DIRTY LAUNDRY

Analyzing Solutions to Fashion's Plastic Problem

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ABSTRACT

Microfibers, tiny fibers (<5mm) that shed from synthetic clothing are released in the hundred thousands every time we wash our clothes. Microfibers are textile-derived, and these tiny specks have been found to be one of the biggest sources of microplastic pollution in the ocean. Other sources of microplastics include diverse items such as car tires, personal care products and city dust, to name just a few. Microfibers have infiltrated rivers, lakes, dams and ultimately the oceans. They make their way up the food chain and have been shown to threaten aquatic ecosystems and potentially human health.

Research on microfibers is fairly new and still emerging, so the full range of adverse effects is not yet known. However, long term exposure to plastic on a macro or micro level is unlikely to be healthy for humans and animals alike. As more research becomes available, possible solutions need to be explored so that microfiber pollution can be mitigated, regulated and eventually eliminated, if possible.

There are various upstream and downstream solutions. While downstream solutions, such as filtration at washing machines, can serve as an intermediary fix, upstream solutions, like moving away from fossil-fuel derived textiles will likely provide long term resolution. Ultimately the potential solutions are likely to be relatively complex to achieve and will require careful planning. New legislation and cooperation from consumers, washing machine producers and fashion brands will be vital for change to occur.

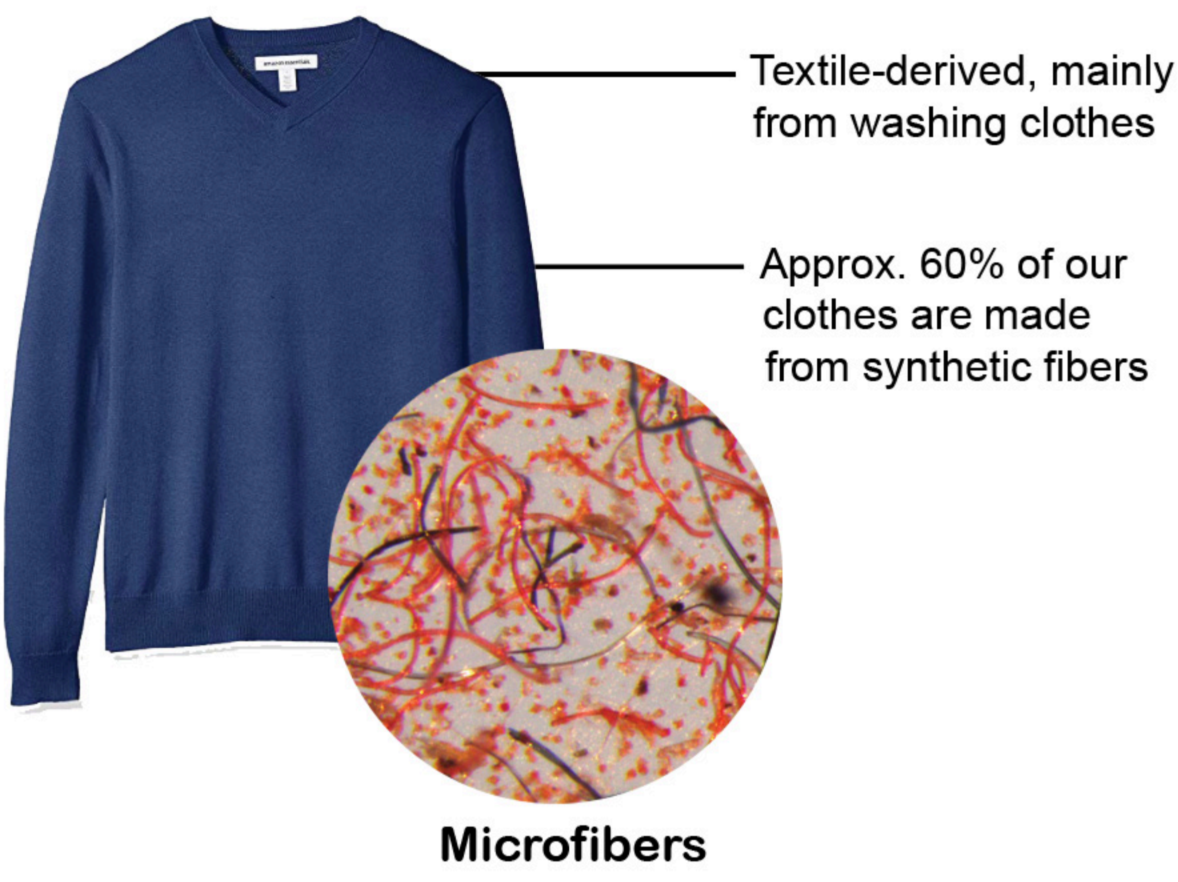


Image sources: Amazon and Patagonia

CLIENT

SURFRIDER FOUNDATION

The Surfrider Foundation USA is a U.S.501(c)(3) grassroots non-profit environmental organization based in San Clemente, California.

According to their mission statement, Surfrider Foundation is "dedicated to the protection and enjoyment of the world's oceans, waves and beaches through a powerful activist network."

Surfrider has over 50 employees in roles that range from CEO, to Water Quality Manager, Staff Scientist, Youth Network Manager and Legal Director.

The organization also relies on their dedicated chapter volunteer network, which includes 81 chapters and 85 youth chapters around the US, who collaborate on both local and national levels with regional staff and issue experts. These groups serve as the first response to local threats and help carry out localized campaigns and educational initiatives.

Surfrider focuses on five key areas, which are:

- Keeping beaches accessible for all to enjoy,
- Protecting our water resources and preventing pollution from reaching the ocean,
- Ocean protection,
- Coastal preservation, and
- Reducing the impacts of plastics in the marine environment

The organization has carried out many projects to address the above issues, including helping to stop Maui's use of wastewater injection wells (2011), opposing seismic testing off the Atlantic Coast (2012), fighting against offshore fracking in California (2013), urging beach towns in San Diego to adopt a sea level rise plan (2018), as well as various plastic straw and bag bans.

Surfrider has been involved in the microplastic pollution issue, as they strive to increase public awareness and education on the topic, and participate in research efforts, including a partnership with 5 Gyres, the San Francisco Estuary Institute, and a coalition of other organizations to form the San Francisco Bay Microplastics Project. As a collective, they aims to investigate critical data on microplastics in the Bay Area and generate scientifically supported, regional recommendations for solutions to plastic pollution.

Surfrider was eager to collaborate with me on this project, as they would like to have a detailed research report for their charter network, as well as a shorter public-facing document on their website that educates readers on the sources, threats, potential solutions and successful policies concerning microfiber pollution.

SURFRIDER FOUNDATION

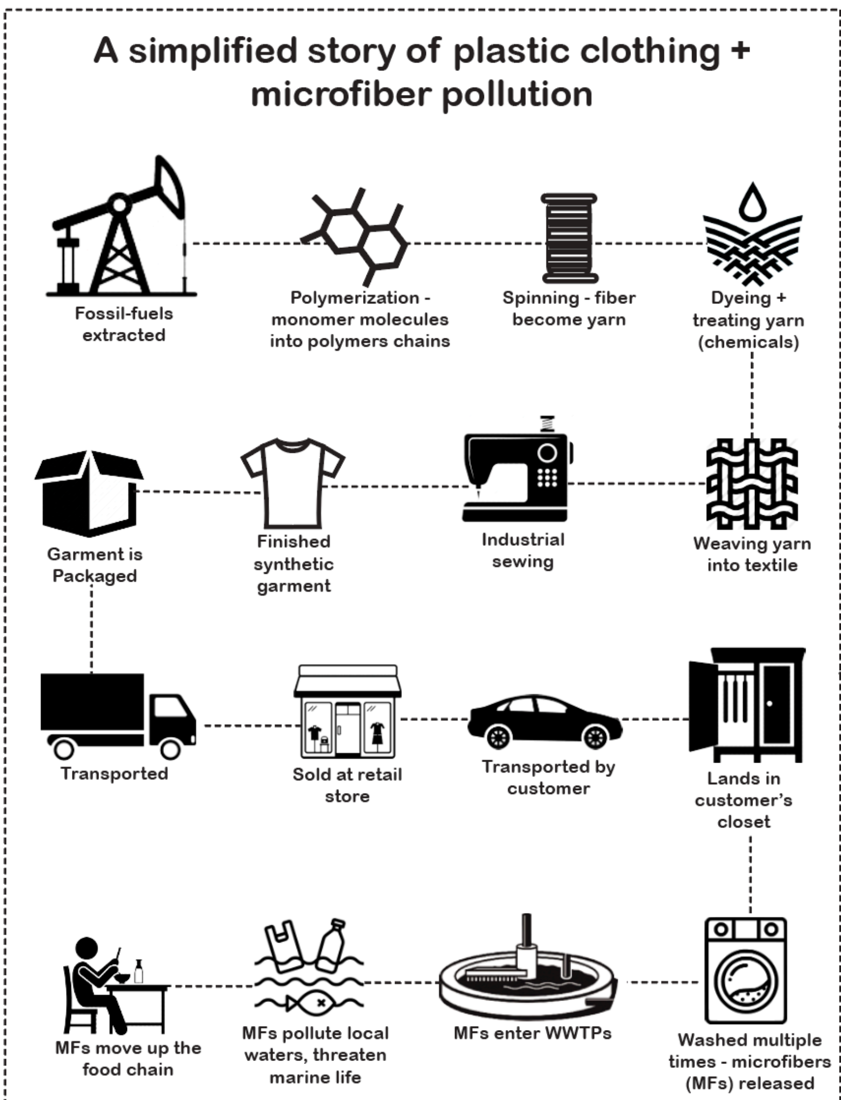
Image sources: Surfrider Foundation

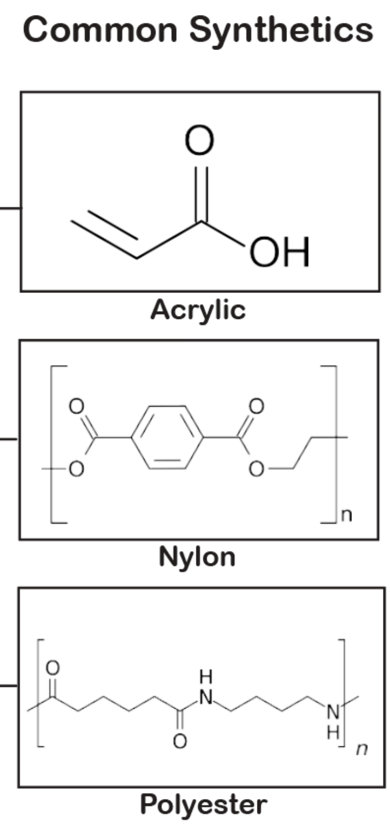
INTRODUCTION & RESEARCH QUESTION

It is 2019 and our world is suffocating in plastic. It has infiltrated almost every industry sector and natural landscape. Big, small and sometimes invisible to the naked eye, plastic is scarily abundant. The majority of clothing today is made from plastic. That fuzzy, smooth or soft material we feel against our skin is more often than not derived from petroleum, turned into synthetic fibers and woven into a seemingly innocent yarn that mimics naturally-derived textiles, such as cotton, wool and silk.

Every time we wash our clothes in the washing machine, tiny microfibers smaller than 5mm, are released in the hundred thousands, infiltrating our rivers, lakes, oceans and soils, where they make their way up the food chain, harming aquatic, terrestrial ecosystems and potentially humans.

This report will discuss various downstream and upstream solutions for reducing microfiber pollution in the city of New York, including such methods as filtration at laundromats, washing machine modifications and the potential of emerging technology for wastewater treatment plants. Additionally, fiber innovation will be investigated as a promising upstream solution for the near future. Passed and proposed bills addressing microfiber pollution will be highlighted to demonstrate how regulation can play a role in microfiber prevention and awareness, followed by recommendations outlining the way forward for NYC.





CONTEXTUAL RESEARCH

PLASTIC & MICROPLASTIC

Plastic is one of the most widely used materials today. Cheap, versatile, malleable and lightweight, most humans come into contact with plastic every single day of their lives. Plastic has revolutionized production, allowing manufacturers to produce en masse for a wide variety of industries, such as packaging, transport, medicine, cleaning and fashion. Today, the global plastic industry is worth a staggering $600 billion (Smith, M, et al. 2018). While recognizing its many benefits, the negative impacts of widely used plastic products cannot be ignored. It is a major, non-biodegradable, environmental pollutant, threatening the health of valuable ecosystems of plants, animals and humans alike.

Plastic pollution can range from large items, such as plastic bottles and bags to the tiniest fragments, known as microplastics. Microplastics, which are smaller than 5mm and often invisible to the naked eye, tend to derive from abrasion (e.g. the erosion of motor vehicle tires when driving) and maintenance of plastic products (e.g abrasion of synthetic textiles during washing) (Boucher, J, Friot D. 2017).

In this report, the term “microfiber” will specifically reference microparticles from synthetic clothing, while “microplastics” will be associated with all types of man-made microparticles.

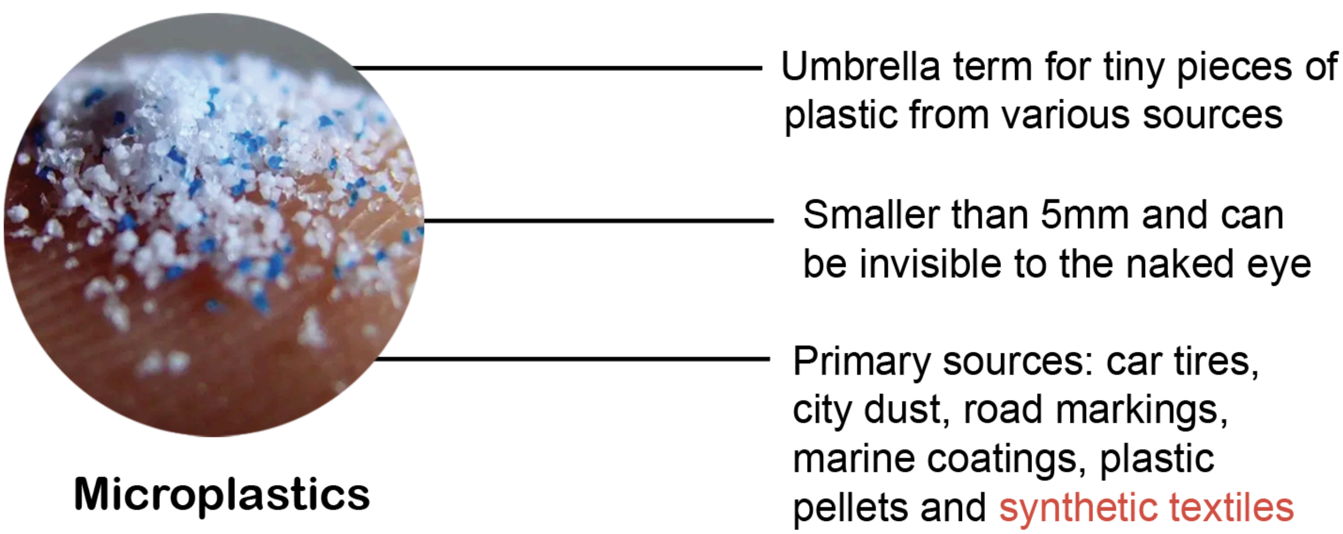


Image source: Washington Post

CONTEXTUAL RESEARCH

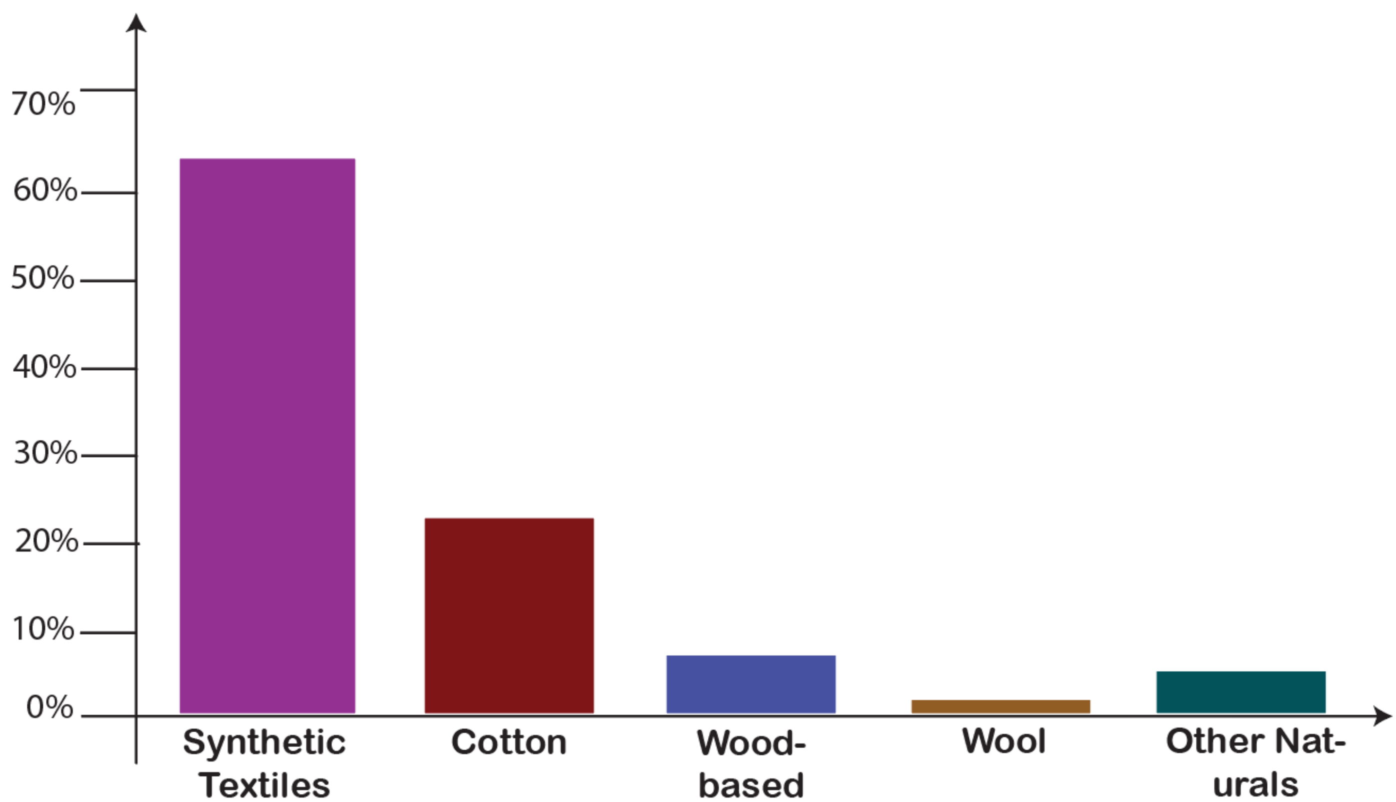
PLASTIC CLOTHING

The benefits accrued from plastic have dramatically altered the composition of today's clothing. Plastic-derived fibers, known as synthetics, have allowed textile mills to create fabrics that mimic cellulosic and animal-based textiles, such as cotton, silk, wool and fur. Synthetic fibers are also blended with natural fibers, not only to drive down costs, but also to add superior technical properties, such as wrinkle and odor resistance, metallic shine, sweat wicking, and the ability to be machine washable.

Commonly used synthetic fibers include polyester, elastane, acrylic and nylon. These dominate the fast fashion space and are set to continue to do so, overtaking natural textiles, which often take longer to cultivate and require more resources, like water and land. According to Statista, synthetic fibers accounted for an estimated 64.2% of the total global consumption of fibers in 2017. Cotton accounted for 24.1%, while wood based fibers (e.g. lyocell) accounted for 6.2%, wool was 1.1% and other natural fibers were 4.4%. Of all the synthetic textiles, polyester is the most widely used. Textile World has projected that demand for polyester, which surpassed cotton for the first time in 2002, will reach 70 million tons in 2030, while that for cotton will be just over 30 million tons in the same year (Bornenman, J. 2015).

Most closets in the West contain garments predominantly made from synthetic blends. In this day and age, that is almost unavoidable. However, the manner in which we maintain and wash our clothes can have a significant impact on water systems near and far.

Distribution of fiber consumption worldwide in 2017, by fiber type



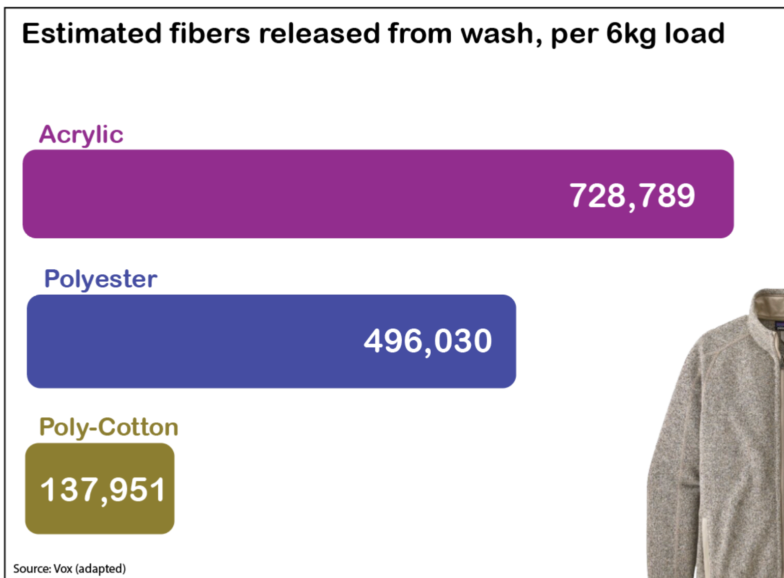
Source: Statista (adapted)

CONTEXTUAL RESEARCH

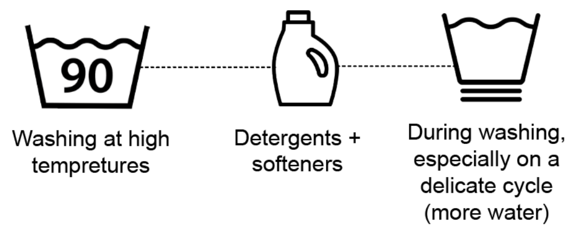
DIRTY LAUNDRY

Although the invention of washing machines reduced the burden on consumers of frequent and physically taxing garment washing, it has brought new and unanticipated problems. With every load of clothing, comes the release of microfibers.

One 6 kg load of washing has the potential to release 100,000 - 700,000 fibers per wash (Napper, I.E., Thompson, R.C. 2016). Shedding potential varies based primarily on the type of textiles being washed. For example, studies show that acrylic fibers shed more than polyester or poly-cotton (Resnick, B. 2019). Fleece, a synthetic textile with a fluffier feel is known to have high shedding potential with researchers finding that one fleece sweater can release up to 1900 fibers per wash (Browne, M.A., et al. 2011). As a sweater ages, the fibers often become looser which can also result in increased shedding over time (Hartline, N.L. 2016).



Factors that increase shedding:



Although it had been thought that washing clothes on a delicate cycle reduces shedding, it has been found that the opposite is true. This is because a high volume of water is used during the delicate cycle phase, which is supposed to protect one's clothes, but actually results in increased shedding (Newcastle University. 2019). It has also been found that using detergents and softeners promotes shedding (Goes, J. 2018).

Conventional washing machines are not equipped with filters to capture the released microfibers, so these enter wastewater treatment plants (WWTPs) via wastewater effluent.

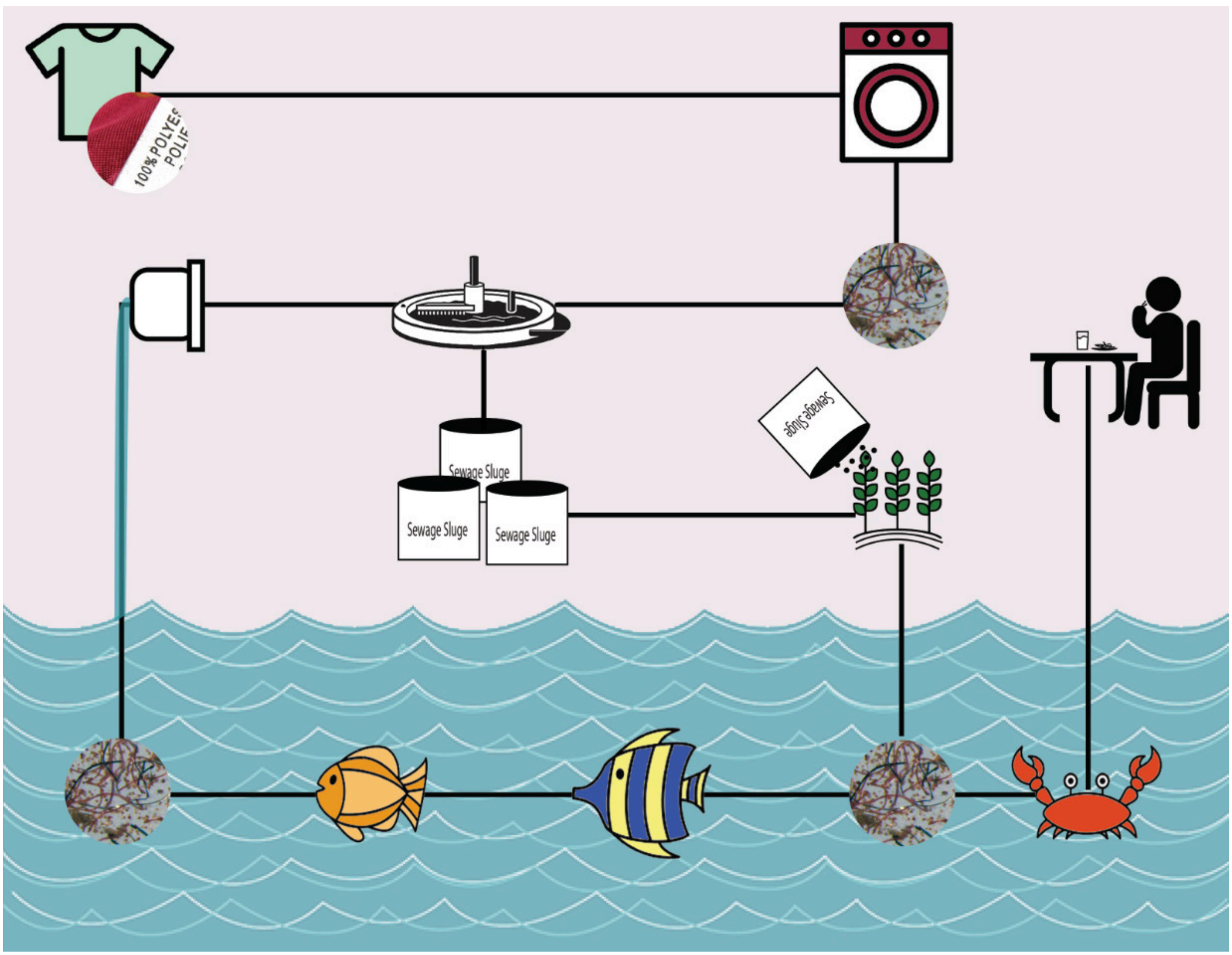
In the process of wastewater treatment, a significant portion of microfiber pollution may be mitigated. During the preliminary and primary phases of treatment, which involves grease removal and the settling of solids, approximately 88% of fibers can be captured (Noventa, K, et al. 2019). In the course of the entire treatment process, it has been reported that conventional WWTPs, which do not include filtration or "tertiary treatment," can remove up to 90-98% of microplastics, but due to the amount of effluent discharged each day, thousands of micropolluting pieces still enter the environment (Pico,Y, Barcelo, D. 2019). For example, researchers studying a major WWTP in Vancouver, Canada found that even though approximately 1.8 trillion plastic particles were filtered and removed from the wastewater, about 30 billion particles were still released into the ocean annually (Gies, E.A., et al. 2018).

Image source: Patagonia

Despite the majority of fibers being captured, it does not mean they disappear. Captured fibers (and other anthropogenic litter) at WWTPs end up retained in sewage sludge. This is problematic because sludge reenters the environment via fertilizer for agricultural land, soil production and landfill cover (The Swedish Environmental Protection Agency. 2019). Therefore, fibers can pollute terrestrial ecosystems, as well as make their way into waters via runoff.

Most of the micropollution in sludge are fibers derived from synthetic clothing, with researchers in China finding that 63% of the microparticles caught in their sludge samples were fibers, while in Finland 80% of the particles in sludge samples were fibers (Noventa, K, et al. 2019).

However, size matters, as the tiniest of microfibers ranging in size between 20-190 microns and invisible to the naked eye, bypass WWTPs, even if there is a filtering membrane, as in tertiary treatment, which is typically employed for drinking water, as opposed to wastewater (Noventa, K, et al. 2019).



System diagram showing the flow of microfibers from garment to washing machine, through to wastewater treatment plant and eventually, waterways. Microfibers either directly flow into local waters through the wastewater treatment plant, or settle into the sewage sludge where they re-enter the environment via fertilizer or runoff. Microfibers work their way up the food chain, contaminating food and drinking water.

CONTEXTUAL RESEARCH

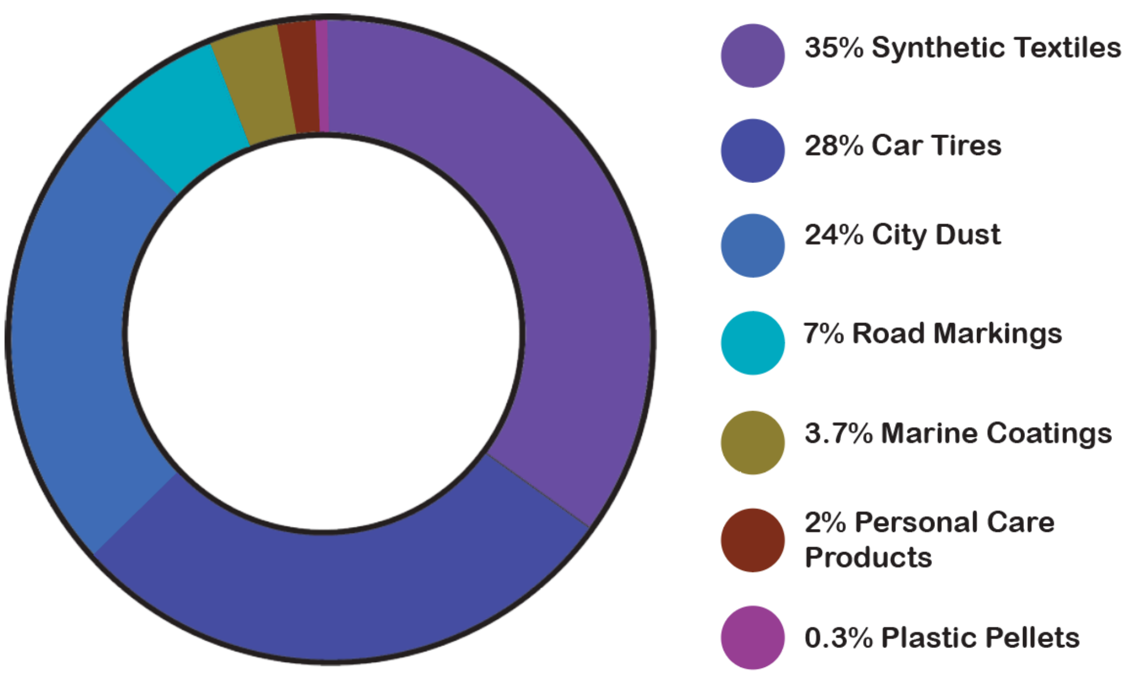
PV SEA

Microplastic is found in waters worldwide, with microfibers from synthetic clothing being a primary source.

Between 2013 and 2017, the most extensive microparticle research study to date was undertaken (including microfibers, microplastic and other anthropogenic litter[1]), during which 1,393 1-liter grab samples were obtained across the globe. This revealed that worldwide marine surface waters contain 11.8 ± 24.0 particles per liter (three orders of magnitude higher than model predictions), and most importantly, 91% of the particles were predominantly microfibers, meaning textile-derived (Barrows, A.P.W, et al. 2018).

These findings are further supported by a 2018 report by the The International Union for Conservation of Nature (IUCN) stating that the majority (35%) of oceanic microplastics worldwide derives from synthetic textiles, while the other two greatest sources are from car tires (28%) and city dust (24%). Significantly smaller percentages come from road markings (7%), marine coatings (3.7%), personal care products (2%) and plastic pellets (0.3%).

Distribution of ocean microplastic sources worldwide as of 2018



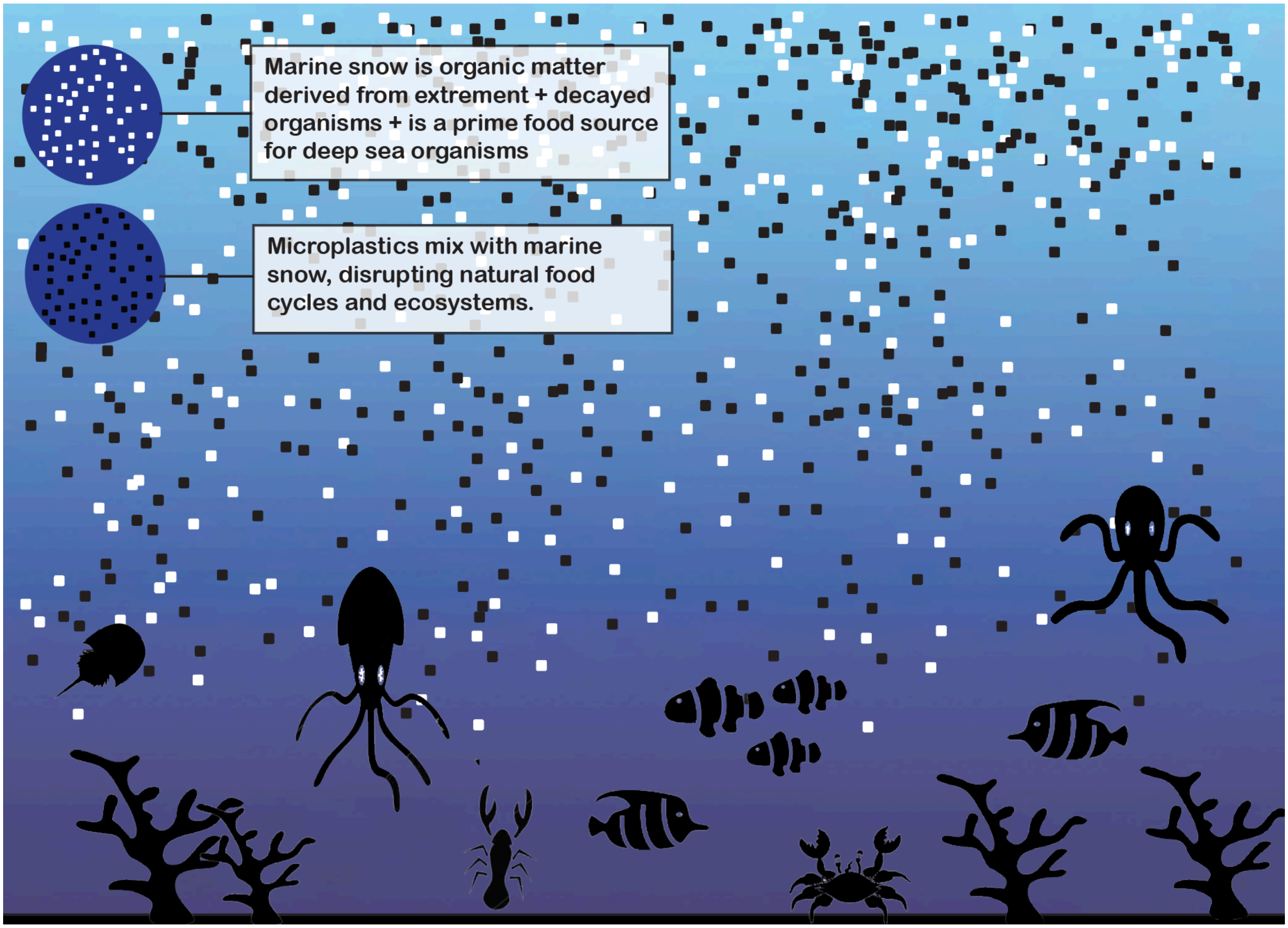
Source: Statista (adapted)

In the New York Hudson River, researchers observed that about 1 liter of water contained an average of 1 microfiber (Miller, R.Z., et al. 2017). This may sound minimal, but actually equates to the Hudson River releasing approximately 300 million microfibers into the Atlantic Ocean daily (Carey, T. 2017). It was discovered that approximately half of the fibers were derived from synthetic fabric and, interestingly, the fiber concentration was evenly distributed across the river, as opposed to being higher in areas close to WWTPs (Miller, R.Z., et al. 2017). This means that fibers disperse widely from WWTPs and could also be entering waters via air.

1 Man-made pollution

CONTEXTUAL RESEARCH

A NEW FOOD GROUP: PLASTIC



With microplastics becoming so widespread in our waters, they inevitably come into contact with marine life, from small to large. In fact, a UN report found that about 1/4 of all marine species ingest microplastics (Smith, M., Et al. 2018).

One point of entry is marine snow, biological matter that falls from surface water layers to the ocean floor and looks like tiny snowflakes. This is an important food source for deep sea organisms (NOAA. 2018). However, microplastics greatly resemble marine snow and mix with it. Microplastics, like acrylic, viscose and polyester have been found in deep sea organisms, such as Cnidaria (e.g jellyfish), Enchinoderma (e.g. sea cucumbers) and Arthropoda (e.g.crabs, lobster and sea spiders) (Taylor, M.L., et al. 2016). Microplastics have also been detected in larger aquatic life, like manta rays, whale sharks and baleen whales that ingest microplastics through polluted waters or contaminated prey (Germanov, E.S., et al. 2018). This demonstrates that microplastics move up the food chain and that seafood-eating humans are at-risk of ingestion, too. For example, researchers have estimated that a frequent European shellfish consumer eats approximately 11,000 plastic particles annually from shellfish alone (Smith, M., et al. 2018).

Although there is currently very little research on the human impact of microplastic ingestion, the implications for marine organisms are increasingly being observed.

CONTEXTUAL RESEARCH

SMALL PARTICLES, LARGE IMPACT

Microplastic ingestion by animals has been shown to impact metabolic function, as well as lead to organ dysfunction and several other disorders.

Plastic particles are known to linger in the body longer than the natural diet and can therefore cause more harm over time. As just one example, microplastics take 14 days to pass through crabs' digestive systems, as opposed to the usual 2 day period (Akpan, N. 2014). This interferes with the crabs' natural feeding habits and leads to early death (Kontrick, A.V. 2018).

It has also been found by researchers at Tasmania's Institute for Marine and Antarctic Studies (IMAS) that the flesh-footed shearwaters (seabirds) on Lord Howe Island, off the eastern coast of Australia, are experiencing high cholesterol, decreased kidney function and stunted growth as a result of ingesting microplastics (Picheta, R. 2019). This is because plastic is composed of harmful chemicals including phthalates, endocrine disruptors that can also cause developmental disorders and allergies, as well as Bisphenol-A (BPA), which is also known to cause hormonal issues, along with cancer, type II diabetes and asthma (Made Safe. 2019).

According to Steven Allen - a researcher who has been studying microplastic pollution in the Pyrenees, France - chemical components of plastic impact animals' endocrine and lymphatic systems, which regulate the production of hormones and the elimination of bodily toxins (Stack, L. 2019). While Deonie Allen, a fellow researcher noted that microplastics can alter the chemical composition of the environment by absorbing pheromones that fish and insects depend on to trigger their fight-or-flight response. This, in turn, reduces the organisms' ability to protect and defend themselves (Stack, L. 2019).

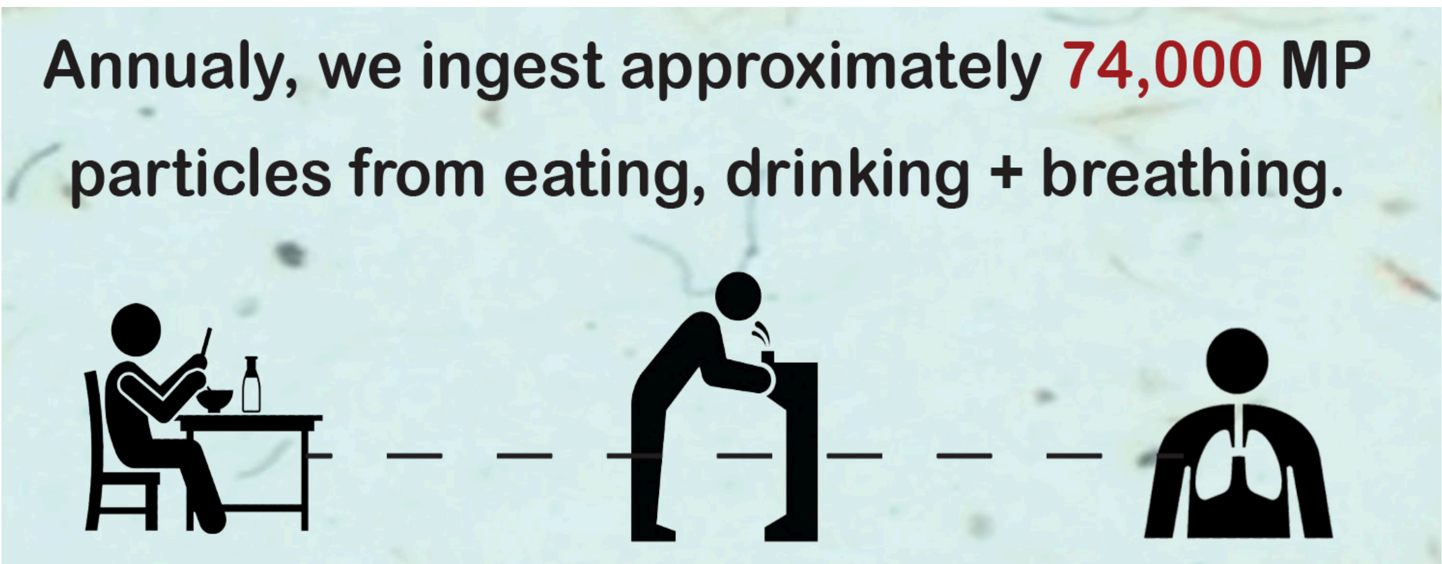
Therefore, ingestion of microplastics can gradually lead to the decline of various species and ecosystems. Researchers at RISE (Rockaway Initiative for Sustainability and Equity) at the Jamaica Bay Wildlife Refuge in Queens, NY, share this sentiment, which led them to analyze fecal samples of diamondback terrapins (native turtles) to determine microplastic ingestion. The results showed that every terrapin studied had ingested microplastic, averaging almost 20 particles per fecal sample (Branco, B; et al. 2019). The most prevalent particles were microfibers, at 83%. The researchers are concerned because microplastic ingestion can diminish a species vital to maintaining healthy marshes: The terrapins at Jamaica Bay control the salt marsh snail population and without them, the marshes could become overgrazed, weakening coastline resiliency (Branco, B., et al. 2019).

It is important to note that plastic and chemical-makeup are not the only negative issues, as free-floating pollutants washing off the land and into our seas, like polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and mercury and other heavy metals tend to adhere to the surfaces of microplastics (Royte, E. 2018). These chemicals are also known to be cancer-causing and endocrine disrupters and are surely harmful to marine life.

A recent study has linked the spread of mercury, a heavily regulated and hazardous compound that can cause neurological disorders, with microplastic pollution. Through methylation, mercury in the ocean becomes methylmercury (an organic and more toxic form of the element), attaches to microplastics and spreads via biomagnification, whereby mercury becomes more concentrated up the food chain, as it bioaccumulates in the bodies of marine life (Li, V. 2019). This indicates that microplastic from synthetic clothing and other sources have the potential to be more toxic than originally thought.

Microplastics also have the ability to transfer from the gut to other parts of the body, as observed in zebrafish. Microplastic particles can translocate from their digestive tracts to their gills and livers (Yifteng, L., et al. 2016). The same is true for European anchovies, European pilchards and Atlantic herrings which were found to contain microplastics in their hepatic tissue (Collard, F., et al. 2017). Although the livers and guts of marine life tend to be removed before human consumption, sea life that are consumed whole, like certain mollusks, for example, are more likely to expose microplastics to the human diet (Smith, M., et al. 2018).

Of course, human consumption of seafood isn't the only point of entry for microplastic into our bodies. Researchers in the US have calculated that we ingest approximately 74,000 microplastic particles every year through simply eating, drinking and breathing (Cox, D.K., et al. 2019).



Although some researchers have claimed it is unlikely that microplastics cause severe harm in humans, the known adverse effects of microplastics on animals may predict their potentially negative impact on humans to some extent (Robertson, R. 2018). Larger microplastics (>0.15 mm) can pass through our bodies without any issues, but problems may arise when the tiniest, invisible to the naked eye, microplastics enter our systems, as they have the potential to penetrate our gut walls and move to other parts of the body (Hugh, 2018).

Early research presented at the at the Rutgers Center for Urban Environmental Sustainability in the spring of 2019 showed that mothers may be able to pass microplastics through the placenta to developing fetuses, exposing unborn babies to harmful chemicals (Loria, K. 2019). Furthermore, in preliminary studies, research has shown that accumulated microplastics in humans may disrupt the gut microbiome, as well as enhance an inflammatory response (Smith, M., et al. 2018). We also currently don't know how cooking fish containing microplastics alters their impact on the human body. These and other adverse effects remain to be evaluated in future scientific studies (Royte, E. 2018).

Microfiber pollution is a global issue and as more scientific research becomes revealed, policymakers need to start thinking about how it can be managed, regulated and possibly eliminated over time. All solutions will most likely be difficult to implement and will take time, money and cooperation from multiple stakeholders, from filter producers, washing machine manufacturers, legislators, government agencies, fashion brands and consumers. Importantly, reducing microfibers should as convenient as possible for consumers, as this will increase the likelihood of any individual strategy being successful.

The next part of the report will discuss the feasibility of various intermediary and long term solutions to mitigate microfiber pollution from synthetic clothing. Intermediary solutions include add-on filtration systems for washing machines, filtration integrated into washing machines and utilizing plastic-eating live matter at WWTPs. Long term solutions imagine the future of textiles, where bioengineered and natural textiles are widely utilized.

DOWNSTREAM SOLUTIONS

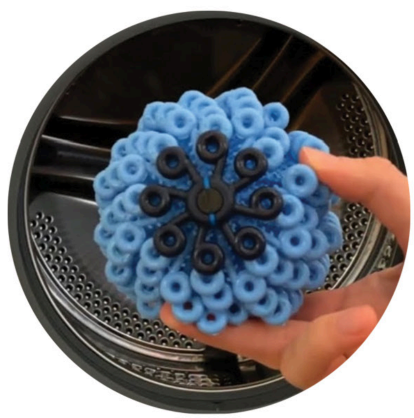
CONSUMER PRODUCTS

Downstream solutions can be thought of as interim measures. Such measures mitigate a problem, while the problematic system stays intact (i.e. the fashion industry continuously produces clothes derived from fossil fuels). So, solutions at the washing machine and WWTP level will be examined here, as they serve as an intermediary fixes until larger systemic change occurs.

Two consumer products that reduce microfiber pollution from washing machines include the Guppyfriend, a high-tech garment wash bag that has the ability to filter out the tiniest of fibers, with an 86% capture rate, and the Cora Ball, a nano ball made from recycled plastic that traps shed microfibers and can cut microfiber release by 25% with each wash (Whittle, P. 2018). Both products retail for about $30 and although they can be viewed as long term investments, they may not be affordable, or even acceptable, to all. As a low-cost alternative, simple garment wash bags made from monofilament yarn would also have some positive impact, as they are highly durable and tend to shed very little when compared to conventional yarn (Nini, J. 2018).

Another approach targeted to consumers is an attachable washing machine filter that, in most cases, needs to be wall-mounted. There are very few companies producing domestic filters, and only one brand, Planet Care, developing a filter for commercial use today.

GuppyFriend



Cora Ball

Filtrol 160

The domestic LUV-R filter by Canadian company, Environmental Enhancements has a fiber capture rate of 87% and according to the creator, Blair Jollimore, has a lifespan of 20 years (Rochman Labs. 2019). Jollimore is still using his prototype from 2003 and claims that customers do not need to replace their filters, unless the exterior housing cracks from being dropped or mishandled. He also refurbishes parts as needed.

There is also the Filtrol 160, a domestic filter by US-based company, Filtrol, that has a 89% capture rate (Johnson, J. 2019). The company estimates that their filters have a lifespan of 10+ years, but only time will tell since their product is fairly new to the market.

In talks with both Environmental Enhancements and Filtrol, neither company is considering the end-of-life of their products, nor making it easy for users to deal with the microfibers that are captured by the filters. Attachable filters require some plumbing skills for initial installation, as well as frequent maintenance, since the inner filtration mediums need to be cleaned approximately every 3 weeks for a family of four (Jollimore, B. 2019). Users also need to ensure that when they clean their filtration mediums, microfibers are not washed down

Image source: GuppyFriend, Cora Ball, Filtrol

the drain but instead placed in the trash, which is ultimately sent to the landfill. This is surely inconvenient for users and can hinder adoption. Filters are also expensive, with an average price of $140 and therefore not accessible to many.

Although consumer education can motivate the public to buy solution-driven products, this report aims to seek mitigation strategies at the legislative level, where the onus is not on consumers. The next section will explore methods for filtration at laundromats, the incorporation of filters into commercial washing machines, and potential new WWTP technology with a view to devising relevant new legislation.

When assessing the feasibility of installing filtration systems at laundromats, materials, lifespan, costs and maintenance all need to be considered.

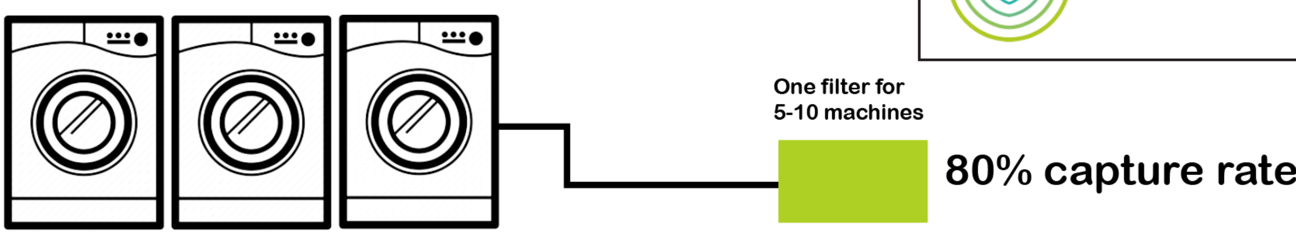
DOWNSTREAM SOLUTIONS

COMMERCIAL INTERCEPTIONS

The Planet Care filter will be discussed in more detail since they are the only company currently designing add-on filters for commercial use.

Planet Care is a Slovenian-based start-up that is creating microfiber filtration systems for both domestic and commercial washing machines. While their current products are designed as "one filter per machine" there is also an upgraded commercial filtration system in development that can serve 5-10 washing machines at a time (Vrhovec, M. 2019). This is particularly important because space can be an issue in tightly packed laundromats, where there is a lack of wall space and separation between machines. Having 1-2 "master filters" connected to a group of machines through the drain pipe might be a successful interim method to handle microfiber pollution, while retaining the current laundromat layout.

Similar to Planet Care's current products, the company plans to design the upgraded commercial filtration system as sustainably as possible, while ensuring that the trapped microfibers do not enter the environment.



To illustrate the company's conscious design thinking, the composition of the materials used in the current commercial filter (one filter per machine) will be examined in detail, as this is what is currently available in the public realm, and will most likely predict the materials used in the upgraded "master filter" version (one filter for 5-10 machines).

The company's filter is composed of three main parts:

- The filter housing
- The filter cartridge body with a 50 micrometre mesh integrated in the cartridge wall
- The internal filter composed of a tubular filter holder and the tailored filtering medium

According to Planet Care, the majority of the filter is made from polypropylene (PP), while the integrated mesh is made from non-woven polyester (PET). Polypropylene is known to be a safe thermoplastic that can be easily recycled. Planet Care has suggested that their used PP parts be turned into fuel, but they do not anticipate these parts being thrown away very often. Just like the LUV-R filter and the Filtrol 160, the structural elements of the Planet Care filter (minus the cartridges) have the potential to last 10-20 years.

The part that will be regularly replaced, however, is the filter cartridge with the integrated mesh, which is made from polypropylene and polyester respectively. The company plans to keep the cartridge in circulation by refurbishing it and sending fresh one back to consumers. This will be achieved via a subscription service. According to Planet Care's Chief Product Officer, Miha Vrhovec, laundromats and other commercial establishments with the upgraded commercial filter will have to exchange their cartridges roughly once per month

Image source: Planet Care

and that collection hubs will be established in the cities where Planet Care has customers.

As part of the refurbishing process, the company will extract and store the accumulated microfibers from the-cartridges, and once stock is built up, recycle the fibers into insulation panels for washing machines (Krazan, A. 2019).

This shows that Planet Care may be able to create a cradle-to-cradle product where its parts are in continuous circulation, as well as creating a market for recycled microfiber pollution. This has never been done before and unlike other filter brands, the fibers will not be sent to the landfill where there is a chance they will reenter soils and local waters.

However, the company's idealized model is not without drawbacks. Although customers do not have to be too concerned about maintenance, Planet Care's subscription model means increased carbon emissions from transportation and additional logistical issues might arise. For example, there may not be enough customers in a particular city to justify the transportation costs. Also, the cartridges may be too damaged for refurbishment, which could potentially lead to incineration and eventual greenhouse gas pollution.

Discussions with a sustainably-focused laundromat in Brooklyn revealed that they would be interested in acquiring a commercial filter and feel that other younger establishments would be keen, too. The laundromat in Brooklyn is already collecting lint from their dryers and partnering with Fabscrap, a NY-based textile recycling and resale establishment, to turn their lint into insulation. Therefore, taking extra steps to protect the environment is not foreign practice for them. However, they do not see buy-in from older laundromats because of the installation, training and maintenance involved (albeit minimal).

It is also evident that all parts of the Planet Care filter are fabricated from fossil fuels, including polyester, which is somewhat counterintuitive to the business' goal of reducing microplastic pollution from synthetic garments. Although the company eventually wants to make their product out of bioplastics, it is uncertain as to when they will have the finances to do that (Krazan, A. 2019).

The costs of the filtration systems need to be accounted for, too. Although the upgraded commercial filtration system is still under development, Vrhovec has estimated that it would retail for approximately $2000 with a monthly subscription fee of $50 (includes collection and refurbishment). Outlay costs could be an issue for many laundromats in New York City and would most likely hinder wide adoption unless the filters were subsidized or funded by the City.

As a hypothetical calculation, it is relevant to estimate just how much money Planet Care's filtration system could potentially cost NYC.

The data gathered for the below calculations were taken from The Wall Street Journal, Planet Care and two laundromats in Williamsburg, Brooklyn.

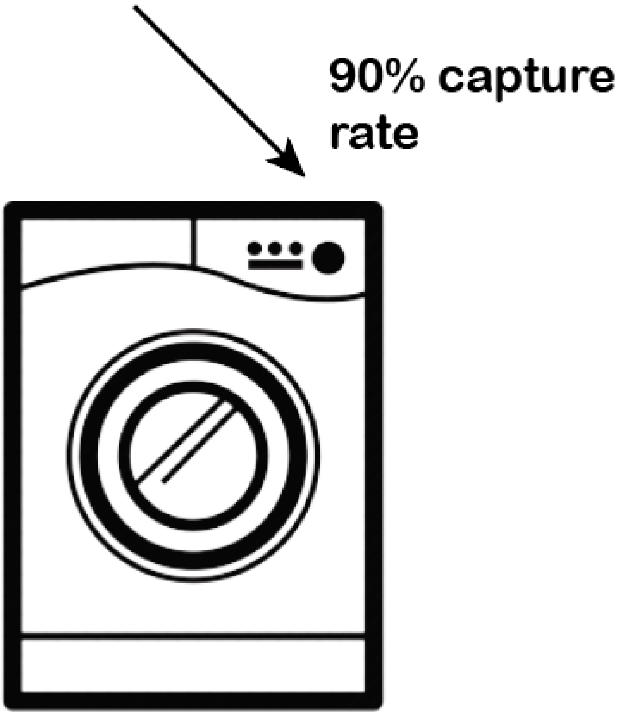
Average number of laundromats in NYC	**2500**
Average number of washing machines per laundromat	**20**
Average number of PC filtration systems per laundromat	**2**
Cost per PC system	**$2000**
Subscription for cartridge refurbishment	**$50 (per system per month), $600 (per system per year)**

Year 1	**2500*(2000*2) + 2500*(600*2)**	**= $13,000,000 or $5200 per laundromat**
Year 2	**2500*(600*2)**	**= $3,000,000 or $1200 per laundromat**

In total, this shows just how expensive filtration at laundromats could potentially be annually. Per laundromat, it could easily equate to a New Yorker's rent for 2-4 months. However, this calculation assumes that all laundromats in NYC will install filtration systems and have the same number of machines, which is unlikely. Additionally, this is based on one brand's prices. New innovations may bring down the costs significantly, and the technology could improve over time to where cartridge replacement is not needed.

Of course, it would be much simpler if filters were built directly into washing machines, like they are in dryers. This would make maintenance easier, as well as drive down costs, and greatly reduce emissions from production and transportation. Currently there are no commercial washing machines being produced with built-in filters. However, one European company, Arcelik, has recently promoted a domestic washing machine with a built-in filter that has a 90% capture rate (Hussain, D. 2019).

According to the company's press release, the product is still in its "fine tuning phase" and is planned to bring to market in 2020. Areclik has open-sourced their technology, so there is a chance that a commercial-producing company will eventually start integrating similar filters into their washing machines.



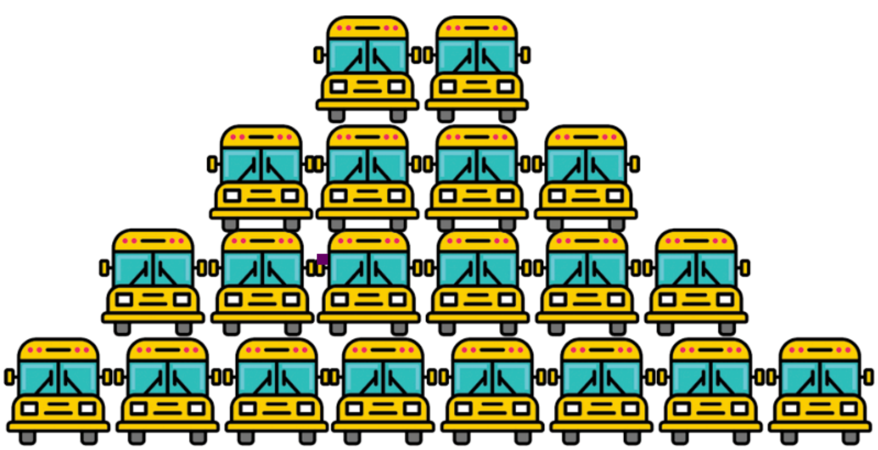
As another hypothetical calculation, it is interesting to see just how many microfibers could be captured if all of the laundromats in NYC had machines with built-in filters. As above, the data gathered for the below calculations were taken from The Wall Street Journal, Planet Care, and two laundromats in Williamsburg.

Average number of laundromats in NYC	2500
Average number of washing machines per laundromat	20
Average load per wash	7 kgs
Average washes per day	75
Average amount of synthetic garments	60%
Fibers released per wash	900 mg/kg (0.0009 kg)
Capture rate	90%

Image source: Arcelik

Annual microfiber release for all laundromats for the City of New York		
Amount of washing per day for NYC	2500*75*7	= 1312.5 tons per day
Quantity of synthetic garments	1312.5*0.6	= 787.5 tons
Amount of microfibers released per day	787500 kg * 0.0009	= 708.75 kg per day (1,563 pounds)
Amount of microfibers released per year	708.75*365	= 258,693 kg per year (570,320 pounds)

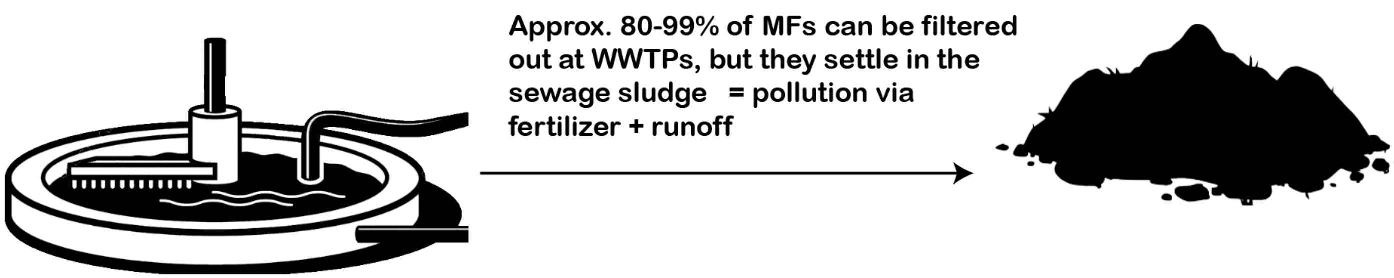
The estimated cumulative amount of fibres that could be prevented from polluting our environment in one year if all laundromats in NYC had internal filters with a 90% capture rate	
258,693*0.9	= 232,824 kg (513,289 pounds)



That weight is equivalent to 20 school buses.

Although this is a promising result, it is also the best case scenario. It must also be noted that the average lifespan of an industrial washing machine is 10-28 years, so wide adoption via replacement will take some time (Consumer Reports. 2018).

WWTPs is another possible site of interception, as microfibers feed directly into them via washing machine effluent. As previously discussed, even conventional WWTPs without tertiary treatment captures close to 90% of the fibers. Tertiary treatment is generally only applied to drinking water treatment plants (DWTPs), but has the ability to capture close to 100% of fibers. For example, studies looking at advanced treatment efficiency found that 99.4% of fibers were captured using a membrane bioreactor (MBR), a tertiary treatment process which includes microfiltration or ultrafiltration with a biological wastewater treatment process, while 98.3% of fibers were captured via an activated sludge process, which, like MBR, includes live bacteria and protozoa (Pico,Y, Barcelo, D. 2019).



According to the NYC Department of Environmental Protection's Matt Burd, none of the plants that treat wastewater in NY include tertiary treatment, while roughly 40% of the DWTPs have the activated sludge component. Burd also cited that processes like MBR and activated sludge are known energy hogs and are generally more expensive to run. Retrofitting WWTPs to include tertiary treatment is an expensive endeavor and can range between $3-5 million dollars (excluding on-going maintenance costs) (Meyer, M.J. 2019). Funding this type of project would also be challenging since the city of NY would most likely have to fund the retrofits themselves, with some help from the State Revolving Loan Fund and grant money (Burd, M. 2019). Retrofits would also take a considerable amount of time, ranging between 2-10 years (Burd, M. 2019).

Furthermore, even if the majority of the fibers are captured via ultrafiltration, they settle in sewage sludge and can easily reenter the environment via fertilizer and runoff. Therefore, there is a need for improved technical solutions.

Researchers in China have looked into the possibility of burning sewage sludge for fuel through various methods, such as anaerobic digestion, combustion, pyrolysis and gasification. Their conclusion was that all of these methods would be extremely costly, as they involve overly lengthy pre-/post- or inter-stage treatment, while also contributing to adverse environmental impacts, such as toxic fumes and greenhouse gas emissions (Oladejo, J., et al. 2019). This is because sludge not only contains microplastics and fibers, but also high moisture, ash, toxic heavy metals and organic contaminants, which can easily taint the final product.

Currently, the type of microbes used at WWTPs biodegrade organic matter only, so another possible solution could be the addition of fungi or bacteria to help break down the plastic particles that enter the treatment plants. For example, a specialized bacteria known as *Ideonella sakaiensis* has the ability to break down polyethylene terephthalate (PET), one of the most widespread plastics that include the synthetic textile, polyester (Patel, N.V. 2019). Researchers have also found that the fungus, *Zalerion maritimum*, can effectively biodegrade polyethylene (PE), another common plastic, with minimum nutrients required (Paco, A., et al. 2017).

These discoveries seem promising, but are still in their early phases of investigation at the lab-scale (Pico,Y, Barcelo, D. 2019).

In talks with Susanne Brander, a professor in the fields of toxicology, endocrinology, and ecology, it was cautioned that testing bacteria and fungi for their effectiveness at WWTPs could be a long and costly process. She also said it would be important to investigate how the current bacteria would live and interact with the addition of new bacteria (Brander, S. 2019).

Opportunity to incorporate plastic-eating bacteria and/or fungi

Still, this type of downstream solution has the potential to be relatively effective for now and the near future while the majority of the world still relies heavily on plastic material.

In summary, city-mandated filtration at the washing machine level and enhancing capabilities at WWTPs are only temporary fixes. For greater and more enduring change, upstream solutions must be considered.

Image source: Science Mag

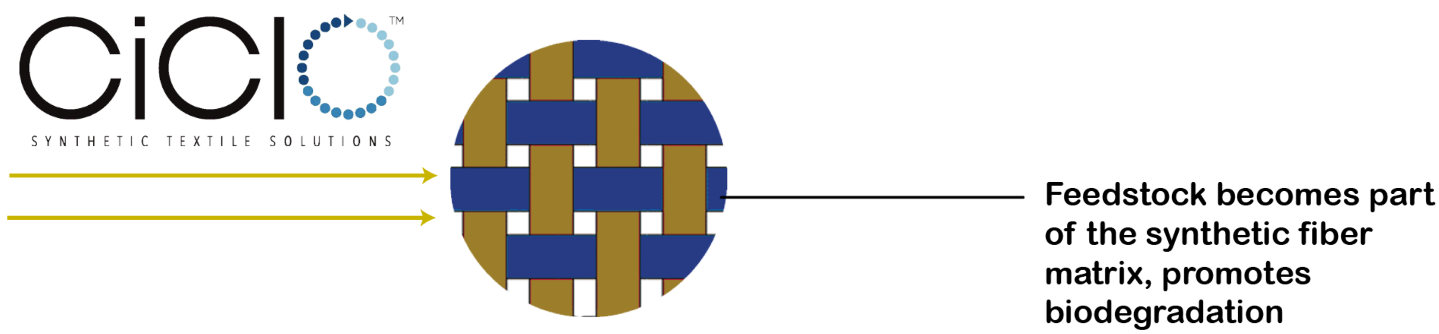
UPSTREAM SOLUTIONS

FIBER LEVEL

Upstream solutions are ones that treat the issue at its origin. These often take more time and initial resources, as well as adjusting to new standards. But, the long term benefits would be worth the investment of necessary resources.

Although it is highly likely that synthetic textiles, like polyester, elastane and acrylic will be produced and be in circulation for many years to come, there are innovative products that are tackling the microfiber pollution issue at the source. These include technologies that speed up biodegradation, create fully biodegradable biopolymers, as well as harnessing the power of natural fibers to replace synthetics.

Intrinsic Textiles is a company that is embracing synthetic textiles, while providing a feedstock, known as Ciclo, that allegedly speeds up biodegradation in seawater, landfill and WWTP conditions. Although the company was unwilling to reveal the composition and other technical details of the product, it is Okeo-Tex certified[1], meaning it is free from harmful chemicals and is safe for human use (Okeo-Tex. 2019). Ciclo is added when the polymer is going through the melting and extruding phases, and becomes part of the matrix of the plastic fiber (Ferris, A. 2019). The founder of Intrinsic Textiles, Andrea Ferris explained that, essentially, Ciclo helps bacteria access and breakdown synthetic fibers in anaerobic and aerobic conditions. In contrast, traditional synthetic fibers have long molecular chains which hinder bacteria from breaking them down.



According to Ferris, their tests show that within 60 days, 15% of the Ciclo-embedded synthetic fibers are broken down by bacteria at WWTPs, and continue to biodegrade in biosolids. Ferris also stated that their studies have shown full biodegradation in landfills[2], which is where most sewage sludge ends up in NY (Burd, M. 2019). Intrinsic Textiles have also tested their technology in soils and have found 50% biodegradation after approximately 100 days (Ferris, A. 2019). This is notable since sewage sludge is also used as fertilizer and can result in toxic microfibers polluting the ground. The fibers can also degrade in seawater, but the rate depends on conditions like the temperature and the microbe content (Ferris, A. 2019).

While the above technology appears to be positive, a significant downside is that it does not discourage brands from using synthetic fibers. Although it will most likely be a slow transition away from plastic fibers, consumers should be wary of how a synthetic garment embedded with Ciclo is marketed, as it may mislead them into thinking that their garment can easily biodegrade and can be "planted" in their garden or thrown in the ocean, for example. Biodegradation of these materials is still being tested and will only occur if the

1 The Okeo-Tex certification is unrelated to biodegradability.

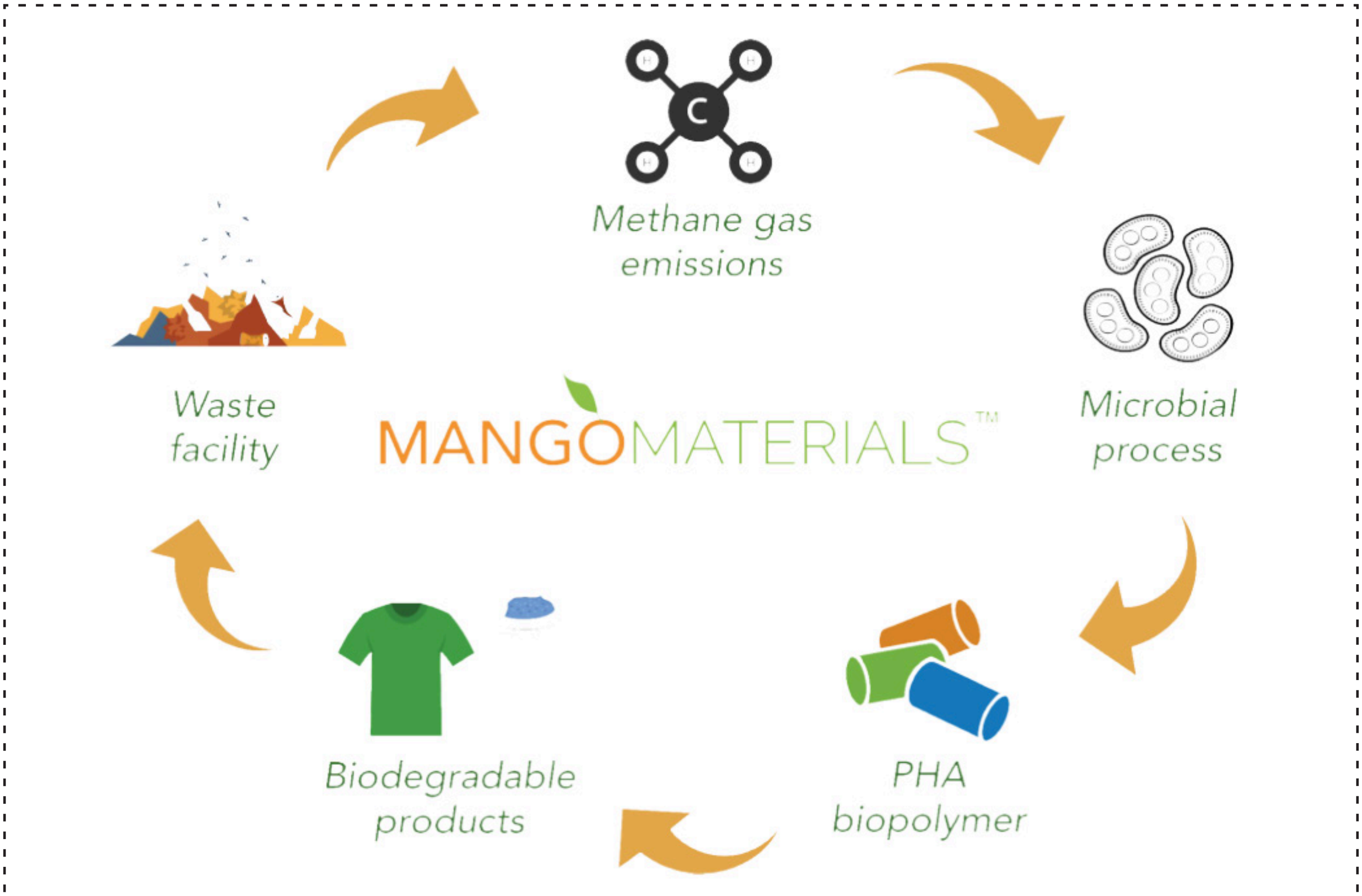
2 Not all landfills promote biodegradation. Certain modern landfills are designed to recirculate leachate and promote biodegradation.

Image source: Intrinsic Textiles

garment is placed in the right conditions, which is usually accomplished via industrial decomposition processes. Microbe content differs in soils, while the temperatures of the sea also widely changes, depending on geographic location.

While Intrinsic Textiles's technology is utilizing synthetic fibers we've been producing and wearing since the Industrial Age, tech start-up, Mango Materials has come out with a unique biopolymer that is changing the way we think about synthetic textiles. The company is in the process of creating a biodegradable plastic, using PHA (Polyhydroxyalkanoates), derived from waste methane.

In short, bacteria are bred in fermenters at WWTPs where they are exposed to waste methane gas, oxygen and other undisclosed additives (Mango Materials. 2019). After the bacteria have been sufficiently fed, they are transformed into PHA, dried and turned into pellets (Joyce, C. 2019). Like PET pellets, they can be spun into polyester-like yarn or turned into hardier plastic items. When garments made from Mango's biopolymer are washed, the released fibers will easily break down at WWTPs in anaerobic conditions. Entire garments can also be fully broken down in landfills[1]. According to Mango Material's VP of Customer Engagement, Anne Schauer-Gimenez, their PHA fibers biodegrade within a few weeks in the anaerobic digesters at WWTPs, and take approximately 6 weeks to fully biodegrade in other water bodies (as seen in a Berkeley Marina study). Schauer-Gimenez explained that they are able to keep their fiber price competitive with polyester because methane is widely abundant and cheap and their process is also energy efficient. The company will be partnering with methane producers at landfills, WWTPs and agricultural facilities, and anticipate their textile being used across a variety of sectors, from outdoor to footwear (Schauer-Gimenez, A. 2019).



1 Not all landfills promote biodegradation. Certain modern landfills are designed to recirculate leachate and promote biodegradation.

Image source: Mango Materials

Mango Materials' innovation is particularly important because it has the potential to prevent the potent greenhouse gas, methane, from entering the atmosphere while creating a product that goes fully back to the earth. A future garment made by the company's fiber doesn't need to be recycled, avoiding the associated excess emissions during the recycling production process and decreased garment quality.

It could be some time before Mango Materials and Intrinsic Textiles become mainstream, as they are still in their early phases of development and are not producing anywhere near the same levels as polyester producers. Since demand for synthetic textiles is increasing at a rapid rate, it will take strong industry change for these kinds of technologies to become widespread. Intrinsic Textiles have said that fabric embedded with Ciclo is price competitive with recycled polyester, while Mango Materials have suggested that their textile is price competitive with polyester prices. If this is true, they may be able to get broader adoption by fast fashion brands that traditionally buy synthetic materials. However, realizing the true effectiveness and costs of each product will only come to fruition when production scales up and big brands start utilizing these respective technologies.

While new textile technology is an exciting development, textiles that have been used for centuries, like wool, still play a role in microfiber mitigation. In this day and age when industries should employ conscious practices for climate change abatement, regenerative wool should be the modus operandi.

Regenerative wool is related to regenerative agriculture, whereby farming practices build soil health and fertility, manage grazing to improve plant health, and boost water retention and percolation (Regenerative International. 2019). This in turn, naturally sequesters CO2.

Wool is a special fiber because it is extremely versatile with great technical properties, such as odor resistance, wrinkle resistance, stretchiness, breathability and the ability to be machine-washed (Woolmark. 219). Most importantly, it can biodegrade in natural environments. Wool can be manufactured into warm, thick layers, but also light, soft textures for activewear. In recent years technical Merino wool items have grown in popularity with some brands claiming that their T-shirts only need to be washed every 46 days (Unbound Merino. 2019).

Image sources: Filson and Textile Learner

If more brands adopted wool as opposed to synthetic fibers in their garments, their customers would have access to higher quality fabrics and would not have to wash their clothes as often, reducing cellulosic microfiber pollution.

Wool is not the sole answer and increased production may lead to unanticipated problems (even if the regenerative methods are applied). It also cannot currently compete in price with synthetic or even bacteria-derived fibers. For example, a polyester activewear T-shirt could retail for about $20, while a Merino activewear T-shirt goes for approximately $40-$60 (Best Hiking. 2018).

Perhaps wool fiber can be lab-grown, which has the potential to drive down costs. With tech start-ups like Bolt Threats growing spider-free silk and Modern Meadow creating cow-free leather through the isolation of proteins, this could be a possible angle for up-scaling the production of superior wool fibers.

All in all, there needs to be more investment in the future of textiles so that the fashion industry and consumers no longer depend on synthetic fibers. This will certainly take time, especially when one considers that the fast fashion industry produces approximately 1 billion garments per year, most of which are synthetic, and profits around $3 trillion per year (Cooper, K.L. 2019). To effect change would require global cooperation and international laws in place.

CASE STUDY
MICROBEAD BAN

In 2012, non-profit organization, 5 Gyres, partnered with SUNY Fredonia to study microbead pollution in the Laurentian Great Lakes. Finding many microparticles of multicolored spheres and aluminum silicate, the researchers estimated that approximately 20% of all microparticles were microbeads from cosmetic products (Eriksen, M. 2013).

As these pollutants were threatening to aquatic life, 5 Gyres, along with other non-profits and activists formed a coalition to get microbeads banned in California. They worked with giant cosmetic brands, such as Procter & Gamble, Johnson & Johnson, L'Oreal and Unilever to voluntarily phase out plastic microbeads from their products (5 Gyres. 2019).

Thereafter, the bill, AB 888 was passed in 2015 in California, which prohibited the sale of personal care products containing microbeads, such as soap, shampoo and toothpaste. California influenced other states to follow suit and in 2015, President Obama signed The Microbead-Free Waters Act into law, making microbeads illegal in the United States, effective 2018.

Although this was certainly a triumph for environmental groups and the ocean, it did not address microplastic pollution from other high emitting sources. However, this kind of activism illustrates how microfiber regulation can gain attention in one state and eventually become federal law.

It is also important to note that the nature of microbeads is different from microfibers in that their addition to a product is not a requirement. Toothpaste can still function perfectly well without synthetic beads, while maintaining its core ingredients. A polyester sweater, on the other hand, is made from synthetic fiber so an outright ban is not a practical decision in the short term. Therefore, different types of regulatory strategies need to be assessed to curb microfiber pollution.

Image sources: BBC and Charcoal & Body

POLICIES
BILLS SETTING THE STAGE

Public policies have the ability to command change. With careful planning, microplastic-related policies can deepen our understanding of microplastics, curb micropollution, create widespread awareness and bring innovative mitigation strategies to the fore.

Although there is no current regulation to reduce microfiber pollution from synthetic clothing, there are bills in place in California to promote the understanding and testing of microplastics from all sources.

PASSED BILLS:

Bill SB 1263 requires a government body, the Ocean Protection Council (OPC) to develop, adopt and implement a statewide microplastic strategy in order to assess risks and seek solutions (Szczepanski, M. 2019). According to the bill, OPC must submit their strategy to the Legislature by December 31, 2021, while providing policy recommendations by December 31, 2025 (California Legislative Information. 2019).

The year 2025 is a long time to await any policy recommendations but studies such as these will most likely bring more insights and consequently, informed action.

Another California bill, SB 1422 requires the Water Resource Control Board to adopt a definition for microplastics, as well as establish a standard to test drinking water by July 2020. The bill also states that the test results would need to be disclosed to the public, making consumers aware of how many microplastics they are potentially ingesting (Dooley, E.C. 2018).

This type of bill will certainly make many consumers wary of their so-called “clean drinking water” and will possibly inspire them to put pressure on brands and government officials to actively mitigate microplastic pollution (in garments and beyond).

PROPOSED BILLS:

So far in New York, there’s been a proposed bill, AB 1549 that requires fashion brands to conspicuously label garments that are composed of 50% or more synthetic fiber as microfiber pollutants. For example, the label would inform consumers that “this garment sheds plastic microfibers when washed, which contributes to marine plastic pollution. Hand washing recommended to reduce shedding” (The New York State Senate. 2019). While consumer education is vital, this bill puts the onus on the consumer to “fix” the problem and realistically will not change mass behavior since consumers have become accustomed to using machines for saving time and labor. Practically and financially, hand washing clothes and avoiding synthetic garments is simply not feasible to many.

California has a similar proposed bill, AB 129, that asks for labelling standards like AB 1549, but takes it a step further by requiring laundromats and other public entities using a laundry system to install filtration to capture microfibers during washing (California Legislative Information. 2019).

AB 129 is thus forcing consumers and laundromat owners to mitigate microfiber pollution. According to the bill, laundromats who purchase filters will be subsidized, an extremely important part to the bill.

An example of what our care labels could look like with the labelling standards in place. This could promote better washing habits + motivate consumers to buy natural when possible.

There have also been discussions about passing a bill requiring all new washing machines to have built-in filters, similar to lint filters found in dryers (Sarnoff, R. 2019). As previously cited, the average lifespan of a washing machine is 10 years, while some can last as long as 28 years (Consumer Reports. 2018) Therefore, it will certainly take some time for consumers and laundromat owners to adopt new washing machines with built-in filters, if the bill is passed.

Finding the ideal prevention and mitigation strategies for microfiber pollution is not a simple task, owing to the number of potential entry points for microfiber pollution and the multiple stakeholders involved. The aforementioned bills all serve an important starting point and can be adapted for the NY State Legislature, with the ultimate goal of eventually becoming federal law.

RECOMMENDATIONS
THE WAY FORWARD

This section will discuss the feasibility and viability of the prior mitigation measures and solutions, through the lens of regulation. As there are still many knowledge gaps on this topic, additional background research is required before any new legislation can be proposed.

While filtration systems at laundromats and filters integrated into washing machines can be enforced locally, it would be extremely difficult to change the fashion industry's dependence on synthetics, which would potentially require global laws and certainly widespread industry cooperation. Therefore, the way forward for New York will focus specifically on what can be practically accomplished at the municipal level in the near future.

Filtration at laundromats may be a viable intermediary solution for NYC as it will avoid a multitude of microfibers from entering WWTPs, soils and waterways. However, a funding plan to subsidize laundromat filtration would need to be considered. For example, either the City could sponsor the filtration systems or laundromats could pay for them, while receiving some compensation or rebate from the City. As previously shown, a single laundromat may have to spend approximately $5200 for the first year of filtration, which includes purchasing the product, as well as receiving fresh cartridges monthly. After year one, cartridge refurbishment fees would equate to roughly $1200 per year. If NYC was solely sponsoring the filtration this would equal to approximately $13,000,000 in year 1 and $3,000,000 in year 2 for all 2500 laundromats in NYC. For the City to take full financial responsibility is an unlikely scenario, however. Whether the City or laundromats were covering the majority of the costs, it is surely expensive and may not be an acceptable option. However, these cost figures are based solely on Planet Care's commercial filtration system and perhaps another company will design a less expensive commercial filtration solution and/or one that does not include cartridge refurbishment.

Other costs involved in implementing filtration at laundromats include staff training and regular maintenance by laundromat managers. Maintenance at some NYC laundromats may be problematic since most laundromats are self-service and don't necessarily have staff on-site on a regular basis to attend to or clean the machines (Sarnoff, R. 2019). With that said, there may need to be consumer signage, which teaches laundromat users to change the cartridges. This too can lead to complexities since users may not follow the instructions correctly or even take note of them.

It would also be beneficial for the City to set up a collection and recycling program to ensure the microfibers do not enter the environment. They could potentially team up with Planet Care or a curbside collection organization, Terracycle, to carry this out since this is already part of the respective companies' business models. According to Planet Care CEO, Miha Vrohev, the company's target countries for the next 6 months include The Netherlands, Denmark, Germany and the UK where cartridge refurbishing hubs will be established. If this model appears to be successful, it could be a relatively easy partnership for NYC. On the other hand, Terracycle is already established in New Jersey, NY and focuses on collecting non-recyclable pre-consumer and post-consumer waste and turning this into raw material for new products, through strategic partnerships. Being locally established, it may be a smoother transition to collaborate on microfiber collection and recycling with Terracycle.

Estimated transportation emissions should be calculated, as this may reveal that the costs outweigh the benefits for such a service. Similarly, an in-depth product lifecycle analysis for the commercial filtration system needs to be undertaken to determine its full environmental impact. This would include all phases, from material extraction, production, use to end-of-life. The use phase would be an important aspect, since running machines with add-on filters has been shown to require more energy, resulting in more CO_2

(The Swedish Environmental Protection Agency. 2019). Comparing fossil-fuel derived components used in the filtration system with bio-based materials would also be an enlightening study to investigate whether the carbon emissions could be reduced. Essentially, researchers should ascertain the extent to which "pollutant swapping" is occuring, if any of the processes could be offset by renewable energy or more ecologically sensitive components, and if the addition of filtration systems at laundromats are really worth the time, resources and money.

Filtration may be able to serve as an intermediary solve while new washing machines with built-in filters are manufactured. Upgraded washing machines will, in turn, mean less maintenance for users and has the potential to prevent 90% of microfibers from entering WWTP per wash. Similarly to California, NYC could propose a bill stating that all new washing machines sold in the city must have integrated filters. Given the economic and cultural influence held by NYC and California, this initiative could inspire other cities or states to do the same and the idea could possibly spread to other parts of the world to become the new standard, like the Microbead Ban. But, the process of transitioning to upgraded washing machines could potentially take between 5-30 years. This will vary based on the age of the respective machines at the different laundromats around the city, which makes a good case for intermediary add-on filtration.

Additionally, new machines with integrated filters would most likely cost more than conventional washing machines since washing machine producers would have to spend more on R&D and additional manufacturing costs. This may hinder commercial establishments and consumers from upgrading their machines since they may not have the finances or wish to spend extra money on an already pricey appliance (a Google search reveals that upgraded domestic machines could range between $400-$1000, while commercial machines could retail for approximately $1000-$4000). At present there is no available pricing for the soon-to-be-released washing machine with an integrated filter by Areclik, so these estimates are speculative. The City may be able to enforce a pricing limit on upgraded washing machines to encourage buy-in and ensure there is more accessibility.

With regards to WWTPs, it does not appear that upgrading primary and/or secondary treatment plants to tertiary treatment (which includes micro or ultra filtration with a biological process) makes logical sense at present. This is because the majority of microfibers still make their way into sewage sludge from wastewater influent and reenter the environment via runoff and fertilizer. Since there is no sustainable way of treating the sludge currently, it would make more sense to explore plastic-eating live matter at WWTPs. Testing to see if plastic-eating bacteria and fungi can thrive with microbes that eat organic matter should be undertaken, as well as investigating the possibility of retrofitting WWTPs to add a new treatment step for microplastic breakdown by bacteria and/or fungi. This project would most likely require a significant amount of funding and research time with highly experienced scientists in the microbial field. Once again, the feasibility of a funding plan would need to be explored.

Consumer awareness and education have the potential to change clothes washing habits. NY's proposed bill (AB 1549) requiring fashion brands to label their synthetic garments as microfiber pollutants may motivate consumers to hand wash their garments more frequently and/or purchase garments with more natural fibers. Importantly, conspicuous microfiber labelling on new clothing may encourage consumers to put pressure on fashion brands to change their textile assortment. Fashion brands may even take it upon themselves to start changing, as they may not want to be associated with known polluting products. Similar to California's passed bill (SB 1422), testing and reporting on the microplastic levels in NYC's drinking water could also promote consumer defiance and brand evolution. Attributing a portion of the microplastic pollution levels in drinking water to synthetic garments will be a key education step to start changing perception and fashion purchasing habits.

Additionally, a consumer-awareness campaign at laundromats and digital platforms may also persuade consumers to purchase their own microfiber-reducing products. But it is highly unlikely that this would result in mass adoption due to price and current accessibility. Some sustainable fashion brands and environmental groups have spoken out about the chemicals used in clothing production, with a smaller percentage talking about microfiber pollution. These kinds of establishments tend to reach consumers who already care about these issues, so finding a way to address a broader audience would be an ideal strategy and could be promoted and/or partly funded by the City of NY and other organizations in the sustainable fashion space.

Ultimately, the true responsibility of mitigating and eliminating microfiber pollution from synthetic clothing lies with the fashion brands that are creating plastic garments. Since the fashion supply-chain is so vast and widely spread, with the majority of garments being produced in Asia, perhaps NYC could enforce a tax on brands that are bringing synthetic garments into the City, and the money accrued would go towards microfiber research and reduction methods (Bedat, M. 2019).

Successful fast fashion brands like H&M and Zara presumably have the financial resources and influence to invest in up-and-coming start-ups specializing in bio-engineered and organic, naturally-derived textiles that are plastic-free and hence, better for the environment. The fashion industry needs to reevaluate the old, toxic way of garment production, as well as band together to start evolving in a direction that values and celebrates natural processes. Innovative alternatives, like bacteria-grown polyester (a la Mango Materials), lab-grown silk and leather exist, but will only become mainstream if there is buy-in and support from the fast fashion giants. New materials will be more expensive, but with higher production orders comes lowered costs, which will help consumers transition to superior textiles that can last longer and require less washing, as exemplified in a technical wool T-shirt.

Conversely, consumer buying habits also need to change. We've come accustomed to buying plastic clothing for so long and are used to the extremely low prices, too. Fashion brands need to educate their customers as to why certain fibers are better for the environment than others, so that consumers can become empowered and make better choices. Brands should also be careful not to use greenwashing tactics by making sure to fully vet and test their technologies before making vast claims that their garments are fully biodegradable when they are not, as this will lead to consumer confusion. Perhaps NYC regulation could be introduced to avoid false marketing claims related to greenwashing.

Strategies behind mitigating, preventing and eliminating microfiber pollution from synthetic clothing will not be a quick or easy feat for NYC or the fashion industry at large. As researchers still do not know the extent to which microplastics are affecting human health, it is challenging to create public awareness or urgency to justify the need for any of these strategies. However, as more research comes to the fore, it is important to have some foundations in place, as well as some well considered plans for NYC and beyond based upon the current state of our knowledge.

Summary of Solutions: Pros & Cons

Long term to short term

Potential Solution	Pros	Cons
Add-on filtration at NYC laundromats	80% of fibers captured per wash Relatively easy to maintain Long lasting product Intermediary solution while MF mitigation methods develope	May be expensive Requires staff or customers to maintain Fossil-fuel derived = CO2 Need to ensure MFs do not enter the environment - logistical issues
Washing machines with integrated filtration	Approx. 90% of fibers captured per wash - legislation Easier to maintain, no installation Improves wastewater quality Innovation in washing machine space	Average cost of washing machines likely to increase Product currently not ready for market Adoption may take 5-30 (depending on age of machines)
WWTP retrofitting	Improve water quality for ecology and humans alike Promotes research + innovation, e.g. plastic-eating bacteria + fungi	Costly to upgrade to tertiary treatment Upgrades could take 2-10 years Research into the addition of live matter will be expensive and take time - may not be effective or successful
Labelling synthetic clothings as MP pollutants	Promotes consumer awareness + better washing practices May motivate consumers to avoid synthetics, put pressure on brands to change, and purchase MF-reducing products (e.g. GuppyFriend)	Will need cooperation from brands to adhere to labelling rule May not change consumer behavior due to time and money constraints (e.g. may not have time to hand wash synthetic items)
Taxing fashion brands selling synthetic garments for MF research	Putting the responsibility on fashion brands May promote textile evolution Money going directly into MF research, mitigation + elimination strategies	May recieve push-back from fashion industry and lose retailers Hard to control in the internet/online shopping age Will need country-wide cooperation + agreement - will take time
Fashion industry adopting biodegrad-able fibers, rejecting synthetics	Reduces synthetic MF pollution - may eliminate over time Uplift smaller businesses in the bioengi-neerd + natural textile technology space Transform the industry for the better - avoiding plastic (CO2, GHGs)	Will take a long time for the fashion to transition from synthetics Price of innovative textiles may not be able to compete with synthetics or be scaled-up in the same way Greenwashing may occur = consumer confusion, brands skipping steps

CONCLUSION

Microfibers from synthetic clothes are polluting the natural environment, threatening ecosystems and potentially human health. The production of synthetic clothing does not seem to be slowing down, while trillions of fibers are released into waters regularly on a global scale.

Research into microparticle pollution, which includes microfibers, is still new territory and requires more investigation. However, intermediary and long-term solutions exist and can be carried out with regulation and cooperation. Money, resources and time will be essential for any of the solutions to come to fruition.
However, with the right leadership and dedication, the microfiber conversation can enhance consumer awareness, as well as drive innovation in the washing machine and textile space to change the respective industries for the better.

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