DO CLOTHES MAKE US SICK?

FASHION, FIBERS AND HUMAN HEALTH

PLASTIC SOUP FOUNDATION

FORWORD

FAST FASHION IS OUT OF FASHION

In 2019, scientific results on the potentially detrimental effects of micro- and nanoplastics on our health were presented at the Plastic Health Summit in Amsterdam. That was a world first three years ago.
The amount of scientific evidence in recent years has increased enormously and we now know much more about the harmful effects of microplastics on our lungs. Synthetic fibers dislodged from clothing are a major cause of acute or chronic inflammation.

This report, for the first time, brings together the most important facts from recent scientific research, providing insight into the negative effects of microplastic fibers on our health. The evidence is piling up that the fast fashion industry is creating a disaster when it comes to our health. Let us together prevent this from happening now, rather than cure it later.

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EXECUTIVE SUMMARY

The fashion industry is one of the largest polluters in the world, with enormous environmental impacts such as water pollution, release of toxic chemicals, greenhouse gas emissions, soil pollution, and rainforest degradation. Almost 70% of the clothes manufactured by fashion brands and most of the upholstery on sofas, curtains, and carpets are made of synthetic materials (polyester, nylon, acrylic). When these items are made, used, or washed, they release microplastic fibers into the air that we breathe and deposit in water and food that we drink and eat. The release of such microplastic fibers is just the latest addition to the list of environmental impacts and the question arises if microplastic fibers have an effect on human health. Does fast fashion make us sick?

Scientific evidence that micro- and nanoplastics (mnps) pose a health risk to all life on earth is accumulating rapidly, with nearly 400 publications in 2021 and 2022 on 'microplastic' and 'health'. Microplastic (or synthetic) fibers, are everywhere. Outdoor and indoor dust contains microplastic fibers and particularly the indoor environments contain high concentrations (around 30%). In most societies, people spend about 90% of their time indoors, where they are exposed to these particles.

Exposure and possible intake of mnps through inhalation of air is considerably higher than through ingestion. Once inhaled, synthetic fibers can penetrate in the lung tissue and cause chronic inflammation, which is known to be a leading cause of diseases such as cancer, heart disease, asthma, and diabetes. Inhaled mnps can potentially reach the liver, heart, kidneys, and brain and even the foetus.

Through ingestion of foods and drinks, mnps enter the gastrointestinal tract and cause intestinal inflammation, oxidative stress, increased permeability, intestinal flora disorder, and other intestinal health hazards. There is a clear relationship between high exposure to microplastic fibers (nylon) and two types of irritable bowel disease (IBD; Crohn's disease and ulcerative colitis).

The level of toxicity and effects of microplastic fibers on humans depends on the dose (expressed either in number of particles or as mass-weight), the length and diameter, deposition rate, the durability of the fibers and human defense mechanism (measured as the level of inflammation caused). Young children (< 0.5 years of age) inhale twice the number of synthetic fibers and ingest twelve times more than adults because small children have greater natural hand-mouth activities. Spending much time crawling around on the floor, gives them a higher exposure risk to microplastic fibers. In their early biological development, children are particularly vulnerable for adverse effects.

An emerging concern of plastics in the environment is the potential for microplastic to transport and transmit pathogens from one area to another. Certain zoonotic protozoan parasites are capable of latching onto microplastics, including polyester microfibers, in seawater. Fish and shellfish that ingest the infested fibers can cause illness in humans consuming these sea products. Many chemicals are added to fibers and textiles as flame retardant, waterproofing, (e.g. PFAS), UV blocking, and colorants. Chemical additives such as phthalates and bisphenol A (known endocrine disruptors) may leach from the particles inside the body and interfere with hormones.

The global transportation of microplastic fibers through the atmosphere, leads to a world-wide distribution of these particles and associated health risks, including to some of the remotest parts of the earth. The burden of disease attributable to air pollution is now estimated to be on a par with other major global health risks such as unhealthy diets and tobacco smoking. 99% of the world's population breathes air with pollution levels (including plastic particles) that exceed World Health Organization limits.

This report presents recommendations for the fashion industry and retailers and for the European Commission. The fashion industry urgently needs to take drastic steps to reduce the amount of microplastic fiber shedding from the clothes that they produce. At the same time, far-reaching, binding policy measures are vital in tackling microplastic fiber pollution, because only in this way, brands can be held accountable for their contribution to global plastic pollution.

Do our clothes make us sick? The scientific evidence is mounting; the plastic emission from our clothes is reason for serious concern. It is practically impossible to avoid exposure to microplastic fibers in our daily lives and removing these polluting microfibers from the environment is just not feasible, microplastic fiber loss causes irreversible pollution. It is therefore imperative to take mitigating actions to decrease plastic microfiber release at the source. We do not need more proof; we need less emission of microplastics to the environment. The time for change is now!

INTRODUCTION

THE (FAST) FASHION PROBLEM

The fashion industry is one of the largest polluters in the world. Water pollution, toxic chemicals, textile waste, greenhouse gas emissions, soil pollution, and rainforest degradation are some of the environmental impacts of this industry. The industry has also been accused of not respecting human rights in developing countries where poor working conditions in textile factories have been observed. The release of harmful microplastic fibers from clothes is just the latest addition to this list.

THROUGH WEAR AND TEAR, SMALL FRAGMENTS OF SYNTHETIC MATERIALS ARE RELEASED FROM CLOTHING AND END UP IN THE ENVIRONMENT

Over two-thirds of the clothing material worldwide comprises plastic materials such as polyester, acrylic, and nylon; and are igniting both the plastic and climate crisis by the use of fossil fuels needed to manufacture them [1]. To illustrate this: the world needed an incredible 59.7 million tonnes of virgin fossil-based fibers in 2020 [2]. Of all the materials used worldwide for clothing, polyester is the most used one. With a production volume of 57 million tonnes, polyester was the most used fiber accounting for 52 percent of the global fiber market in 2020 and polyamide (nylon) had a market share of 5 percent [2]. It is expected that by 2030, the global demand for fibers is 135 million tonnes annual with over 75% made of synthetic materials [3].

In 2000, 50 billion new garments were made; nearly 20 years later, that figure had doubled, according to the Ellen MacArthur Foundation. Each year, 100 billion new pieces of garments are produced globally, which is almost 14 items for every person on the planet, and clothing production doubled between 2000 and 2014 [4]. The average consumer buys 60% more garments each year, but only use them 50% of the time they did 15 years ago.

The increase in production of cheap garments is closely related to a decline in the quality of garments. Affordable fashion has resulted in consumers buying more clothes than they might initially need and the poor quality of those clothes requires frequent replacement.

Fashion has an enormous environmental footprint, from the production process through to the disposal of used and unused clothes. Clothing manufacturing requires a considerable amount of energy and resources, uses toxic fabric dyes and other chemicals that contaminate fresh water, and requires synthetic materials made from fossil fuels. Fast-fashion, commonly referred to as a business strategy that focuses on creating an efficient accelerated supply chain in order to produce fashionable merchandise and attend consumer demand [5], has increased that environmental footprint. Low-quality materials (i.e. synthetic fabrics) are used in order to bring inexpensive garment styles to the end consumer rapidly. These low-quality materials shed fibers more readily.

In summary, fast-fashion produces a tenth of the world's carbon emissions [6] and releases microplastic fibers when manufactured, worn, and washed. Clothes from fast fashion are made to be thrown away after a few uses. Fast fashion brands have also been linked to disrespecting human rights and forced labor.

MICROPLASTICS AND HUMAN HEALTH

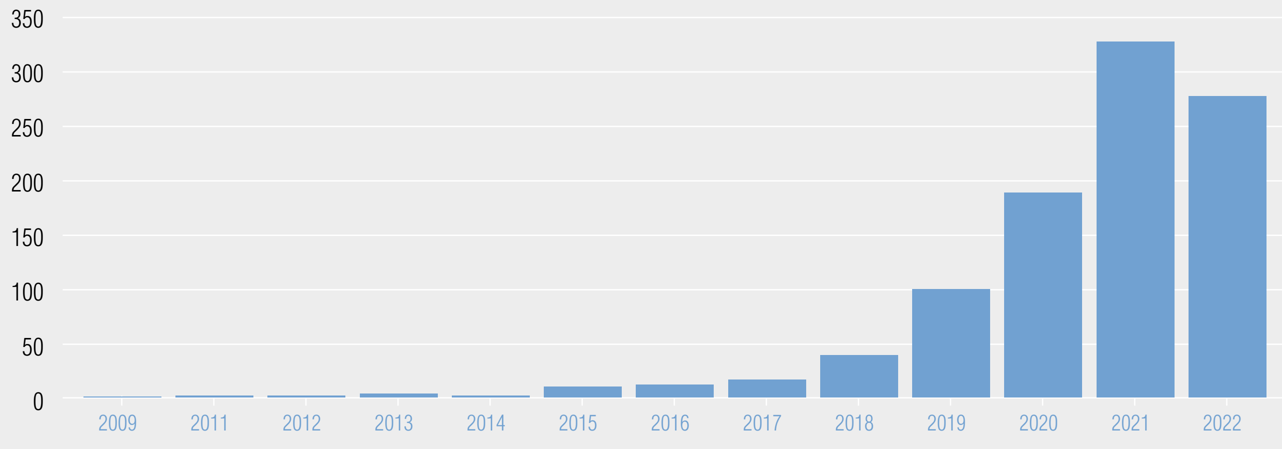
Nine million tonnes of plastic end up in the ocean each year, 80 % of which comes from coasts and rivers [7]. Plastic debris has been found in all major ocean basins, with an estimated 4 to 12 million tonnes of plastic waste generated on land entering the marine environment in 2010 alone [8]. About 9% of that plastic waste is recycled once, 12% is incinerated, and 79% accumulated in landfills or the natural environment. If current production and waste management trends continue, roughly 12,000 tonnes of plastic waste will be in landfills or the natural environment by 2050 [9].

Upon release into the environment, plastic material is fragmented into smaller particles, fragments with sizes less than 5 mm (microplastics), or into even smaller fragments of < 0.1 µm (nanoplastics) [10]. The vast majority of microplastics come from the breakdown of larger plastic waste, for example through exposure to UV light, physical abrasion [11, 12] of household wastes, washing clothes, agricultural foils, construction work, or fishing nets. This breakdown results in a wide variety of irregular shaped micro-and nanoplastics (mnps), most commonly referred to as fibers, films, filaments, foams, fragments, granules, pellets, and microbeads, all of which are observed in different ecosystems. The diversity of sources and breakdown processes, results in a range of different mnp properties, such as shape, size, density and polymer type.

The properties of mnps influence the biological effects and therefore also their risks [13,14]. When there is a high probability of ingestion, inhalation or absorption, this diversity in properties contributes to the various potential risks that microplastics may pose to humans and the environment [15,16]. What started as a marine environmental contamination issue has become a human health issue as well [17].

Since the start of the 21st century, scientific evidence that mnps pose a health risk to all life on earth has increased tremendously. A quick search in a scientific publications database (web of science) with keywords ‘microplastic’ and ‘health’ showed that the first publication appeared in 2009 [18] with 1-4 publications per year until 2014. Since the first edition of the Plastic Health Summit in 2019, the significance of microplastics and health gained traction; numbers of papers rapidly increased to nearly 350 publications in 2021, and already 300 at the time of publication of this report (October 2022, see figure 1).

FIGURE 1 ANNUAL NUMBER OF SCIENTIFIC PAPERS PUBLISHED ON MICROPLASTICS AND HEALTH (SOURCE: WEB OF SCIENCE)



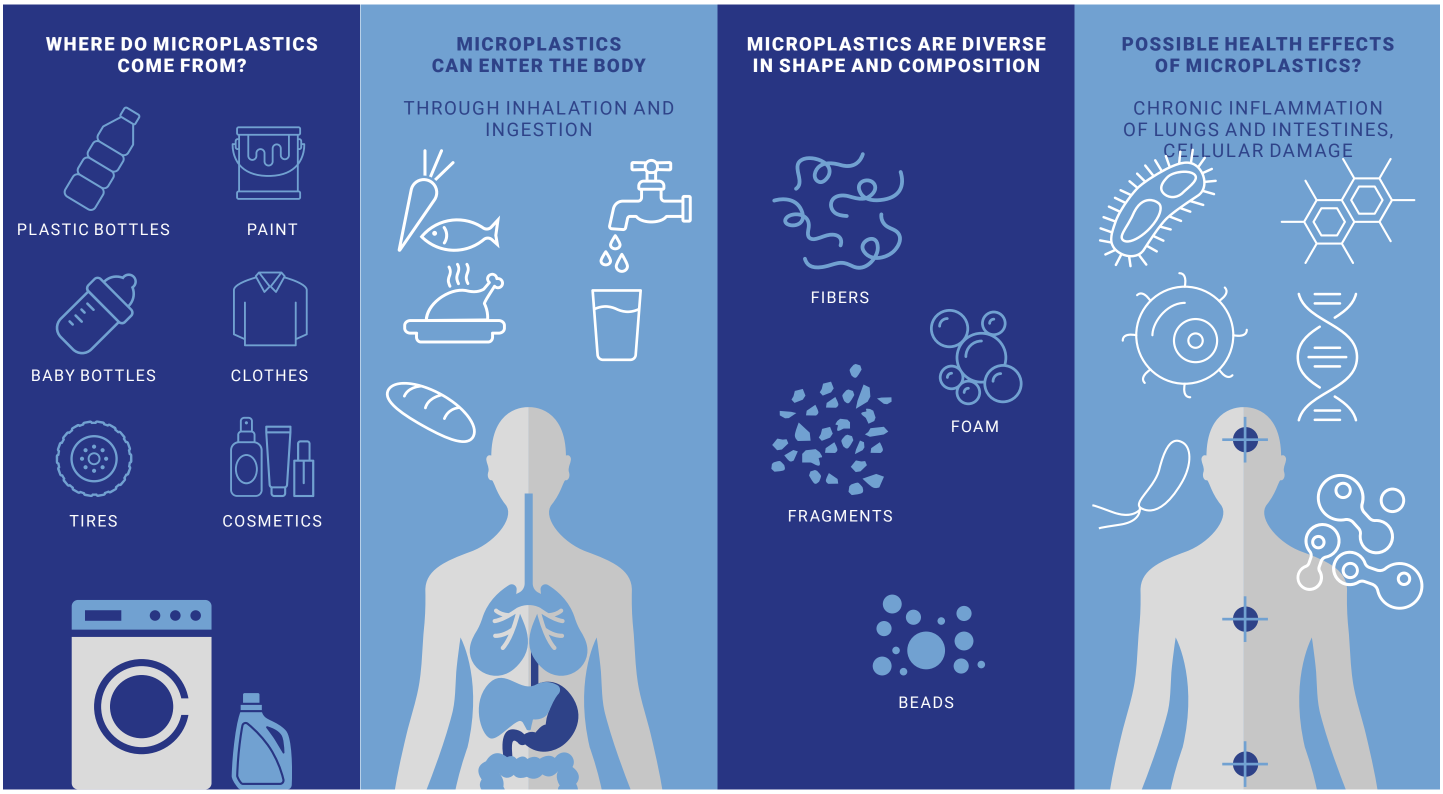
The problem of microplastics has gained huge momentum and the awareness of the problem is reaching the global community. The explosive growth of plastic production [19] and our addiction to using plastic in everyday life, has increased our exposure to plastic breakdown products (mnps) enormously [20]. It is now generally known that we eat, drink and breathe plastic every day and everywhere [17].

In major world cities such as Paris [21] and London [22], the outdoor air contains large amounts of fibers, of which 29% and 17% respectively consisted of purely petrochemical-based plastic (i.e. synthetic) fibers. The air we breathe is polluted with microplastics [23]. Atmospheric transport is a major pathway of microplastics to remote regions of the globe [24,25]. Once mnps have been inhaled or ingested, they can migrate to various organs in humans and animals, such as liver, kidneys [26], brain [27], and placenta [28].

Although the number of scientific studies on the exposure and effect of microplastics on environmental and human health is growing rapidly, the full extent of that exposure and the consequences are still relatively poorly understood [29]. Most of what is known today is based on in-vitro studies, rather than on cause and effect studies in humans or animals (in-vivo studies). According to senior scientist in microplastics and health research Dick Vethaak, the findings of those in-vitro studies cannot be extrapolated to the general population because of the small sample size and because the amount of microplastics required to cause disease are unknown [29].

Fibers, released from textiles are just one of the many different forms of microplastic particles that are omnipresent in the environment. This document summarizes the current scientific knowledge about human exposure to synthetic fibers and the associated health risks (figure 2). This document is also intended as a reference document for industry as well as policy makers trying to stop microplastic fiber release into the environment and thus reducing the possibly serious health risks associated with microplastic fiber ingestion and inhalation.

FIGURE 2 MICROPLASTICS AND HUMAN HEALTH



2. FIBERS

SYNTHETIC VS NATURAL

Microfibers refer to small-sized particles that are released or shed to the environment from all kinds of fibrous materials, such as clothes, agricultural, industrial, and home textiles during the production process, use, or due to disposal and disintegration of the end products [30, 31]. Fibers can be of natural origin (cotton, wools, wood, etc) or man-made (synthetic) (see figure 3).

DEFINITION OF MICROPLASTIC FIBERS [31]

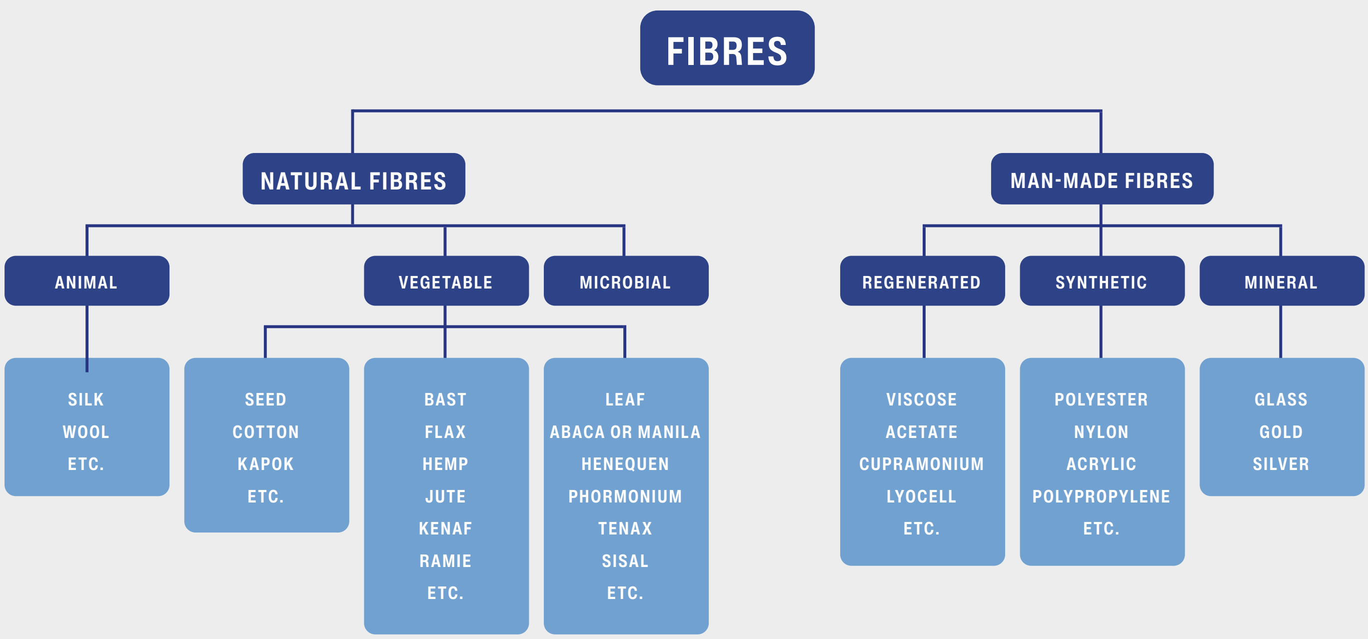
Microplastic fibers are solid, polymeric particles with a length less than or equal to 5 mm, and a length to diameter ratio of greater than 3. The most common types of microplastic fibers are made of polyesters; polyamides (Nylon, Kevlar, Nomex); and combinations of polyester, and polypropylene.

Textile fibers can be spun into yarn, which in turn are woven, knitted or bonded into fabric. They have several uses, such as in household products (e.g. carpeting, furnishing, curtains, linen), for industrial purposes (e.g. medical textiles, geotextiles, agrotextiles, architectural textiles, protective clothing), and other uses (e.g. toys, tents, flags, nets). The most common use of textiles is for clothing. Fiber properties and the process used to produce fabric is directly related to its performance.

Natural fibers that have been coated with chemicals for e.g. colouring, waterproofing, or durability, loose their naturalness and become synthetic fibers. It is estimated that 30,000–465,000 microfibers per m^2 (or 175–560 microfibers/g) are detached from textile garments primarily through washing [33].

In this document, we refer to microplastic fibers defined as particles derived from petrochemicals.

FIGURE 3 **DIFFERENT TYPES OF NATURAL AND SYNTHETIC FIBERS** [32]



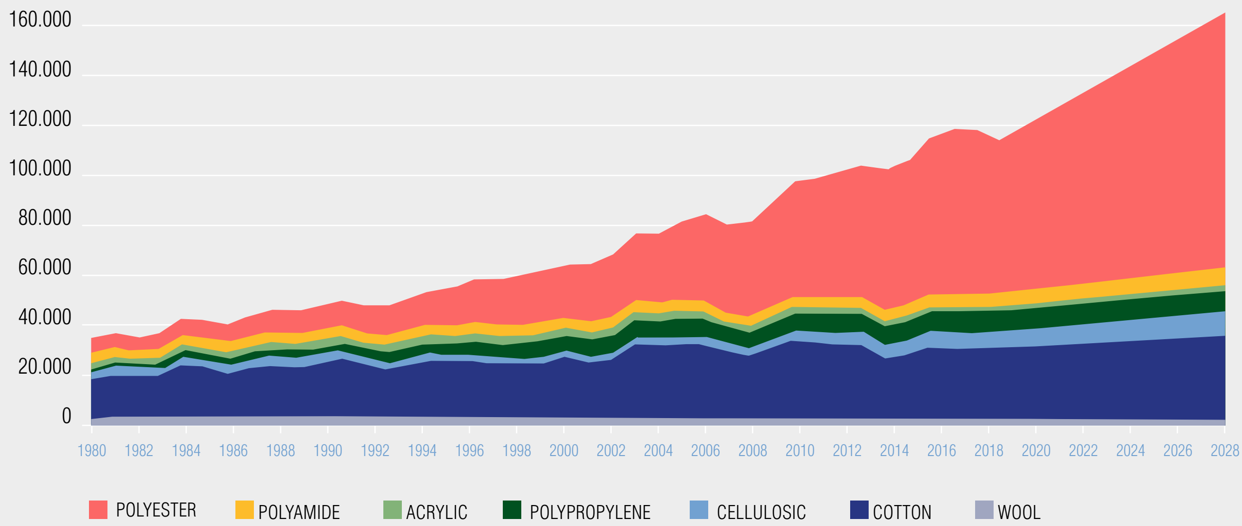
Of all microplastics found in the environment, in urban areas and areas far removed from human activities, microplastic fibres are often the dominant type of microplastic encountered. Studies on microplastics in the environment, found synthetic fibers to be dominant in the air [24], marine [34,35] and freshwater [36] environments, and in soils [37]. Even snow on the highest summits of the Alps [24,38] and ice in the Arctic region contain synthetic fibers [39]. Most plastic rainfall debris in the US consists of microfibers from textiles used for clothing, including cotton, polyester, and nylon [40]. The most prevalent synthetic fiber type in the Arctic region is rayon (54%), followed by polyester (21%) and polyamide (nylon) (16%). Other types of fibers include polypropylene, polystyrene, acrylic, and polyethylene [39].

Multiple types of microplastics were identified in snow samples from the Austrian Alps but only polyethylene terephthalate (PET) was detected in the nanometer range, which showed that the most dominant airborne microplastics are polyester fibers [38].

FIBER SHEDDING

In a study carried out in 2011, scientists collected shoreline sediment samples from 18 sites across the globe (in Australia, Japan, the Arabian peninsula, Africa, Europe, and North and South America).
The researchers also sampled effluent from sewage treatment plants and washing machine wastewater. Nearly 85% of the synthetic fibers in the sediment samples consisted of polyester, acrylic and nylon, and the composition resembled that of the sewage treatment plant samples. This suggested that the microplastic fibers found in shoreline sediment were mainly derived from sewage via washing clothes, rather than fragmentation or cleaning products [34].
Microplastic fibers are extremely difficult to remove from sewage water. More than 10 years after draining into the marine environment was discontinued, former sewage disposal-sites still contained 2.5 times more microplastics than reference sites [34].
By analysing wastewater samples from domestic washing machines, the researchers were able to demonstrate that a single garment can produce more than 1900 fibers per wash. This study was the first to

FIGURE 4 **GLOBAL FIBER PRODUCTION INCREASE SINCE 1980** (THOUSAND METRIC TONNES)



SOURCE: TECNON ORBICHEM [43]

suggest that a large proportion of synthetic fibers found in the marine environment come from the washing of clothes [34]. Different types of fabrics shed different amounts of fibers. The release of synthetic fibers from polyester, polyester-cotton blend and acrylic fabrics into waste water during each use of a washing machine could be as high as 700,000 microscopic fibers [41].

Subsequent research work confirmed that washing garments resulted in significant release of fibers, which increases with higher water temperature, detergent use and rotations per minute [42]. After first washing of a polyester garment, approximately 0.3% of its mass before washing is recovered as microfiber mass. Top-load conventional home washing machines release approximately 7 times more fibers than those washed in front-load machines [33].

Polyester and cotton knitted fabrics represent the greatest portion of the global fiber production for natural and synthetic fibers[43] (see figure 4). Comparisons of washing garments made of these two different types of material but with the same knit, showed that garments made of cotton release more fibers than those made of polyester. However, cotton is completely biodegradable (as long as it is uncoated and not dyed), while polyester does not undergo significant changes over time. In other words, polyester accumulates in the aquatic environment and cotton doesn't [42].

Synthetic microfibers can be expected to persist in the environment for long periods of time. As the human population grows and people use more synthetic textiles, the contamination of habitats and animals by persistent synthetic microfibers will increase and this is a serious cause of concern.

FIBERS AND US

Microplastic particles surround us everywhere, particularly in our homes. They become visible when for example a ray of sunlight reflects off particles. These microplastics come from our clothes and our furniture. Almost 70% of the clothes manufactured by fashion brands and most of the upholstery on sofas, curtains, and carpets are made of synthetic materials (polyester, nylon, acrylic). When these items are made, worn, or washed, they release synthetic microfibers into the air that we breathe and deposit in water and food that we drink and eat.

In its report on The State of Global Air, the Health Effects Institute (an independent US research organization) says that "air pollution, comprising ambient particles measuring less than 2.5 µm, ozone, and household air pollution, is an increasingly important risk factor contributing to death and disability worldwide. In 2019, air pollution ranked 4th among major mortality risk factors globally, accounting for nearly 6.75 million early deaths and 213 million years of healthy life lost" (44).

What is the role of synthetic fibers in this health risk?

EXPOSURE

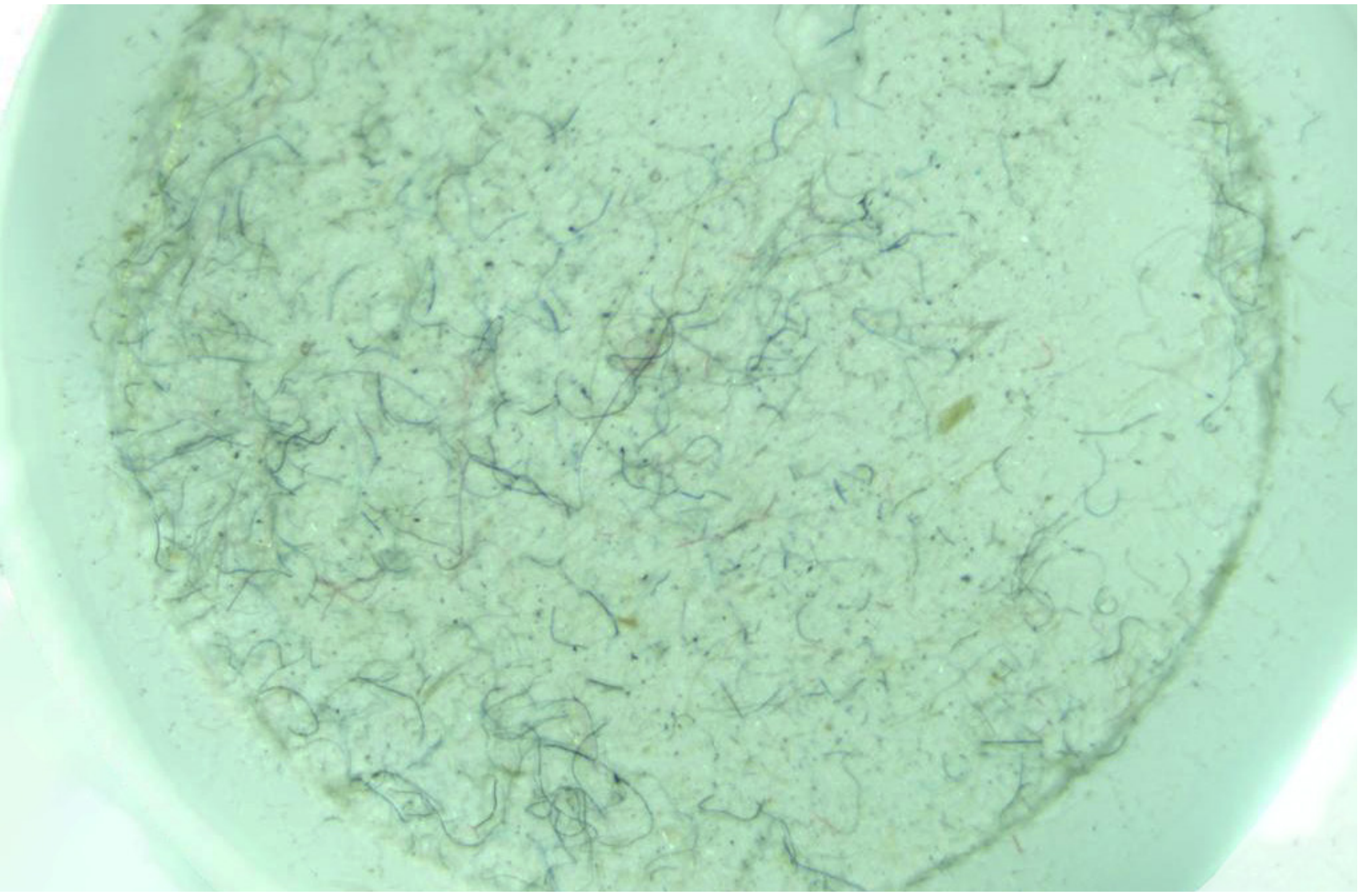
With the ubiquitous presence of microplastics, and particularly of synthetic fibers, humans are exposed to these particles everywhere and it is now generally known that we eat, drink and breathe plastic every day. For example, honey, sugar (45), salt (46), beer (47), milk (48), and bottled drinking water (49) contain microplastics, as does cultivated seafood such as oysters, mussels and clams (50), and fish (51). The consumption of mnps via food and drinks in the US has been estimated to be 110 particles per day for children, and 134 for adults and on a global level, humans may ingest 0.1–5 g of microplastics weekly through various exposure pathways (52). Throughout a lifetime of exposure to microplastic via different food types and inhalation, children and adults are estimated to take in 553 particles/capita/day (184 ng/capita/day) and 883 particles/capita/day (583 ng/capita/day) respectively (53), measured in the gut, body tissue, and stool.

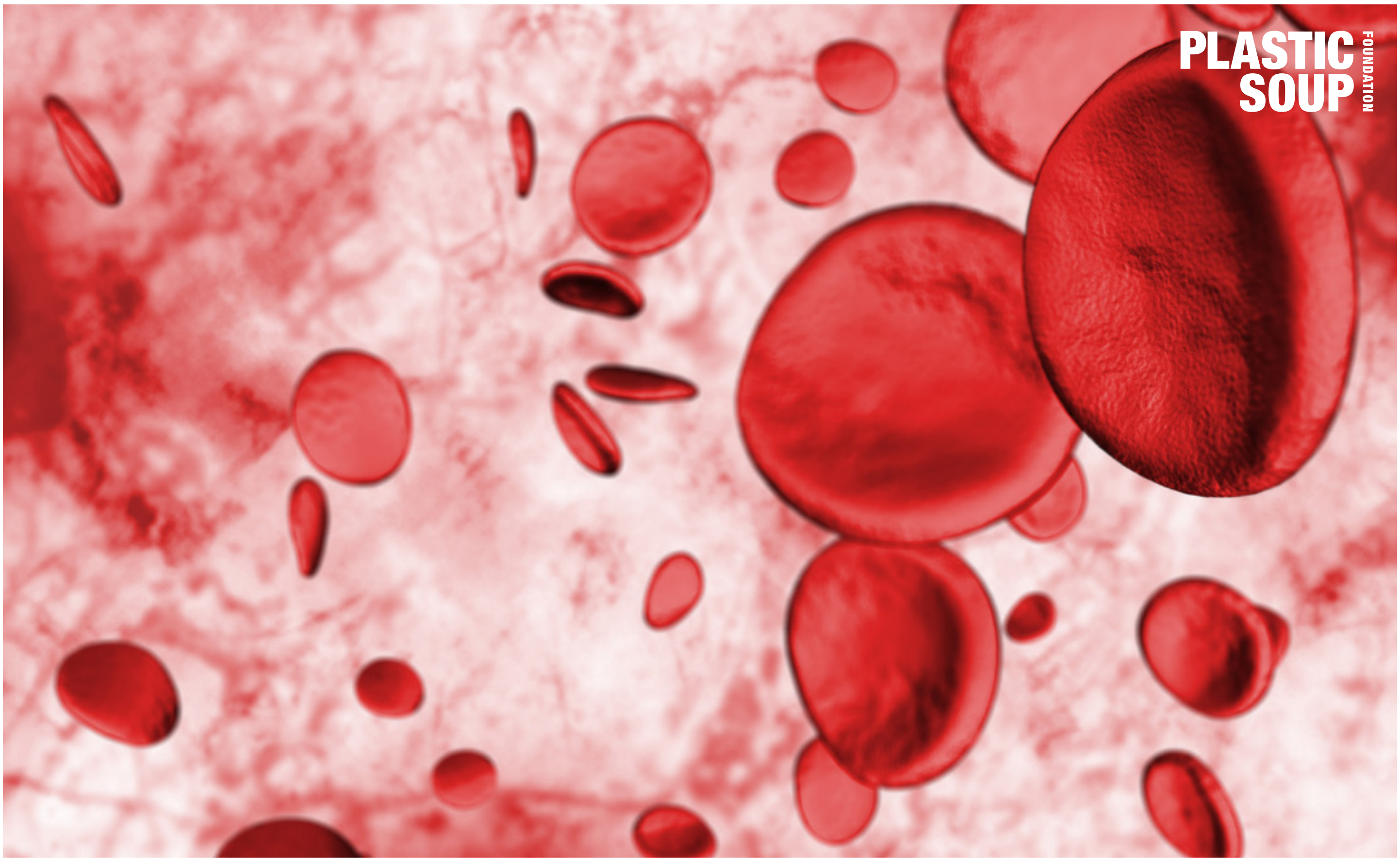
Exposure and possible intake of mnps through inhalation of air is considerably higher than through ingestion. This is not surprising with evidence of synthetic fibers in atmospheric fallout in e.g. Paris(54) and London(22). Synthetic textiles are thought to be among the most important sources of microplastics in the air (55), with concentrations of airborne mnps being higher in indoor environments compared to outdoor environments. These are

predominantly composed of polypropylene and polyethylene terephthalate (PET) polymers, mainly from using, washing and drying clothes [56].

Apart from inhaling fibers as fine dust in outdoors environments, humans are also exposed to indoor airborne microplastic pollution. On average, people spend about 90% of their time indoors [57], yet relatively little is known about human exposure to fibers, especially indoors. The first study looking into fiber pollution in indoor environments was done in two apartments and an office at a 10 km distance from Paris. All samples contained fibers, 33% of which were of petrochemical (synthetic) origin [21]. Subsequent studies found similar results. For example, human exposure to airborne microplastics in indoor environments was tested in 3 different apartments in Denmark using a breathing thermal manikin (BTM) [58]. This type of testing, which simulates human metabolic rate and breathing, provides a more accurate exposure estimate because of a natural mixing of local airstreams around the manikin, and thus a truer mix for that given situation. The researchers found similar quantities of synthetic and natural particles among all 3 homes. They also found that an average male person doing light activity would potentially inhale up to 272 mnps per day. In Australia too, all 32 homes sampled in different parts of Sydney contained airborne mnps, the majority of which were natural (42%) or transformed natural-based fibers (18%), and 39% were entirely synthetic petrochemical fibers [59]. A recent study found 30% of the dust captured in air conditioning filters from dormitories, offices, and living rooms were micro-plastic fibers [60], with polyester, rayon, and cello-phane as the dominant polymers. This study also showed that microplastic fibers accumulate over time and found particularly heavy accumulation in dormitories in comparison to living rooms and offices.

MICROPLASTIC FIBERS IN AIRSAMPLE | PHOTO M. REZAEI, WUR





Fiber fragments are released from clothes and indoor textiles through use, wear and tear [21,59]), washing of garments [61,62], and drying. A single tumble dryer could be responsible for releasing 120 million synthetic microfibers into the air each year and are one of the main sources of microfiber pollution in the atmosphere [63].

Yet, there remains a large knowledge gap in our understanding of day-to-day exposure to inhalable synthetic fibers in different indoor environments that most people frequently visit. Plastic Soup Foundation and Wageningen University and Research are currently conducting catalysing research to fill this gap. The results of this study will be released early in 2023.

HUMAN HEALTH EFFECTS

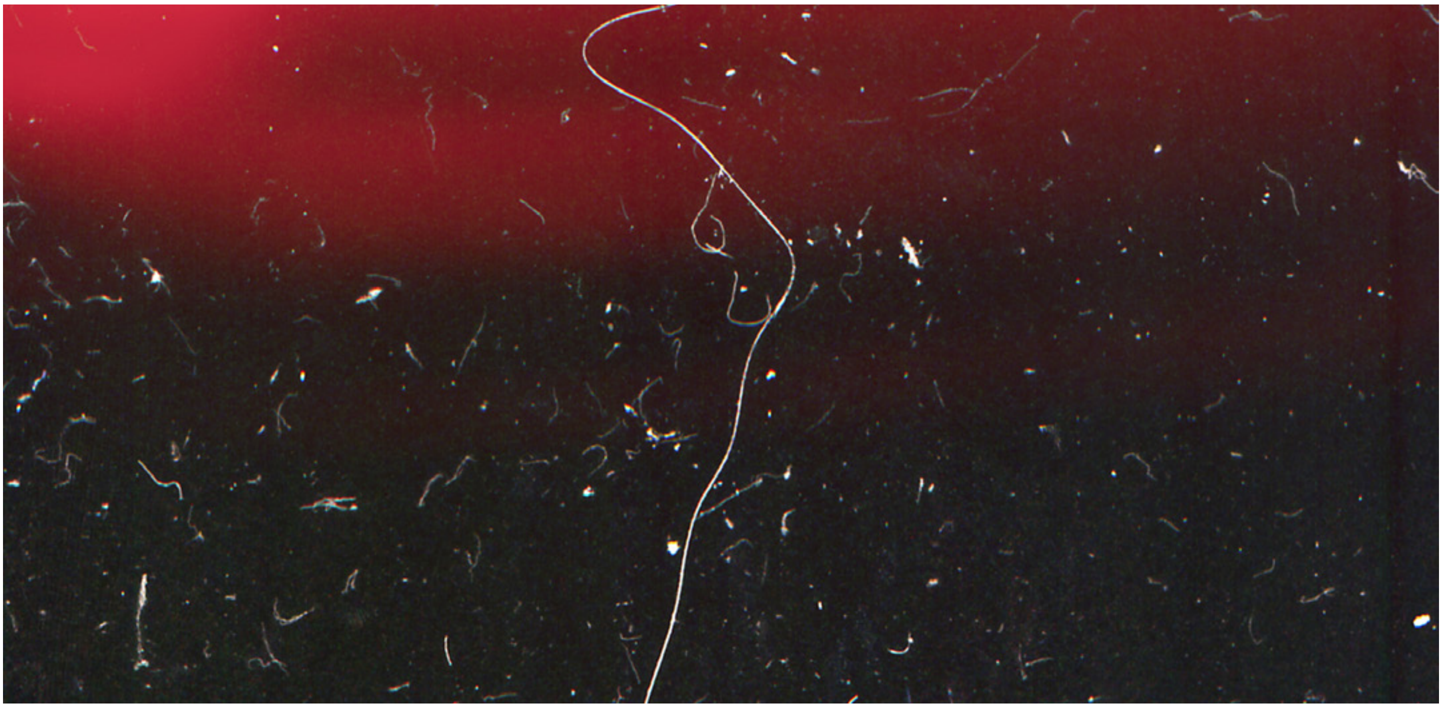
The level of toxicity and effects of microfibers on humans depends on the dose (expressed either in number of particles or as mass-weight), the length and diameter, deposition rate, the durability of the fibers and human defence mechanism (measured as the level of inflammation caused).

Small particles can enter and exit our bodies and translocate to internal organs. Humans and animals exposed to high doses of fibers can experience effects to their respiratory, hepatic (liver), immune, and gastrointestinal systems. These health effects differ by plastic-type, shape and size. Thorough knowledge of the behaviour of fibers in the air is essential to understand the relationship between an external concentration, internal exposure and toxic effects. Most of our current understanding of the health effect of synthetic fibers stems from flock worker and asbestos industry studies. Ongoing inhalation toxicological studies use controlled laboratory experimentation using cells, tissues, animals or volunteers focusing on the toxicology of particles and fibers in the air.

Effects through inhalation

Airborne microplastics could seriously harm human immune health. Synthetic fibers can penetrate deep into the lung. Both cellulosic and plastic microfibers were found in lung tissue taken from patients with different types of lung cancer. Lung tissue of these diseased patients was studied with a microscope and 97% of the specimens contained fibers. The length of the fibers was averaged 50 µm but they were sometimes longer than 250 µm [(64)]. High exposure to inhalable microplastics, as found in the flocking industry, can lead to interstitial lung disease, a work-related condition that induces coughing, dyspnea (breathlessness), and reduced lung capacity. 4% of workers from nylon flock plants in the US and Canada suffered from this condition after they had been exposed to synthetic fibers for extended periods [(65)]. Histopathological analysis of lung biopsies from workers in the textile (nylon, polyester, polyolefin, and acrylic) industry showed interstitial fibrosis (scarring of the lung) and immune responses to acrylic, polyester, and/or nylon dust [(66)]. These studies show that fibers cannot always be cleared from the lung, for example by coughing and that, if they persist, they may induce acute or chronic inflammation [(67)].

In her presentation at the first edition of the Plastic Health Summit (2019), researcher Dr Fransien van Dijk from Groningen University (RUG), said that an average household generates about twenty kilos of domestic dust a year; it is estimated that six kilos of this dust consist of microplastics. She showed that particularly nylon microfibers inhibit the growth and development of airway organoids. She demonstrated that this effect was mediated by components leaking from nylon. Therefore, microplastic textile fibers may especially harm the developing airways or airways undergoing repair. Their results call for a need to assess exposure and inhalation levels in indoor environments to accurately determine the actual risk of these fibers to human health [(68)]. Using advanced in-vitro models that represent the tissue architecture and cell type diversity of the lung and gut, researchers from TNO (Dutch independent technical research organization) and RUG were also able to show that a relatively high acute single dose of mnps, can pass the epithelial barrier of the lung and gut, potentially causing health effects in secondary organs (e.g. liver, kidney, brain). Exposure to several of the tested mnps led to inflammatory responses by lung cells and damaged the integrity of the lung-



tissue barrier (69). High exposure to inhalable synthetic fibers may make it more difficult for the lungs to recover from damage, according to professor Barbro Melgert, leading this group from the RUG. She warns that this may particularly affect people with viral infection or children, whose lungs are still developing.

“You must be worried by now”, said Professor Dr Raymond Pieters at the second edition of the Plastic Health Summit (2021), where he presented ongoing research at the University of Utrecht (UU), which showed that once inhaled, synthetic fibers can penetrate in the lung tissue. As a response, important cells in the immune system, so-called dendritic cells and macrophages, will engulf the plastic particles. Macrophages have the machinery to break down bacteria, but they lack the tools to break down plastic particles. They do try but fail, and keep trying. This process will causes chronic inflammation. Chronic inflammation is known to be a leading cause of diseases such as cancer, heart disease, asthma, and diabetes.

The immune system takes care of efficient removal of particles or pathogens through phagocytosis, a mechanism which resembles eating. In this way immune cells can even dispose of large particles (≥ 10 μm). However, when inhalation rates of plastic particles are high and exceed the clearing capacity of organisms, accumulation will occur and this will impact the health of the affected tissues or organs. The dimensions of the fibers play a role in toxicity. Thinner fibers are respirable, their elongated shape allows fibers to deeply penetrate the lung. Longer fibers are more persistent and toxic to lungs cells; fibers of 15–20 μm cannot be efficiently cleared from the lung by alveolar macrophages and mucociliary clearance, which are the primary innate defense mechanisms of the lung (70). Fibers < 0.3 μm wide and >10 μm long are most carcinogenic (71). Shorter (9.8 μm) but wider (1.6 μm diameter) nylon respirable fibers showed no significant impact on lung weights, pulmonary inflammation or macrophage function in male rats up to the highest concentration tested (57 fibers/cm^3) compared to control animals (72). Indeed, microplastics have been found deep in autopsied lungs (73) , as well as in lungs of living humans (74,75).

Dr Phoebe Stapleton from Rutgers University in the American state of New Jersey wondered what happens to plastic particles after inhalation. Together with her co-researchers, she exposed pregnant rats to airborne nanoplastics (< 0.1 μm) and then determined the amount of plastic in tissues of both mother and foetuses (unborn rats). They concluded that nanoplastic particles transferred to unborn rats within 9 hours. Plastic was not only found in the lungs of pregnant rats, but also in liver, lungs, heart, kidneys, and brain of unborn rats (the foetus) (76). Stapleton indicated that this could also apply to humans after inhalation. These studies were published by Plastic Soup Foundation for the first time in the 2nd episode of the Plastic Health Channel, in February 2021.

The use of fine-diameter (1–5 μm) synthetic fibers for fabrics has increased. Shedding of these fibers increases human exposure and thus increases the health risks associated with these types of mnps. Ongoing research is collecting more and more evidence that synthetic fibers indeed affect the function of critical organs. Most knowledge to date is available from studies of occupational exposure and effects of synthetic fibers (summarized in table 1). ((65,66 77-89))

TABLE 1 EFFECTS OF SYNTHETIC FIBERS IN OCCUPATIONAL EXPOSURE STUDIES AT TEXTILE (BLUE), PVC (YELLOW), AND NYLON (GREEN) INDUSTRIES. (REPLICATED FROM ZARUS ET AL. 2021 WITH PERMISSION)

INDUSTRY	FINDINGS	NOTES TO THE STUDY	STUDY METHODOLOGY	AUTHORS, YEAR
Synthetic fibre manufacturing	Colorectal cancers	Higher in fibre drying areas: 44% of the cancer patients worked here	Case control study of colorectal cancers	Vobecky, Devroede, & Caro, 1984
Synthetic fibre hosiery; ventilation installed.	Chronic respiratory symptoms (dyspnea, sinusitis, and nasal catarrh); acute systems (cough, throat dryness) and decreased lung function	Manufacturing process included spinning and weaving fibres and cutting and finishing stockings.	Cross sectional study; unmeasured polyester dust.	Zuskin et al., 1998
Synthetic textile workers	Colorectal cancers	Mortality rates were low	Retrospective cohort study	Goldberg & Theriault, 1994
Textile workers	Colorectal cancers; dyes increased colon cancer	>20 years of exposure associated with increased risk of cancer	Case cohort analysis in the EU only	De Roos et al., 2005
Synthetic textile	Inflammation and damage of the lungs.		Workers and transfer of disease to guinea pigs. Textile fibres and dust examined	Pimentel et al., 1975
Aramid	Upper-respiratory symptoms, infected gland, sore throats, and infections	56% Spinning workers, 27% Finishing workers	Case study of workplace exposures in two departments	NIOSH, 2000
Polyvinyl chloride	Lung cancer associated with exposure to PVC dust		Nested case reference study of workers	Mastrangelo et al., 2003
Polyvinyl chloride	Scarring (fibrosis) of the lungs.	Low risk of lung cancer.	Cohort study of 1216 workers	Mastrangelo et al., 1979
Polyvinyl chloride	Liver tumors with deaths		Correlations between 5498 workers by occupation (during 1940–1974) and cancer type	Jones et al., 1988
Polyvinyl chloride	Cancer risk		Meta-analysis of 6 worker studies.	Boffetta, et al., 2003
Polyvinyl chloride and vinyl chloride	Liver tumor related death, and cardiovascular disease deaths		Comparing death-rates depending on job four categories	Gennaro et al., 2008
Nylon flock	Respiratory symptoms	Studies on rats: acute inflammation	Worker questionnaire, chest X-ray, spirometry; and lung diffusing capacity tests	Burkhart et al 1999
Nylon flock	Reduced lung volume; reduced lung capacity		Patient reports	Eschenbacher et al., 1999
Nylon flock	Lung deseases affecting bronchi, pulmonary arteries, and lymphatic vessels	coughing, increasing shortness of breath	Chest radiography, pulmonary function tests, computed tomography & serologic testing and bronchoalveolar lavage, lung biopsy.	Kern et al., 1998
Flock	Reduced lung volume among the 5 cases		Lung biopsy review and questionnaire	Kern et al., 2000
Polyethylene flock	Reduced lung function and reduced lung volume over 4 years		Case study of symptomatic female flock workers	Barroso, et al., 2002
Polyethylene flock	Respiratory symptoms (Shortness of breath, cough, phlegm, wheezing, or chest tightness). Lung inflammation		Questionnaire, physical examination, chest radiograph, and pulmonary function testing	Atis et al., 2005

Effects through ingestion

Another major exposure route for humans is via ingestion. Based on the consumption of foods, the estimated intake of microplastics is 39,000–52,000 particles per person per year (55). When mnps enter the gastrointestinal tract they can enter the circulation and reach other tissues, such as the placenta (28) or potentially the brain (100). Mnps can cause intestinal inflammation, oxidative stress, increased permeability, intestinal flora disorder, and other intestinal health hazards (90). A recent study investigated patients with irritable bowel disease (IBD) in relation to their exposure to mnps through their drinking and dietary habits and working and living conditions (91). Of all types of mnps they found in the stool of patients, over 1/3 consisted of fibers and patient with high exposure to dust had significantly higher concentrations of fibers in their stool. The researchers found that concentrations of fecal mnps positively correlated with disease severity of two types of IBD (Crohn's disease and ulcerative colitis) (91). Nylon fibers were the second most dominant fiber type detected, possibly from synthetic textiles. They conclude that the air deposition of fibers may contribute to their ingestion causing gastrointestinal exposure.

Synthetic fibers can accumulate through the food chain (90). The health effect of ingested microplastics was tested on rats that were fed with polyethylene microplastics. After 28 days, polyethylene micro-plastics were detected in the lung, stomach, small intestine, and serum (92).

Other studies have been done in aquatic organisms, human-derived cells, and organs of the gut and reproductive system of mammals. Microplastics can accumulate in the gills, liver, and gastrointestinal tract of aquatic organisms, such as fish and shellfish (51). In all cases, studies showed inflammatory responses, metabolic disturbances, cellular damage, and toxicity to specific organs.

Nylon fibers in various sizes (0.05–100 µm) were tested in a gut model called InTESTine™ (69).
The nylon fibers and their supernatant were causing immune activation with predominant effects on local secretion of pro-inflammatory cytokines. These are types of alarm molecules that not only affect local cells but can also affect tissues far away from the site of production.

HEALTH RISK

Despite the accumulation of knowledge on possible effect of mnps on human health, our understanding of microplastic particle toxicity is still limited [29] and largely influenced by exposure concentration, particle properties, adsorbed contaminants, tissues involved and individual susceptibility. Understanding the extend of the health risk of synthetic fibers on humans requires risk analysis. A recent risk assessment study from the University in Hull (UK), reviewing the exposure results of a large body of work, suggests that the amount of mnps that we are ingesting, is indeed at such level that it in many cases poses a risk to human health [93]. The mnps effects are related to cytotoxicity (cell death), immune responses (allergic reactions), barrier function (cell membrane damage or passing), and oxidative stress (leading to cell and tissue damage). Shape was found to be the single (physical) characteristic of particles that significantly affects cell death [93] and this study confirmed that indeed mnps concentration (μg/mL) and duration of exposure significantly affected both cytotoxicity and the induction of immune responses.

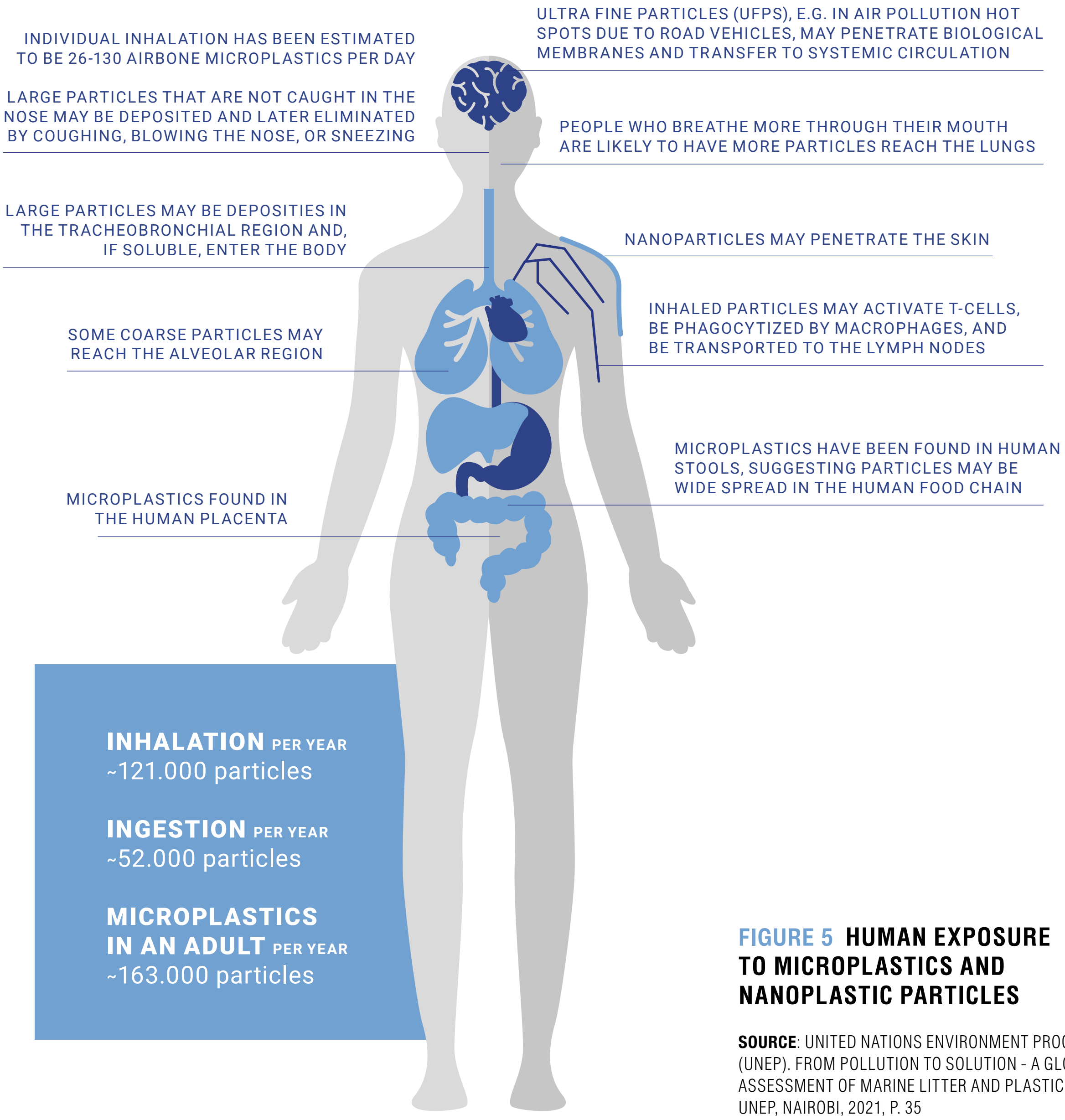


FIGURE 5 HUMAN EXPOSURE TO MICROPLASTICS AND NANOPLASTIC PARTICLES

SOURCE: UNITED NATIONS ENVIRONMENT PROGRAMME (UNEP). FROM POLLUTION TO SOLUTION - A GLOBAL ASSESSMENT OF MARINE LITTER AND PLASTIC POLLUTION. UNEP, NAIROBI, 2021, P. 35

Children's health risk
Children under the age of 6 inhale 3 times more microplastics than an average adult [59]. This was concluded in a study of Sydney homes which showed that Australian estimates of deposition and inhalation rates are at the lower end of the exposure spectrum compared to other similar studies in other parts of the world. Young children (< 0.5 years of age) inhale twice the amount of synthetic fibers and ingest twelve times more than adults over 20 years of age because small children have greater natural hand-mouth activities as part of their normal development behaviors. Furthermore, young children spend much time crawling around on the floor and thus have a higher exposure risk to microplastic particles, including synthetic fibers. Children are most likely to be at risk from adverse effects because their systems are developing [59]. Carpets are an important source of polyethylene, polyester, polyacrylic, and polystyrene fibers. Homes with hard floors have more polyvinyl fibers, which probably come from polyvinyl chloride floor varnishes or from the PVC surface itself [59]. The exposure risk was reduced in homes that were frequently vacuum cleaned.

Newborns and one-year-old infants have been reported to have significantly higher concentrations of PET particles in their bodies compared to adults [94], probably attributable to extensive use of plastic products/articles such as baby feeding bottles and toys. Infants of that age group are known to frequently put plastic products and clothing in their mouths. A study of pregnant women and their children in New York, found PET microplastics, mainly used in the production of textile fibers, in samples of meconium and infant and adult feces [94]. Their values were 2–3 orders of magnitude higher than modelled estimates of mnps exposure in children and adults via eight food types and inhalation [53].

In a recent review of 18 published articles on the exposure and impacts of nano- and microplastics during pregnancy and the associated impacts on child health, the authors found that estimates on children's exposure were based on generic assumptions, such as the calculation of particle intake by particle-contaminated seafood [95]. The studies evaluated toxicological effects of ingestion, inhalation, and placental transfer of particles, as well as aspects such as allergy, asthma, embryo development, and reproductive effects. One study followed an epidemiological approach looking at exposure as well as eye and airways irritation in a school environment. The authors identified many knowledge gaps, and while none of the studies focused on fibers, they emphasized that the "evidence base around early life exposures to nano- and microplastics provides cause for concern." [95].

Microplastics risk to the brain
With growing concerns regarding the risk of mnps to our health, one of the biggest questions is whether these particles can enter the brain. The smaller the particle, the more easily it could make its way to various organs through transportation in the blood. It is now clear that mnps can be absorbed into human blood [96]. Is it possible that, once mnps have been inhaled through the mouth or nose, they can cross the membrane barrier between blood and the brain (the so-called blood-brain barrier)? And if so, what would the effects be? In-vitro studies have shown that the permeability varies between differently sized particles influenced by the various possibilities that cells have to facilitate uptake [97]. Fine and ultrafine particles can indeed cross this barrier and possibly cause a range of respiratory and cardiovascular issues [98]. Polystyrene nanoparticles have been shown to accumulate in the brain of living mice [99]. This study suggested that polystyrene particles can pass through the blood-brain barrier and induce neurotoxicity in mammals [99]. As discussed earlier, ultra-fine particles (with diameters of 2.5 µm and smaller) enter the lungs through breathing, pass through the alveoli into the bloodstream, and trigger inflammation which may indirectly affects the central nervous system [97], contributing to neurodegenerative diseases, such as Alzheimer's disease. Microplastic particles are indeed able to make their way to the brain and potentially increase our vulnerability to develop brain disorders [100]. However, it is still uncertain if similar effects occur in humans.

Pathogens and parasites risk

An emerging concern of plastics in the environment is the potential for microplastic to transport and transmit pathogens from one area to another. The potential for marine microplastics to house distinct communities of microbes on their surfaces was first described in 2013 (101). In seawater, plastic surfaces will develop a biofilm of microbes that is taxonomically different to that of the surrounding seawater (101). Reports of the presence of numerous pathogenic microbes on both macro- and microplastic surfaces from across oceans, are worrying. Vibrio, a type of bacteria that can cause diarrhea, nausea, headaches, but also cholera, have been found in high abundances within plastisphere communities (102) and was also found on polyethylene fibres in the North Sea (103).

Certain zoonotic protozoan parasites were capable of latching onto microplastics, including polyester micro-fibers, in seawater (104). These pathogens, when ingested by fish and shellfish can cause illness in humans consuming these sea products (105). More parasites adhere to microfiber surfaces as compared to microbeads and form a novel pathway by which mnps may be mediating pathogen transmission in the marine environment (104, 106), or the terrestrial environment (107), with important ramifications for wildlife and human health.

Chemical toxicity risk

Besides the risks associated with the mnp particles, microplastics could also present chemical and biological risks. It is estimated that more than 10,000 chemicals are added to plastics to give it its desired properties. For fibers and textiles, this includes for instance flame retardants (prevent the start or slow the growth of fire), waterproofing (PFAS, also known as forever chemicals), and colorants.

Many plastic additives have been listed to be of very high concern because of their endocrine disrupting or carcinogenic properties and other toxicological hazards. If an organism has ingested or inhaled mnps, chemical additives may leach from the particles inside the organism, exposing the tissues to chemicals such as phthalates and bisphenol A. These are known endocrine disruptors, i.e. substances that even in very low concentrations interfere with hormones (109). Endocrine disrupting chemicals have been found to potentially put 54% of toddlers at risk of developmental neurotoxicity associated with language delay (110). Chemicals leaching from mnps may also lead to local effects on the immune system (111-113).

FIGURE 6. TYPES OF CHEMICALS USED IN THE TEXTILE INDUSTRY (108)

FUNCTIONAL CHEMICALS

- Dyestuffs and pigments
- Crease resistant agents
- Anti-shrinking agents
- Oil, soil, and water repellents
- Plastizisers
- Flame retardants
- Biocides for defined functionalities in articles, e.g. antibacterial agents
- Stabilizers
- Stiffening agents
- Reactive resins for various finishing treatments

AUXILIARY CHEMICALS

- Organic solvents
- Surfactants
- Softeners
- Salts
- Acids and bases
- Biocides as preservatives in the process or during storage and transport

RECOMMENDATIONS

The world's population continues to grow and all those people need to be dressed. Full dependency on natural materials is no longer an option because there simply is not enough material and growing capacity available in the world. As a result, there is a high demand for synthetic yarn. With the cheap production costs, plastic yarn production has become a huge business in the fashion industry.

Most material flow calculations within the fashion industry are based on the current high throughput of clothing. Yet, that throughput is heavily influenced by the industry's unsustainable businesses. 'Fast Fashion' is the leading business case with continually changing fashion trends and low-quality products. Plastic yarn is an ideal material to create garments with an increasingly shorter functional lifespan. As a result, the amount of fiber loss and post-production and post-consumer waste is immense. This makes the fashion industry one of the most polluting sectors in the world.

As shown in the previous sections, there is enough evidence to be concerned about the possible environmental and human health impacts of micro-plastic fiber pollution. Therefore, the textile industry urgently needs to take drastic steps to reduce the amount of microplastic-shedding from clothes that they produce. Furthermore, far-reaching, binding policy measures are vital in tackling microfiber pollution, because only in this way, brands can be held accountable for their contribution to global plastic pollution.

Below we will present some recommendations for the European Commission and the fashion brands and retailers. The focus should be primarily on the early stages of the textile value chain; on reduced production, better design, manufacturing techniques etc. It is important to note that when prevention measures are prioritized, reducing microplastic fibers at every step of the textile value chain will have the most impactful effect.

RECOMMENDATIONS FOR THE EUROPEAN COMMISSION

The European Union (EU) published the 'plastics strategy' in 2018. In its strategy, the EU recognizes the serious negative effects plastics can have on the environment and human health. Therefore, the EU is taking measures to tackle plastic pollution and marine litter. One of the objectives in the strategy is to take measures to address and reduce micro-plastics that are unintentionally released into the environment such as resulting from the use of a product, for instance by fragmentation or abrasion [116].

The upcoming initiative aims to reduce the unintentional release of microplastics in the environment, and ultimately reduce environmental pollution and potential risks to human health [116]. It focuses on a few sources that have been established to be the biggest cause of pollution, one of which is synthetic textiles. Currently, the European Commission is working on a proposal for legislation.

We recommend that the Commission includes the following points in their proposal:

1. **Recognize the scientific evidence.**
It is of utmost importance that the European Commission recognizes the raising concerns about the impacts of microplastic fibers on the environment and human health, and therefore fully abides by the precautionary principle. Far reaching, legally binding measures are needed to stop the ongoing accumulation of microplastics in the environment (and our bodies).

2. **Reduce the volume of synthetic textiles being produced and placed on the market.**
This can be achieved by introducing a tax on virgin plastic, also covering the use of virgin synthetic fibers. Alongside this, it is important that the use of plastic waste from other materials as feedstock for fibers in the textile industry is not incentivized.

3. **Establish minimum design requirements for textiles and associated manufacturing techniques and set a legally binding maximum threshold for microplastic shedding.**
In this way, selection of the best performing fabrics at design and production stages of the textile lifecycle (production, use and end-of-life) will be promoted. Furthermore, the environmental impacts linked to wet treatment, cutting, dyeing and printing (including 3D printing) of garments also need to be assessed.

4. **Include a mandatory microplastics information label.**
The label should highlight the presence of plastic in textile products and the environmental and toxic impact of microplastics to inform purchase decisions. In this way, consumers can make a more informed decision when buying a product. At the same time, there needs to be independent testing of the final garments for microfiber release.

5. **Mandate the industrial pre-washing and waste water filtering of textiles.**
Throughout the manufacturing phase newly manufactured textiles and garments should be pre-washed with filter systems to capture microplastics [114]. This should account for all textile products being put on the EU market, and therefore for production that takes place in- and outside the EU. In this way large quantities of microplastics are washed out and collected before they reach the European market – putting the responsibility for this on the producers, not the consumers.

6. **Introduce EU legislation for domestic and industrial microplastic filters.**
The EU should ensure that all washing and drying appliances for both domestic and industrial use, are equipped with filters and systems to filter greywater. It is important that appropriate handling of filter material will be promoted. This end-of-pipe measure should only be promoted in addition to the other recommendations that reduce microplastic fiber release at the source. Manufacturers and retailers should primarily be held responsible for garments they bring onto the market.

7. **Include microplastic shedding in the Product Environmental Footprint for Apparel and Footwear methodology.**
The European Commission considers using the PEF method for assessing the environmental impacts of clothing. However, the methodology is incomplete and at the moment poses a risk of misleading well-intentioned consumers. The critical environmental impacts of microplastics shedding should be included to better inform consumer choices.

RECOMMENDATIONS FOR THE FASHION INDUSTRY

It is evident that much fiber shedding takes place during the use, washing, tumble drying of clothes, and in the end-of-life phase. Plastic Soup Foundation believes that an extensive system change is urgently needed to prevent the problem of fiber-loss from textiles. We recommend the following actions for the fashion industry:

1. **Move away from the fast fashion business model**
   Start with a transparent, sturdy plan and strong goals to stop with fast-fashion. Reduce the use of synthetic materials and invest in high quality products that will last long and do not shed microplastics. By doing so, the amount of generated waste will also decline.

2. **Self-assign ambitious and measurable targets to avoid microfiber release**
   Commit to ambitious goals to rapidly reduce synthetic fiber release from your garments. Invest in quality yarns with a significantly better and measurable performance regarding fiber release. Make sure that every garment is tested for fiber release by independent testing methods (like the WOMA testing method). To avoid release of fibers during manufacturing processes, make sure that all garments are pre-washed at least 3 times before shipping.

3. **Take full responsibility for the textile products you put on the market**
   Create garments that are designed for repair, repurpose and recycling. Avoid post-production and post-consumer waste as much as possible. Be part of the extended life cycle of your products and take full responsibility for the generated waste streams that cannot be avoided. These products should not be exported to other countries (for instance in Africa) where they are landfilled. Do not make use of material displacement (e.g. garments made from PET bottles) but make sure produced garment material is reused or recycled in a certified closed loop within the fashion sector.

4. **Provide transparent information about microplastic release risk of your garments**
   Be transparent about the environmental effects of your products, in reporting as well as in product communication. Make sure product labelling is clear and understandable for consumers. Move away from unsubstantiated claims on the recyclability of garments sold, in the absence of any fibre-to-fibre recycling technology. Make sure all suppliers are aware of your requirements and that there is a thorough review system to keep them on the same page.

5. **Openly support progressive legislation on microfiber release, waste reduction and transparency in the industry**
   Legislation on unintentional release of microplastics will possibly be valid on a short term. It is highly necessary to support this and other related policy measures and lead the way. Encourage competitors and your value chain to follow your example. Stop collaboration with industries and companies that oppose, delay or undermine progressive legislation and implementation.

WOMA LABELS LEVELS MICROFIBER RELEASE

CONCLUSION

Do our clothes make us sick? The honest answer is that we are not sure yet. However, the scientific evidence is mounting; microplastic fiber dust in the air has potential health risks associated with it. With around 30% of dust in our homes consisting of microplastic fibers, we are exposed to and inhale these particles every day. Similarly, microplastic fibers that end up in the aquatic and terrestrial environment through deposition from the air or from river effluent or run-off, are affecting the organisms living in that environment. As we eat from the sea or the land, these fibers enter our bodies. With the range of studies summarized in this document, we provide up to date facts about the range of different pathways in which synthetic fibers, shed from clothes and other textiles can potentially make us sick. Children are a particularly vulnerable group to the adverse effects of mnps.

As the number of microplastic fibers in the environment increases and thus our exposure too, it is possible that these plastic particles are bio-accumulating. Our natural biological systems are capable of getting rid of particles (e.g. through excretion or coughing), however, it is unclear whether or not this elimination process can keep up with the number of toxic particles that we take in. When will we reach a tipping point?

The global transportation of these microplastic fibers through the atmosphere, leads to a world-wide distribution of these particles and associated health risks, including to some of the remotest parts of the earth. The burden of disease attributable to air pollution is now estimated to be on a par with other major global health risks such as unhealthy diets and tobacco smoking [115]. 99% of the world's population breathes air with pollution levels (including plastic particles) that exceed World Health Organization limits [115].

This document does not address the health effects of synthetic fibers associated with waste management, or the lack thereof. In countries without waste management systems, unused or disposed of garments are burnt in the open air, releasing highly toxic fumes (e.g. dioxines). Without serious attempts to overhaul plastic fiber production and waste management practices, the abundance of airborne microplastics will continue to increase.

Is plastic emission from our clothes reason for serious concern? Yes, without a doubt. It is nearly impossible to avoid exposure to microfibers in our daily lives because concentrations of micro- and nanoplastics in the environment (water, air, soil) continue to increase over time. Removing these polluting microfibers from the environment is practically not feasible. It is therefore imperative to take mitigating actions to decrease microplastic fiber release at the source. We do not need more proof; we need less emission of microplastics to the environment. The time for change is now!

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