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BREATHING IT IN:

A REVIEW OF INDOOR AIRBORNE MICROPLASTIC RESEARCH

Prepared by:
Kristine Roy
Thea Caplan
Zachary Adams

WORCESTER POLYTECHNIC INSTITUTE
WPI

Breathing It In: A Review of Indoor Airborne Microplastics Research

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by
Zachary Adams
Thea Caplan
Kristine Roy

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Report Submitted to:
Prof. Barbara Rothen-Rutishauser, Prof. Alke Fink, Dr. Patricia Taladriz, and Dr. Ruiwen He
Adolphe Merkle Institute

Prof. Laura Roberts and Prof. Christopher Brown
Worcester Polytechnic Institute

Abstract

This project was conducted in association with the BioNanomaterials Group at the Adolphe Merkle Institute, in Fribourg, Switzerland. The aim was to obtain a complete picture of existing research on indoor airborne microplastics, and provide recommendations for improvements to future research. We performed a literature review and conducted semi-structured interviews with relevant professionals in order to gain a complete perspective on the current state of the field. This insight was used to inform a set of recommended practices for future research, including particle and method standardization, in addition to a call for increased transparency between microplastic research groups. This report is accompanied by a set of tables containing information used in the literature review.

Executive Summary

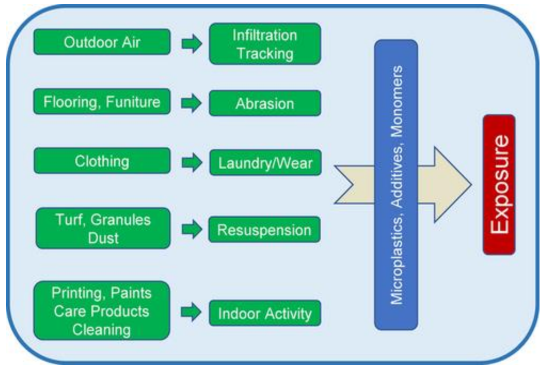


Figure 1: A diagram displaying

Microplastics (MPs) are plastic particles smaller than 5 mm. Due to their size, MPs can become airborne, and are easily transported. These indoor airborne microplastics (IAMPs) are of particular concern, as humans spend over 90% of their time indoors (Kacprzak & Tijing, 2022). Figure 1 depicts pathways to MP exposure. Societal concerns have recently arisen regarding the effects of MPs on both humans and the environment, some speculating that long-term exposure to MPs may result in detrimental health effects. IAMP research only emerged as a new area of study in 2016, and these effects have not yet been proven.

The project goal was to assist the BioNanomaterials Group at the Adolphe Merkle Institute to identify the extent of current research on IAMPs by conducting interviews and reviewing relevant studies. We identified three key objectives to achieve this goal (Figure 2).

Figure 2: A graphical representation of the project objectives

Our Methods

We conducted research within the field of IAMP by performing a literature review and conducting semi-structured interviews with professionals working in IAMP and related fields. For our literature review, we identified 46 papers relevant to airborne MPs, evaluating each by abstract and findings to identify papers high or medium-relevant to IAMP. 30 identified papers were then reviewed to create categories for organizing data. Categories were defined for experimental (N=20) and review (N=10) papers separately. Finally, papers were evaluated based on these categories within tables to organize data in an easily comparable manner.

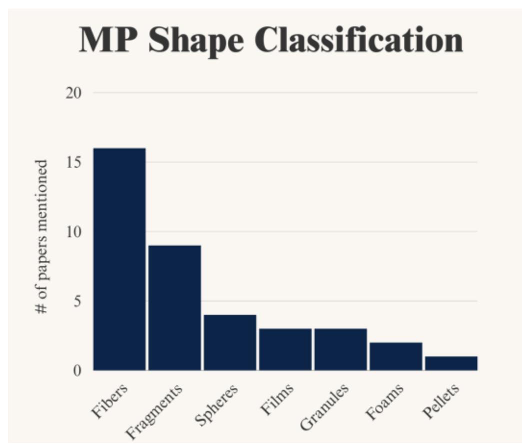
Our interviewees included an indoor air quality laboratory head, an air pollution specialist, a toxicologist, and four researchers at the Adolphe Merkle Institute. Interviews were conducted in a semi-structured format, and snowballing was used to find additional contacts for interviews. Our research was compiled into two final products: a report detailing our research process, findings, and suggestions for improvement in the field of IAMP, and tables with our compiled information from the reviewed studies. These deliverables will be used by the BioNanomaterials Group as the basis for a grant proposal.

Findings

Inconsistency in Defining Physical Characteristics

MPs encompass a large range of sizes. Although the upper bound of 5 mm is widely agreed upon (ECHA, 2023), the lower bound is not as clear and ranges from 1 nm to as high as 20 μm (Hartmann et al., 2014), which poses a problem for consistency in studies, as different tools are adapted for different size ranges. In addition, none of the tools employed in this field are capable of measuring particles along the entire size range - for example, the commonly used μ-FTIR cannot examine particles below 1 μm. Due to the size variation, studies use different tools to measure MP particles, which leads to difficulties in comparability between studies.

Shape classification is one of the areas containing the most confusion. In addition to the commonly defined fibers and fragments, there are several categories present only in a few papers, including films, foams, granules, nurdles and pellets (Figure 3). Even common particle types are inconsistently defined - fibers, for example, depending on the study, can have length-to-diameter ratios of 3:1 (Chen et al., 2021), 5:1 (Choi et al., 2022), or something else entirely.



MP composition is highly variable, and depending on the sampling environment can feature dozens of different polymer types. In addition, many plastic products contain additives which improve properties such as flexibility and flame retardation. Much of the current work on IAMPs does not investigate additives in detail, as they are difficult to identify even without the existing problems surrounding identification of these particles.

Concentration is another important metric for understanding IAMPs, particularly for risk assessment and health effects. Current research uses a wide variety of units, many of which are completely independent of each other, such as μg/g and $\mu g/m^3$ (Bergmann et al., 2019, Zhang et al., 2019). Disparity in units makes it difficult to compare many of the results of different studies.

Controls

Differences in the controls implemented between studies may lead to doubts regarding the validity of some study's results. Several categories of controls were identified between the studies examined within this review: a negative control, a positive control, clean air conditions, and plastic substitutions. Negative controls, like blanks, are used to ensure there is no contamination through the collection or testing process (Rosenburg, 2022) by the use of a sample which is known to not include any of the substance which is being tested for. Positive controls are used to ensure that the results which a study is producing are correct (Rosenburg, 2022). This may mean testing a sample with a known concentration of the substance which is being tested for, and comparing the value determined through testing to the known value. Studies may also utilize clean air conditions, such as a fume hood or clean room, to keep sample contamination to a minimum. Some laboratories will reduce the amount of plastic present by replacing plastic tools for other materials, only wearing all-natural clothes, and wearing gloves or a facemask. Unlike current research, ideal studies would utilize all four of these sampling methods (Table 1).

CONTROLS COMPARISON

PAPER	NEGATIVE CONTROL	POSITIVE CONTROL	CLEAN AIR CONDITIONS	PLASTIC REDUCTION
(ABBASI ET AL., 2019)	✗	✗	✗	Only clothing made of natural fibers worn; Gloves worn; Facemask worn
(BERGMANN ET AL., 2019)	✓	✗	✓	Plastic equipment substituted; Only clothing made of natural fibers worn
(CAI ET AL., 2017)	✗	✗	✗	Plastic equipment substituted
(CHEN ET AL., 2022)	✓	✓	✗	Only clothing made of natural fibers worn; Gloves worn; Facemask worn
(CHOI ET AL., 2022)	✗	✗	✓	Only clothing made of natural fibers worn; Gloves worn

Plastic equipment substituted · Gloves worn · Only clothing made of natural fibers worn · Facemask worn

Table 1: A chart comparing the controls used

Techniques

The most common techniques used within IAMPs include Fourier-transform infrared spectroscopy (FTIR), Attenuated Total Reflectance FTIR (ATR-FTIR), Raman, scanning electron microscopy (SEM), and fluorescence microscopy

TECHNIQUE USAGE AND ADEQUACY

	ADEQUATE	INADEQUATE	UNUSED
FTIR	12	1	7
RAMAN	2	0	18
SEM	5	0	15
FLOURESCENCE MICROSCOPY	2	1	17

Table 2: Count of studies using

(Table 2). FTIR and ATR-FTIR, a more accurate variation, are used to identify the composition of MPs. Raman spectroscopy is used to identify the shape and composition of MPs, though it shows a bias toward crystalline structures. SEM is used to identify the morphology and texture of MPs. The minimum size of each of these instruments is debated. For example, five studies specifically mentioned the FTIR machine used as the Nicolet iN10 MX, which has a minimum size measurable of 50 µm without liquid nitrogen and 3 µm using ATR-FTIR (Thermo Fisher Scientific, n.d.), while some reviews list the minimum size as 20 µm (Zhang et al., 2020), and other studies do not specify the minimum examined size at all.

Software vs Manual Characterization

Studies either use manual visual characterization or software to identify physical characteristics. For manual optical microscopy, one study stated the minimum effective size viewable was 100 µm, but other studies claimed the limit was 20 µm (Kacprzak & Tijing, 2022). Studies using software for MP characterization to identify physical characteristics (N=5) use programs such as ImageJ or MPhunter to count particles and to measure dimensions.

Software is used in MP studies to characterize composition (N=8). Spectral libraries such as Thermo Fisher's OMNIC are used to determine composition. Noise within readings and additives in MPs can cause incorrect readings. Studies specified varying confidence interval thresholds from 60-90% for accepting a match from a library, while others did not specify the implemented confidence interval threshold at all. An interviewee suggested generating reference spectra specific to the experiment being run with the same equipment could increase accuracy, however only one reviewed study implemented such a process.

Health Effects

While it is generally assumed that there will be health effects associated with MP inhalation, there have been no conclusive studies proving the specific effects of MPs. The size, shape, ability to accumulate, toxicity, and additives of MPs may determine the health effects they cause. Smaller MPs are easily inhaled, and below 10 µm are able to bypass the lungs' filtration systems and remain in the deep lung. Fibers, the most common MP shape (Enyoh et al., 2019), are hypothesized to be the most dangerous. The fiber shape confuses cells, making them more likely to persist in the lungs. They may also poke holes in cells due to their shape, despite their flexibility. When MPs, such as those that are small or fiber shaped, begin to build up in the lungs, bioaccumulation may occur (Vianello et al., 2019). Increases of MP concentration within the body is concerning, as toxicology and concentration are closely related.

Additives, or the chemical compounds added to pure plastics to give them mechanical properties, are purposefully added and known to be toxic, causing another possible source of health effects. Several additives are known to be carcinogenic, or toxic to the reproductive and nervous systems (Salthammer, 2022). When IAMPs are inhaled, these factors may combine to result in an inflammatory reaction. This reaction may result in conditions such as fibrosis and certain autoimmune diseases. However, not all researchers are convinced that MPs pose a serious threat to human health due to their inert nature and low concentrations within the body.

Recommendations

Our recommendation is to increase communication between researchers working in the field of IAMP. Methods are constantly being developed, and one interviewee expressed his opinion that due to the pace at which methods are developed, it is impossible to determine whether each is effective. Collaboration would lead to the development of fewer, more standardized, and more effective methods. These methods may become a Standard Operating Procedure, or an outline of the methods and controls necessary for a particular process. The use of a Standard Operating Procedure would lead to more consistent and reliable results.

MPs may need to be standardized to create a standard operating procedure, as not every method will be effective on every MP. The process of standardizing MPs would be easier if researchers collaborated, as some create their own categories of MPs throughout the course of their studies. The prospect of collaboration is impeded by the competitive nature of research, but if this obstacle is overcome, the field of IAMP research would greatly benefit.

To aid in the mitigation of IAMPs, we recommend that legislation continue to be implemented to stem the production of MPs. The EU law passed in September, 2023, which restricted major MP sources such as turf, is a great example of legislation which may be passed to aid in MP reduction. Future legislation may follow in the EU's example by restricting the use of plastic products which are known to be MP sources. Once MPs are not produced in such high quantities, researchers may devote their attention to removing MPs which currently persist in the environment.

Authorship Statement

	Primary Author	Primary Editor
Abstract	Zachary Adams	
Authorship Statement	Kristine Roy	Thea Caplan
Executive Summary	All	All
AI Statement	Kristine Roy	
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AI Statement

The AI tool, Research Rabbit, was used to find sources for this paper. Papers that were the most relevant to the topic were entered into the system, which then created a network of other similar sources. This was helpful, as most research regarding microplastics focuses on aquatic environments, and it became difficult to identify sources which focused on indoor airborne microplastics.

MEET THE TEAM

Kristine Roy
B.S. Chemical Engineering
Class of 2025
Koroy@wpi.edu

Thea Caplan
B.S. Computer Science
Class of 2025
Tcaplan@wpi.edu

Zachary Adams
B.S. Mathematical Sciences
Class of 2025
Zwadams@wpi.edu

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Chapter 1: Introduction

The goal of this project was to assist the BioNanomaterials Group at the Adolphe Merkle Institute (AMI) in identifying the extent of current research on indoor airborne microplastics (IAMP) by conducting interviews and reviewing relevant studies. The information gathered in this paper may be used to inform future research in this field.

The importance of this project stems from recent societal concerns about the effects of microplastics (MPs), in the absence of conclusive scientific evidence regarding their effects on human health. It is known in the scientific community that the news may hyperbolize inconclusive findings of research to sound falsely definitive (Ratcliff & Wicke, 2022). This is especially dangerous when life-threatening effects are broadcast based on inconclusive science. This coverage can lead to increased public unrest regarding topics that have not yet been sufficiently researched to determine a positive or negative impact, particularly concerning human health. In addition, current research being conducted on MPs, especially IAMP, lacks standardization, resulting in experts in the field disagreeing on the validity of findings. While MP research has yet to come to consensus on the effects of MPs on human health, a small number of studies suggesting negative health effects are frequently and sensationally referenced in news articles. However, studies that show minimal health effects, or which focus on developing the quality of IAMP studies themselves are not. This may lead to public perception that MP exposure is far more dangerous than current research has suggested. By improving the quality of IAMP studies, more conclusive results can be found, detailing the true effects of MP exposure on human health and these results can be shared with the public with confidence. Current research on MPs has in large part been directed towards mitigating them in natural environments, due to their effects on ecosystems and animal life. However, the nature and effects of airborne MPs, particularly IAMP, have been minimally researched.

The known correlation between long-term exposure to other small particles and higher risks for health conditions has caused concern about the effects of long-term MP inhalation. Given that humans spend over 90% of their life indoors, particles present in indoor air pose a much more significant risk of inhalation than those in other environments due to exposure alone (Kacprzak & Tijing, 2022). Despite potential correlations between long-term exposure to MPs and higher risk for health conditions in living organisms such as fish, the effects of IAMP accumulation have not been heavily studied.

1.1 - Classification and Composition of Microplastics

MP are plastic particles defined as having an outer diameter between 1 μm and 5 mm (Kacprzak & Tijing, 2022). Due to their size, MPs are easily transportable and can be found in almost any environment.

There are currently two recognized classifications of MPs: primary and secondary. Primary MPs are plastic particles introduced to an environment while already under 5mm in size, including microbeads, used in toothpastes and cosmetic products, and plastic pellets used for the manufacturing of plastic products. Secondary MPs are introduced to an environment as larger products, such as water bottles or plastic bags, which then break down due to environmental effects, releasing MPs into the environment (Choi et al., 2022). MPs may consist of a variety of materials, including polyester, polyvinyl chloride, micro-rubbers and polyethylene (O'Brien et al., 2023). As these materials become increasingly common, the issue of MPs and their growing presence in the environment is an increasing cause of concern.

Studies on MP deposition in indoor environments have revealed that over 90% of indoor MPs originate from the deterioration of low-quality textiles composed of polyester or nylon (Zhang et al., 2020). However, MP composition is highly dependent on the type of environment in which sampling is conducted - MPs in a factory workspace might be primarily composed of PVC or microbeads, for example, rather than textile fibers (Torres-Agullo et al., 2022). In addition, factors such as land topography, population density and wind speed also affect indoor MP distribution and composition (Nematollahi et al., 2022).

1.2 - Sources of Indoor Airborne Microplastics

MP can originate from a multitude of sources, from outdoor activity and environmental abrasion of trash in landfills to everyday actions within homes. Understanding the many sources of MPs is essential to determining mitigation strategies, especially in indoor environments where there is limited airflow.

Airborne MPs may originate from a number of sources within indoor environments. The most common is indoor textiles, particularly those containing synthetic materials such as polyester and rayon, examples ranging from clothes to mattresses. As the fabric is placed under stress, such as when clothes are worn or carpets are walked on, abrasion allows microscopic fibers to disengage from their source material and become suspended in the air. One study collected and analyzed airborne MP particles within a dormitory, and found that most of the airborne MP fibers collected matched those produced by textiles. In particular, the most common fibers present in these environments came from low-quality synthetic textiles, particularly clothing. Conversely, higher quality textiles were noted to produce far fewer MPs (Zhang et al., 2020).

Of all known indoor sources, synthetic clothing is the largest producer of MPs. Clothing is subject to the constant movements and frictions of everyday life, each abrasion pulls MPs from the textile and introduces it into the environment. Some clothes undergo abrasion testing, where the ability of the fabric to hold up against abrasions is examined (Salthammer, 2022). However, this study focuses on the integrity of the material's surface, not the release of MPs. Despite this, clothes made of higher quality fabrics perform better in abrasion testing, and are likely to produce less MPs (Zhang et al., 2020). Other textiles, such as flooring and furniture, may be tested as well. These textiles show a similar correlation between performance in abrasion testing, and a decreased likelihood of producing MPs. Though they are not textiles, shoes may also produce MPs when their plastic soles are worn down. If one were to brush against an interior wall while walking, their clothes and shoes would not be the only sources of MPs. The wall paint and floor finish would also likely produce MPs, as a result of the friction created (Przekop et al., 2023).

Factors beyond everyday movements add to the concentration of MPs within the indoor environment as well. MPs may be produced if a plastic is subjected to high levels of heat. 3D printing is a probable source of MPs within the indoor environments (Przekop et al., 2023). Other activities may contribute to increasing concentrations of MPs indoors, especially those which involve artificial turf. Turf is often found in both indoor and outdoor arenas for sports activities, and may be categorized as either artificial grass or rubber mat. Artificial grass consists of organic polymers, and rubber mats are produced using recycled materials. There are high levels of stress exerted on these flooring materials, and as a result, high concentrations of airborne particles may be produced (Salthammer, 2022). As these particles often exist in such high concentrations in their source environments, they may be spread by airflow or human carriers to other indoor environments.

A study conducted in 2022 by Chen et al., also found that MP fibers can accumulate in air conditioner filters. Results, in addition, showed that long before the end of the filters' useful lifespan, enough MP particles built up in the filter that they could be picked up by the air exiting from the unit. This was shown to, after that point, lead to a significantly increased concentration of MP particles present in the air surrounding the unit, which was noted as a concern due to potential health effects (Chen et al., 2022).

Studies have also found that other household items such as toys, bowls, utensils, electrical cables, and electronics become a source of MPs as they wear down over time (Ageel, Harrad, & Abdallah, 2022). Small plastic beads are commonly added to a number of household products, such as cosmetics, personal care products, detergents, and cleaning agents (Salthammer, 2022). These beads are not only a notable primary source of MPs, as they may persist within the indoor environment in which they are used, but are also at risk of ending up in water systems, as they are often small enough to bypass filtration devices. Salthammer (2022) identifies multiple pathways to indoor MP exposure (Figure 1).

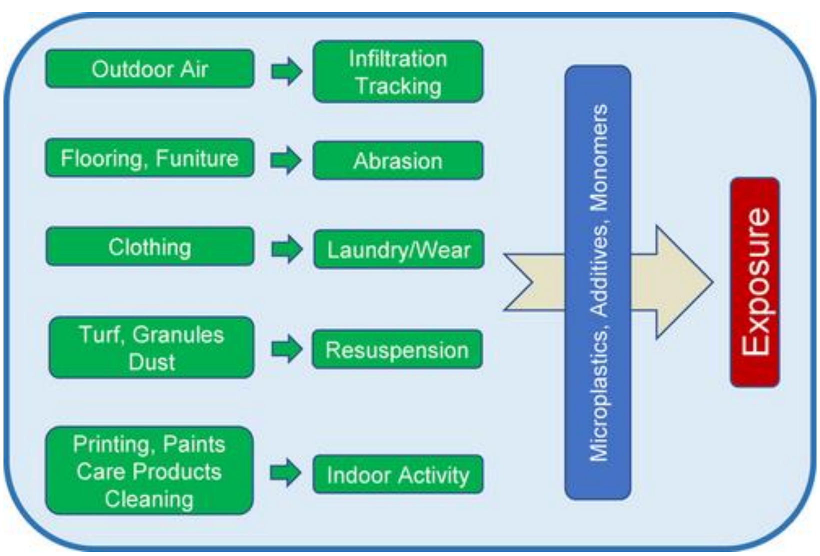

Figure 1: This diagram displays possible pathways to MP exposure indoors (Salthammer, 2022)

1.3 - Medical Effects of Indoor Airborne Microplastics

As the concentration of MPs in the environment increases, human exposure will only increase. The health effects of MP exposure are still heavily debated, but it is believed by some researchers that these effects are likely detrimental (Wright & Kelly, 2017). The prevalence of MPs in all environments makes studies of their effects on human health difficult as there are no control groups. Adverse health effects tied to high MP exposure include obstruction, inflammation, and accumulation in organs (Ageel et al., 2022). These effects may lead to conditions such as chronic bronchitis, lung disorders, and autoimmune diseases (Przekop et al., 2023). As production of materials prone to producing MPs continues without the technology to remove them from the environment, their predicted health effects will only become more of a concern.

The primary method of ingesting IAMPs is inhalation. When MP particles are inhaled, most are trapped by the natural filtration mechanisms in human lungs. However, in some cases, small enough fibers may bypass these safety measures, and remain within the lung (Wright & Kelly, 2017). This buildup of MPs may lead to serious health issues. When MPs enter an organ, such as the lung, at a faster rate than they are removed, there is a risk of particle and chemical toxicity, or microbial toxins. This risk persists even if particles are low in concentration, as long as the deposition rate exceeds the clearance rate (Enyoh et al., 2019). This means that any health concerns associated with MPs would likely grow in severity as the concentration of MPs in the body increases.

This buildup of MPs in the body leads to additional health risks. Chemical additives used in plastic production processes can leach from the MPs inside the body (Lehner et al., 2019). These include several additives with known negative health effects, such as reproductive toxins like DEHP and BPA, carcinogens such as vinyl chloride and butadiene, and mutagenicins which can cause mutations within the body, including benzene and phenol (Wright & Kelly, 2017). MPs can decompose into nanoplastics, which are small enough to pass through the walls of pulmonary alveoli, as well as blood-brain, gastrointestinal and placental barriers. Foreign bodies not impeded by these barriers pose significant risks to human health (Lehner et al., 2019). The material properties which make plastics so desirable for manufacturing purposes, such as their resistance to being broken down, make them a unique challenge to human health after being introduced to the body.

Not all researchers are convinced of the risks of MP ingestion to human health, however. Some findings have even suggested that the concentration of airborne MPs is too low to have any adverse effects on human health (Lehner et al., 2019). Another study directly compared the respiratory health effects of superabsorbent polymers and paper dust, finding that workers exposed to a combination of the two, or exposed to only the paper dust experienced major negative health effects, whereas the effects for the polymer were far less significant (Holm, Dahlman-Höglund, & Torén, 2011). It has been argued that these results suggest that inhaled MPs pose no particularly significant risk as compared to other particles. Following this conclusion, exposure to MPs would be considered of no particular significance, especially when compared to exposure of other foreign airborne particles.

1.4 - Shortcomings of Existing Research

The first studies on IAMP only appeared in 2016 (Enyoh et al., 2019). Unlike the thoroughly studied field of MPs in aquatic environments, there is not a wealth of research on indoor MPs, meaning that drawing reputable conclusions from the limited number of sources is difficult. The difficulty of tying specific health effects to a certain cause, especially one as ubiquitous as MPs, means that most academic writing on the health effects of MPs is speculative.

It is extremely difficult to compare the results of current studies due to the lack of a standard operating procedure (SOP) in the research. A SOP explains in detail how to perform a laboratory process both safely and effectively. This ensures both the safety of laboratory technicians, and consistent experimentation across different laboratories. Another obstacle in creating a SOP is the lack of a “standard” MP particle. As MPs are generated from a wide variety of sources, they are extremely diverse. They may vary in size, shape, density, and chemical composition (Lehner et al., 2019), meaning that the methods used to collect and analyze certain MPs are typically tailored to their specific qualities. This variation in methods often leads to varying results, as demonstrated by one study which standardized the results collected by 27 studies. This study found that results found by separate studies were incongruent (Wright et al., 2021). This is likely a result of the lack of a SOP, emphasizing the difficulty of conducting research in a field without standardized testing methods.

1.5 - Approach

As plastics are continuously manufactured on a massive scale, MPs will endure as a possible health risk to humans and to the environment at large until properly identified and evaluated. The combination of there being relatively few papers on IAMP and results which cannot be compared due to non-standardized research practices create obstacles when examining the conclusions drawn by researchers. As such, an SOP must be developed for proper data analysis. The extent of the health effects that MPs pose to humans are not fully understood, but research that suggests negative effects gains more media attention, leading to growing public concern. If the sources of IAMP and relevant mitigation strategies are identified and studied, any harmful effects found can then be properly researched and reduced.

In order to develop a more complete understanding of IAMP sources and mitigation strategies, it is necessary to evaluate the current research practices in use. This will allow for a fuller understanding of presented results, as well as ensure any considered results are a result of credible research. The sponsors of this project, the BioNanomaterials Group at AMI, focus on the impact of nanoparticles, particularly nanoplastics, on the environment, human health and other societal issues. The BioNanomaterials Group employs techniques including cell culture and microscopy, synthesizing nanoparticles on-site in order to develop a better understanding of the effects of nanoparticles on human and environmental health (Université de Fribourg, n.d.). This project has been established to help the BioNanomaterials Group gain a better understanding of the particular characteristics of IAMP, and inform future research within the field.

In this study, we conducted a review of existing literature on the subject and interviewed professionals in relevant fields in order to better understand the methods and conclusions of previous studies. We identified and evaluated common, as well as contrasting techniques used in IAMP research. This aids IAMP research by identifying what parts of the field must be further classified and standardized so that future study results can be easily verifiable and comparable to other studies.

The tables which we present in this report allowed for the collection of a greater variety of information, while also ensuring it was presented in an easily understandable manner. The separate tables for experimental studies and reviews allowed for evaluation of the important common categories each included.

The information that is gathered in these tables was used to suggest improvements for standardizing research within the field of IAMP, an issue which has proved to be a major limitation and prevented researchers from sharing conclusions. Based on the discovered commonalities and discrepancies between studies, recommendations are listed within this report for future improvements.

Chapter 2: Methods

The goal of this project was to assist the BioNanomaterials Group at AMI in identifying the extent of current research on indoor airborne microplastics (IAMP) by conducting interviews and reviewing relevant studies. We conducted research and analysis of the sources, methodologies, conclusions, and limitations present in current IAMP research and compiled information into tables, which we were able to use to compare our findings.

2.1 - Objectives

The research process was broken into three distinct objectives in order to streamline research efficiency and direction; the objectives are depicted in Figure 2:

Figure 2: A visual representation of the project objectives.

Our first objective aimed to collect information from studies relevant to indoor airborne microplastics research, as well as tangential fields. This research was supplemented by interviews with professionals in relevant fields, and aided in directing research towards areas of improvement for IAMP research. We analyzed research studies and reviews conducted in regards to any airborne MPs, rather than just IAMPs, due to the limited research on IAMPs. This analysis was conducted by defining categories of common attributes of IAMP research and reviews, such as analysis methods, calculated compositions, and conclusions. We then evaluated MP studies and reviews within tables using these criteria such that later analysis could compare these categories with ease.

The absence of a SOP in research on IAMP led to limitations when comparing results. Our second objective identified these limitations by analyzing the results found in order to clarify the causes of discrepancies and uncertainty in the results of IAMP studies.

Our third objective was to evaluate the current status of IAMP research with respect to the limitations identified in objective two. Through this evaluation, we produced suggestions for the direction of future research and possible mitigations.

2.2 - Literature Review

One of the primary sources of insight came from a review of existing literature on IAMP, published in large part between 2016 and 2024. Due to the underdeveloped nature of the field, we included research concerning airborne MPs not limited to IAMPs. After initial identification of possibly relevant papers (N=46), we evaluated papers for relevance specific to IAMP, defined categories for paper evaluation, and finally evaluated (N=30) papers based on said categories.

2.2.1 - Sorting by Relevance

Once enough papers related to MPs were identified, we conducted an in-depth analysis with a focus on publications we deemed highly relevant to the project. We defined relevance based on the abstract of each paper, extracting the objectives, research topics, and major findings. We then categorized papers by sampling environment (indoor, outdoor, both, neither), with indoor sampling deemed more relevant than outdoor. Based on the extracted information and sampling environment, each paper was classified as low, medium, or high relevance (Table 1). Papers were classified by at least two team members with a final classification agreed upon by the majority classification. Experimental reports sampling airborne particles were prioritized over those sampling particle deposition. High and some medium-relevance papers were included in in-depth evaluations.

Table 1: Paper counts based on relevance and sampling environment

PRIORITY SCREENING

ENVIRONMENT \ RELEVANCE	HIGH	MEDIUM	LOW	ENVIRONMENT TOTALS
INDOOR	7	4	1	12
OUTDOOR	0	7	15	22
BOTH	5	3	1	9
NEITHER	2	0	1	3
RELEVANCE TOTALS	14	14	18	46

2.2.2 - Categories for Review

Once we had sorted publications by relevance, we established a set of categories of common content to characterize and compare studies. As we were examining both research studies and reviews, separate categories were defined to distinguish experimental papers and reviews.

The characterization of papers focused primarily on examining methodology due to the current lack of a SOP in the field. The investigated categories for experimental papers are displayed in Table 2. Review papers were examined based on categories displayed in Table 3. We defined these categories through individual reading of papers, suggestions from interviews and meetings with our project sponsors.

Table 2: Categories used for compiling study paper information

IAMP STUDY EVALUATION CATEGORIES

CATEGORY	MEANING
PRIORITY	The importance of the study as it related to IAMP
OBJECTIVE	The study's goal
COLLECTION	The method used to collect samples, such as tools, time period, and location
ANALYSIS	Tools used to process and analyze data
PHYSICAL CHARACTERISTICS	The characteristics of analyzed MPs including size, shape, and color
COMPOSITION	The materials which comprise the MPs
CONCENTRATION	The amount of MPs in a defined space
SOURCES	Possible and defined sources of MPs
CONTROLS	Measures taken to ensure that data is accurate
CONCLUSIONS	Statements made based on experimental measurements and observations
LIMITATIONS	Restrictions or restraints present within the study

Table 3: Categories used for compiling review paper information

IAMP REVIEW EVALUATION CATEGORIES

CATEGORY	MEANING
PRIORITY	The importance of the study as it related to IAMP
OBJECTIVE	The study's goal
PHYSICAL CHARACTERISTICS	The characteristics of analyzed MPs including size, shape, and color
COMPOSITION	The materials which comprise the MPs
CONCENTRATION	The amount of MPs in a defined space
SOURCES	Possible and defined sources of MPs
FINDINGS	Conclusions present within reviewed studies
CONCLUSIONS	Statements made based on experimental measurements and observations
LIMITATIONS	Restrictions or restraints present within the study

Studies were evaluated for the content they contained, and content was organized into these defined categories. Using these categories within a table allowed us to organize our findings such that future data comparisons and analysis were efficient.

2.3 - Interviews

We conducted semi-structured interviews with key stakeholder groups to gain additional insight into IAMP research. Our use of interviews was instrumental to this project, as they allowed for gathering additional information and experiences which were not present within the published papers which were reviewed. Conducting semi-structured interviews allowed us to use a pre-established line of inquiry, while maintaining flexibility. This allowed professionals to guide the trajectory of the interview to the areas that they viewed to be the most helpful, while also ensuring that discussions stayed relevant to the research being conducted.

We conducted (N=7) interviews with professionals both within and outside of the field of IAMP. Throughout our research, we interviewed the director of an indoor environmental quality laboratory, a project leader at the Swiss Tropical and Public Health Institute, a toxicologist at the Imperial College of London, and four researchers within AMI. The laboratory director and one of the researchers we interviewed did not have experience specific to MPs.

As the research field of IAMP is still new, supplementing information from this field with information gathered from more established fields of research, such as outdoor air pollution and particulate matter, allowed us to form a well-rounded understanding of the field. These interviews focused on investigating indoor air quality, especially as MPs are involved; current perceptions of MPs, both in the public and research spheres; policy creation; and the findings of current research, as well as its limitations.

Further interview subjects were found through snowball and purposive sampling (Gill, 2020). When snowball sampling, the current interviewee was asked if they had any recommendations for other professionals they believed it would be beneficial to interview. When purposive sampling, candidates were selected based on their qualifications and area of study for interviews.

2.4 - Ethical Considerations

All interviews were conducted with interviewees' informed consent. All interviewees gave consent prior to being recorded.

2.5 - Conclusion

Our process for conducting our research allowed for a streamlined process for gathering data for future analysis. Our literature review, aided by the categorization conducted early in the project, allowed us to gain a broad perspective on both the research practices and current results in the field. The interviews gave us a broader perspective of the field of IAMP that could not be filled in by research papers alone, giving us insight into the thought processes that scientists implement to create experimental studies and conduct research. Through these two methods, we were able to collect data in a concise manner that enabled future analysis to be efficient and insightful.

Chapter 3: Findings

Through a combination of interviews and a literature review, our team was able to compile information regarding the status of IAMP research and identify both key areas where advances are being made and areas which require further attention. We created tables to compare information presented in the studies and reviews we examined: one on controls, one on our review of studies, and one on our meta review. We were able to use the trends demonstrated through these tables along with information gathered through interviews to understand the state of understanding on MPs from a multi-disciplinary perspective.

3.1 - Classification

According to the World Health Organization (WHO), particles are generally classified based on five properties: size, shape, material composition, surface geometry, and additives (*Dietary and*, 2022). However, our research has found that with regards to IAMPs, research has focused almost entirely on size, shape and material composition, with surface geometry and additives being under researched. As such, the following section will discuss these three well-researched elements.

3.1.1 - Microplastics have a Variety of Sizes

Microplastic size classifications ranged from 1 nm to 5 mm across studies. MPs are defined based on their size, so an appropriate understanding of size is essential to classify and understand them. In addition, MPs are not the only size category for plastic categorization. Nanoplastics are smaller than MPs, while mesoplastics and macroplastics are larger, occurring at sizes greater than 5 mm (Lehner et al., 2019). Defining MPs as smaller than 5 mm is consistent across most MP studies and corroborated by the European Chemicals Agency (ECHA, 2023). Although our initial research indicated the lower bound was conventionally 1 µm, some studies have set it to 20 µm, or as low as 1 nm (Hartmann et al., 2014). This poses a problem for consistency, as one study's nanoplastic range may be partially encompassed in another's MP range.

Further, the stated range is far larger than can be covered by any one type of scanning equipment. The commonly used μ-FTIR, for instance, cannot examine particles below 1 μm. (*Particle Size*, n.d.). In many cases, this will lead to different technologies being used to generate results depending on where they define the MP size range to start and end. Two methods with frequently overlapping investigated size ranges are μ-FTIR and μ-Raman, which produce slightly different outputs on identical samples and as such are difficult to compare (Gaston et al., 2020).

These inconsistencies in size definition pose a particular problem for legislation, as we learned in our interviews that particles smaller than 10 μm are able to bypass the initial filtration present in human lungs, leading to concerns about bioaccumulation and long-term health effects, which are not yet well-defined due to a lack of research.

3.1.2 - Composition is Dependent on Environment

The composition of sampled IAMPs is highly variable depending on the study, and depending on the specific sampling environment. The most common materials for IAMP in the reviewed papers are polyethylene (PE), polyester (PET), polypropylene (PP), polystyrene (PS), rayon, and nylon (Figure 3).

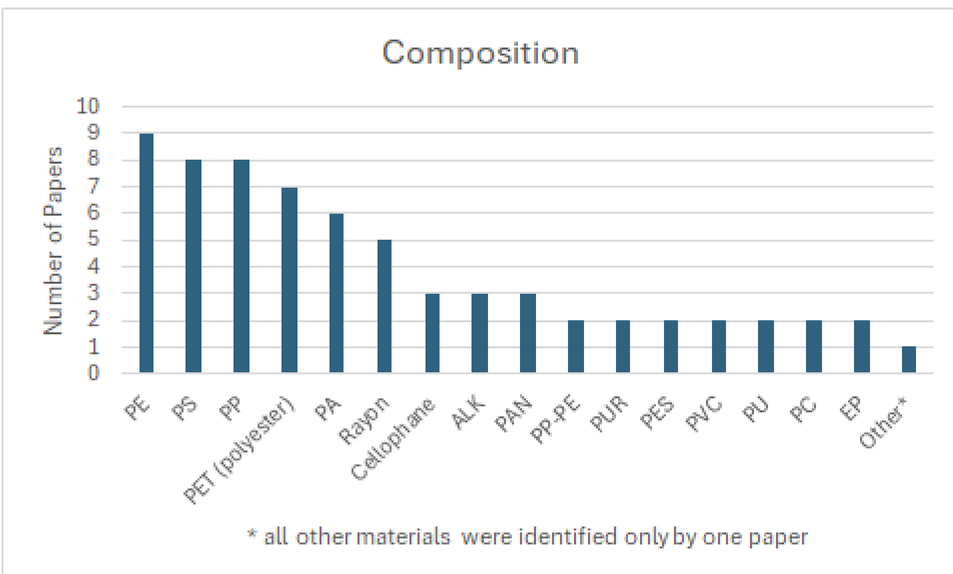

Figure 3: Materials found in reviewed studies.

In addition to the compounds that make up MP particles, there are numerous additives present in plastic products which improve certain properties, including stability when exposed to heat or UV light, plastic flexibility, flame retardation, and others. Most of the studies which currently exist on IAMPs do not investigate these additives in detail, as identification of these compounds the existing problems surrounding polymer identification in these particles.

Unfortunately, most studies conclude that IAMP are influenced by the compositions of local sources (Deghani et al., 2017), leading to difficulties acquiring representative samples. Composition is highly dependent on the environment, which can change even between two rooms in the same residence.

3.1.3 - Shapes are Inconsistently Defined

Shape classification in existing research is one of the areas containing the most confusion. In addition to the common classifications of fibers and fragments, papers include other, often ill-defined, categories including films, foams, granules, nurdles, and pellets. Figure 4 displays the wide variety of particle types in the results of the 20 experimental studies reviewed for this report.

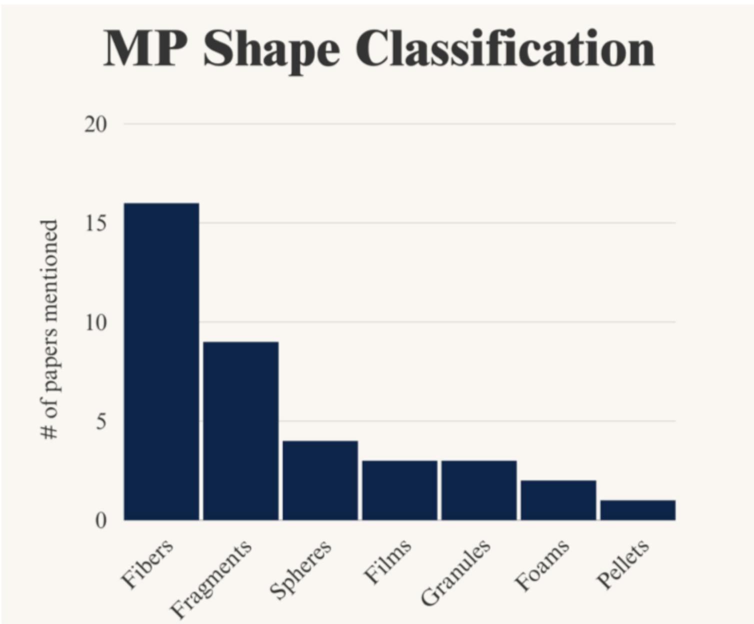

Figure 4: A bar chart showing the number of experimental studies that used each particle type

The most common category, fibers, is inconsistently defined: one paper suggested these be defined by a 1:3 diameter-to-length ratio (Chen et al., 2021), another suggested 1:5 (Choi et al., 2022), and most others made no suggestion of specific classification for fibers at all. A proposed classification of bio persistent fibers was released by the WHO, defining them as having a length of < 5 μm, a diameter of < 3 μm, and a length-to-diameter ratio of 3:1, but this is not currently universally used (*Determination of*, 1997*)*. No attempts have been made to formally classify other particle types, however, many of which are simply determined based on optical microscopy and manual classification by researchers.

3.1.4 - Concentration Units are Varied

Concentration is an important metric for recording MP presence in air, as it allows for more accurate risk assessments. One of the problems with concentrations in existing IAMP literature is the wide variety of units used, as presented in Table 4. Although some units, such as particles/m^3 and particles/l can be compared, most units used in different studies are completely incomparable. Table 4 groups the units found within reviewed papers into categories based on units comparable by derivation.

Table 4: Comparison of papers using different units, some comparable and some not

COMPARISON OF UNIT USAGE

PAPER	UNITS
(Bergmann et al., 2019) (Choi et al., 2022) (K. Liu et al., 2019a) (K. Liu et al., 2019b) (Vianello et al., 2019) (Wang et al., 2020)	Particles / L Particles / m^3
(Dris et al., 2017) (Li et al., 2021) (Stanton et al., 2019)	Fibers / m^3 Fibers / mL Fibers / L
(Cai et al., 2017) (Chen et al., 2021)	Particles / m^2 / day
(Dehghani et al., 2017) (C. Liu et al., 2019) (J. Zhang et al., 2020)	Particles / 30g mg/kg μg/g
(Holm et al., 2011) (Przekop et al., 2023)	mg / m^3 g / cm^3

Measured concentrations of IAMP particles are also highly variable depending on the study. Similarly to material composition, the concentrations of IAMPs are diverse and dependent on the environment, specifically the actions performed within the area, which makes representative measurement challenging.

3.2 - Methods

Without a SOP defined for MP research, studies use a variety of methods to conduct experiments. This can be seen through different procedures used for sample collection, sample preparation, and analysis. Information key to making a study reproducible often is missing or unclear, resulting in unverifiable data. Inconsistencies in data cannot be explained without a standardized reference for proper procedures.

3.2.1 - Sample Collection

As IAMP research, and MP research in general, is still a developing field, gathering realistic samples is essential for measuring real-world concentrations and characteristics of MPs. Sample collection takes into account information such as the sampling period, location, and tools used. Detailed documentation of this process increases a study's reproducibility and quality.

3.2.1.1 - Time and Location

Within the reviewed MP studies, common locations for IAMP research include apartments, offices, dormitories, schools, and universities. In residential areas, living rooms and other areas with high human traffic were central locations for sample collection (Chen et al., 2022). One study specifically looked at a factory (Holm, Dahlman-Höglund & Torén, 2011). Outdoor MP studies had locations including roofs of office buildings and apartments, waterworks, and gyms (Cai et al., 2017). Studies focusing on measuring MP inhalation picked locations with high human activity, collecting samples only during work hours, only when the lights were on, or only when the area was occupied (Dris et al., 2017; Holm, Dahlman-Höglund & Kjell Torén, 2011; Vianello et al., 2019). Timing of sampling ranged from a single instance to one hour to continuous sampling over months. This depended on the intent of the study; studies that measured deposition often, but not always, made singular collections, whereas airborne sampling took more time. Dris et al., (2017) measured indoor air for 4 to 5 hours, outdoor air for

10 to 40 hours, and dust collection for 4-15 days. This study also made measurements in all four seasons to test the effects of seasonal change on MP concentration.

3.2.1.2 - Tools for Collection

Descriptions of the tools used to sample MP within studies are essential for reproducibility. Some studies utilized simple collection methods such as vacuums or sweeping, whereas others used specialized equipment such as a breathing thermal manikin or particulate samplers (citation needed). The types of filters used within each study also determined the types of MP that were sampled due to mesh size and area. One study used a 20 µm mesh with a 25 mm diameter (Choi et al., 2022). Another used a 2.5 mm mesh (Dris et al., 2017). Each study had great variety in the types of tools used, which influenced final results.

3.2.2 - Controls

Negative controls, or blanks, are samples which are examined to ensure that there is no contamination throughout the collection and testing process, as well as to calibrate instrumentation. (Rosenburg, 2022). In the context of MP research, this may mean testing a sample which is not supposed to contain MPs. Procedural blanks, or blanks which undergo the same testing procedure as the sample, are common within this field of research, and are helpful in determining if there are any sources of contamination within the testing process. As a result of the ubiquity of MPs, it is more than likely that there will be contamination present. In this case, blanks are used to quantify the amount of contamination so that any results may be altered to be as accurate as possible to the original sample collected. To ensure quality of results, it is recommended that studies use three or more blanks to measure contamination. One study employed the use of three procedural blanks to measure contamination which stemmed from the sample preparation, and found an average contamination which equaled 4.9 ± 3.9% of each sample's total count of MPs (Vianello et al., 2019). Not all studies describe their blanks in such detail, if at all. As one reviewer writes in an examination of the state of IAMP research, "The relatively poor inclusion of blanks across several of the studies, however, and how the information is reported represents a general cause for concern" (Wright et al., 2021, p. 9). Negative controls are necessary to ensure the validity of any reported data, and without them, any data produced cannot be fully trusted.

Negative controls are not the only control needed to ensure the validity of a study's results. Positive controls are used to ensure that a study is producing expected results (Rosenburg, 2022). In studies conducted in MPs, a sample with a known amount of MPs may be tested. The quantity determined through testing may be compared with this known amount to determine the effectiveness of the testing methods. Positive controls are not widely used in this field despite their importance; according to Wright et al., (2021) only two of their 27 evaluated studies contained mention of a positive control. One of these was a study conducted on MP content within house dust. The objective of this study was to depolymerize PET and PC into BPA and TPA in order to determine the concentration of MPs within the dust without interference of other PM. For a positive control, researchers spiked TPA and BPA into dust and calculated their recovery to be 105 ± 5.9% and 92.6 ± 10.7% respectively (Zhang, Wang & Kannan, 2020). With both recoveries reaching illogical values over 100% without uncertainties, there was likely an issue within the process. Without the use of a positive control, these recovery rates would have been unknown, as well as any possible issues associated with them.

3.2.2.1 - Clean Air Conditions Reduce Contamination

There are several steps a researcher may take to decrease the likelihood of samples becoming contaminated. A practice that many researchers adopt is working under clean air conditions. Clean air conditions may be met by several different practices, including the use of a clean bench, fume hood, laminar flow cabinet, or clean room. Clean benches are enclosed workspaces designed to prevent contamination by airborne PM. Any air which enters the clean bench must pass through an air filter (*What is*, 2018). One study performed on air samples performed all sample pre-treatment on a clean bench to avoid contamination (Choi et al., 2022).

Fume hoods and laminar flow hoods are both used by researchers studying IAMP. They use similar principles, but have slightly different purposes. Fume hoods reduce a researcher's exposure to a sample, particularly any that have harmful fumes, while laminar flow cabinets reduce the sample's exposure to contaminants (Rioux & Elliott, n.d.). One study examined the concentration and distribution of MPs in dust, cleaned their collection tools and allowed them to dry on a clean bench. Any experimentation performed on collected samples was performed either on a clean bench or in a fume hood (Liu C et al., 2019). A different study testing snow for MP content performed all filtration steps in a laminar flow cabinet (Bergmann et al., 2019).

Clean rooms are another practice which may be employed to ensure clean air conditions. Clean rooms are able to monitor and reduce airborne particle concentrations present within (Ailouche, 2022). A study involving the source, transport, and effects of MPs on the environment performed verification of suspended atmospheric MPs in an ultra-clean, stainless steel room in order to ensure the minimum amount of contamination possible (Liu, 2019a). Ensuring conditions which result in the least amount of contamination is extremely important, especially in a field dealing with something as ubiquitous and difficult to detect as IAMP.

3.2.2.2 - Replacing Plastic Items Reduces Contamination

In an effort to reduce MP contamination within the lab, many studies replace plastic items with non-plastic alternatives. Specific examples of these replacements include using non-plastic brushes for sample transfer (Nematollahi et al., 2022), and using tools made of polytetrafluoroethylene, commonly known as Teflon, which cannot be detected with the imaging instruments used in the study (Bergmann et al., 2019). Additional precautions taken included wearing cotton lab coats, a practice employed by over 50% of our reviewed studies, or wearing non-plastic gloves, which occurred in 30% of reviewed studies.

3.2.2.3 - Controls are Implemented Inconsistently

In Appendix A, each of the reviewed studies were examined for the inclusion of a negative control, positive control, clean air conditions, and steps taken to reduce the amount of plastic contamination to the sample, such as including substituting plastic equipment, wearing synthetic clothing, wearing a facemask, and wearing gloves.

By looking at the chart in Appendix A, it is obvious to see that the standards for controls vary greatly between studies. There are no studies which employed the use of all three controls: a negative control, a positive control, and clean air conditions. 65% of studies reviewed used negative controls, 10% used positive controls, and 35% operated under clean air conditions. Of the plastic reduction strategies, 20% of studies mentioned using non-plastic tool alternatives, 55% ensured researchers wore all-natural clothing, 35% mentioned glove usage, and 10% mentioned mask usage. As there is so much variety between each study in the steps taken to ensure a reliable result, it is incredibly difficult to compare the results and conclusions each of them have come to.

3.2.3 - Sample Preparation Prevents Contamination

Once a sample is collected, it may undergo several steps to ensure that any contaminating non-MP particles are removed. Many studies accomplish this by rinsing with distilled or Milli-Q water. Other studies may use a technique such as Nile Red Dye to stain MP particles a particular color, visually separating them from other particles which may have been collected. Some studies do not prepare their sample before analysis, and may have to attempt to visually identify what particles are and are not MPs. Even when samples are prepared, non-MP particles may be present. One study examined the elemental makeup of its sample, and found that there was not only carbon, oxygen, and nitrogen, which make up MPs, but aluminum, calcium, silicon, magnesium, sodium, and iodine. The presence of these elements was attributed to either extraneous particles of dust or soil, or materials which had been used to prepare the sample (Abbasi et al., 2019). If additional non-MP particles are present within a sample and unaccounted for, calculated MP concentrations may be exaggerated compared to their true values.

3.2.4 - Techniques for Analysis

Once samples are properly collected and treated, the next step is identification of particle size, shape, composition, and concentration. Depending on what characteristics a study intends to measure, different techniques are required. For chemical and physical characterization, common methods include μ-FTIR, μ-Raman, and SEM, with Nile Red dye occasionally used as well (Gaston et al., 2020; Salthammer, 2022). For identification of size and shape, studies often use manual identification, but automated software identification was included in some studies.

Within each of these analytical techniques, there are many discrepancies between studies, mostly due to utilizing niche techniques outside of the original intended use. For instance, multiple publications claim different size ranges capable of being visualized by the same technique. The results of each study were heavily influenced by the chosen techniques, and therefore only studies using the same techniques with the same settings can properly be compared. Table 5 shows the number of times a method was used within the 20 experimental studies and if they were considered adequate by the authors.

Table 5: Count of studies using different techniques

TECHNIQUE USAGE AND ADEQUACY	ADEQUATE	INADEQUATE	UNUSED
FTIR	12	1	7
RAMAN	2	0	18
SEM	5	0	15
FLOURESCENCE MICROSCOPY	2	1	17

3.2.4.1 - Fourier Transform Infrared Spectroscopy

The most commonly agreed upon technique for characterization of MP is μ-Fourier Transform Infrared Spectroscopy (μ-FTIR) (Enyoh et al., 2019; Salthammer, 2022; Wright et al., 2024; Zhang et al., 2020). FTIR is a spectroscopy technique that uses infrared radiation and produces a spectrum graph that can be used to identify the chemical composition of a particle; μ-FTIR uses FTIR on samples smaller than 1mm. Attenuated Total Reflectance FTIR (ATR-FTIR) is a form of μ-FTIR that includes a highly refractive crystal to direct the infrared light (Mathias, 2023). ATR-μ-FTIR aids with looking at smaller particles than μ-FTIR can reach on its own, and allows for analysis of shape, size, and surface of particles (Salthammer, 2022). ATR-FTIR and transmission FTIR, another form of FTIR, measure the IR signal after it passes through the sample. Reflectance FTIR instead measures the IR signals reflected from the sample (Reflectance Infrared (FT-IR) spectroscopy, n.d.). The detail each study included on the use of FTIR varied, resulting in mentions of specific types of FTIR, specific machine, settings, and size ranges being missing from a majority of studies. One study noted how FTIR has difficulty identifying certain particulate shapes such as synthetic textile fibers due their small and curved surfaces (Stanton et al., 2019).

Of all the reviewed studies (N=20), 13 used FTIR as a method of identifying the composition of microplastics. Of the 13 studies that used FTIR, only one was unable to produce adequate results. According to this study, the fibers were too small for ATR-FTIR detection and the readings from reflectance FTIR were too noisy to draw meaningful conclusions (Stanton et al., 2019).

Within the studies that used FTIR, five studies specifically mentioned the FTIR machine used as the Nicolet iN10 MX (Cai. et al., 2017; K. Liu et al., 2019a; K. Liu et al., 2019b; Wang et al., 2020; Zhang et al., 2020). This specific machine's stated minimum size measurable is 50 μm without liquid nitrogen, and 3 μm when using ATR-FTIR (Thermo Fisher Scientific, n.d.). Alternatively, some reviews list the minimum size FTIR can measure as 20 μm (Kacprzak & Tijing, 2022; Zhang et al., 2020). Within studies that found FTIR applicable, there were variances between the minimum size that FTIR was capable of measuring according to each study, if the minimum was stated at all. Within studies considering FTIR adequate (N=12), only seven studies clearly stated either the minimum size limit or the smallest size they were able to measure (Bergmann et al., 2019; Choi et al., 2022; Dris et al., 2017; Gaston et al., 2020; Liu et al., 2019b; Zhang et al., 2020). Three studies stated unclear limits, such as not specifying a specific cutoff number (Cai et al., 2017; Chen et al., 2021; Vianello et al., 2019). As shown in Appendix B minimum size limits and measurements are varied, suggesting that individual studies had differing understandings of what size range of MP they were capable of looking at.

3.2.4.2 - Raman Spectroscopy

μ-Raman spectroscopy, or Raman spectroscopy, is another common technique used for characterization of MPs. Raman measures the scattering of light based on electron-photon interactions (Arif, Al-Athel, & Mostaghimi, 2017). However, as Raman measures scattered light from a laser, it is biased towards better identifying more crystalline structures. Raman can be used to characterize shapes as well as composition, and can separate MP from non-plastic substances, even identifying synthetic dyes and additives (Kacprzak & Tijing, 2022).

Within reviewed studies (N=20), only two studies used Raman spectroscopy, with both producing usable results (Gaston et al., 2020; Nematollahi et al., 2022). Gaston et al., (2020) noted a bias in Raman as the technique was found to identify PVC strongly in comparison to other compounds. Both studies utilized a 785 nm laser, Gaston et al., (2020) testing and concluding said wavelength as the strongest signal with minimum fluorescence. Higher energy lasers at 532 nm and 684 nm were tested, but found to have a higher likelihood of burning the MP particle, ruining the sample.

Gaston et al., (2020) measured MPs between 5 µm and 75 µm, whereas Nematollahi et al., (2022) identified MP only down to 50 µm. This is contradicted by some reviews which stated Raman is ideal only for particles from 1 µm to 10 µm (Kacprzak & Tijing, 2022; Zhang et al., 2020), whereas another review stated the lower bound as 1 µm but did not set an upper bound (Salthammer, 2022). Overall, the usage of Raman spectroscopy had fewer discrepancies in terms of size range than FTIR.

3.2.4.3 - Scanning Electron Microscopy

Scanning electron microscopy (SEM) uses a beam of high-energy electrons to produce measurable signals on the surface of the sample (Swapp, 2024). SEM is another common technique used in MP studies to identify morphology and texture and is also used in conjunction with Electron Dispersive X-ray Spectrometry (EDX) to identify composition. In order to improve SEM signals, samples are often coated in gold or another conductive material to increase the signal-to-noise ratio (Luyk, 2019). SEM has a high resolution, however the size resolution lowers looking within the nanometer range (Salthammer, 2022).

SEM within the reviewed studies was used for characterization of composition, texture, size, and shape. Of the reviewed studies, five studies used SEM, all of which considered the technique adequate (Abbasi et al., 2019; Cai et al., 2017; Dehghani et al., 2017; Li et al., 2020; Nematollahi et al., 2022). Of these studies, 60% mentioned coating samples in gold before analysis (Dehghani et al., 2017; Li et al., 2020; Nematollahi et al., 2022). Unlike FTIR, the specific tools used to perform SEM were different between studies. In addition, most studies used SEM-EDX and characterized composition, Cai et al., (2017) only used SEM due to only characterizing the surface.

SEM was key for identifying any degradation patterns within samples, clearly identifying patterns such as fragmentation, fracturing, adhering particles, flaking, pits, and grooves (Abbasi et al., 2019; Cai et al., 2017). SEM was also able to identify elemental composition, measuring high levels of C and O, as well as other elements in smaller quantities (Abbasi et al., 2019; Li et al., 2020; Nematollahi et al., 2022).

SEM is capable of measuring size down to at least 50 nm with precision, meaning SEM is the technique with the largest measurable size range (Swapp, 2024). However, some reviewed studies implementing SEM either did not clearly mention the size range viewed, were limited by size due to other factors, or still measured above 50 µm. Li et al., (2020) measured down to 5 µm, and Abbasi et al., (2019) noted a minimum limit of 2 µm.

3.2.4.4 - Fluorescence Microscopy

Fluorescence microscopy is a less common technique used in MP studies. Fluorescence microscopy is a type of light microscopy, like FTIR, that uses fluorochromes to emit light after being excited by a specified wavelength (Ockenga, 2011). Of the reviewed studies, only 3 were found to have used fluorescence microscopy (Abbasi et al., 2019; Dehghani et al., 2017; Gaston et al., 2020). According to Dehghani et al., (2017), the use of fluorescent pigments, dyes, and other additives identifiable by fluorescence microscopy is common in MP. Abbasi et al., (2019) noted that MP can absorb wavelengths of ultraviolet or 300 to 400 nm and radiate purple and blue, or 400 to 480 nm. Within one of the studies, fluorescence microscopy was found to be ineffective at detecting MP, and suggested that preparation for fluorescence microscopy can cause loss of sample (Dehghani et al., 2017).

A common accompaniment to fluorescence microscopy is Nile red dye. The dye can be added to MPs, sticking to the surface and making MPs easier to count. With Nile red dye, MP can be identified down to 20 µm, or 10 µm with a dark background to help MPs stand out (Kacprzak & Tijing, 2022). In Gaston et al., (2020) the dye was used in conjunction with fluorescent microscopy to stain MPs and increase the number of MPs detectable. However, it was noted that not all MPs stain well with Nile red, causing bias in the types of MPs visible through this technique.

3.2.4.5 - Software vs Manual Characterization

As the field of IAMP is still relatively new, specialized software has not yet been designed and standardized. As such, studies either use manual classification through visual references or use software either still in development or with capabilities matched to similar particles.

In manual characterization for physical characteristics, samples are magnified using different microscopic techniques such as optical microscopy. Optical microscopy refers to microscopy often involving magnification through one or more lenses. Viewing the sample through an eyepiece is considered traditional and through a computer is considered digital (Smith, 2023). Magnification power, such as 40x, 100x, 400x, or 1000x, of the given microscope allows for visualization of particles 5 mm, 2 mm, 450 µm, and 180 µm in size respectively. (*Microscope images*, n.d.). Traditional microscopy is suitable for identifying the physical characteristics of MP between 100 µm and 500 µm. One study used a 100x magnification followed by a 40x digital magnification and states the minimum size viewable with effectiveness was 100 µm, though some studies have claimed to identify particles down to 20 µm. (Kacprzak & Tijing, 2022).

Studies using software for MP characterization to identify physical characteristics (N=5) use programs such as ImageJ in order to generate results. ImageJ is a public domain Java image processing program that allows for customization of image transformations and calculations (*Introduction*, n.d.). As the program is customizable, specifications as to the program parameters used within studies should be expected. However, of the three studies using ImageJ, only one study specified any information, specifically stating version 1.51j8 (Wang et al., 2020). Two studies used ImageJ for classification of size (Abbasi et al., 2019; Wang et al., 2020). One study used ImageJ for counting (Nematollahi et al., 2022).

Another study using software for identifying physical properties used a new software called MPhunter to count particles as fibers or fragments and measure dimensions, then compared these results to manual classification (Vianello et al., 2019). MPhunter is a program with a friendly user interface designed specifically for semi-automated MP analysis. (*About*, n.d.). The software was mainly used to determine if the ratio of major to minor dimensions was above or below 3:1. The study manually measured 50 fragments and 50 fibers, then compared to MPhunter approximates of the shapes. The final conclusion of the study was that MPhunter was an acceptable program to use for size classification. The error between manual and automated classification of size was deemed acceptable, and it was noted that MPhunter had less error when identifying particles below the 3:1 ratio, or fragments (Vianello et al., 2019).

Software is especially used in MP studies for characterizing composition (N=8). These databases compare generated data from microscopy techniques and compare to a predefined dataset, eventually generating a composition classification. Of the reviewed studies, six used the OMNIC software or spectra library by Thermo Fisher (Cai et al., 2017; Gaston et al., 2020; C. Liu et al., 2019; K. Liu et al., 2019a; K. Liu et al., 2019b; Zhang et al., 2020). However, the data produced from FTIR, Raman, and SEM all includes noise from different factors, causing the generated compositions from software to not always be accurate. For instance, Raman spectroscopy is capable of identifying composition of MP, as well as synthetic dyes and additives (Kacprzak & Tijing, 2022). There is a large quantity of unique additives used in production of MP sources, and those additives are often not known outside of production. If using a library to identify compounds using Raman, the signals produced from the unknown additives have a chance of creating an incorrect reading due to the library not including that specific combination of additives and polymer. Studies also defined varying confidence interval thresholds for accepting a match from a library: five studies set the threshold to 70%, one to 90%, and two to 60%. The remaining studies (N=4) did not specify the implemented confidence interval threshold. To avoid incorrect identification, it was suggested within an interview that generating reference material specific to the experiment being run with the same equipment could increase accuracy. Within the reviewed studies, only Stanton et al., (2019) generated a library specifically for its samples.

3.2.5 - The "Black Box" Problem

Our interviews with several researchers suggested that MP research has been made more difficult by a lack of transparency from companies that manufacture scanning equipment. This is particularly relevant with methods such as FTIR, where the infrared absorption of particles is compared to a database in order to identify them. As previously discussed, small variations in environment can cause different results, making it vital to routinely verify the accuracy of databases when setting up equipment.

We have learned from interviews that despite the need for transparency, many equipment manufacturers do not make it possible for researchers to access the raw data from their experiments. This makes it extremely difficult to verify the generated results, as this lack of transparency causes the machines to behave as a sort of "black box," where only the inputs and results are accessible to those using it, such that there is no way to prove or disprove the machine's accuracy outside of trusting manufacturer calibration. Due to this, all research using this equipment is made significantly more challenging, as other methods must be employed in order to verify results. In many cases, there are no viable alternatives and the accuracy of all results is dependent on the manufacturers' claims.

Transparency is important in research due to the necessity for peer-review, particularly in new research fields - the increasing number of "black box" machines contradicts this purpose, by instituting a knowledge gap in all research generated using them.

3.3 - Human Biology

When MPs are introduced into the body through ingestion or inhalation, the properties derived from their size, shape, potential to accumulate and increase in concentration, as well as toxicity and additives determine the health effects which may result.

3.3.1 - Size

The size of an inhaled MP determines how difficult it is to remove from the body. The smaller a MP is, the deeper into the lungs it may deposit, making it more difficult to expel from the body. MPs larger than 100 µm will deposit in the upper airways, which consists of the nasal and oral cavities, pharynx, and larynx. MPs between 10 and 100 µm will deposit in the oropharynx, or the area of throat behind the mouth. MPs between 5 and 10 µm will deposit in the central airway's mucus layer. MPs beneath 5 µm may reach the alveoli. Nanoparticles may cross the alveolar-capillary, or blood-gas, barrier (Przekop et al., 2023). MPs which travel deeply into the lungs are unlikely to be expelled. One study touched on the issue of MPs deposited in the deep lung, writing, "these particles (especially the longer fibers) tend to avoid clearance and show extreme durability in physiological fluids, likely persisting and accumulating when breathed in" (Vianello et al., 2019, p. 1). The accumulation of these MPs, especially fibers, concerns researchers within the field.

3.3.2 - Fiber Interaction

The shape of MPs helps determine the risk that they pose. Fibers are believed to pose a particular threat. During an interview one chemist summarized this issue, stating that fibers confuse cells. Macrophages will likely try to consume the fiber, but they are only about 1 μm. If the fiber is any larger than this, it will kill the macrophage. Despite their flexibility, fibers may poke holes in cells due to their shape.

Long fibers are both more toxic, and more persistent. These larger MPs are less likely to bypass the lung's protective measures, but if they do, they are difficult to remove. In particular, fibers between 15 and 20 μm can't be cleared from the lung by macrophages or mucus (Wright & Kelly, 2017). Thin fibers are more easily respired than thicker fibers, meaning that fibers that are both long and thin pose a considerable threat. Fibers less than 0.3 μm thick and more than 10 μm long were the most carcinogenic (Wright & Kelly, 2017). The danger associated with fiber-shaped MPs is especially concerning considering that fibers have been found to be the most common shape of MPs (Enyoh et al., 2019). As fibrous MPs begin to build up in the lungs, especially those which fall under the most difficult size ranges to remove, further effects may become evident.

3.3.3 - Bioaccumulation

Bioaccumulation, or the buildup of particles within the lungs, has become an area of worry as a possible outcome of MP inhalation. MPs are inert, so if few are inhaled and deposited in the deep lung, it is not a major cause for concern. However, if the body is unable to rid itself of these particles and additional MPs are inhaled, they may accumulate in the lung.

MPs are incredibly biopersistent, meaning that they are difficult, if not impossible, to break down within the body through chemical pathways (Wright & Kelly, 2017). The ability of microplastics to accumulate is an essential factor in their threat level, as this may lead to physical or chemical threats as their concentrations increase within the body (Wright & Kelly, 2017). Issues may arise within the lungs due to MPs physical presence within them, such as reduced lung capacity and dyspnea, or shortness of breath, which was identified among workers exposed to polyesters or nylon fibers. These symptoms may point to an inflammation reaction stemming from the intake and accumulation of these particles (Li et al., 2020). Chemical leaching may occur in tissues and fluids as a result of accumulation as well (Wright & Kelly, 2017). Many additives used within the plastic production process are known to have harmful effects, and as they are carried into the lungs on MPs and build in concentration, harmful effects may emerge.

MPs may accumulate in other places within the body, such as in mucus. This accumulation has been found to lead to a decrease in mucus viscosity, which negatively affects its protective functions (Przekop et al., 2023). The issue of bioaccumulation is only predicted to grow in severity as humans are exposed to increasing amounts of MP. One study states that, given current trends, it would be justified to estimate that the ingestion rate will increase by 800% by the year 2070 (Wright et al., 2024). Given this estimate, the importance of understanding the ability of MPs to accumulate, as well as the effects this accumulation may have, cannot be understated.

3.3.4 - Toxicity

Toxicity is the measure of how much damage a substance can do to an organism. Many opinions vary within the field of IAMP on the degree of toxicity MPs possess, and which properties are the biggest contributors. One biologist explained to us that toxicity has everything to do with concentration. We spoke with a chemist who agreed with this idea, but stipulated that exposure concentrations used in studies are often too high, and therefore unrealistic to current exposure concentrations. Particulate exposure above 200 µg/ml to cultured cells is likely to be toxic, regardless of the particle's toxicity (Wright et al., 2024). To avoid unrealistic experimentation, exposure concentrations and proportions from published research should be replicated (Wright et al., 2024). Polystyrene is often used for studies on MP toxicology due to its consistent spherical shape and ease of use. However, this may be another source of inaccuracies within toxicological studies on MPs (Wright et al., 2024). Real-world plastics exhibit a variety of properties, such as shape, size, and composition, and within this variety lies their complexity and danger. Conducting research on a select group of uniform MPs negates their differences in properties, which is a significant contributor to their harm.

MPs are stable, partially as a result of their chemical inertness. Despite their lack of reactivity, MPs may increase in toxicity as their size decreases. Not only does this affect their ability to travel deeper into the lungs, but their characteristics may change as well. Particularly when MPs are reduced to nanoplastics, either purposefully or due to environmental degradation, they may exhibit new characteristics which influence toxicity (Wright & Kelly, 2017). These smaller particles have an increased surface area, especially when compared to their volume. Increased MP surface area is thought to lead to increased inflammation in many cases (Wright et al., 2024). Increased surface area may also lead to static, which increases absorption despite MPs' lack of reactivity, as one chemist explained. Hydrophobic organic compounds from surrounding environments, many of which are highly toxic, have the potential to bind to MPs and detach within the body. Wright and Kelly (2017) noted that some of these hydrophobic organic compounds are known to be endocrine-disrupting, carcinogenic, mutagenic, and immunotoxic.

3.3.5 - Additives

It is the opinion of some MP researchers that the biological harms associated with MPs are derived not from the plastics themselves, but their additives. Additives are used during the plastic production process to create certain mechanical properties. Speaking candidly, one chemist expressed that through her experience in experimentation, cells "did not care" about pure plastic pellets. This chemist equated their behavior toward the MPs to tattoo ink, which is consumed by macrophages once introduced into the skin (Relhan, 2020) without any negative effect to the macrophages. Many plastic additives are known to be harmful, with several being either banned or substituted. According to Salthammer (2022), plasticizers and flame retardants are currently being substituted due to their interference with the endocrine system.

Additives are not chemically bound to the surface of plastics, meaning that they are easily able to leech into external mediums (Wright & Kelly, 2017). In the case of MP inhalation, the external medium is the human body. Many additives are volatile or semivolatile organic compounds, some of which have been found to be carcinogenic and cause damage to the nervous system, among other effects (Salthammer, 2022). Additives such as bis(2-ethylhexyl) phthalate, used as a plasticizer to increase flexibility, are toxic to the reproductive system. Vinyl chloride, used to make PVC, and butadiene, used to increase toughness, are carcinogenic (Wright & Kelly, 2017). Legislation exists to regulate the quantity of additives included throughout the plastic production process. However, plastic producers are able to get around these regulations by using small amounts of many different additives. One chemist suggested that the number of individual additives used in some plastic products may be as many as 200. In addition, it is difficult to obtain specifics regarding what additives are included in a certain product, as these mixtures are considered proprietary.

3.3.6 - Health Effects

The issue of determining what health effects may be attributed to MPs was well-summarized in one review which wrote that there were “widely varying conditions and uncertainties that make health risk assessment difficult” (Salthammer, 2022). As was discussed in previous sections, many properties unique to particular MPs have a cumulative effect in determining the particular effects they may have on human health. A general negative effect of MP inhalation appears to be an inflammatory response, which may lead to oxidative stress, fibrosis, and autoimmune diseases (Przekop et al., 2023). Given that humans are exposed to MPs throughout their entire lifetime, slow-emerging effects are difficult to quantify through laboratory experimentation. Given this difficulty, some studies have chosen to focus on human subjects rather than cells. One study investigated the symptoms of exposure to paper dust, a superabsorbent polymer, or a mixture of the two. The results showed no significant association between exposure to the superabsorbent polymer and health effects, though there was a positive correlation between these effects and exposure to paper dust (Holm, Dahlman-Hoglund & Toren, 2011). Due to the level of uncertainty and disagreement in the field of MP-related health effects, more research must be conducted to increase understanding of MPs role within the body before health effects can be accurately determined.

3.4 - Legislation

Due to the lack of available conclusive research on sources, particle properties, and health effects, our research has found that legislation has been slow to develop. We also learned from our interview at the Swiss Federal Office of Public Health that legislation on issues affecting human health gets passed far more quickly than those grounded in environmental risks.

However, there have been efforts to implement legislation to slow MP production, both due to their contribution to environmental pollution, and as a preventative measure, anticipating the discovery of effects on the human body. The most notable example of this is an EU law banning intentional MP production, passed in September 2023. Various MP sources are affected by this ban, with transition periods of 6-12 years – overall, this is expected to reduce the EU's total MP production by over 500,000 tons over 20 years (*Commission regulation*, 2023). Laws in multiple other countries, including the United States and the United Kingdom, have been passed to specifically target microbeads used in cosmetics, due to their significant contribution to rising pollutant levels in natural environments (Zuccaro et al., 2024). According to Zuccaro et al., (2022), little has been done outside the EU to target artificial turf, or other sources of primary MP production.

All current legislation aimed at MPs only concerns outdoor environments, and currently no legislation has been passed that aims to specifically curb MP production indoors. Reduction in outdoor MPs decreases the number of particles present in indoor air due to tire wear, turf fields and construction, but that alone is not sufficient to curb indoor MP production. This is because most indoor MPs originate from textiles and furniture (Nematollahi et al., 2022), sources which are unregulated indoors, particularly in private residences.

Legislation regarding plastics is strongly affected by public opinion, which can change the willingness of lawmakers to pass and enact it in the first place due to political factors. Further, one public health official explained that the effectiveness of legislation on consumer plastic products is highly dependent on the willingness of consumers to embrace alternatives to those products containing microplastics.

However, MPs have become a “hot topic” in popular media over the past several years, with articles frequently misrepresenting the dangers of MPs to be far more significant than they are currently proven to be (Pinto-Rodgriguez, 2023, Jacobs, 2024). This may help increase legislation's effectiveness as popular sentiment supports a reduction of their presence in the environment. As such, legislation like the REACH amendment in the EU has a path to political support, especially if it supports development of alternative products.

Additionally, our interviews with professionals have suggested that treating IAMPs as ordinary PM10, PM2.5 or ultrafine particles for regulatory purposes may help more quickly implement legislation governing them. As it stands, the lack of knowledge on MP particle characterization and sources makes it difficult to implement effective legislation, particularly in the largely unregulated indoor environment, and more general legislation might help circumvent this.

Chapter 4: Results and Recommendations

Once our interviews were completed and all information obtained from the literature review was organized into tables, we analyzed the data to identify key points of improvement within the field.

4.1 - Project deliverables

As our project intends to be a review and the basis of future research within the field of IAMP, our project deliverables include two distinct parts: this report containing highlights of our findings and our recommendations, and tables containing the information we collected from our literature review of MP studies and reviews.

4.2 - Assessment of Limitations

Our research has found several issues with research in the field of IAMPs, which have been corroborated by our interviews with experts in the field. The three overarching elements are a lack of standardization, agglomeration of particles on test surfaces, and limitations of the machines used by researchers.

4.2.1 - Particle Classification with Current Technology

The absence of any standard particles for MP experiments is problematic, particularly given the complex nature of MP composition and geometry (Ageel et al., 2021). In addition to this complexity, a lack of coherence between methodologies across studies in the field leads to problems with comparison, given different methods are biased towards identifying different materials, and cannot be compared. The lack of standard size ranges for MP and nanoplastics compounds this problem, as definitions across studies are highly inconsistent. Another issue noted in both our discussions with professionals and in our literature review is a lack of clarity regarding equipment's limitations. This has been particularly prevalent in research examining smaller particles: researchers have declared their ability to visualize particles smaller than the minimum reliable resolution of their equipment, which creates problems for the credibility of their research. We have also noted a lack of documentation regarding minimum particle sizes by equipment manufacturers. Most manuals, such as for the ThermoFisher Nicolet iN10, used for FTIR analysis, only state an upper bound for the machine's particle detection size (Thermo Fisher Scientific, 2021). In addition, our interviews revealed that some researchers do not understand their equipment's inherent non-size limitations, including scanning techniques requiring crystalline particle structures.

4.2.2 - Agglomeration

Another limitation in the field originates at the sample processing stage. MP particles that dry out on filters tend to agglomerate, leading them to be measured by scanning equipment as a single larger particle instead of multiple smaller particles. In addition, for techniques such as spectroscopic analysis, this can pose problems for material identification, given these agglomerated particles are typically not homogeneous in composition. This was not mentioned in the reviewed studies, but was discussed extensively in interviews as a significant concern for experiment credibility.

4.3 - Recommendations

With the current limitations of IAMP research identified, we produced recommendations to push IAMP research past these limitations. These recommendations focus mainly on standardization within the field for the purposes of better comparisons between studies.

4.3.1 - Further Research

Through our literature review and interviews, we have discovered that IAMP research is underdeveloped. The wide variety of methods in use, disagreement regarding when each of these methods are effective, and a lack of consistency in controls between studies means that studies' results cannot be compared against one another. The differing methods also often result in differing units, which provides another barrier between comparing multiple studies. Due to these discrepancies, there is often no way to prove the validity of findings.

More time is required to continue research on IAMPs and expand the existing research base. As further studies are conducted, current methods may be improved upon, and new methods may be discovered. If methods are improved and, more importantly, multiple studies are conducted with identical methods, findings will be able to be verified, and researchers will have more concrete data on which to base their findings.

4.3.2 - Standardized Particles

MPs are incredibly complex, each has unique properties which depend on factors such as their shape, size, and composition. The extreme variation in properties creates issues for researchers, as each MP may respond differently to the same stimulus. Beyond differences in properties, two researchers given the same MP will likely use different descriptions due to discrepancies between the definitions of classifications, such as shape and size. Some papers will describe the shapes of MPs in terms of fibers and fragments, while others will break this further into granules, films, nurdles, foams and pellets. Even the definitions within each of these classifications, particularly fibers, are inconsistent. We recommend implementing a standard vocabulary with which to describe MP particles, as well as specific descriptions regarding what MPs belong in each category.

4.3.3 - Standard Operating Procedure

Once MP particles are more clearly defined, the use of consistent methodologies within an SOP may be implemented. Different SOPs may need to be developed for certain MPs, as a result of their varied properties. If all researchers studying a certain MP were to follow the same set of standardized steps throughout their experimentation, the variability between studies may be reduced and results will likely be more consistent. Controls may also be included within a SOP. Given the high chance that a sample may be contaminated with MPs through standard laboratory practices, measures which minimize and quantify contamination are crucial in producing viable results.

4.3.4 - Communication

The field of IAMP research is still relatively new, and reliable methods for detecting and identifying MPs are still being developed. However, many laboratories develop their methods independently, which may lead to methods being developed at a rate such that the methods cannot all be vetted by other researchers. We spoke with one toxicologist whose research is on the cutting edge of the IAMP field. This researcher expressed frustration at a lack of communication between scientists at different institutions regarding the advantages and limitations they have discovered within different methods. He shared his opinion that collaboration between researchers is key to overcoming the obstacles which plague the field of IAMP research.

4.3.5 - Mitigation

MPs are incredibly difficult to remove from the environment, which is only more concerning considering the rate at which they are produced. As MP concentrations grow, the question of how to reduce their concentrations becomes increasingly concerning as we continue to produce and use plastic products. Filtration and ventilation may be useful in reducing concentrations of IAMP. One chemist we spoke with suggested using plastics which intentionally break down into larger plastic particles, rather than nanoplastics or MPs. As a general rule, the smaller a plastic particle is, the more difficult it is to remove from the environment, and the more likely it is to cause harm to humans. These larger particles may be easier to remove from the environment and less toxic to humans, but they would still contribute to the overarching problem of plastic pollution.

Legislation is another possible mitigation strategy, though its aim is to stop MP production rather than removing MPs currently present in the environment. The EU’s ban on synthetic turf fields is just one prominent legislative measure which has been taken to aid in the reduction of MPs. Legislation has been, and must continue to be proactively implemented despite the lack of consensus regarding the health effects of MPs. Clean air policies may aid in the mitigation of outdoor airborne MPs through measures meant to reduce air pollution. As outdoor airborne MPs are likely to travel indoors, the reduction of these outdoor airborne plastics would lead to a decrease in IAMP concentrations as well.

4.4 - Limitations to our research

Throughout our research and analysis, we ran into roadblocks that influenced the way we conducted our research. Our research reflects these key limitations that we noted throughout our process, especially with the limited time frame to acquaint ourselves with an almost completely unknown subject with minimal development.

The biggest limitation within our research process, attributed to the field of IAMP being in its early stages, was the limited number of experts we were able to find and talk to within the project time frame. With the short time frame of seven weeks, the process for setting up interviews took place within the first few weeks, leaving only the latter weeks of the project to hold interviews. As previously mentioned, most interviewees were within adjacent fields such as air pollution or indoor air quality - only one of the interviews we held included a scientist who had worked with microplastics for an extended period of time. As most of the interviews were held with experts in adjacent fields, it is important to consider that their perspectives were often influenced by their specialty and sometimes missed key information specific to the field of IAMP.

4.5 - Conclusion

Through the research conducted throughout the course of this project, we have identified key areas of improvement within the field of IAMP. As a new area of study, IAMP research still needs to be further developed through communication and standardization between researchers. Through the standardization of the definitions of MPs and units, the results of studies can be better compared. Through communication, the best techniques for IAMP research can be identified and shared across the scientific community, and studies will become more repeatable and reliable. Once these developments have been made, epidemiological studies can be performed to gain insight into the health effects MPs have on the human body, and legislation can be passed to reduce the quantity of MPs within the environment.

References

About. Simple Plastics. (n.d.). https://simple-plastics.eu/about.html

Ageel, H. K., Harrad, S., & Abdallah, M. A.-E. (2022). Occurrence, human exposure, and risk of microplastics in the indoor environment. *Environmental Science: Processes & Impacts*, *24*(1), 17–31. https://doi.org/10.1039/d1em00301a

Aliouche, H. (2022, January 31). *Importance of cleanrooms in laboratories*. News. https://www.news-medical.net/life-sciences/Importance-of-Cleanrooms-in-Laboratories.aspx#:~:text=A%20Clean%20Room%2C%20or%20cleanroom,at%20a%20very%20low%20concentration

Arif, A. F. M., Al-Athel, K. S., & Mostaghimi, J. (2017). 3.4 residual stresses in thermal spray coating. *Comprehensive Materials Finishing*, 56–70. https://doi.org/10.1016/b978-0-12-803581-8.09199-2

Chen, Y., Li, X., Zhang, X., Zhang, Y., Gao, W., Wang, R., & He, D. (2022). Air conditioner filters become sinks and sources of indoor microplastics fibers. *Environmental Pollution*, *292*, 118465. https://doi.org/10.1016/j.envpol.2021.118465

Choi, H., Lee, I., Kim, H., Park, J., Cho, S., Oh, S., Lee, M., & Kim, H. (2022). Comparison of microplastic characteristics in the indoor and outdoor air of urban areas of South Korea. *Water, Air, & Soil Pollution*, *233*(5). https://doi.org/10.1007/s11270-022-05650-5

Commission regulation (EU) amending reach regulation as regards synthetic polymer microparticles. Internal Market, Industry, Entrepreneurship and SMEs. (2023, September 25). https://single-market-economy.ec.europa.eu/publications/commission-regulation-eu-amending-reach-regulation-regards-synthetic-polymer-microparticles_en

Determination of airborne fibre number concentrations: A recommended method, by phase-contrast optical microscopy (membrane filter method). (1997a). . World Health Organization. https://www.who.int/publications/i/item/9241544961

Enyoh, C. E., Verla, A. W., Verla, E. N., Ibe, F. C., & Collins, E. A. (2019). Airborne microplastics: a review study on method for analysis, occurrence, movement and risks. *Environmental Monitoring and Assessment*, *191*(11), 1-17. https://doi.org/10.1007/s10661-019-7842-0

Felipe-Rodriguez, M., Böhm, G., & Doran, R. (2022). What does the public think about microplastics? insights from an empirical analysis of mental models elicited through Free Associations. *Frontiers in Psychology*, *13*. https://doi.org/10.3389/fpsyg.2022.920454

Filtration / Disinfection. ASHRAE. (n.d.). https://www.ashrae.org/technical-resources/filtration-disinfection

Gill, S. L. (2020). Qualitative Sampling Methods. *Journal of Human Lactation*, *36*(4), 579–581. https://doi.org/10.1177/0890334420949218

Hartmann, N. B., Hüffer, T., Thompson, R. C., Hassellöv, M., Verschoor, A., Daugaard, A. E., Rist, S., Karlsson, T., Brennholt, N., Cole, M., Herrling, M. P., Hess, M. C., Ivleva, N. P., Lusher, A. L., & Wagner, M. (2019). Are we speaking the same language?

recommendations for a definition and categorization framework for plastic debris. *Environmental Science & Technology*, *53*(3), 1039–1047. https://doi.org/10.1021/acs.est.8b05297

Holm, M., Dahlman-Höglund, A., & Torén, K. (2011). Respiratory health effects and exposure to
superabsorbent polymer and paper dust - an epidemiological study. *BMC Public Health, 11*(1), 557–557. https://doi.org/10.1186/1471-2458-11-557

Introduction. (n.d.). https://imagej.net/ij/docs/intro.html

Jacobs, A. (2024, March 9). *Microplastics are a big problem, a new film warns*. The New York Times. https://www.nytimes.com/2024/03/09/health/microplastics-sxsw-health-plastic-people.htm

Kacprzak, S., & Tijing, L. D. (2022). Microplastics in indoor environment: Sources, mitigation and fate. *Journal of Environmental Chemical Engineering*, *10*(2), 107359. https://doi.org/10.1016/j.jece.2022.107359

Lehner, R., Weder, C., Petri-Fink, A., & Rothen-Rutishauser, B. (2019). Emergence of nanoplastic in the environment and possible impact on human health. *Environmental Science & Technology*, *53*(4), 1748–1765. https://doi.org/10.1021/acs.est.8b05512

Luyk, E. (2023, June 12). *Sputter coating for SEM: How this sample preparation technique assists your imaging*. Advancing Materials. https://www.thermofisher.com/blog/materials/sputter-coating-for-sem-how-this-sample-preparation-technique-assists-your-imaging/

Mathias, J. (2023, March 16). *How does ftir analysis work?*. Innovatech Labs. https://www.innovatechlabs.com/newsroom/672/stuff-works-ftir-analysis/
Microplastics - ECHA. (n.d.). https://echa.europa.eu/hot-topics/microplastics

Microscope images at different magnifications. Microscope Images at Various Magnifications | Microscope World Resources. (n.d.). https://www.microscopeworld.com/t-microscope_images.aspx

Nematollahi, M. J., Zarei, F., Keshavarzi, B., Zarei, M., Moore, F., Busquets, R., & Kelly, F. J. (2022). Microplastic occurrence in settled indoor dust in schools. *Science of the Total Environment*, 807, 150984. https://doi.org/10.1016/j.scitotenv.2021.150984

Ockenga, W. (2011, April 27). *Fluorescence in microscopy*. Science Lab | Leica Microsystems. https://www.leica-microsystems.com/science-lab/life-science/fluorescence-in-microscopy

O'Brien, S., Rauert, C., Ribeiro, F., Okoffo, E. D., Burrows, S. D., O'Brien, J. W., Wang, X., Wright, S. L., & Thomas, K. V. (2023). There's something in the air: A review of sources, prevalence and behaviour of microplastics in the atmosphere. Science of The Total Environment, 874, 162193. https://doi.org/10.1016/j.scitotenv.2023.162193

Particle Size Analysis (TEM, SEM). Creative Bioarray. (n.d.). https://www.creative-bioarray.com/services/particle-size-analysis-tem-sem.htm
Pinto-Rodrigues, A. (2023, April 10). *Microplastics are in our bodies. here's why we don't know*

the Health Risks. Science News. https://www.sciencenews.org/article/microplastics-human-bodies-health-risksl

Press corner. (n.d.). European Commission - European Commission. https://ec.europa.eu/commission/presscorner/detail/en/mex_23_4607

Przekop, R., Michalczuk, U., Penconek, A., & Moskal, A. (2023). Effect of microplastic particles on the rheological properties of human saliva and mucus. *International Journal of Environmental Research and Public Health*, *20*(22), 7037–7049. https://doi.org/10.3390/ijerph20227037

Ratcliff, C. L., & Wicke, R. (2022). How the public evaluates media representations of uncertain science: An integrated explanatory framework. *Public Understanding of Science*, *32*(4), 410–427. https://doi.org/10.1177/09636625221122960

REACH Regulation. (2024, February 8). Environment. https://environment.ec.europa.eu/topics/chemicals/reach-regulation_en#:~:text=The%20Regulation%20on%20the%20registration,can%20be%20posed%20by%20chemicals

Reflectance Infrared (FT-IR) spectroscopy. Bruker. (n.d.). https://www.bruker.com/en/products-and-solutions/infrared-and-raman/ft-ir-routine-spectrometer/what-is-ft-ir-spectroscopy/reflectance-infrared-spectroscopy.html

Relhan, V., Garg, V. K., Ghunawat, S., & Mahajan, K. (2020). *Comprehensive textbook on Vitiligo* (1st ed.). Taylor & Francis Group. 2024, https://ebookcentral.proquest.com/lib/wpi/detail.action?docID=6340975

Rioux, R. M., & Elliot, W. A. (n.d.). *Fume hoods and laminar flow cabinets: Principle and Operation: Lab Safety*. JoVE. https://www.jove.com/v/10372/fume-hoods-and-laminar-flow-cabinets-principle-and-operation#:~:text=Principles-,Fume%20hoods%20and%20laminar%20flow%20cabinets%20are%20engineering%20controls%20that,reduce%20workspace%20exposure%20to%20contaminants

Rochman, C. M., Kross, S. M., Armstrong, J. B., Bogan, M. T., Darling, E. S., Green, S. J., Smyth, A. R., & Veríssimo, D. (2015). Scientific evidence supports a ban on microbeads. *Environmental Science & Technology*, *49*(18), 10759–10761. https://doi.org/10.1021/acs.est.5b03909

Rosenburg, A. (2022, May 3). *What Are Controls and Why Do We Need Them?*. BioIVT. https://bioivt.com/blogs/control-matrices

Salthammer, T. (2022). Microplastics and their additives in the indoor environment. *Angewandte Chemie*, *134*(32). https://doi.org/10.1002/ange.202205713

Smith, Y. (2023, July 19). *What is optical microscopy?*. News. https://www.news-medical.net/life-sciences/What-is-Optical-Microscopy.aspx

Swapp, S. (2024, March 8). *Scanning electron microscopy (SEM)*. Geochemical Instrumentation and Analysis. https://serc.carleton.edu/18401

Thermo Fisher Scientific. (n.d.). Nicolet in10 MX ft-IR microscope.

https://assets.thermofisher.com/TFS-Assets/CAD/brochures/D12900~.pdf
Thermo Fisher Scientific. (2021, December 25). *Nicolet IN10 User Guide*. Thermo Fisher Scientific. https://knowledge1.thermofisher.com/Molecular_Spectroscopy/Fourier_Transform_(FT)_Infrared_(IR)_and_Near_Infrared_(NIR)/Nicolet_Microscopes/Nicolet_Microscope_Operator_Manuals/Nicolet_iN10_User_Guide
Université de Fribourg. (n.d.). Adolphe Merkle Institute. BioNanomaterials Group at the Adolphe Merkle Institute. https://www.ami.swiss/bionanomaterials/en/
What is clean bench? (Basic Knowledge). Matsusada Precision. (2018, December 6). https://www.matsusada.com/column/clean_bench_basic.html
World Health Organization. (n.d.). *Dietary and inhalation exposure to nano- and microplastic particles and potential implications for human health*. World Health Organization. https://www.who.int/publications/i/item/9789240054608
Wright, S. L., & Kelly, F. J. (2017). Plastic and human health: A micro issue? Environmental Science & Technology, 51(12), 6634–6647. https://doi.org/10.1021/acs.est.7b00423
Wright, S. L., Gouin, T., Koelmans, A. A., & Scheuermann, L. (2021). Development of screening criteria for microplastic particles in air and atmospheric deposition: Critical Review and applicability towards assessing human exposure. *Microplastics and Nanoplastics*, *1*(1). https://doi.org/10.1186/s43591-021-00006-y
Zhang, Q., Xu, E. G., Li, J., Chen, Q., Ma, L., Zeng, E. Y., & Shi, H. (2020). A review of microplastics in table salt, drinking water, and air: Direct human exposure. *Environmental Science & Technology*, *54*(7), 3740–3751. https://doi.org/10.1021/acs.est.9b04535
Zuccaro, P., Thompson, D. C., de Boer, J., Watterson, A., Wang, Q., Tang, S., Shi, X., Llompart, M., Ratola, N., & Vasiliou, V. (2022). Artificial Turf and crumb rubber infill: An international policy review concerning the current state of regulations. *Environmental Challenges*, *9*, 100620. https://doi.org/10.1016/j.envc.2022.100620
Zuccaro, P., Thompson, D. C., De Boer, J., Llompart, M., Watterson, A., Bilot, R., Birnbaum, L. S., & Vasiliou, V. (2024). The European Union ban on microplastics includes artificial turf crumb rubber infill: other nations should follow suit. *Environmental Science & Technology*. https://doi.org/10.1021/acs.est.4c00047

Appendix A - Control Table

A chart comparing the controls used in each of the 20 examined studies in terms of negative controls, positive controls, clean air conditions, and efforts to reduce plastic contamination.

CONTROLS COMPARISON

PAPER	NEGATIVE CONTROL	POSITIVE CONTROL	CLEAN AIR CONDITIONS	PLASTIC REDUCTION
(ABBASI ET AL., 2019)	✗	✗	✗	Only clothing made of natural fibers worn; Gloves worn; Facemask worn
(BERGMANN ET AL., 2019)	✓	✗	✓	Plastic equipment substituted; Only clothing made of natural fibers worn
(CAI ET AL., 2017)	✗	✗	✗	Plastic equipment substituted
(CHEN ET AL., 2022)	✓	✓	✗	Only clothing made of natural fibers worn; Gloves worn; Facemask worn
(CHOI ET AL., 2022)	✗	✗	✓	Only clothing made of natural fibers worn; Gloves worn
(DEHGHANI, MOORE & AKHBARIZADEH, 2017)	✓	✗	✗	Only clothing made of natural fibers worn; Gloves worn
(DRIS ET AL., 2017)	✗	✗	✗	✗
(GASTON ET AL., 2020)	✓	✗	✗	Only clothing made of natural fibers worn
(HOLM, DAHLMAN-HOGLUND & TOREN, 2011)	✓	✗	✗	✗
(LI ET AL., 2020)	✗	✗	✗	✗
(C. LIU ET AL., 2019)	✓	✗	✓	Plastic equipment substituted
(K. LIU ET AL., 2019A)	✓	✗	✓	Only clothing made of natural fibers worn; Gloves worn
(K. LIU C ET AL., 2019B)	✗	✗	✓	Only clothing made of natural fibers worn; Gloves worn
(NEMATOLLAHI ET AL., 2022)	✓	✗	✗	Plastic equipment substituted
(PRZEKOP ET AL., 2023)	✗	✗	✗	✗
(STANTON ET AL., 2019)	✓	✗	✗	Only clothing made of natural fibers worn
(VIANELLO ET AL., 2019)	✓	✗	✓	✗
(WANG ET AL., 2020)	✓	✗	✓	Only clothing made of natural fibers worn; Gloves worn
(ZHANG, WANG & KANNAN, 2020)	✓	✓	✗	✗
(ZHANG ET AL., 2020)	✓	✗	✗	Only clothing made of natural fibers worn

Plastic equipment substituted

Gloves worn

Only clothing made of natural fibers worn

Facemask worn

Appendix B - FTIR Usage Table

A Table showing the information studies using FTIR included about their FTIR usage.

FTIR USAGE

PAPER	FTIR "SUCCESSFUL"	NICOLET IN10 MX SPECIFIED	ATR SPECIFIED	REFLECTANCE (1/cm)	MINIMUM MEASURED SIZE (µm)
(BERGMANN ET AL., 2019)	✓	✗	✗	✗	11
(CAI ET AL., 2017)	✓	✓	✗	4,000 - 500	< 200
(CHEN ET AL., 2022)	✓	✗	✗	✗	312 ± 430
(CHOI ET AL., 2022)	✓	✗	✗	✗	20
(DRIS ET AL., 2017)	✓	✗	✓	✗	5
(GASTON ET AL., 2020)	✓	✗	✗	✗	5
(C. LIU ET AL., 2019)	✓	✗	✗	✗	50
(K. LIU ET AL., 2019A)	✓	✓	✗	✗	12.45
(K. LIU C ET AL., 2019B)	✓	✓	✗	✗	10
(STANTON ET AL., 2019)	✗	✗	✓	4	Unmentioned
(VIANELLO ET AL., 2019)	✓	✗	✗	✗	< 11
(WANG ET AL., 2020)	✓	✓	✗	✗	10
(ZHANG ET AL., 2020)	✓	✓	✗	✗	50

Appendix C - Additional Information

There has yet to be a clear method for mitigating the effects of MPs, or for removing them from indoor or outdoor environments. As current understanding of the dangers of MPs to the environment and to human health increases, there have been initiatives to reduce both the current concentrations and quantity produced overall of MPs.

C.1 - Filtration

In order to reduce the quantity of IAMP already within the indoor environments we frequent, the most prominent mitigation strategy is proper indoor ventilation. Some current ventilation systems are capable of lowering concentrations of MPs, but have high maintenance costs.

One study conducted in urban Seoul, South Korea tested the effects of indoor ventilation on MPs by modifying the ventilation times within residential homes and determined that increased ventilation time also decreased the quantity of indoor MPs (Choi et al., 2022). Given this correlation, implementing proper filters and ventilation systems into indoor environments could lower indoor airborne MP concentrations.

However, current ventilation options are not ideal for most indoor environments. In order to be effective in removing microscopic IAMP, a filter must be of a high efficiency and quality. Introducing filters which meet this standard is unrealistic in most indoor environments. Higher filter efficiency leads to increased pressure drops within the system, which not all systems can support (“Filtration / Disinfection”, n.d). The quality of the filters also increases installation, usage, and maintenance costs, leading most building owners to seek compromises between filtration quality and the financial burden (Kacprzak & Tijing, 2022). As such, filtration is not a realistic solution for removing all airborne MPs from indoor environments, and must be paired with techniques for decreasing the concentrations of MPs produced.

C.2 - Legislation

Many governmental and commercial guidelines aiming to reduce overall MP production have begun to take effect around the globe. Much of this legislation results from research into

MP presence in outdoor environments. As such, it does not cover all aspects of indoor airborne environments, but it does provide an example of what anti-microplastic legislation currently looks like, and contributes to decreasing the production of MPs.

A major breakthrough in MP legislation was made in September 2023, when the EU implemented legislation banning the sale of some common sources of MPs, in the hope of reducing MP production by 500,000 tonnes over the next 20 years (*Microplastics*, n.d.). The ban includes products with primary microplastics or that produce secondary MPs, such as some rubber floorings (Zuccaro et al., 2024). This ban follows previous legislation limiting the inclusion of microbeads, a primary microplastic, in personal care products.

One study had estimated that in one day, eight trillion microbeads are released into aquatic environments in the United States alone (Rochman et al., 2015). In 2014, the Netherlands became the first country to ban MPs from cosmetic products. By 2019, Australia, Canada, Italy, Korea, New Zealand, Sweden, the United Kingdom, and the United States had all produced legislation banning microbeads (Watkins et al., 2019), with the EU following in 2023. Legislation passed regarding the restriction of microbeads provides an excellent precedent for further MP legislation, which is still necessary as personal care products are estimated to account for only 2% of MPs being introduced into the environment (Zuccaro et al., 2024).

The ban implemented by the EU was done so under the chemical legislation REACH, which regulates the registration, evaluation, authorisation, and restriction of chemicals, and covers certain synthetic polymer particles. In order to be included in this ban, a particle must be below 5 mm, organic, insoluble, and resist degradation (*Press Corner*, n.d.). An eight year transition period follows the passing of this ban, during which time eco-friendly alternatives, such as coconut fibers, cork, and sand, will replace plastics.

Once major product which this ban affects is artificial turf. Artificial turf is often filled with crumb rubber, made from shredded car tires. The European Chemicals Agency has estimated that this infill represents about 38% of the total estimated MP release in Europe (Zuccaro et al., 2024). This has the potential to become a major issue, as MPs may leach harmful chemicals into the environment.

C.3 - Public Awareness

While public awareness of airborne MPs is still limited, marine plastic debris has gained significant attention. By increasing public awareness of the effects of MPs not only on aquatic environments, but indoor environments and humans as well, more progress could be made in mitigating the effects of MPs through individual action.

Current public awareness about MPs focuses on the effects MPs have on aquatic environments, and less about how MPs are created. Using a survey with a free association technique, one Norwegian study looked into current public perceptions on MPs (N = 2720). After breaking down results into categories of solutions, consequences, evaluations, spread, sources, and other, it was determined that the most commonly noted category was spread, or where MPs were found. Most respondents focused on aquatic environments and aquatic animals, with air being one of the least common responses. The least common category noted was possible sources, with only 24.1% of participants including sources in their answer. Of the sources listed, the most common ones were clothing and litter, with a few mentions of artificial turf, personal care products, paint, and car tires. The study noted that while the participants noted many negative effects of MPs, there was little identification of how MPs arrived within aquatic and other environments and a negative perspective questioning the feasibility of MP mitigations. With these discoveries the study concluded that the public understanding of MPs was mainly focused on the possible negative effects, and awareness campaigns should focus on specific instances of MP sources and suggest individual actions to mitigate MPs (Felipe-Rodriguez, Böhm, & Doran, 2022).

Other studies ran focus groups to evaluate current knowledge of MPs and openness to following mitigation recommendations. Within a group of 20 participants from Australia, most knowledge about plastics was found limited to plastic bags and microbeads. A group of 42 in the United Kingdom showed slightly more knowledge about plastic pollution based on media representation. In general, both groups' current knowledge was lacking, limited to media portrayals of plastic litter rather than the link between every-day activities and MP production. Once properly informed of the possible dangers of MPs, they became more open to taking on individual mitigating strategies (Kacprzak & Tijing, 2022). These studies demonstrated that with proper education and increased public awareness, populations would be more willing to introduce mitigating measures into their own lives to reduce MPs.

Individuals can reduce their contribution to MP production by educating themselves on the impact of the products they purchase. This is particularly significant in countries without bans on microbeads, where opting for cosmetics that employ biodegradable or natural exfoliants can reduce an individual's contribution to MP generation. In addition, purchasing higher-quality or natural textiles reduces the risk of clothing deterioration contributing to MP production, and avoiding use of single-use plastic products reduces the amount of MP sources introduced to the environment. The more individuals follow these practices, the more concentrations of MPs within indoor environments will decrease.

C.4 - Synthetic Microplastic Creation

IAMP research is still a developing field, and there is disagreement between researchers regarding what methods are the most accurate, and whether some work at all. Most studies are conducted on samples collected from real-world sites, there may be many variables which cannot be accounted for, such as non-MP environmental contaminants. The combination of uncertainty in the viability of the methods used and properties of the sample leads to questions regarding the viability of results. Some researchers have begun to conduct testing with MP particles created in a laboratory setting. There are two prominent methods by which this is done: milling and nanoprecipitation. As one chemist explained, milling is a simpler process used for the creation of larger MP particles, while nanoprecipitation uses surfactants to create smaller MP particles, typically beneath one micrometer. Synthetically creating MPs allows researchers to control certain properties, and perhaps better compare results of studies across different methods, and better understand their limitations. There are downsides to this strategy, as the variability of MPs is one of their most defining characteristics, and this is not reflected in the uniformity of synthetically created MPs, which may make major differences in the properties they exhibit.