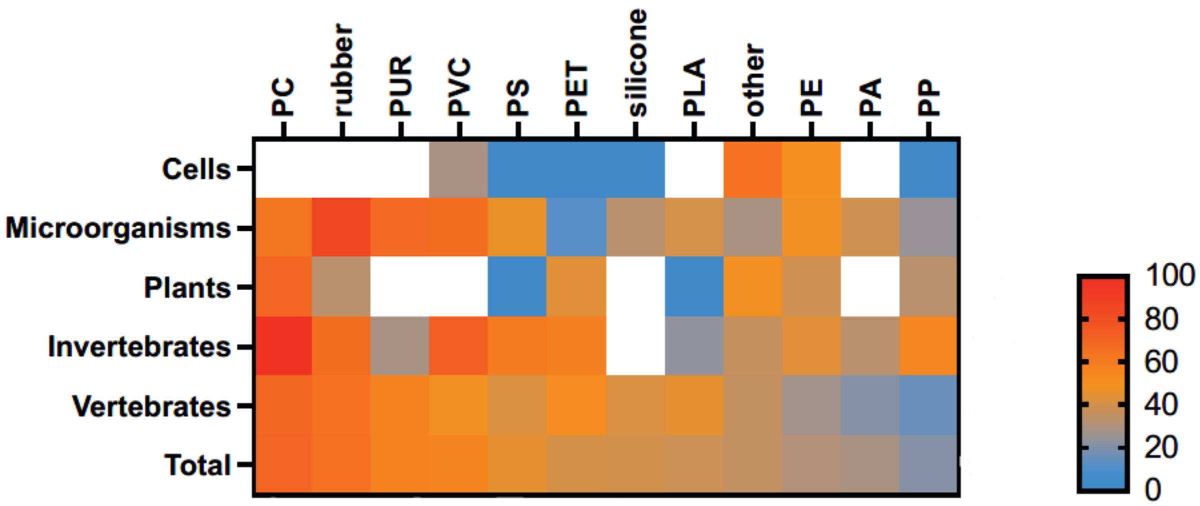


Figure 4: Heatmap of leachate toxicity across polymer types and affected taxa (Source: Wagner et al., 2024). The colour of the heatmap represents the proportion of datapoints that indicate an adverse effect (main polymers studied in this report are LD/HD-PE, PP, PET, PS+EPS and PVC).

The heatmap in Figure 4 shows that of the 6 plastic types studied, PVC may be the most toxic due to leachate toxicity in general and PP the least toxic. Though it may also be observed that the leachate toxicity is not the same for al taxa's (e.g. see the difference in leachate toxicity of PS for plants versus invertebrates). The higher relative toxicity of the leachates of PVC may (partially) be explained by the use of additives in plastics, which is not evenly distributed among the different plastic types. PVC requires by far the most additives of all types of plastics. PVC for instance needs heat stabilisers to prevent the polymer from degrading during processing and needs plasticisers to become flexible (Lithner, 2011).

2.4 Hazardous properties for the environment and organisms

2.4.1 Effects on marine life

2.4.1.1 Effects on ocean sediments

Apart from floating in the seas, plastic pellets can also settle at the bottom and form a plastic sheeting. The impact of plastic sheeting which blankets the biota of soft sediment, reef and rocky substrata has already been described in 1997 (Uneputty & Evans, 1997). This sheeting can also lead to anoxia and hypoxia induced by inhibition of gas exchange between different bodies of water (Goldberg, 1997; Gregory & Andrady, 2003). As is described in 3.4.2.1, the presence of plastic pellets in sediments can also negatively affect microbial activity and live present in sediments.

2.4.1.2 Effects of ingestion

The effects of ingesting (micro)plastics have been proven to affect both marine and terrestrial (3.4.2.2) organisms in multiple ways. Ingesting (micro)plastics has been described in sea birds (3.4.2.3), turtles (Nelms et al., 2015; Wilcox et al., 2018), marine mammals (Jacobsen et al., 2010; Williams et al., 2011; Nelms et al., 2018), sea urchins (Rendell-Bhatti et al., 2021), oysters (Sussarellu et al., 2016), mussels (Gandara Silva et al., 2016) and fish (Neves et al., 2015; Rummel et al., 2017; Justino et al., 2021) often because these animals mistake plastic debris for prey (Audrezet, 2022). Additionally ingestion has also been described in 39 zooplankton species with a wide variety of negative effects, ranging from impaired growth, reproduction, homeostasis, feeding behaviour, endocrine disruption and reduced lifespan (Ospar, 2014; Boterell et al, 2019; Landrigan et al., 2023; Wagner et al., 2024). The biofilm which growths on (micro)plastics in seawater (see 3.3.4) makes them even more likely to be targeted as prey by animals by affecting chemo detection through smell (Vroom et al., 2017). Several negative ingestion effects of ingestion by microalgae have also been described by (Prata et al., 2019; Audrezet, 2022).

The study performed by (Nelms et al., 2018) also revealed an indirect but alarming potential pathway of (micro)plastic transfer to higher trophic levels, up to humans themselves which is further described in chapter 2.3.4.

2.4.2 Effects on terrestrial life

2.4.2.1 Effect on sediments:

After spillage of plastic pellets into the water they are, due to their persistent and buoyant properties, prone to become widely dispersed in the marine environment through hydrodynamic processes and currents (Claessens et al., 2011). Eventually many plastic pellets will end up in sediments and beaches where they alter the composition and physical properties of the sediments. These effects on sediments can both occur in the seabed as well as on the shores.

Sediments with plastic particles were confirmed to warm more slowly and reach lower maximum temperatures than sediments without plastic pollution. These changes in sediment temperatures have a variety of effects on beach organisms and can in some cases even affect sex-determination in eggs of species such as sea turtles. The insulating effects of the plastic present in the soil increases the incubation time off the turtle eggs and lead to lower numbers of hatching females disturbing the population's sex ratio and stability (Carson et al., 2011). Furthermore, the presence of plastic pellets in sediments can also affect soil pH, respiration and enzymatic activities depending on the shape and polymer type of the plastic (Zhao et al., 2021). Soil respiration, an indicator of soil microbial activity (Rousk et al., 2009), is very sensitive to environmental factors which can easily be altered due to microplastic presence (de Souza Machado et al., 2019; Lozano et al., 2021-a) and affect substrate and/or nutrient availability (Zhou et al., 2020; Lozano et al., 2021-b).

2.4.2.2 Effects of ingestion:

The presence of plastics in the environment can lead to plastic ingestion by a wide range of animals. Once plastic is ingested by animals it provides a pathway through which the attached pollutants and additive chemicals can be transferred to the tissues of animals, their circulatory system and potentially bioaccumulate in the food web (Ryan, 1988; Mato et al., 2001; Browne, 2008). Furthermore, it could also lead to internal wounds, blockage of the digestive tract followed by satiation, debilitation and even starvation; drowning and limited predator avoidance, adsorption of toxic compounds and death (Gregory, 2009). Research into the exposure of pollutants through plastic mediums has shown that depending on the type of plastic, lugworms (*Arenicola marina*) experienced a reduced ability to remove pathogenic bacteria from their tissues and engineer sediments, were more susceptible to oxidative stress (>30%), and experienced a >55% increase in mortality rate because of the oxidative stress and reduced ability to remove pathogenic bacteria (Browne et al., 2013).

2.4.2.3 Effects on seabirds:

Seabirds are known to ingest high rates of plastic which makes them susceptible to the effects and bioaccumulation of the chemical pollutants present in those plastics (Yamashita et al., 2019). More than 100 species of sea birds have been known to ingest plastics (Laist, 1997). Ingestion of plastics by sea birds can have a variety of effects on their health. The presence of plastic in the stomach of birds have been proven to limit food intake which leads to reduced lay down of fat deposits and a reduction in fitness and growth, lowered reproductive performance and even starvation (Day et al., 1985; Ryan P.G., 1988; Laist, 1997).

Apart from the direct and indirect effects of ingestion of plastic pellets for foraging sea birds, another way these plastic pellets affect multiple species of sea birds is by smell. As discovered by Savoca et al., in 2016, marine seasoned microplastics emit a dimethyl sulphide (DMS) signature that functions as a chemical cue for seabirds to localize a food source, i.e. a prey. Savoca et al. found that this triggers these birds to ingest increased numbers of plastic pellets that emit the DMS signature mistaking them for food and lead to increased exposure to the toxic effects of the chemicals in the plastic pellets to the tissues of these birds.

2.4.3 Hazardous properties for humans

The effects of plastic pellets on organisms via ingestion stated in chapter 3.4.2.2 are also relevant for humans. Humans find themselves at the top of the world's food chains and are therefore even more prone to bioaccumulation of chemicals than most other species (Miranda & Carvalho-Souza, 2015). Micro and nano plastics (MNP's) are typically found in the gastrointestinal (GI) tract of animals. For larger animals the GI tract is normally removed before consumption, making sure that the plastic contents will not be consumed. For smaller animals like anchovies, sardines and most bivalves this, however, is not the case since they are consumed in their entirety leading to direct human exposure to plastics and plastic associated chemicals and their accumulation in the human body (Landrigan et al., 2023).

Micro and nano plastics (MNPs) are increasingly found in the human body. So far, plastic particles have been found in at least but not limited to the following parts of the human body: the lungs (Amato-Lourenço et al., 2021; Jenner et al., 2022), the blood (Leslie et al., 2022), the kidneys (La Porta et al., 2023), the placenta (Ragusa et al., 2021), breast milk (Ragusa et al., 2022), intestinal tissue (Schwabl et al., 2019) and heart muscle (Li et al., 2023).

Plastic additives that can leach chemicals into the human body, can lead to a range of unwanted side effects. Plastic additives have been proven to disrupt endocrine function, increase risk of premature births, and lead to neurodevelopmental disorders, male reproductive birth defects, infertility, obesity, cardiovascular disease, renal disease and various types of cancers (Landrigan et al., 2023). While the evidence is not complete, emerging evidence indicates that MNPs could cause toxicity due to their physical and toxicological effects (paragraphs 3.3.2. and 3.3.3.) as well as by acting as a vector for toxic chemicals and invasive species into new environments and hosts as described previously in paragraph 2.3.4 (Landrigan et al., 2023).

3. Risk assessment of plastic pellets

In order draw conclusions of the risks of the plastic pellets in general, risk assessments are needed. Below, some of the important aspects on exposure and risks of plastic pellets and polymers are summarised and discussed.

The thousands of chemicals in plastics—monomers, additives, processing agents, and non-intentionally added substances—include amongst their number known human carcinogens, endocrine disruptors, neurotoxicants, and persistent organic pollutants. These chemicals are responsible for many of plastics' known harms to human and planetary health. The chemicals leach out of plastics, enter the environment, cause pollution, and result in human exposure and disease. All efforts to reduce plastics' hazards must address the hazards of plastic-associated chemicals (Landrigan, 2023).

3.1 Emissions and exposure

Pre-production pellets have been found on beaches and in open waters, all over the world, since the early 1970s (Karlsson, 2021). Already at that point, the researchers warned that the increased production of plastics, coupled with unsuitable waste management practices, and spills of pellets during transportation and storage, would lead to an increase of plastic particles in the ocean and surrounding areas. Plastic pellets end up in the environment due to continuous small-scale spills and due to larger spills following (marine) accidents.

These plastic pellets may be intrinsically hazardous because of their chemical makeup, though the pellets may also serve as a transportation vehicle of a wide range of sorbed environmental pollutants (Yamashita, 2018) as has been further described in 3.3.4.

Hazardous substances may be emitted from plastic pellets and may consist of a wide range of plastic chemicals (e.g. raw materials, monomers, catalysts, solvents, by-products from production, and additives) or other (biological) pollutants, as well as degradation products of the nonpolymeric substances and from the polymer itself (i.e. micro- and nano plastics) (Wagner et al., 2024; Lithner, 2011) as described in 3.2 and 3.3.

Factors that control the emission/leaching potential of these pollutants include the permeability of the polymer matrix, the size of voids and gaps between polymer molecules, and other physicochemical properties such as solubility, temperature and environment. The toxicity of pre-production pellets is not a fixed given, but changes according to its environment. I.e.: when exposed to the environment, the physical properties of the pellets change and thus their ability to adsorb, leach and transport chemicals and other pollutants as described in 3.3.

It can be concluded, therefore, that not only does release of plastic pellets into the (marine) environment lead to the emergence pollutants in the environment, such as microplastics, but it also changes the physicochemical properties of the pellets and emerged plastic particles itself. Indeed, scientists state that due to these changing properties of plastic pellets after release into environment, plastic pellets can no longer be regarded as a regular solid waste but as a solid waste carrying pollutants (Fotopoulou, 2012; Zhang, 2019; Audrezet, 2022). Meaning that the intrinsic (possibly) hazardous properties of plastic pellets increase due to environmental exposure.

3.2 Environmental fate

3.2.1 Degradation

The main polymer types are generally resistant to biodegradation (e.g. by microorganisms), though they may be degraded by environmental factors such as heat, oxidation, radiation and erosion. This may lead to altered physicochemical properties and thus their sorption and emission/leaching potential. These environmental factors may lead the plastic pellets to become brittle and fragmented and fall apart into small pieces, generating micro- and nano plastics. Complete degradation, i.e. degradation to the monomers or CO_2, could take several hundred years (Lithner, 2011). During the environmental degradation, under influence of surrounding factors, chemicals and other pollutants leach from the pellets, such as chemical components of the monomers (e.g. chlorine from PVC) and other plastic chemicals, other (biological) pollutants and micro- and nano plastics as described in Chapter 2.3.

3.2.2 Distribution

As has been introduced in Chapter 1, plastic pellets are widely distributed across the planet mainly via transport over sea. Plastic pellets are the second largest source of primary microplastic pollution (plastics smaller than 5 mm) that is found in the aquatic environment with an estimated annual input into the oceans of 230,000 tonnes (Eunomia, 2016; Cedre, 2023). Plastic pellets that end up in the marine environment can be transported far by currents, for instance in the great oceanic gyres. Large and increasing amounts of plastic products, debris, fragments and micro-particles are found in all oceans, both on the surface and in the deep, in sediments and beaches and have been presented in scientific reports since the late 1960s (Lithner 2011).

3.3 Quantifying the risk

Plastic pellet pollution has adverse effects on the environment, from biochemical and molecular to population and ecosystem levels (Landrigan et al., 2023). As has been described in Chapter 2, plastic pellets can have a variety of negative effects on the environment and organisms through various ways. Although direct human exposure is yet still limited, accumulation in the food chain and other effects of plastic pollution on ecosystems upon which all humanity depends for food, oxygen, well-being and livelihood are all becoming increasingly negatively impacted (Landrigan et al., 2023). The growing number of produced plastics and increasing number of plastic pellets present in the environment by leakage during transport only further increases this problem.

Although the effects of (virgin) plastic pellets are quite well described and studied, the quantities of toxic substances in the environment from plastic pellets and subsequent chances and effects of exposure to humans and other organisms remain hard to identify. During this study, very limited information was found about the exact chemical composition of plastic pellets and their quantities. This is partly due to the fact that all plastic producers are not entirely open about which exact chemicals are present in their virgin pellets, and no studies have been found that were able to identify the exact composition of virgin pellets either. Nevertheless, it is clear that there is a large quantity and variation of toxic and non-toxic chemicals available, used, present and released from plastic pellets as has been described by Wagner et al., 2024 and in Chapter 2.2.2. To further quantify the risk of plastic pellet pollution, additional information about the quantities and types of chemicals present in (virgin) pellets must be obtained. By doing so, the effects of plastic pellets on organisms and the environment, described in chapter 3, can be further quantified.

Hann et al., 2018 states that only in Europe, 10Mt of plastic pellets are shipped annually via sea transport. Cedre 2021 shows that the intra-Asian market alone already represents transport of more than 30 million containers with plastic pellets per year across the sea. The global production of plastics was approximately 2 million tonnes (Mt) per year in the 1950's and has shown exponential growth since the second world war, reaching 367 Mt in 2020 (Cedre 2023).

However, reliable data on the quantity of pellets lost at sea is lacking. There is no legal obligation yet to report lost containers from ships, although this obligation had been introduced by IMO entering into force in 2026, let alone an obligation to report on the hazardous contents of the lost containers if the hazard has not been recognized and documented. The best source of information that was found, is from the World Shipping Council (WSC). The WSC estimates that in the period of 2008-2022, on average a total of 1566 containers – *with plastic pellets or any other goods or substances* - was lost at sea each year [2]. Figure 5 shows the number of lost containers per year between 2008 and 2022. Since not all relevant shipowners are a member of the WSC and reporting of lost containers is difficult to monitor and enforce, the numbers are believed to be much higher in reality.

[2] CCC 9/13 (2023), Estimate of containers lost at sea – 2023 update submitted by the World Shipping Council (WSC)

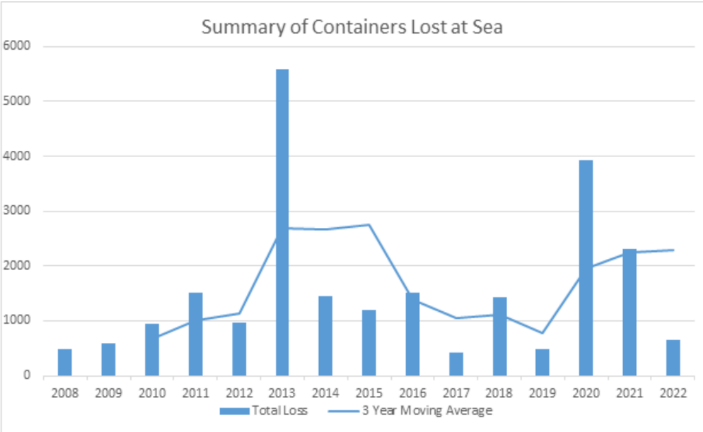


Figure 5. Analysis of the sixteen-year trends in containers lost at sea, Source: WSC - CCC 9/13, 24 May 2023

Apart from leakage from containers falling overboard or leaking containers during transport, during transportation over sea, there is always a risk for larger accidents to happen, only adding to the amount of plastic (pellet) pollution in the marine environment. Examples of large-scale accidents as mentioned in Chapter 1.1.2 with the X-Press Pearl and MSC Zoë had significant environmental and economic impacts.

Environmentally, the clean-up of plastic pellets from the ocean and beaches is a very labour-intensive, costly, and time-consuming exercise, which ultimately will not result in the retrieval of most plastic pellets. Apart from their physical risks via ingestion, the addition, sorption, and consequent leaching of plastic chemicals and other pollutants in and from plastic pellets pose additional risks for marine and terrestrial organisms and their habitats.

Economically, the general loss of health in humans due to plastic's harms results in significant costs. In 2015, the health-related costs of plastic production exceeded $250 billion globally (Landrigan, 2023). Specific for plastic pellet introduction into marine environments, the most costly effect originates from clean-up activities and reduced tourist profits when spills contaminate beaches and marine ecosystems, as has been described in the literature (Karlsson et al., 2021; Cedre, 2023).

The more these leakages and accidents happen in the years to come, the greater the build-up of plastics in the marine environment and the more likely and profound the adverse effects on the environment and organisms will become.

4. Options for regulating sea transport of plastic pellets

4.1 Introduction to this chapter

The hazards and risk assessment in the previous chapters provides a convincing number of arguments why plastic pellets pose a threat to the environment and human life. They substantiate that the sea transport of plastic pellets should be regulated in such a way that these risks are prevented or mitigated as much as possible. This chapter elaborates on the legal options of the International Maritime Organization (IMO) for regulating the sea transport.

4.2 Conformity of plastic pellets with legally established criteria

In order to regulate the international sea transport of plastic pellets, the established legal structure and approach of the United Nations (UN) and the IMO towards the sea transport of dangerous goods must be followed.
The most obvious approach would be to demonstrate that plastic pellets meet the UN and/or IMO criteria for dangerous goods. The relevant UN/IMO criteria for hazardous substances are set out in:

1. IMO - MARPOL Annex III[3], Appendix Criteria for the identification of harmful substances in packaged form
2. IMO - IMDG Code[4] Chapter 2.9.3 Environmentally hazardous substances (aquatic environment)
3. UN - GHS[5] Chapter 4.1 Hazardous to the aquatic environment

If plastic pellets would meet the criteria in either 1, 2 or 3, the substance would qualify as 'harmful substance', or 'environmentally hazardous substance to the aquatic environment', which would either way lead to classification of the substance in the IMDG Code class 9 (*Miscellaneous dangerous substances and articles and environmentally hazardous substances*). The IMDG Code contains the transport regulations for the safe carriage of dangerous goods by sea, for example in terms of packaging, stowage, documentation and segregation from other dangerous goods. The IMDG Code therefore qualifies as an appropriate and well-established instrument to mitigate the risks of sea transport of plastic pellets.

Unfortunately, studies on toxicological effects of plastic pellets are few, and the above-mentioned classification criteria for hazardous substances mostly work by defining hazardous substances through toxicological studies. This makes it difficult to substantiate that plastic pellets classify as 'hazardous'.

Nevertheless, one study was found which can be used as a stepping stone for further research and function as further support for the (toxicological) effects described in Chapters 2 and 3. The study of Ward et al., 2022 investigated the direct effects of plastic pellets and the various chemicals they contain on barnacle Nauplii. They found that seawater leachates of plastic pre-production pellets are acutely toxic to stage II barnacle nauplii. A lethal concentration 50 (LC50s) was observed in 24-h leachates from dilutions ranging from 0.007 to 2.1 mg/mL of seawater (Ward et al., 2022), proving that plastic pellets and the chemicals they can contain can be deadly for marine life.

However, this single study provides insufficient proof to confirm that plastic pellets meet the above-mentioned criteria. Yet, many signs show in that direction. With future research, it is likely that the above-mentioned classification of plastic pellets as a hazardous substance can be further substantiated. Future research should include better indications of the number of additives present and leached from virgin and non-virgin plastic pellets from initial producers, and further research using high-throughput nontargeted chemical analyses of plastic pellets (Tallec et al., 2024). Additional toxicological studies like that of Ward et al. (2022) will help to

[3] IMO - International Convention for the Prevention of Pollution from Ships Annex III - Regulations for the prevention of pollution by harmful substances carried by sea in packaged form.
[4] IMO - International Maritime Dangerous Goods Code (Res.MSC.477(102)) (Amendment 41-22)
[5] UN - Globally Harmonized System of Classification and Labelling of Chemicals, 10th revised edition 2023

identify if and to what extend plastic pellets leachates can induce toxicity on different taxa. These studies will also ensure that better account can be taken of potential 'cocktail effects' when plastic pellets are exposed to other chemical substances after entering the water (e.g. oil or other chemicals present in the water) (Wagner et al., 2024; Tallec et al., 2024).

It is concluded that at this moment in time, insufficient scientific proof has been found available to confirm that plastic pellets meet the criteria for harmful substances in the appendix to MARPOL Annex III, or the criteria for environmentally hazardous substances (aquatic environment) in the IMDG Code, or the requirements for substances hazardous to the aquatic environment in the UN Globally Harmonized System.

However, the fact that plastic pellets do not meet these criteria does not have to be a showstopper for setting sea transport regulations in IMO, as will be explained in the following paragraph.

4.3 Considerations on options to regulate plastic pellets

One option for IMO would be to amend the criteria in the MARPOL Annex III appendix and in the IMDG Code chapter 2.9.3, so that these would recognize plastic pellets as a harmful substance. This would be a difficult assignment, as this would entail the risk of other substances unintentionally falling within the criteria as well. It could lead to an extensive discussion on a new definition of 'harmful substances'.

Other options that have been proposed in submissions of the various IMO member states to the Sub-Committee on Pollution Prevention and Response (PPR)[6], are:

- A new chapter to MARPOL Annex III that would prescribe requirements for the transport of plastic pellets in freight containers without classifying the cargo as a harmful substance/dangerous goods;
- An amendment to MARPOL Annex III to split the definition of harmful substances into substances covered by the IMDG Code and substances that are not (e.g. plastic pellets), combined with new regulations in MARPOL Annex III on the transport of plastic pellets outside of the scope of the IMDG Code; and
- An addition to MARPOL Annex V (*Regulations for the Prevention of Pollution by Garbage from Ships*); this annex already does recognise the harmful effects of plastics on marine ecosystems but only prohibits the intentional discharge of plastics into the sea in the form of 'litter' and not the unintentional loss of plastic pellets as 'cargo'.

All of the above options have in common that they do not easily fit in the existing IMO legislation structure and would require significant amendments to an annex to MARPOL. The debates to be held in the relevant IMO (Sub-)committees to amend these annexes could easily degenerate into lengthy debates on the legal constructs rather than focus on the content. The procedures to reach an agreement on such amendments may take numerous years and would cause uncertainty of the result and timeframe in which the legislation becomes effective. Following that, the individual member states would have to make arrangements for the enforcement of the adapted annexes, which also takes time.

The last option for consideration would be to assign plastic pellets to *another* category in class 9 of the IMDG Code, which is defined as *'Other substances and articles presenting a danger during transport, but not meeting the definitions of another class'*. Paragraph 2.9.2 of the IMDG Code contains the assignment of goods to class 9. The type of potential danger for this category is not specified, therefore plastic pellets could fit in this category without any major negative legal consequences. There are several examples of goods that have been classified in class 9 without specifying the type of potential danger. Examples for dangerous goods in this category are UN 3171 BATTERY POWERED VEHICLE or UN 3359 FUMIGATED CARGO TRANSPORT UNIT.
This option would lead to effective transport regulations for plastic pellets in the existing IMO legal framework (the IMDG Code) and takes no changes in existing legal structures or need for implementation of new enforcement instruments in member states.

[6] PPR 11/13/1, PPR 11/13/3

4.4 Conclusion on regulating sea transport of plastic pellets

- It is concluded that at this moment in time, insufficient scientific proof has been found available to confirm that plastic pellets meet the criteria for harmful substances in the appendix to MARPOL Annex III, or the criteria for environmentally hazardous substances (aquatic environment) in the IMDG Code, or the requirements for substances hazardous to the aquatic environment in the UN Globally Harmonized System.
- Other options to regulate plastic pellets in IMO entail amendments to MARPOL Annexes, which may lead to lengthy debates in IMO (Sub-)Committees on the legal constructs rather than focus on the content.
- Therefore, from a pragmatic perspective it is concluded that the classification of plastic pellets in the IMDG Code class 9 would be the preferred option to regulate the sea transport of plastic pellets, in terms of certainty and effectiveness of the outcome.[7]
- The most obvious way to reach this would be to assign plastic pellets to class 9 of the IMDG Code in the category *'Other substances and articles presenting a danger during transport, but not meeting the definitions of another class'.* Therefore, this report further explores this option.

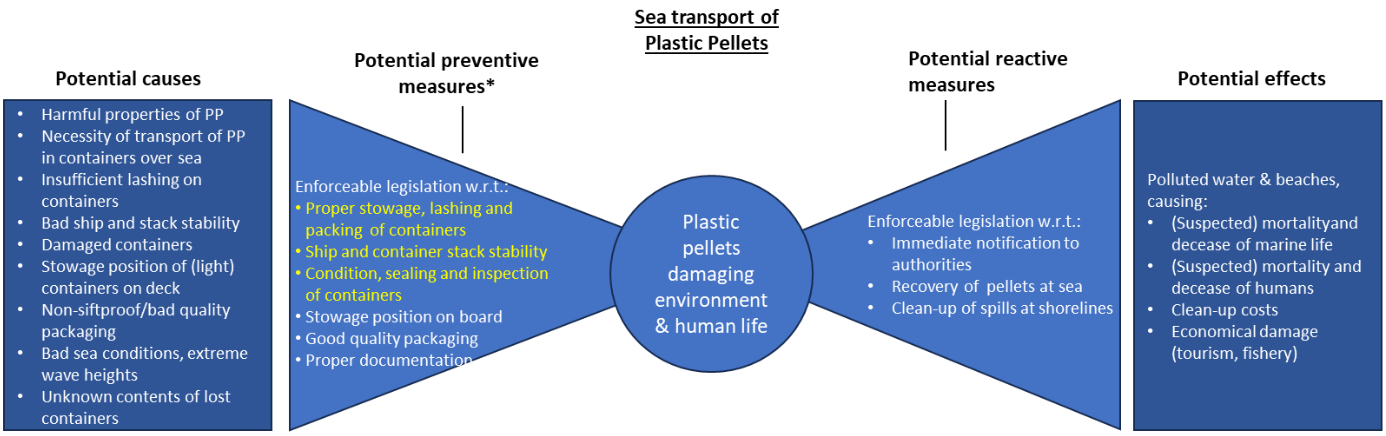
[7] It should be noted that this conclusion does not mean that the other options that have been considered are completely wrong. The assessment that was made in this chapter is subject to assumptions on how the options would be handled in IMO, which is not set in stone.

5. Risk preventive and reactive measures

5.1 Introduction to this chapter

In order to regulate the sea transport of plastic pellets in such a way that the risks of plastic pellets damaging the environment and human live are effectively prevented or mitigated, risk preventive and reactive measures need to be studied. This chapter elaborates on the possible measures and their effectiveness, and on the practical implementation of these measures in the IMDG Code class 9. It only elaborates on the potential measures that are within the scope of IMO. So, for example, measures that concern reduction of the harmful properties of plastic pellets by adapting the substance composition, or reduction of the sea transport of plastic pellets are not covered in this report, because this it out of its scope. The matter is approached from a *pragmatic* point of view, based on the principles of safety science.

In the simplified bow-tie diagram in Figure 6, the coherence between causes, measures and effects of an incident with plastic pellets during sea transport is visualized:



**Only the potential preventive measures which are within the scope of IMO are mentioned.*
The yellow measures are generic measures to prevent containers from falling overboard, regardless of the contents.

Figure 6. Bow-tie diagram on the risk of sea transport of plastic pellets

The potential preventive and reactive measures are assessed on their effectiveness in the following paragraphs.

5.2 Preventive measures

The goal of most preventive measures is to prevent containers with plastic pellets from falling overboard. There are a number of *generic* measures to prevent containers from falling overboard, and there are some *specific, additional* measures which could apply to the transport of plastic pellets in containers only.

Generic measures
The generic measures are printed in yellow in the bow-tie diagram and are related to:

- Proper stowage, lashing and packing of containers
- Ship stability and container stack stability
- Condition, sealing and inspection of containers

These measures are extremely important to prevent the loss of containers with plastic pellets. Containers with plastic pellets are often carried on deck. Once a container has fallen overboard, the likelihood that it remains undamaged, closed and sealed is low. A fall from the deck of a (container) vessel on to the seawater surface is usually tenths of metres. Containers are not constructed and tested for that kind of forces, even tank containers (CSC Code Annex II and IMDG Code chapter 6.7.2). The techniques for cleaning up of plastic pellets from the seas and from shorelines are limited and not fully developed [8]. Preventing containers from falling overboard is therefore of utmost importance.

IMO has long been working to ensure the safe transport of containers, including through guidelines on container stowage (The Code of Safe Practice for Cargo Stowage and Securing (CSS Code)). The work still continues through a new output on '*Development of measures to prevent the loss of containers at sea'* and *'Revision of the Revised guidelines for the preparation of the Cargo Securing Manual' (MSC.1/Circ.1353/Rev.2)* to include a harmonized performance standard for lashing software to permit lashing software as a supplement to the Cargo Securing Manual, which were approved by MSC 107 and are being considered by the CCC Sub-Committee. Also from a (shipping) industry perspective every container overboard is one too many, so there are numerous initiatives and efforts to prevent the loss of containers. Therefore it is assumed that these measures have been properly identified and have the necessary attention of IMO.

Additional, specific measures
Regarding the additional, specific measures for transport of plastic pellets, *voluntary recommendations for the carriage of plastic pellets by sea in freight containers* have recently been established in IMO (MEPC.1/Circ.909, 19 April 2024). The effects of IMO recommendations in this respect are questionable, as there are no means to enforce or even to properly monitor compliance. This leads to continued pollution of the seas. If IMO wants to effectively stop the pollution from plastic pellets as soon as possible, *mandatory* regulations which reflect *effective* preventive measures need to be established.

Classifying plastic pellets in class 9 of the IMDG Code would be the preferred option, as was substantiated in chapter 4. Therefore, in the next paragraphs, for each measure is elaborated on the implementation of that measure in the IMDG Code class 9 by adding plastic pellets under a new UN number to the IMDG Code Dangerous Goods List.

5.2.1 Good quality packaging

To mitigate the risk of loss of plastic pellets after a container has fallen overboard and has possibly been damaged or burst open, the packaging of the pellets inside the container should be strong enough to keep the pellets contained and prevent the pellets from spreading as loose particles. It should be noted that even undamaged, dry (standard) containers without liners are not designed to be sift proof: small particles such as plastic pellets may still leak from an undamaged container if the packaging of the pellets within the container has been damaged e.g. due to shock or tear during a fall overboard. Undamaged tank containers are sift proof, but may no longer be after a fall from height (and no additional packaging is provided in a tank container).

Presently, there are five main types of packaging for plastic pellets in use (MEPC 80.INF.15 and CCC 9/2/3):

1. 20 kg bags (containing approx. 1,000,000 plastic pellets) on pallet (60 bags/pallet; 1500 kg)
2. 500-1300 kg octabins
3. 500-1000 kg big bags
4. Sheeted containers
5. Silo trucks

A fall from the deck of a (container) vessel on to the seawater surface is usually tenths of metres. None of the above packaging is constructed and tested to withstand a fall from such heights on the seawater surface (IMDG Code Part 6), although packaging within a dry container may be protected to a certain extend by the surrounding container.

In the *Recommendations for the carriage of plastic pellets by sea in freight containers*, the packaging recommendations are defined as follows:

'Plastic pellets should be packed in good quality packaging which should be strong enough to withstand the shocks and loadings normally encountered during transport. Packaging should be constructed and closed so as

[8] From: State of knowledge on pollution by plastic pellets, CEDRE, 20 March 2023

to prevent any loss of contents which may be caused under normal conditions of transport, by vibration or acceleration forces.'

These recommendations are not sufficient for the prevention of loose plastic pellets in the environment *after* a container has fallen overboard, considering the conditions that the packaging must endure during the fall and while floating in the seawater. The recommendations do not address the issue of a container falling overboard; they only refer to 'normal conditions of transport'.

A submission of France to the CCC Sub-committee (CCC 9/2/3) contains a proposal for packaging with more suitable (airtight, resistant, practical, etc.) and more responsible (reusable, sustainable, etc.) characteristics:

- ICS 55.140-certified, reusable steel, aluminium or plastic drums,
- containers approved under the International Convention for Safe Containers (CSC), of the silo tank container type, or
- any other packaging with equivalent design and construction characteristics.

Although this type of packaging would significantly improve the unintentional loss of pellets during handling and transport and is therefore of great added value, also this type of packaging is not constructed and tested to withstand a fall from tenths of metres in a container. It may or may not lose its contents.

Concluding from the above, none of the current and proposed packaging types are constructed and tested to keep pellets contained after a fall from a container ship of tenths of metres.

Instructions for packaging could be set if a new UN number would be assigned to plastic pellets and following implementation of that number in the IMDG Code List of Dangerous Goods. However to set these instructions, first of all it needs to be determined what packaging types would be suitable, considering the conditions that the packaging must endure during the fall and while floating in the seawater. The IMDG Code does provide 'extreme' packaging instructions, e.g. for Class 6.2 (Infectious substances of Cat. A) and Class 7 (Radioactive material) substances. However, it is not realistic to require such packaging types for plastic pellets, as this would make the transport of plastic pellets almost impossible.

Concluding from the above, the measure of 'good quality packaging' is only effective if a suitable (practical and not extremely expensive) packaging type could be determined that keeps plastic pellets contained after a fall from tenths of metres in a container on to the water surface and floating in the seawater for a longer period of time. Such type of packaging is not realistic for transport of plastic pellets. Therefore we conclude that the effectiveness of prescribing 'good quality packaging' is low, as long as 'good quality' does not relate to the above conditions.
This does not change the fact that unintentional loss of pellets during normal handling and transport[9] could be prevented by more suitable types of packaging (e.g. as suggested in CCC 9/2/3), and therefore should definitely be pursued.

5.2.2 Stowage position on board

Containers packed with pellets are often carried on decks of the containerships. This increases the risk of falling overboard compared to underdeck stowage, especially if stowed in the outer rows on deck. Triggers can be (a combination of) extreme motions and accelerations due to bad weather, inadequate container securing (missing twistlocks, unlocked twistlocks, damaged containers or lashing gear and lashings becoming loose in a seaway), adjacent container stack clashing, improperly packed containers, etc. [10].
If we aim to prevent the risk of containers with plastic pellets from falling overboard, it would be most effective *not* to stow these containers in the outer rows on deck. The inner rows provide more protection from falling

[9] In the context of the International Maritime Dangerous Goods (IMDG) Code, 'normal transport conditions' refer to the standard conditions under which dangerous goods are transported by sea. This includes the typical handling, stowage, and environmental conditions that can be expected during the journey.

[10] For a concise overview of generic causes of, and solutions for containers falling overboard: Article: Container stack collapses – causes and solutions - Standard Club

overboard, but still are more vulnerable to falling overboard than stowage positions under deck. In case of a complete loss of a ship due to an accident, stowage under deck would provide the best chances for containers with pellets to be recovered without spilling the pellets, as part of the salvage of the vessel.

Stowing conditions could be set if a new UN number would be assigned to plastic pellets and following implementation of that number in the IMDG Code List of Dangerous Goods. This would require a specific stowage condition 'Stowage under deck or inboard in sheltered areas of exposed decks only'. As an example, a similar (but non-mandatory and less effective) stowage condition is already in place for all marine pollutants in the IMDG Code 7.1.4.2:

Stowage of marine pollutants and infectious substances of UN 2814, UN 2900 and UN 3549:
Where stowage is permitted on deck or under deck, under deck stowage is preferred. Where stowage on deck only is required, preference shall be given to stowage on well-protected decks or to stowage inboard in sheltered areas of exposed decks.'

An important remark to the above is that 'sheltered areas of exposed decks' are not clearly defined in the IMDG Code, which leads to different interpretations and therewith difficulties in enforcement. This definition should be (re-)considered when drafting a new stowage condition.

It can be concluded that the assignment of a specific new, well defined stowage condition 'stowage under deck or inboard in sheltered areas of exposed decks only' to plastic pellets would effectively contribute to prevention of pollution from plastic pellets.

5.2.3 Proper documentation

In order to be able to take any of the specific preventive measures for transport of containers with plastic pellets, first of all it is necessary that the containers and their hazardous contents are properly documented. The documentation should identify the UN number and class, the total quantity and the stowage location on board the ship as a minimum. With this information, the containers can be stowed in the correct position, and if these containers would fall overboard, information on the hazardous nature of its contents would be readily available for immediate emergency response. In an emergency situation, the documentation would have to be available both on board of the ship, as well as with the authorities ashore.

The above-mentioned requirements for documentation of *all* dangerous goods are well covered in the IMDG Code paragraph 5.4.3 *Documentation required aboard the ship*. It can be concluded that these requirements are considered a measure that effectively contributes to the prevention of pollution from plastic pellets.

5.3 Reactive measures

5.3.1 Immediate notification to authorities

The IMO Maritime Safety Committee (MSC) recently adopted amendments to SOLAS Chapter V, Regulations 31 and 32, requiring mandatory reporting of all containers lost at sea. Entering into force on January 1, 2026, these amendments will require mandatory reporting of all containers lost at sea, which will hopefully lead to less collisions between ships and drifting containers, and more successful recoveries of containers by shipowners and coastal States in general.
However, the Master of the ship is unaware of the contents of the lost containers, except if the containers contain dangerous goods as listed in the IMDG Code (see the above paragraph 5.2.3). Since at present plastic pellets are not listed in the Dangerous Goods List of IMDG Code, the Master cannot report it to the coastal State, leaving the risk of pollution of water and shorelines unknown until the pellets are noticed in the environment.

This is a very clear consequence of not listing plastic pellets as dangerous goods under the IMDG Code. If plastic pellets were classified and consequently listed in the IMDG Code Dangerous Goods List, the mandatory reporting would already exist in SOLAS Chapter VII Regulation 6 *Reporting of incidents involving dangerous goods*[11].

5.3.2 Recovery of pellets at sea and clean-up of spills at shorelines

In case a lost container at sea is undamaged and the packaging of the pellets in the container is still intact, it may lead to full recovery without any release of pellets into the environment. This will only happen if a number of preventive measures would be in place: Undamaged, closed and sealed containers, excellent quality packaging, as well as immediate reporting of the loss including the harmfulness of its contents to the coastal State in order to trigger immediate recovery. This scenario may have a happy ending, but at present is not very likely to happen.

The *Guidelines on the clean-up of plastic pellets from ship-source spills* which were adopted MEPC 82, provide the following less optimistic scenarios:

- *A container breaks up on deck/on contact with water, spilling its cargo directly into the environment;*
- *A container is lost overboard, after which it sinks or continues to drift for a period of time, and then breaks up and releases cargo, or;*
- *A container may eventually sink to the bottom intact, whereby no cargo is released immediately. However, if left in-situ for long periods, the structural integrity of a sunken container may be compromised, subsequently spilling its contents.*

If the pellets are released into the sea, the chances on full recovery of the pellets are close to zero. Quoting from the conclusions of the CEDRE (2023) report: *'To our knowledge, no offshore response operations have been implemented following a pellet spill (e.g. aerial surveys, containment and recovery method deployments). Future tests of response operations at sea are necessary to prepare for future accidents, and to assess the performance of existing equipment.'*

In the above-mentioned guidelines another pessimistic scenario is provided for the clean-up of shorelines: *'Past cases have demonstrated that shoreline clean-up of releases of plastic pellets is laborious and protracted. This is a result of the characteristics of the pollutant and its highly mobile behaviour when lost to the marine environment, as well the rudimentary tools available to recover spilled plastic. For these reasons, the recovery of pellets from contaminated shorelines has been observed to take between months and years until agreed sign-off of sites by the authorities. Even then, the complete recovery of lost cargo is considered to be largely impossible. Recent cases have demonstrated between a 40 – 70 % recovery rate.'*

The above quotes emphasize the need for measures to *prevent* containers with plastic pellets from falling overboard. The likelihood and effectiveness of recovery and clean-up are far less. Therefore the effectiveness of guidelines on the clean-up of plastic pellets from IMO is considered no more than 'informative'.

5.4 Conclusions on risk preventive and reactive measures

From this chapter it can be concluded that:

- Effective measures to mitigate damage to the environment and human life from plastic pellets spilled at sea are within reach of IMO. General measures to prevent containers from falling overboard, as well as specific additional measures for the transport of plastic pellets can be taken.
- The effectiveness of measures for plastic pellets (to be) defined by IMO is considered as follows:

[11] SOLAS Chapter V Regulation 6: When an incident takes place involving the loss or likely loss overboard of dangerous goods in packaged form into the sea, the master, or other person having charge of the ship, shall report the particulars of such an incident without delay and to the fullest extent possible to the nearest coastal State. The report shall be drawn up based on general principles and guidelines developed by the Organization.

Table 3. Effectiveness of potential measures.

Potential IMO measures to prevent harm from plastic pellets:	The measure affects:	Effectiveness of measure during normal transport conditions: [12]	Effectiveness of measure after container with pellets has fallen overboard:
Generic measures: • Proper stowage, lashing and packing of containers • Ship stability and container stack stability • Condition, sealing and inspection of containers	Prevention from: • falling overboard of containers in general • instability of container stacks and ship • leakage of contents of containers	High, all measures are effective to prevent containers from falling overboard.	Very low, only the container condition and sealing may have some effect.
Good quality packaging	Prevention from spreading of plastic pellets into the environment in loose particles.	High. Good quality packaging such as ICS 55.140-certified drums and tank containers can prevent unintentional loss of pellets.	Low. Packaging must be constructed and tested to withstand conditions during/after the fall overboard and in sea, requirements for such packaging are not realistic.
Stowage of containers below deck or inboard	Prevention from falling overboard of containers with plastic pellets.	High. The likelihood of containers falling overboard is minimized.	n.a.
Proper documentation	Awareness of hazardous nature of goods and vital information for emergency response.	High. Necessary for awareness and proper stowage position.	Medium. Hazardous nature immediately known to emergency response services, but recovery of containers/pellets is very difficult.
Immediate notification to authorities	Increases the chances of recovery of lost containers.	n.a.	Medium. Hazardous nature immediately known to emergency response services, but recovery of containers/pellets is very difficult.
Recovery of pellets at sea	Reduction of damage to the marine environment, the economy, human life and prevention from pellets washing ashore	n.a.	Low. Cleaning techniques are inadequate.
Clean-up of spills at shorelines	Reduction of damage to shorelines, its wildlife, the economy and human life	n.a.	Low. Cleaning techniques are inadequate.

- Stowage of containers under deck or inboard in sheltered areas of exposed decks is by far the most effective measure, provided that 'sheltered areas of exposed decks' are defined in a clear way. It will prevent containers from falling overboard. This should be supplemented by good quality packaging inside the container to prevent loss of pellets under normal transport conditions.
- Reactive measures (recovery at sea and clean-up at shorelines) are far less effective, and, with the current recovery methods, will not lead to satisfiable results.
- In addition to general measures to prevent containers from falling overboard, setting specific regulations for plastic pellets in the IMDG Code class 9 under a new UN number can facilitate all necessary specific preventive measures to ensure safe sea transport of plastic pellets.

[12] In the context of the International Maritime Dangerous Goods (IMDG) Code, 'normal transport conditions' refer to the standard conditions under which dangerous goods are transported by sea. This includes the typical handling, stowage, and environmental conditions that can be expected during the journey.

6. Classifying plastic pellets

6.1 Introduction to this chapter

In chapter 5 it was concluded that setting specific regulations for plastic pellets in the IMDG Code class 9 under a new UN number can accommodate all necessary preventive measures to ensure safe sea transport of plastic pellets. The effectiveness of potential measures is summarized in Table 3, and it was concluded that stowage of containers under deck or inboard in sheltered areas of exposed decks only, is by far the most effective measure, supplemented by good quality packaging inside the container to prevent loss of pellets under normal transport conditions.

In this chapter, insight is provided into the process to achieve the entry of a new UN number for plastic pellets in the IMDG Code with effective transport conditions. This process consists of 2 steps, namely (1) the entry of plastic pellets in the Dangerous Goods List of the UN Model Regulations, and (2) the subsequent implementation in the IMDG Code. The complications that may be encountered in this process are discussed, as well as the timeframe in which regulations could take effect. Lastly, the implications of adoption of plastic pellets in the IMDG Code for the industry are touched upon.

6.2 Classifying plastic pellets in the UN Model Regulations

To classify plastic pellets, the UN Model Regulations on the Transport of Dangerous Goods[13] should be met. Accordingly, a proposal for classification of plastic pellets in class 9 must be submitted to the ECOSOC Sub-Committee of Experts on the Transport of Dangerous Goods (SC-TDG).
The proposal can be submitted via a so-called working document or informal document by a member state or a trade association affiliated to the Sub-Committee. *Working document* are official documents on which a decision is made. *Informal documents* are used for various purposes and could in this case also be used to introduce plastic pellets as a new topic to gauge how the Sub-Committee thinks about it, without immediately asking for a decision.
To submit a classification proposal for plastic pellets, in principle both types of documents can be used as a starting point. However, as soon as a decision has to be made, this has to be done based on a working document (or an informal document that links up with a previously submitted working document).
Once a positive decision on the classification has been made, the classification and the conditions of carriage are included in the Dangerous Goods List (Model Regulations Chapter 3.2).

Considerations on classification
Practice shows that, in general, a proposal for classification is not adopted at once. Sub-Committee members often have additional questions or comments. To support the debate on the classification, the following considerations are given up front:

1. The fact that it has not been established that plastic pellets meet the GHS[14] criteria for environmentally hazardous substances in the Model Regulations does not have to be problematic for classification. In chapter 5 it has already been explained that class 9 also provides a category *'Other substances and articles presenting a danger during transport, but not meeting the definitions of another class'*, of which the type of potential danger is not specified.
   An example in this category is UN2216 FISH MEAL (FISH CRAP), STABLIZED, which is fishmeal that is stabilized against self-heating. Due to the need of stabilization, it does not meet the criteria of classes 1 to 8 or the criteria in the GHS. The purpose of assigning stabilized fishmeal to class 9 is to introduce a mandatory provision as to require shippers to declare the details of stabilization. This is one example that class 9 does not only contain substances for which GHS criteria apply. A grasp of other examples for dangerous goods in this category are: UN 3316 FIRST AID KIT, UN 3171 BATTERY POWERED VEHICLE

[13] UNECE - Recommendations on transport of dangerous goods, Model Regulations Rev. 23 (2023)
[14] GHS - Tenth revised edition of the Globally Harmonized System of Classification and Labelling of Chemicals (ST/AG/AC.10/30/Rev.10)

or UN 3359 FUMIGATED CARGO TRANSPORT UNIT. Plastic pellets could also fit in this category based on the hazards and risk analysis described in chapter 2 and 3 of this report, which underline the urgency to set sea transport requirements.

2. It should be noted that *if* plastic pellets would meet the criteria for marine pollutants/harmful substances in the IMDG Code/MARPOL, or if in any other way it would be concluded that plastic pallets are to be classified as environmental hazardous substances (e.g. based on the GHS criteria), according to IMDG Code 2.10.2.3[15] the substance would automatically be assigned to UN 3077 ENVIRONMENTALLY HAZARDOUS SUBSTANCE, Solid, N.O.S..
   However, the transport conditions in the IMDG Code for UN 3077 do not cover the effective risk mitigating measures as were considered in chapter 5. This is further substantiated in Annex 3 *Assessment of transport conditions for UN 3077* to this report. Table 4 in Annex 3 shows the present transport conditions for UN 3077 in the IMDG Code Dangerous Goods List. The 4 comment boxes address the changes that need to be considered to these conditions, in order to accommodate effective transport conditions for plastic pellets.
   From a classification point of view, it would be complicated to amend the transport conditions of UN 3077 without compromising on the necessary packing and stowage conditions for plastic pellets, or without unwanted extra requirements for other substances allocated to UN 3077. Therefore it seems more realistic to apply a new UN number for plastic pellets than to modify the transport conditions for UN 3077. (This possibility is also offered in IMDG Code 2.10.2.3 by the condition '*unless there is a specific entry in class 9'*.)

3. It is further important to note that marine plastic litter has been regulated for a long time under MARPOL Annex V, which prohibits the discharge of plastics into the sea. The regulations recognise the harmful effects of plastics on marine ecosystems. Trying to ban plastic litter from ships is based on the knowledge that plastics have to be treated as a specific category, because they have specific harmful effects on marine ecosystems. While these regulations address the disposal of plastic litter, they do not address the unintended loss of plastics into the marine ecosystems if transported in the form of cargo. This is rather inconsistent.

4. It could be brought to the table that the dangerous goods regulations only consider chemical hazards. As plastic pellets also exhibit a physical hazard which is more easily proven, the perception might be that they therefore cannot be classified as dangerous goods. However, in this respect it should be noted that the UN Model Regulations contain, for example, an entry for UN 2807 MAGNETIZED MATERIAL, applicable to air transport only. Magnetism is a physical phenomenon, not a chemical one.

5. The sea transport conditions that are required to effectively mitigate the risk of plastic pellets as much as possible have been explored in chapter 5 of this report. However, in further studies it needs to be established what the exact transport conditions would have to be. An important point of attention would have to be the quality of packaging, which should prevent leakages during normal transport conditions, but could also provide some added value in terms of deterioration properties in seawater.

6. A discussion could emerge on the unwanted consequences of classification for other transport modalities besides sea transport. However, the UN Model Regulations contain several UN numbers where a special provision states that this UN number applies only to sea or air transport. As an example, UN 3496 BATTERIES, NICKEL METAL HYDRIDE applies to transport by sea only (see special provision 117 in the UN Model Regulations). Special provision 963 of the IMDG Code, assigned to UN 3496, regulates that only the requirements for documentation, placarding of cargo transport units

[15] IMDG Code 2.10.2.3: *Marine pollutants shall be transported under the appropriate entry according to their properties if they fall within the criteria of any of the classes 1 to 8. If they do not fall within the criteria of any of these classes, they shall be transported under the entry: ENVIRONMENTALLY HAZARDOUS SUBSTANCE, SOLID, N.O.S., UN 3077 or ENVIRONMENTALLY HAZARDOUS SUBSTANCE, LIQUID, N.O.S., UN 3082, as appropriate unless there is a specific entry in class 9.*

(containers) and the stowage requirement on board: *'protected from source of heat'* apply, but no other provision of the IMDG Code. Therefore, these UN numbers have no impact on inland transport or warehousing. Besides this, no intermodal problems are known related to these UN numbers.

Every 2 years (biennium) the Model Regulations are officially revised and a new edition is released. All changes provisionally adopted during those 4 meetings are officially ratified by the *Committee of Experts on TDG and GHS*[16] at the last meeting of the biennium. All changes in the new edition, compared to the previous edition, are then discussed in the modality-specific meetings such as ICAO (aviation), IMO (maritime) and through the Joint Meeting for ADR (road), RID (rail) and ADN (inland waterways). Then the process starts to incorporate the changes of the Model Regulations into the modality specific regulations.

6.3 Harmonizing the IMDG Code with the UN Model Regulations

After classification by the United Nations, the IMDG Code must be updated to include plastic pellets as dangerous goods. This involves harmonizing the new classification and the transport conditions with the regulations in the IMDG Code. This work is done by the Editorial & Technical Group (E&T Group).

[17]The E&T Group is an expert standing subsidiary body of the IMO Sub-Committee on Carriage of Cargoes and Containers (CCC) and is tasked with the review of all technical and editorial issues related to draft texts for new or amended provisions proposed by IMO Member States for inclusion in IMDG Code and the IMSBC Code. With regard to the updating work on the IMDG Code, the E&T Group harmonizes any new or amended provisions with the latest revisions to the UN Recommendations on the Transport of Dangerous Goods (Model Regulations), but without compromising any special safety requirements related to the unique characteristics of sea transport. A specific point of attention for the E&T Group would have to be the definition of the stowage condition 'in sheltered areas of exposed decks' on ships that needs further specification.

After the work of the E&T Group is finalized, the IMO Sub-Committee on Carriage of Cargoes and Container (CCC) and the Marine Safety Committee (MSC) must adopt the amendment to the IMDG Code, making it mandatory for all Member States. These IMO procedures will take at least another 2 years.

6.4 Potential timeline for classification and adoption in the IMDG Code

As mentioned in paragraph 6.2, most proposals to the UN SC-TDG are not adopted in one go. Since the SC-TDG meets twice a year, it will take easily a year on the road to get a change accepted. Every two years the UN Model Regulations are officially revised and a new edition is released. That means there are 4 meetings per 2-year period (a biennium). The next biennium is 2025-2026. All changes provisionally adopted during those 2 years are officially ratified by the Committee of Experts on the TDG GHS at the last meeting of 2026. All adopted changes will then be incorporated into the 25th edition of the Model Regulations, to be released in 2027.

Then, the amended classification for plastic pellets should be discussed in the 2025 - 2026 biennium of IMO. If an agreement would be concluded, the classification could be included in the new version of the IMDG Code appearing in 2029 (Amendment 44-28). It should be noted that this is the most positive scenario. The potential timeline for this classification and adoption timeline is presented in Figure 7.

[16] Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labelling of Chemicals
[17] Editorial & Technical Group of the Sub-Committee on the Carriage of Cargoes and Containers

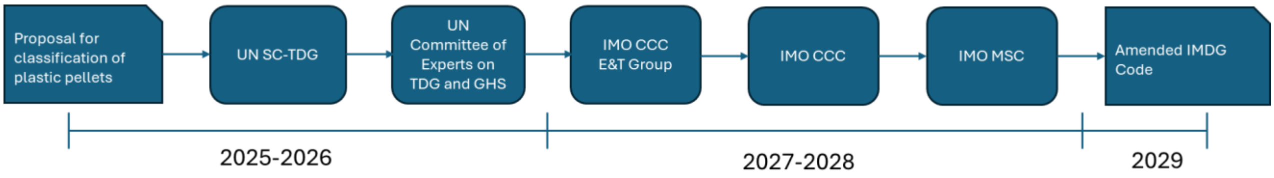


Figure 7. Potential timeline for classification and adoption in the IMDG Code.

6.5 Implications of classification for the industry

Following the classification, the industry would have to accept higher transport costs. These would include:

- Costs for higher quality packaging to prevent leakages of pellets during normal transport.
- A stowage fee for dangerous goods, incorporating the limitations to the stowage position *under deck or inboard in sheltered areas of exposed decks only*.
- A fee for processing of the documentation for dangerous goods.
- Higher insurance premiums, due to the higher risk associated with transporting dangerous goods. Companies may need to purchase additional coverage to protect against potential accidents or spills.

Influence of the classification on the production process of plastic pellets is unlikely, as the classification affects the packaging, stowing and documenting and not the product itself.

6.6 Conclusions on classifying plastic pellets

This chapter provided an insight into the process to be followed to achieve classification of plastic pellets in the UN Model Regulations and subsequent implementation in the IMDG Code. It also touches upon the consequences thereof for the industry.

It is concluded that:

1. During the classification process for plastic pellets in the UN model regulations and subsequent implementation in IMDG Code class 9 in the category *'Other substances and articles presenting a danger during transport, but not meeting the definitions of another class'*, complications may be encountered, but these can be overcome.
2. Appropriate packing and stowage conditions (see chapter 5 for considerations) should be established first and should be defined in such a way that they fit into the framework of the UN Model Regulations and IMDG Code Dangerous Goods Lists.
3. In the most positive scenario, the timeline for classification and adoption of plastic pellets in the IMDG Code could be completed in 2029.
4. Following the classification, the industry would have to accept higher transport costs. Influence of the classification on the production process of plastic pellets is unlikely.

7. Conclusions

The research that has been done leads to the following main conclusions:

Plastic pellet pollution has adverse effects on the environment, from biochemical and molecular to population and ecosystem levels (Landrigan et al., 2023). The substance can have a variety of negative effects on the environment and organisms through various ways. Although direct human exposure is yet still limited, accumulation in the food chain and other effects of plastic pollution on ecosystems upon which all humanity depends for food, oxygen, well-being and livelihood are all becoming increasingly negatively impacted (Landrigan et al., 2023). The growing number of produced plastics and increasing number of plastic pellets present in the environment by leakage during transport only further increases this problem.

Although the effects of (virgin) plastic pellets are quite well described and studied, the quantities of toxic substances in the environment from plastic pellets and subsequent chances and effects of exposure to humans and other organisms remain hard to identify. During this study, very limited information was found about the exact chemical composition of plastic pellets and their quantities. Nevertheless, it is clear that there is a large quantity and variation of toxic and non-toxic chemicals available, used, present and released from plastic pellets as has been described by Wagner et al., 2024. To further quantify the risk of plastic pellet pollution, additional information about the quantities and types of chemicals present in (virgin) pellets must be obtained. By doing so, the effects of plastic pellets on organisms and the environment can be further quantified. It is further established that reliable data on the quantity of pellets lost at sea from ships is lacking, since there is no reporting obligation.

An assessment of the hazardous properties of plastic pellets on the criteria for the identification of hazardous substances as laid down in international (sea) transport legislation (MARPOL, the IMDG Code (IMO) and the UN Globally Harmonized System) shows that, despite the convincing number of arguments why plastic pellets pose a threat to the environment and human life, insufficient scientific proof has been found available to confirm that plastic pellets meet the specific criteria.

Following that conclusion, other options for regulating the transport have been considered, on which it was concluded that assigning plastic pellets to class 9 of the IMDG Code in the category ‘Other substances and articles presenting a danger during transport, but not meeting the definitions of another class’ is the best option in terms of certainty and effectiveness of the process towards regulations. This does not mean that the other options that have been considered are completely wrong; the assessment that was made is subject to assumptions on how the options would be handled in IMO, which is not set in stone.

On the preventive and reactive measures that could be introduced to mitigate the risk of plastic pellets in the environment, it was concluded that apart from generic measures to prevent containers from falling overboard, mandatory stowage of containers with plastic pellets under deck, or inboard in sheltered areas of exposed decks only is the most effective mitigating measure, supplemented by good quality packaging inside the container to prevent loss of pellets under normal transport conditions. Once plastic pellets end up in the sea, their loss with all its harmful effects is very difficult to prevent.

Finally, after exploring the process towards classification of plastic pellets and subsequent implementation in the IMDG Code in class 9, it was concluded that complications during classification can be overcome, as was done for other substances in class 9 of which the type of potential danger is not specified. Appropriate packing and stowage conditions have yet to be established and should be defined in such a way that they fit into the framework of the UN Model Regulations and IMDG Code Dangerous Goods Lists. In the most positive scenario, the timeline for classification and adoption of plastic pellets in the IMDG Code could be completed in 2029.

Annex 1 - References

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CCC 9/13 (24 May 2023)	Any Other Business, Estimate of containers lost at sea – 2023 update submitted by the World Shipping Council (WSC)
CCC 9/2/3 (17 July 2023)	Decisions of other IMO bodies, Recommendations for the packaging of plastic pellets transported by sea, submitted by France
CCC 9/2/4 (19 July 2023)	Decisions of other IMO bodies, Outcome of PPR 10, submitted by Germany and the United Kingdom of the Netherlands
IMO	International Convention for the Prevention of Pollution from Ships (MARPOL), Consolidated edition 2022 (incl. Supplement May 2024)
IMO	International Maritime Dangerous Goods (IMDG) Code, 2022 Edition (incl. Amendment 41-22)
IMO	Resolution MEPC.310 (73) Action Plan to Address Marine Plastic Litter from Ships (adopted on 26 October 2018)
IMO	Resolution MEPC.341 (77) Strategy to address marine plastic litter from ships (adopted on 26 November 2021)
MEPC 80/INF.15 (28 April 2023)	Follow-up work emanating from the action plan to address marine plastic litter from ships, Study on pollution by plastic pellets, submitted by France
MEPC.1/Circ.909 (19 April 2024)	Recommendations for the carriage of plastic pellets by sea in freight containers
MSC.1/Circ.1353/Rev.2	Revision of the Revised guidelines for the preparation of the Cargo Securing Manual
PPR 10/INF.13 (17 February 2023)	Follow-up work emanating from the action plan to address marine plastic litter from ships, Guidelines on clean-up of plastic pellets from ship-source spills, submitted by Norway, South Africa, ITOPF and P&I Clubs
PPR 11/13/1 (17 November 2023)	Follow-up work emanating from the action plan to address marine plastic litter from ships, Proposed amendments to MARPOL Annex III to introduce mandatory measures on the transport of plastic pellets outside the scope of the IMDG Code, submitted by Australia, Cook Islands, Jamaica, South Africa and United Kingdom
PPR 11/13/3 (15 December 2023)	Follow-up work emanating from the action plan to address marine plastic litter from ships, Proposal regarding the mandatory instrument for transportation of plastic pellets, Submitted by Germany and Kingdom of The Netherlands
United Nations	Globally Harmonized System of classification and labelling of chemicals (GHS), 10th revised edition 2023
United Nations	Recommendations on the transport of dangerous goods, Model Regulations, 23rd revised edition 2023

Annex 2 - Abbreviations

BPA	Bisfenol A
BUV	Benzotriazole ultraviolet stabilizers
CCC	Sub-Committee on Carriage of Cargoes and Containers (IMO)
CSC	International Convention for Safe Containers (IMO)
CLP	Classification, Labelling and Packaging Regulation ((EC) No 1272/2008)
CO2	Carbon dioxide
Comm of Experts on TDG and GHS	Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labelling of Chemicals
CSS Code	Code of Safe Practice for Cargo Stowage and Securing (IMO)
DDT	Dichloordifenyltrichloorethaan
DMS	Dimethyl sulfide
E&T Group	Editorial & Technical Group (IMO-CCC)
EPS	Expanded Polystyrene
GHS	Globally Harmonized System
GI	Gastrointestinal
HDPE	High Density polyethylene
IMDG Code	International Maritime Dangerous Goods Code (IMO)
IMO	International Maritime Organization
LDPE	Low density polyethylene
MARPOL	International Convention for the Prevention of Pollution from Ships (IMO)
MEPC	Marine Environment Protection Committee (IMO)
MNP	Micro(nano)plastic
MSC	Marine Safety Committee (IMO)
NIAS	Non-intentionally added substances
OSPAR	Oslo and Paris Conventions
PAH	Polycyclic aromatic hydrocarbons
PBDE	Polybrominated diphenyl ethers
PCB	Polychloorbifenyl
PET	Polyethylene Terephthalate
PP	Polypropylene
PPR	Sub-Committee on Pollution Prevention and Response (IMO)
PS	Polystyrene
PVC	Polyvinyl chloride
SC-TDG	ECOSOC Sub-Committee of Experts on the Transport of Dangerous Goods
WSC	World Shipping Counsel

Annex 3 - Assessment of transport conditions for UN 3077 to accommodate plastic pellets

Table 4. Present UN 3077 entry in the IMDG Dangerous Goods List; the comments 1. to 4. outline what needs to be changed to the requirements in order to accommodate plastic pellets.

UN no.	Proper shipping name	Class or divi-sion	Subsid. Risk(s)	Pack-ing group	Special provi-sions	Limited and excepted quantities		Packing		IBC		Portable tank and bulk containers			EmS	Stowage and handling	Segre-gation
						Limi-ted q.	Excep-ted q.	Instruc-tions	Provi-sions	Instruc-tions	Provi-sions		Tank instruc-tions	Provi-sions			
Ref.	3.1.2	2.0	2.0	2.0.1.3		3.4	3.5	4.1.4	4.1.4	4.1.4	4.1.4		4.2.5, 4.3	4.2.5	5.4.3.2 7.8	7.1 7.3-7.7	7.2-7.7
3077	Environmentally Hazardous Substance, Solid, N.O.S.	9		III	274 335 966 967 969	5 kg	E1	P002 LP02	PP12	IBC08	B3	-	T1 BK1 BK2 BK3	TP33	F-A, S-F	Cat. A SW23	-

1. A new special provision for plastic pellets should set the specific requirements for packaging and stowage, see boxes 3. and 4.

2. For plastic pellets, limited quantities should preferably be reduced to 0 and Code E0, to prevent the ‘escape’ of stowing <5 kg packages with plastic pellets in containers.

3. These packaging requirements leave too many options for improper packaging, such as wooden boxes, bags and sheeted bulk containers. Especially since UN3077 is assigned in packing group III (low danger). They would have to be reviewed to prevent loss of plastic pellets under normal transport conditions.
CCC 9/2/3: Packaging must be airtight to prevent leaks and limit dispersion and spills. It must also be resistant, robust and easy to handle in order to withstand handling and transport conditions. ICS 55.140-certified, reusable steel, aluminum or plastic drums and containers approved under the CSC, of the silo tank container type fit this description.
Packaging requirements which ensure packaging remains intact after a fall in a container from a ship into the seawater are not considered realistic.

4. On deck or under deck stowage is permitted for Cat. A. SW23 refers to transport in bulk containers which is not a proper packing for plastic pellets.
An additional SW Code would have to be added here for plastic pellets, for *Stowage under deck or inboard in sheltered areas of exposed decks only*. However, that code would then be applicable to all substances in UN3077, which is not what we aim for. So, this requirement should be covered in a special provision.

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