Microplastics: Research, Problems, and Solutions

An Interactive Qualifying Project

Submitted to the Faculty of

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An interactive qualifying project submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the degree of Bachelor of Science in Engineering Sciences.

Abstract

Microplastics, by definition, are plastic particles less than 5 millimeters in diameter—due to their extreme ubiquity and potential threat to life, there are strong incentives to study their effects. We conduct a literature review of ~250 papers on top of expert interviews to understand the effects of microplastics and potential solutions. In regards to health, the presence of MPs in the body has been linked to lung cancer, gastrointestinal diseases, reproductive issues, and as a vector for pathogens on top of other potential issues. In regards to the environment, through runoffs and weather breakdowns, MPs have been found in nearly all environments: their massive presence on the ocean surface can be detected by satellites, shape-corrected simulation models suggests presence in the stratosphere, and studies suggests agricultural soil stores microplastics even better than ocean basins. In regards to ecology, numerous species are threatened either directly or indirectly through food web disruption by microplastics: on land the reproductive systems of soil invertebrates and rodents are negatively affected, in the seas species of planktons have been found to also suffer reproductive stress and are more susceptible to predators. In regards to the economy, recycling appears to be a major business opportunity, however, whether recycling is more detrimental to the MP issue than helpful is a point of contention we explore. This literature review was done alongside our own surveys which were designed to investigate how people perceive microplastics—we found that the vast majority of participants felt concerned and were willing to take action while paradoxically believing the vast majority of participants to be unaware and unwilling to take action. We discuss the implications of this through the lens of climate change activism and misinformation as a case study. Lastly we discuss various potential solutions based on the results of our literature search and private survey.

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Chapter 1: Introduction

Microplastics are an abundant issue of the utmost importance in today's world. Found in nearly every corner of the earth, microplastics negatively affect the environment around us: from disrupting surface tension in the ocean, causing adverse health effects in humans, and depleting the environment of nutrients necessary to sustain life. This paper serves a coalition of data and research gathered and conducted to explain what microplastics are and how microplastics originated and spread so thoroughly, as well as emphasize the imperativeness of microplastic removal and offer solutions. The goal of this project was to research microplastics: determine how much effect microplastics have on both the micro and macro scale, determine which groups and aspects of the world are most affected, and ascertain the areas in which need the most attention.

Chapter 2: Background

2.1) Definition of Microplastics

Microplastics, by definition, are plastic particles less than 5 millimeters in diameter, and can be composed of any mixture of plastic polymer, functional additives, or residual impurities. There are different categories of microplastics: primary and secondary (195).

Primary microplastics are intentionally manufactured, “first time use” plastics. There are four subsections of primary microplastics, the first is microbeads (201). Microbeads are tiny plastic particles used in personal care products like toothpastes and exfoliating scrubs. In 2015, the United State’s Food and Drug Administration passed a piece of legislation titled “Microbead-Free Waters Act” that bans the use of plastic exfoliating beads, which are a type of microbead, because of the studied effects in aquatic life. Little did these legislators know, these beads were contributing to a much larger problem (202). The next subsection of primary microplastics are nurdles: small pre-production plastic pellets used as raw materials in the manufacturing of virtually any plastic products. Next, there are plastic fibers which are synthetic fibers released during the washing of synthetic textiles: polyester, nylon, acrylic, elastane, spandex, lycra or microfiber (203). These fibers can originate from clothing, carpets, bed sheets, etc. Any synthetic fabric will produce these plastic fibers. The last part of primary microplastics are the plastic pellets. The second largest source of primary microplastic pollution, plastic pellets are small industrial plastic- pellets-by-product used in a myriad of manufacturing processes (204). There are some sources that believe nurdles and plastic pellets to be synonymous,

however it's the intention that makes these two different: nurdles are used in the raw materials of a process whereas plastic pellets are a by-product of the process.

Next are secondary plastics. When comparing primary and secondary plastics, the proportion of primary plastics in the environment is much smaller than the proportion of secondary plastics in the environment (197). Secondary plastics result from the breakdown of larger plastic items through various physical, chemical, and biological processes. Secondary plastics can either fragment from other larger plastic items, such as bottles or bags, or they can come from degradation of chemical processes that cause plastic polymers to break down over time (205). Additionally, there are different shapes of microplastics due to their composition and fragmentation pattern. Overarchingly, these secondary microplastics can be categorized as fiber, granular, fragment, film, and foam shapes (104). Fibers are akin to thread-like particles and can be flat or spherical; flat fibers are more abundant in the atmosphere than spherical fibers (199, 203). The shapes of secondary plastics can be more closely examined in the figure below.

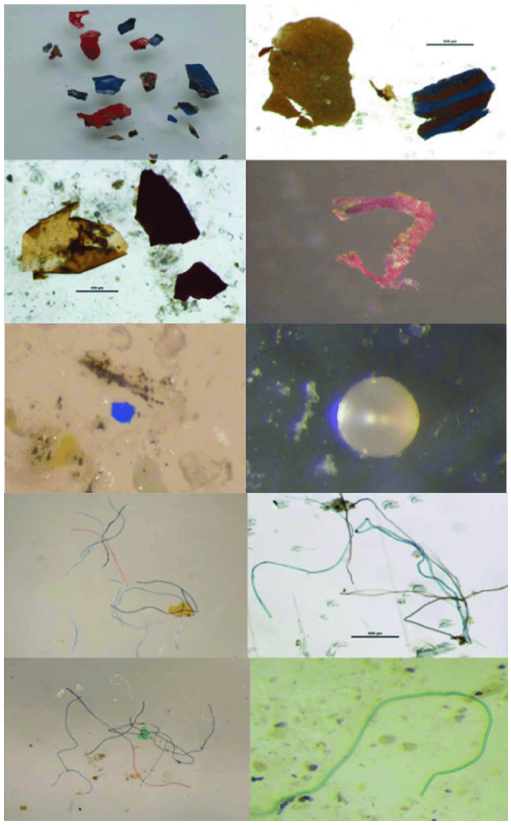

Figure 1: Pictures of microplastic granules, flakes, spheres, fibers, found in Danish water. Photo taken from ResearchGate.net (209)

Fragmentation and decomposition of microplastics can occur from not only chemical processes but biological, physical, or a combination of all three processes. Fragmentation inevitably results from the loss of structural integrity (196). For instance, photodegradation of plastics occurs overtime due to ultraviolet radiation from the sun; in turn, the photodegradation can form cracks, discoloration, and brittleness in the plastic. This structural deficit coupled with abrasion from turbulence will cause fragmentation. Further, fragmentation is even more probable to occur because of plastic's long lifespan. This process can repeat itself until microplastics have reduced to nanoplastic size, particles less than 1000 nm in size (195).

2.2) Sources of Microplastics

Microplastics by definition originate from macroplastics, or what is colloquially referred to as plastic. To best understand the source of microplastics, the investigation of macroplastics must happen first. Plastics are found in almost every aspect of the modern world due to their desirable characteristics for a myriad of uses: high stability, lightweight nature, ease and variability of production, excellent oxygen and moisture barrier properties, thermal and electrical insulation, and extreme versatility (158, 193). Macroplastics do not just have a singular molecular formula, instead macroplastics are created using a plethora of materials to produce the desired product. Thus, macroplastics are the result from a material composition that varies in components and combinations. Typically, macroplastics are most commonly composed of seven materials: polystyrene (PS), polyethylene (PE), polyethylene terephthalate (PET), polyvinyl chloride (PVC), polypropylene (PP), polyurethane (PUR), and polycarbonate (PC) (158, 20, 193). Although there has been movement to implement increased plastic management (47) and improve recycling methods for macroplastics, ultimately the inefficiencies in recycling and reusable methods have encouraged wide misuse of plastics, especially towards the end of their "life" or time when the plastic is used.

When exposed to the environment, plastics undergo fragmentation, creating microplastics. Fragmentation of plastics can be caused by several factors: biological metabolism, UV radiation, water currents and forces, etc (158).

After learning about the process in which microplastics are produced, two assumptions can be made. First, it can be assumed that wherever macroplastics are, microplastics will be present also. Secondly, it can be assumed that studies done on effects of plastics on the environment, humans, etc. will also apply to microplastics, because an accumulation of microplastics make up the constituents of macroplastics.

The question of how microplastics have contaminated every part of the world is fair. Microplastics are physically moved, whether by an organism, water current, the wind, or of an organism consuming something contaminated by microplastics. After further research, microplastics will remain a contaminant unless pointedly removed. Therefore, microplastics will remain in waterways unless remediated. Microplastic contamination will remain in the human body, the soil, the earth, etc unless pointedly removed. These particles will not just disappear overnight, and require immediate and whole attention.

2.3) Origins of Awareness of Microplastics

Macroplastic production began in the 1940s, so it can be assumed that the production of microplastics started then (202). Moreover, macroplastic was first reported as an issue as early as the late 1960s when plastic pieces were found internally in some albatrosses (186, 187). After this revelation, most macroplastic pollution data surrounded oceanic life: the entanglement of marine mammals, litter found in fishing nets, ingestion of plastics by birds, etc. (193, 187). The emphasis on plastic pollution in aquatic environments only increased after the discovery on teh "Great Pacific Garbage Patch" in 1997 (162, 198). After these revelations, awareness of plastic pollution has exponentially increased worldwide.

Narrowing down from "macro", the term "microplastics" was first used in 2004 by Professor Richard Thompson of the International Marine Litter Research Unit to identify plastic particles of size around 20 micrometers on the beaches of the United Kingdom (185). This team, led by Professor Thompson, would then pioneer microplastic research until more of the world became involved. In 2007 and 2008, papers were published surrounding the chemical transport to organisms by microplastics and the ingestion and retention of microplastics by organisms (192). To make it clear, this team did not stop in 2008 but still researches microplastics and has produced trailblazing results ever since their coining of "microplastics" in 2004. However, more of the world became increasingly concerned about microplastics in 2008, potentially stemming from the scientific evidence produced from Thompson's team.

In 2008, the United States held a conference to ascertain the risks and relationships between microplastics and animals, in which mostly the then produced data was discussed and speculative hypotheses of microplastic impact were created. Concurrently, the National Aeronautics and Space Administration (NASA) satellites started tracking macroplastic accumulation in the ocean. These satellites ended up being even more useful in the tracking of plastic than originally intended. While searching for macroplastics gathering in the ocean, these satellites also took note of the ocean's surface tension. In 2009, these satellites recorded data

revealing discrepancies in ocean surface tension, and upon further investigation microplastics and their ability to float were the determined cause (191). Inadvertently, these NASA satellites were tracking microplastics in the ocean.

Today, NASA alongside the University of Michigan have implemented the use of the Cyclone Global Navigation Satellite System (CYGNSS) which are specifically calibrated to measure the roughness of the ocean and wind speeds (190). The CYGNESS satellites have conclusively established that in areas with high concentrations of microplastics, there are larger discrepancies between ocean roughness and wind speed. Initially, the intended use of these satellites may have been to track cyclones, but the accidental benefit of tracking microplastics is now another forefront purpose of the CYGNESS mission according to NASA (188, 189).

2.4) The Dangers of Microplastics

Microplastics pose a substantial issue to life. Arguably, the greatest threat that microplastics bring is the fact they occupy every crevice of the earth currently; microplastics have been found in humans, land and sea animals, the air, soil, water, etc. Microplastics are an unnatural, inorganic substance that have spread in a way no other material has before in history. To put it simply, our world was not designed for microplastics, or macroplastics for that matter, and these tiny particles are wreaking havoc on the world around us. For example, look at microplastics in the human body; the human body was not designed to metabolize or use microplastics for gain. Exploring studies conducted about long term internal human exposure to plastics emphasize the health hazard that plastics can have on the body (15). It's not just the human body that is affected: plants are not able to root as deeply when contaminated with microplastics (83), aquatic and terrestrial animals experience more difficulties with reproduction (78), and oceanic weather patterns are changed (190).

Another concerning aspect of microplastics is their unique chemical and material structure. Because of these intrinsic properties, microplastics have the ability to attach to pollutants from one environment and carry them into a different environment, polluting even further and potentially introducing new hazardous factors into said ecosystem. (145)

A quick aside, when macroplastics are made, the seven most common base plastics are just that, a base. Additives and monomers are used in combination with these bases to create the final desired macroplastic product. These additives and monomers are functional chemicals incorporated in macroplastics to beneficially adjust the mechanical and material properties of the plastic. For instance, these additives may improve an aesthetic aspect like color or enhance a material property like flexibility or fire resistance (159). After macroplastic fragmentation, these

additives and monomers have a leaching effect and can absorb organic hazards from their environs, like heavy metals, and then carry them into a new environment (80). Make no mistake, the hazards that microplastics absorb are harmful; these hazards can potentially be carcinogenic, possess endocrine-disrupting properties, or even cross the blood brain barrier (137, 158). To reiterate an earlier point, microplastics are permanent unless intentionally cleaned from the environment. This resilience and strong adhesive characteristics emphasizes just how dangerous these tiny particles truly are.

Chapter 3: Methodology

To gather research, the team used a method combination of literature search and two styles of interviews. These methods, further explained below, allowed the team to garner information and material to effectively conduct a thorough study and create solutions.

3.1) Literature review methodology

We focused on four categories: health, environment, ecology, and economy and analyzed the results with respect to three identified primary stakeholders: the general public, the government, and the private sector (namely the pharmaceutical, food, and textile industry). Literature from various journals found through online, keyword based search which contained topics of interests were found and organized in a spreadsheet. Sources primarily consisted of academic publications, however, this can be category specific. For instance, several sources used in the economy category came from publications done by management consulting firms to understand the perception and sentiment surrounding microplastics in the business world. Although not traditionally academically reputable, these consulting companies are reputable in the business world and deliver solutions through highly comprehensive research and analysis for clients such as: NASA, Dwight Eisenhower, General Motors, etc which lends credibility to their analysis and publishing. One particular resource heavily utilized when searching for literature was SCOPUS, an abstract and citation database comprised of published articles and peer reviewed journals. More than seventy-five percent of the sources used in the literature review were collected from the SCOPUS database.

Each source is recorded as a row in the sheet and given a unique ID. We categorize each source in this sheet as being either a “health”, “environment”, “ecology”, or “economy” focused source, and also give a brief summary and offer relevance with respect to each of the three

stakeholders identified. Over the course of the project, a total number of 258 sources were analyzed.

3.2) Expert Interview Methodology

3.2.1) Value Proposition: The Need for Understanding Expert Perception

Expert interviews were conducted to gain a better understanding of the perception stakeholders have towards the microplastics issue. It is important to understand how stakeholders within industries affected by microplastics view the issue to understand what solutions are feasible and likely to be implemented. Experts involved in government are also important to interview to get an assessment of the current urgency the issue holds in different levels of government and what might be needed to emphasize the importance so that officials will push for more change to remedy the issue. These interviewees will also provide a basis for what legislation solutions are likely achievable. Experts in microplastic research were also interviewed to obtain information on the current microplastic issue that may not be currently available through traditional literature research. These experts will have a unique insight on possible solutions and how to best spread information to the general public.

3.2.2) Details about the Sample and Limitations

Over the course of this project, seven interviews were conducted with professionals in their field. The professionals were found through Worcester Polytechnic Institute, by recommendation from professors, or by being an author of a paper. In complete transparency, over one-hundred interview candidates were contacted, but only seven professionals were willing to be a part of this process. Of the seven interviewees, two are food industry professionals, one of whom has an extensive knowledge of biodegradable plastics, one is a researcher in a very well-known hospital which an expertise in overall health of the human body, two are biochemical experts on plastics with an emphasis on plastics and polyfluoroalkyl substances (PFAS), and and the last two are microplastic subject matter experts. These experts were asked the same base group of about fifteen questions, and then an additional ten questions based on their personal expertise and interest in the study of microplastics.

3.2.3) Approach Towards Interview and Rationale

For interviews, the team used a combination of methods. First, a master list of questions was generated so that most interviewees were answering the same questions so the data gathered would be accurate. However it is important to point out that experts alongside non-expert civilians alike were both interviewed; for the experts, additional questions were asked given their background and extensive knowledge about the subject. For the non-expert interviews, the team used both an online form and in-person interviews to gather data. In both the in-person style and online form, the questions were identical as to not skew the data and get as accurate of results as possible. The survey style was found to be most effective, but both interviews yielded seventy-two total interviews and data.

3.3) General public perception and sentiment survey methodology

3.3.1) Value Proposition: the Need to Understand the Public Perception and Sentiment

We break down the problem of "How do we sway the public?" into two sub problems: "How do we educate the public?" which involves increasing awareness and perception of microplastics and "How do we convince the public?" which involves swaying the public out of apathy. We believe that in order for effective change to happen these two components are essential and that pursuing only one or the other leads to inadequate results. We therefore propose the following framework for quantifying these two components.

Perception refers to the level of awareness the public currently has surrounding microplastics. This encompasses empirical statements/answers given by the public—statements which the public believe are facts about microplastics. A statement such as "I think microplastics negatively impact ecosystems" would lean closer towards an empirical statement. We aggregate and analyze these statements to gauge the current public perception of microplastics.

Sentiment refers to how the public currently feels about microplastics. These are non-empirical statements/answers given by the public that involve emotions and value judgements about microplastics. For instance: "I feel like I cannot do anything to reduce the amount of plastics in the ocean." would lean closer towards a non-empirical statement.

These are not meant to be mutually exclusive. A single sentiment can be interpreted in many ways. Additionally, what a person knows about a topic naturally influences how they feel towards that topic and a person's feelings and biases influence how what information they ingest.

These two metrics are interrelated by nature; they serve more as a loose abstraction for the purpose of designing a solution than as an accurate psychological model.

3.3.2) Details about the Sample and Limitations

The survey was conducted on Worcester Polytechnic Institute (WPI) students. WPI is a small private institution with a specialized focus in engineering and sciences. According to the official admission website: the average WPI admitted undergraduate student has a GPA of 3.92 and is within the top 9% of their class rank. These biases make it difficult to conclusively extrapolate findings from this sample to the general public.

However, the 'general public' is not a monolith and consists of many sub demographics. We believe these findings will still represent college-educated, young adults. Historically, major movements and protests were often initiated and led by the educated members of the population. Although the sample of WPI students is not representative of the general public, it is representative of one of the most important sub-demographics of the general public.

Due to resource limitations, our sample size is on the smaller side at 65 students.

3.3.3) Previous Works in this Area

Many studies have been conducted studying the sentiment and perception of microplastics within the general public, this is elaborated on in chapter 5. These studies are very comprehensive in investigating what the public is aware of and how they feel about microplastics. However, these studies lack a crucial element: what do people think the public thinks?

People do not organize worker strikes when they believe they will be the only one striking; it is when they believe others will also strike that a worker strike happens. Similarly, people do not attend protests when they believe they will be the only one there; it is when they believe others will also be there that a protest happens. It does not matter where this belief comes from. It could come from word of mouth surveys of others. It could come from information from social media. Fundamentally, if some action A must be taken as a group in order to produce any benefit, then a prerequisite for any rational individual to take action A is that individual must predict that the group will also take action A. Individual actions are governed by their theory of "group mind" so to speak.

The key thing here is that individual actions are not governed by the group action—it is governed by the individual's prediction of the group action. Therefore, rather than only studying the individual action or even the group action, an additional element is imperative to study the individual prediction of the group action: in other words, study what the group predicts of itself. This element was emphasized in the survey because of its crucial nature. Furthermore, we also acknowledge the importance of anticipating opposing misinformation campaigns as well which we elaborate on in section 5.3.

3.3.4) Design of the Survey

In consideration of these questions, each question in the survey falls within one of three categories: (1) general information question, (2) perception questions, (3) sentiment questions., (4) evaluations of others questions. General information questions are intended to get general demographic information such as age, gender, sources of news etc. Perception questions are designed to investigate how aware the participant is of the microplastic issue through a mixture of quantitative and qualitative questions. Inquiring into how often participants have heard of microplastics if they have, where they heard about microplastics from, and a qualitative free response prompting participants to list what they know about microplastics which was intentionally left vague up to interpretation. Sentiment questions are designed to investigate what participants feel about microplastics through a mixture of quantitative and qualitative questions. i.e: "on a scale of 1-4 how concerned are you about microplastics?" Then points of reference are provided such as "where 1 is believing that microplastics are a non-issue and 4 is believing that they are an extinction threat." Evaluation of others questions are questions which are intended to gauge how participants view themselves compared to what they believe is the "average" participant. For instance, following the question "How concerned are you about microplastics", we might immediately ask "How concerned do you think the general public is about microplastics?" Additionally, a series of questions querying how often participants participate in activism were asked; the intent behind these questions is to garner an estimate of how willing a participant is to take action against microplastics while utilizing their previous activism behavior to aid in creating an estimation. These questions range from small tasks like using reusable bags at the grocery store to large tasks such as participating in activism like protests and boycotts. Additionally, each of these questions had a duplicate question which asked participants to instead

estimate how often others participate in the same activism task. This provides us with a point of reference for how the participant views themselves in relation to the average.

Chapter 4: Impacts on Health, Environment, Ecology, and Economy

4.1) Health

4.1.1) Pathways into the Body

The most significant source of microplastic intake in humans is estimated to be from consumption of contaminated food and beverages. A study analyzing microplastic concentrations in food and drinking water estimated that the average person consumes around 39000 to 52000 particles per year (89). This is without accounting for an estimated inhalation of microplastics in the atmosphere. Microplastics have entered the food chain and are found in crops, livestock, and seafood. The blood and meat of livestock including cows and pigs was found to have at least one type of plastic particle according to a study conducted in the Netherlands. Every sample contained some concentration of microplastic, including cow's milk that was intended for human consumption (75). Fish collected from commercial fishing were also found to contain microplastic particles (90). Commercially used salt, a substance used worldwide everyday, has been found to have microplastic contamination which is believed to contribute to long-term adverse effects due to human exposure and consumption (160). The plastic packaging used for food is also likely to be a contributor to the microplastic concentration in the food we eat, although there is not yet research to present an accurate estimate of the effects. Drinking water is also a source of microplastic consumption. Tap water contains an estimated 4 particles/L while bottled water contains an estimated 94 particles/L (89). This combination of microplastic exposure through the consumption of contaminated food and water is a major pathway for microplastic into the human body, although it is not the only one.

Inhalation of microplastics from the atmosphere accounts for another large proportion of microplastic exposure in humans. There are a variety of pathways for microplastics to enter the atmosphere. There have been multiple studies indicating the concentration of microplastics is higher in indoor air instead of outdoor air. One study compared three indoor sites with one outdoor site and found a median concentration of 5.4 fibers/m^3 for the indoor sites and a median concentration of 0.9 fibers/m^3 for the outdoor site (103). Microplastics in the air are then inhaled by humans. Another study attempted to quantify the amount of microplastic

particles inhaled by humans in indoor environments. A breathing thermal manikin was used to collect and measure microplastics based on human breathing. Of the three locations tested, the location with the highest concentration levels caused an average inhalation rate of 11.3 microplastics per hour or 272 microplastics per day (93). Some of these microplastic particles will be filtered out from reaching deep lung tissue through clearance mechanisms of the lung but some will deposit in the deep lung. Once these plastic particles reach the lung they do not dissolve and persist in the lung tissue (92). A study examining microplastics in human sputum samples found microplastics present in every sample measured and an average amount of 39.5 particles/10 ml (16). This further supports the idea that microplastic are inhaled regularly and maintained in the respiratory tract. Along with inhalation, dermal contact is another route of exposure that is less researched. Particles less than 100 nm can pass through the dermal barrier including plastics and remain in the tissue (19).

4.1.2) How Each Part of the Body is Affected

Once microplastics have entered the body, there is a variety of disruptions and effects they can have on various parts of the body. It is important to acknowledge that most research done on the topic involves *in vivo* and *in vitro* studies, meaning trials on animals and human tissue outside of the body. These results cannot always be extrapolated directly to humans. The biological differences between the animal subjects and humans should be accounted for. In many traditional cases on environmental pollutants, the direct relationship to human health is well researched and easily linked through a correlation between high concentrations of the specific pollutant in an area and an increased number of cases of a disease or illness in the population of that area. This is difficult to achieve for this issue due to the ubiquity of microplastics in the environment and the lack of regulation and monitoring of microplastic to determine possible higher concentration areas. Despite this, studies investigating the possible health effects through *in vivo* and *in vitro* models are still very insightful and the data obtained should not be ignored.

One system that has a possibility to be affected is the gastrointestinal tract. Using *In Vitro* gut models, it has been found that microplastics interfere with gut microbiota composition and can cause the development of human pathobionts that can cause diseases (111). The presence of microplastic particles in the gastrointestinal system also has the potential to cause reduced lipid digestion (112). This reduction in ability to absorb necessary nutrients would negatively impact

the body and present a variety of symptoms. There are also various studies that suggest microplastic particles remain in the tissue of the digestive tract, suggesting that it does not all degrade or pass through the body. One study analyzed 11 colectomy samples and found microplastic in every sample, with the average amount being 28.1 +/- 15.4 particles/g of tissue (52). Some *in vivo* studies dosing various animals with microplastics have found that particles larger than 150 micrometers remain lodged in the intestinal mucus layer and cause gut inflammation, while the smaller particles can translocate through tissues to other parts of the body (113).

Moreover, some evidence suggests microplastic consumption has negative impacts on reproductive health. One study dosed pregnant mice with polystyrene microplastics and found that they led to a disruption of immune balance and a higher embryo resorption rate causing fetal loss (114). Another study found negative reproductive effects in male mice as well. Male mice were given water with environmentally accurate microplastic levels and were found to have lower levels of testosterone and abnormal sperm creation (115). Although results in mice cannot be extrapolated directly to humans, mice are biologically similar to humans and these results are an indication of the possibility in humans.

As discussed previously, it is clear microplastics have a presence in the respiratory system through various studies. Even an initial study from 1998 found presence of plastic fibers in lung tissue samples collected from cancer patients and predicted plastic presence in lungs to contribute to lung disease and lung cancer (131).

The blood brain barrier is an important system in protecting the brain from exposure to harmful pollutants and there has been some evidence to suggest microplastics have the potential to pass through it. Polystyrene microplastics 50 nm in size were able to pass through and accumulate in the brains of mice, causing damage including cell and tissue death. The same study found cell damage in human brain tissue exposed through in vitro trials (130). Another study conducted on mice found microplastics located in the brain after 2 hours of exposure. Three different sizes and various surface compositions were investigated and it was concluded that only the smallest particles tested (0.293 micrometers) were able to pass through the barrier and, “the composition of the biomolecular corona surrounding the plastic particles was critical

for passage through the BBB" (1). It is important to consider that these studies are testing subjects with higher concentrations than microplastic presence in the environment, while exposing subjects for shorter periods of time. This means these results do not necessarily consider the long term exposure of smaller concentrations that humans are exposed to in everyday life.

4.1.3) Oxidative Stress

Throughout published literature on microplastics, it is clear that microplastic exposure has been linked to oxidative stress. Oxidative stress is an excess of oxygen reactive species (ROS) or free radicals that cannot be cleared out by the body, causing cell and tissue damage. Free radicals are beneficial in low amounts but cause a variety of issues for the structure and productivity of cells. It can cause DNA lesions and this oxidative DNA damage has been linked with development of cancer (132). Oxidative stress is also linked with diseases and illness that have a detrimental impact on nearly every system in the body. Polystyrene and polyethylene particles have been tested on cerebral and epithelial cells, with results indicating significant levels of ROS generation (134). It has also been found that microplastics particles have damaging effects to cells beyond oxidative stress and increased free radical production. This is partially discussed above as the microplastics studied for the blood brain barrier damaged neurons but it was also specifically investigated in another study that found damage through, "induction of apoptotic and necrotic cell death and decreased proliferation" (133). Another study exposed human blood to microplastics between 10 and 45 micrometers and also found a combination of cytotoxic effects, genotoxic effects, and oxidative stress in human peripheral blood lymphocytes (54). This cell damage can have some of the same negative consequences on human health as oxidative stress.

4.1.4) Microplastics as Vectors

Microplastics serve as a vector for chemicals, bacteria and viruses that cause harm to human health in indirect ways. Microplastics accumulated from indoor environments and AC filters from various locations were found to have a variety of bacteria, with the most prevalent being Staphylococcus (32). These bacteria located on the surface of microplastics that are inhaled in significant amounts could cause damaging infections. Another study analyzing the

presence of bacteria and antibiotic resistant genes on microplastic surfaces within dust for indoor environments found that Proteobacteria was present in all the samples. This is one of the main carriers for antibiotic resistant genes for microplastics (108). Microplastics were also found to be able to absorb viruses and prolong the survival of the pathogens (110). This means that microplastics are not only capable of causing exposure to humans but are contributing to increased infectivity time for the viruses. Microplastics also serve as vectors for organic pollutants and metals that are toxic for humans. The surfaces of microplastics have been found to contain metals such as Bromine, Cadmium, and Chromium which all have toxic effects in humans when consumed or inhaled in high enough concentrations (109).

4.2) Environment

4.2.1) Pathways for Microplastics into the Atmosphere, Soil, Water

Resulting from microplastics' intrinsic breakdown and fragmentation nature, these particles are found everywhere in the environment. After considering how much plastic is generated, used, and thrown away or recycled daily, it should not come as a surprise that microplastics are considered the most abundant type of debris (164). Their journey into the environment is an important point to talk about. There are two main pathways of microplastic production: direction introduction with runoff and weathering breakdown of macroplastic debris (193). While certainly microplastics in the environment stem from the accumulation of macroplastic pollution (162, 163) there are definitely many more ways for plastics to enter the environment. Due to their small nature and absorption abilities, microplastics have a large ability to spread and travel for distances and high concentrations of microplastics have been detected both in urban and rural areas (47). Microplastics are also able to travel in and through organisms and their subsequent food chains. For instance, plastic is used in mulch through plastic mulch films (PMFs) in order to improve crop quality and quantity, but PMFs inevitably degrade into microplastics. One study determined that PMFs are one of the largest contributors to microplastics in soil and the earth (78). Not only will the microplastics travel within soil, but the earthworms and organisms that live in the soil ingest these microplastics (81). Further, another large pathway contributor are tire wear microplastics particles which are microplastics originating for automobile tires. These specific tire microplastics absorb road runoff pollutants which are then released into nearby bodies of water or into the immediate atmosphere (64). The

fishing industry is also supposed to be responsible for a large percentage of microplastics in the ocean and other waterways, specifically the plastic gear used in the fishing industry. Mostly the entire fishing industry uses plastic gear, and it has been determined that about eighteen percent of marine plastic debris is accredited to the fishing industry (193, 194).

There are simply no shortage of ways for microplastics to travel and impact the environment. Microplastics may also originate from the immediate release of microparticles like facial scrubbers, synthetic textiles, and industrial abrasives (20). There are likely still undiscovered routes that microplastics employ to spread their reach, and these are just a few examples of pathways microplastics use because a full and complete list would be an entirely separate report and project. A general rule of thumb should exist that for any plastic that is left unattended overtime, microplastics will be produced. This is the nature of microplastics.

4.2.2) Microplastics in the Ocean and Subsequent Waterways

Microplastics accumulation in the ocean and alike aquatic environments was what initial microplastic research focused on first. First, the focus was on macroplastics: its largely negative effects on marine life and the sheer amount of plastic pollution that has landed in the ocean. One study estimated that there will be at least two-hundred and fifty tonnes of plastic accumulated in the ocean by 2025 (237, 240). Following down this same path, next researchers ascertained the largest producers of microplastics in the ocean: the fishing industry. Worldwide, fishing gear is most completely made out of plastic: the line, the lure, the reels, etc. and inevitably some gear is damaged or lost to the water (193). This same study deduced that about eighteen percent of marine plastic debris results from the fishing industry. While conducting this literature search, the discovery of some staggering statistics really drove home the importance of microplastics and just how many of them there are in the world. Ohe source determined the combination of primary and secondary source microplastics comprise 5.25 trillion plastic particles just on the ocean surface (214).

4.2.3) Microplastics in the Atmosphere

Conclusively, microplastics are known to be in the air around us. In 2019, microplastic awareness started really circulating for the first time, spreading propaganda to the general public that the average human ingests a credit card worth of microplastics a week (233, 234, 235, 236).

This same year, a study published results designating that an average male participating in "light activity" could potentially inhale up to 272 microplastics in a twenty-four hour time period (93). Although microplastics have been detected in virtually every organ in the human body, microplastic fibers were found in the human lung during a biopsy (102). In order for particles to be discovered in the human lung specifically, said particles must be inhaled premortem, signifying that microplastics indeed reside in the air and humans are capable of inhaling microplastics (221, 222). For humans, the inhalation of microplastics does pose a risk of prompting lesions in the respiratory tract amongst other health concerns such as inflammatory responses or oxidative stress, which is expounded upon in section 4.1. When investigating the physical and chemical properties of microplastics, their buoyancy allows them to be "readily inhaled" no matter the height of the microplastic in air; children, who breathe air closer to the ground, and adults, who breathe air much higher than children, alike are inhaling the same concentrations of microplastics in air (223, 225). With children there is an additional concern about microplastic ingestion because microplastic dust will settle anywhere: the ground, on toys, in cribs, etc. Children would not only be inhaling the settled particles, but ingesting them physically by putting things in their mouths; a habit children, especially young children, are prone to (106, 225).

Improper disposal and recycling of macroplastics increases microplastic production, which inevitably leads to a larger accumulation of microplastics in the atmosphere (20). In fact, varying concentrations, chemical compositions, and size of microplastics have been measured in every aspect of the atmosphere: indoor air, outdoor air, and street dust (20). Additionally, indoor air maintains higher concentrations of microplastics than outdoors by astounding quantities (225, 231). The largest contributor of microplastics to indoor dust is polyester, a textile crafted using PET (20, 225, 226). Mechanical abrasion and photodegradation on synthetic polymeric materials like polyester, like the washing and air-drying of clothes, emit microplastics and increase the number of microplastic particles in the air (223). One study found a positive correlation between microplastic fiber abundance and PET concentrations within dust in the air (225). Diving deeper, the study determined that PET fibers originating from polyester were extremely important components in the dust evaluated, and prescribed that indoor dust is a considerable source of human exposure to microplastics. A quick aside, while conducting this literature research, most sources referred to atmosphere particles as "dust"; upon further investigation, "dust" can be

defined as the collection of microscopic material and fine particles (227, 228). Dust is an important indicator when analyzing compositions of air. This dust has the potential of transporting environmental pollutants which could be derived from any number of sources: building materials, cleaning products, indoor activities, or dust from the outdoors that travels inside (225).

The accumulation of outdoor microplastic dust stems from a myriad of sources including but not limited to agricultural processes, improper macroplastic disposal, domestic activities, physical manipulation and wear of tires, and industrial emissions (223).When examining these sources, it can be surmised that all microplastic accumulation in the atmosphere emanates from anthropogenic activity. For instance, industrial emissions, one source that includes recycling, grinding, and incineration of plastics. Likewise, agricultural processes comprise the use of mulch which either employ plastic mulch films or organic fertilizers deriving from sewage sludge in which microplastics are a part of (47, 49, 78, 223). Microplastic concentrations in outdoor environments are considered either atmospheric fallout of suspended dust. Atmospheric fallout is indicated based on rate of settling while simultaneously recording the concentrations. Suspended dust measures concentrations at different altitudes (223).

For the outdoors, there are several factors that affect the concentrations and abundance of microplastics in the air. Weather is a variable that impacts microplastic distribution, and rain is the weather pattern which is the largest influencer on said distribution: higher concentrations of microplastics were measured during wetter weather (223, 229, 230). Also, population density and degree of industrialization will modify concentration numbers. Higher concentrations of microplastics were recorded in urban sites resulting from higher levels of microplastic contamination because urban areas have an exponentially increased consumerism in comparison to rural areas; simply there are more opportunities for plastic degradation in places where more plastic resides, like urban areas (223, 229, 230).

Specifically examining street dust, which are microplastic particulates which gather on the road and street surfaces, the concentration of dust had geographic correlations. Two studies in Iran measured accumulation of street dust in urban and industrial sectors; both studies yielded results conveying microplastic and street dust concentrations are higher in industrial areas as opposed to residential areas (229, 230).

Their many potential sources combined with the ease in which microplastics can travel creates a rather far-reaching pollution problem that will require a creative solution to effectively remediate. One particular study described airborne microplastics as a “superhighway” for pollution, and alluded that microplastic contamination resulting from the atmosphere acts as a main contributor to microplastic contamination in other areas: soil, water, and living organisms (223). However, to make it clear, there is a knowledge gap here and little research has been published to either validate or disprove this statement.

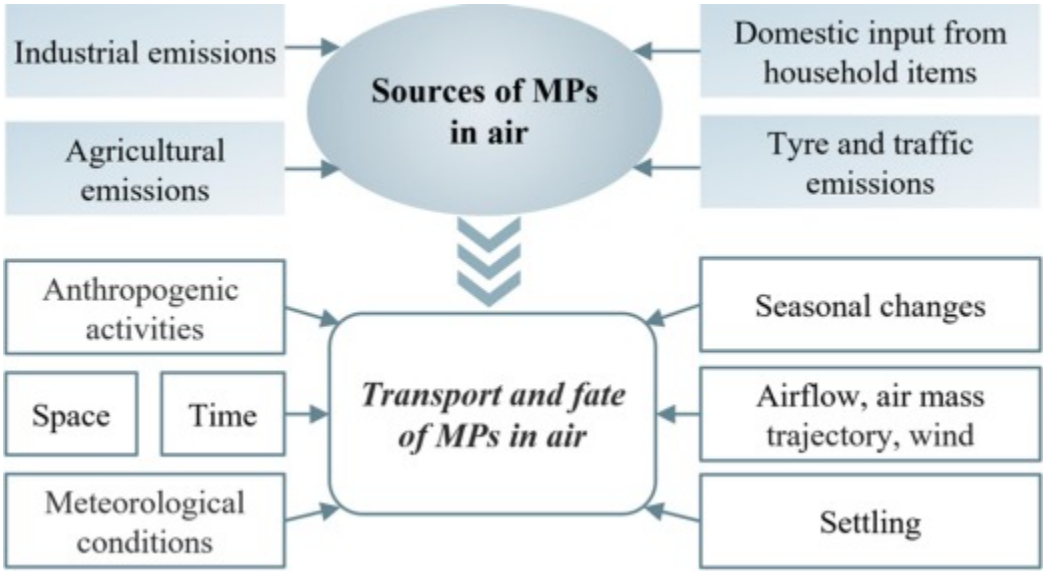

Figure 2: Sources and factors which influence microplastics in the atmosphere

Photo taken from Microplastic Materials in the Environment: Problem and Strategical Solutions (20).

The figure above visually summarizes this entire subsection. This figure communicates the pathways in which microplastics become airborne, the largest sources and creators of microplastics in the atmosphere, and the biggest influences on the dust distribution.

4.2.4) Microplastics in Soil

Soil is an essential biological component to the earth. Soil allows for water and nutrients to pass along to living creatures, houses all plants, and is an active participant in recycling carbon, nitrogen, and other elements. Microplastic contamination might have the greatest effect on soil; one study estimated that approximately thirty-two percent of all macroplastics produced can remain in continental systems and that agricultural soil might store more microplastics than

oceanic basins (164, 165). For this reason, there has been research conducted on microplastics' short and long-term effects on soil and its innate abilities, alongside how plants and soil biota are affected by microplastics. In one study, the presence of microplastics significantly decreased the available phosphate content and increased the ammonium content in soil; phosphates are imperative to maintaining soil health and allow soil to perform its duties of photosynthesis, cell division, energy storage, seeding establishment, and a myriad of other responsibilities (79, 168,79). Adversely, ammonium decreases the carbon composition within soil, one of the largest sources of nutrients in soil (169). Some might then conclude that soil with depleted carbon content would then more readily absorb carbon from the atmosphere which will be better for the planet. However, this conclusion is erroneous. Microplastics have been found to decrease carbon content in soil by increasing ammonium concentrations, and also because microplastics alter the microbial functional genes which adhere to plant roots, which creates an oxygen deprived environment in soil (62). This gene modification is largely impactful. The altered genes in soil then make soil release greenhouse gasses into the atmosphere, potentially a huge contributor in climate change (62). An additional concerning aspect of microplastic pollution in soil is further contamination caused from the organisms and animals that dwell within soil. Soil animals can transport and further fragment microplastics, which can further the spread of microplastics contamination (22).

There has been research conducted to examine the effects of certain microplastics's effect on not just the soil, but the plants or organisms which live and grow in it. In several studies, the types of microplastics (beads, fibers, fragments), the material composition of the microplastic, and the approximated "size" of the effect on plant growth were recorded (24, 27). All types of microplastics had negative effects on plant growth, whether by impacting the soil so negatively that the plants are unable to grow as well, or by altering the plant itself and restricting the ability to successfully root (24, 83). A separate study established that in soil invertebrates, aquatic animals, and rodents, microplastics damaged the integrity of sperm and decreased oocyte quantity and quality (78).

4.3) Ecology

4.3.1) Endangerment of Marine and Aquatic Species

Microplastics are ubiquitous throughout the planet, however, given that the most major source of microplastics originate from the fishing and textile industries—both of whom pollute water streams—marine life is particularly affected. The complete scale of the effects is still poorly understood, but studies have been done on the impact of microplastics on individual marine species.

On the side of microorganisms, multiple studies have been done aiming at understanding the impact of microplastics on marine microorganism life. Interest and research in this area is critical—many marine animals rely on microorganisms as a food source, therefore, any changes to the population of marine microorganisms will ripple up the food chain as well. One study conducted on a certain species of zooplanktons demonstrated that specimens exposed to high concentrations of microplastics were rendered immobile (6) which could lead to a drop in survivability rate and a decline in population. A different study found that "compared with microplastic-free controls, copepods allowed to feed on polystyrene beads ingested fewer algae and also showed a shift in preference for smaller algal prey. Microplastic-fed copepods also displayed reduced reproductive success, as reflected by smaller egg size and reduced hatching success…the results show feeding behavior and reproduction may be compromised" (7). Another study found that Zooplanktons grazing on microplastics could lead to a reduction in grazing pressure upon primary producers, in turn leading to an increase in export production, in turn leading to an increase in remineralization, in turn leading to the acceleration of global loss of oxygen inventory by 0.2-0.5 percent (8). Overall, zooplanktons are a crucial part of the food chain as carbon cyclers, remineralizers, and as a food source for aquatic animals. Effects on this group of microorganisms is likely to spell disastrous consequences towards not just marine animals but potentially for all life.

4.3.2) Endangerment of Terrestrial and Arboreal Species

Most current research that details microplastics and their subsequent effect on animals have been specifically marine life, not terrestrial life. However, both aquatic life forms and non aquatic life forms should be evaluated. As it has been established multiple times in this paper, it can be surmised that any organism which ingests microplastics has been negatively affected by

microplastics. Non-aquatic animals are no different from marine animals in this regard, and most definitely are impacted by microplastics.

In one study, soil invertebrates and rodents were studied specifically concerning the effects of microplastics on animal reproductive systems (78). This study yielded results of lower oocyte quantity and quality and the quality of the sperm was compromised. In a study about nanoplastics, which would most certainly apply to microplastics, it was determined that nanoplastics impair metabolism as well as negatively impact growth, development, and reproduction in several organisms (137). However, the additives and contaminants previously adsorbed on the plastic poses the more significant threat, for example heavy metals and endocrine blockers (137, 145). One study held a systematic review of microplastic impact on soil animals and yielded interesting results. After soil animals ingested microplastics, the microplastics produced a weak nutrition supply while creating a false sense of satisfaction in terms of "fullness" and hunger (22). Similar to humans, these animals also experienced oxidative stress and intestinal damage resulting from microplastic ingestion. Further, another study that provided interesting results measured the quantity of microplastics present in ten different terrestrial animal carcasses, these animals typically utilized for traditional medicinal materials (21). In each of the ten animals analyzed, microplastics of varying compositions and sizes were found thoroughly distributed in every part of the carcass. A specific point was made in the study that these microplastics were found in the intestines of the animals, so they were most likely ingested while the animals were living.

4.4) Economy

4.4.1) Industries and Sectors Most Affected by Microplastics

Industries reliant on plastics are most involved in the microplastics issue. A shift towards plastics alternatives and legislation forcing corporations to clean up microplastics would result in a large financial burden on a variety of industry sectors. Plastic pollution in the environment is also a large financial burden for countries to manage. The economic cost of plastic pollution in the environment annually burdens the global economy by an estimated $19 billion (138). A study conducted by Deloitte came to the conclusion that national economies are hurt by plastic pollution through direct and indirect means. Pollution directly contributes to the clean up costs that governments must bear as well as revenue loss in marine tourism and aquaculture. The

indirect toll is more difficult to quantify as the issue impacts a wide range including public health, the marine ecosystem and real estate (12). One study attempted to quantify the economic loss due to public health concerns and estimated that the plastic-attributable disease burden was $249 billion in 2018 alone (172). An analysis of economic loss in the UK estimated a loss of 54 million euros per year in revenue loss for marine industries through damage to aquaculture bivalves, damage to coastal tour, damage to fishing vessels, and derelict fishing gear (96). Research clearly suggests the marine industries are most economically impacted by microplastics currently but there is still an unaccounted for economic cost for a variety of other industries that are more difficult to quantify. There will also be a further economic burden on industries that rely on plastic as more legislation is created banning or restricting plastics. The private sector is not prepared for a transition away from plastic and needs to consider this as the microplastics issue gains more traction.

4.4.2) Opportunities in Microplastics

Not only is there money wasted for plastics pollution currently and future threats to industries, but there is an economic incentive for countries and private industries to take action to save money through a circular economy. Management consulting groups have determined that there is wasted financial potential in the current linear life cycle of plastics. Maximizing the life cycle of the plastic products used will result in lower costs to produce new plastics and less environmental harm caused by that process in terms of CO_2 emissions. Although, it is important to consider the inefficiencies of the common recycling processes used today and the increase in production of microplastics from recycling that will be discussed further on. BCG is one consulting group that has concluded the process of pyrolysis can help reduce plastic waste and be a profitable economic opportunity for chemical and energy companies (14). The process of pyrolysis involves using heat to break down plastic waste into usable oil and gas. BCG determined that there is a profit to be made from a large-scale application of pyrolysis, rather than traditional landfilling, across a variety of different markets. Another consulting group Bain & Company brought up the concern of microplastic waste being harmful specifically to the textile industry. It was estimated that the amount of pre-consumer microplastic shedding in the textile industry is just as much as the amount of shedding during the product's use during washing and drying cycles. This amount is estimated to be around 0.12 million metric tons of

microfibers released every year across the textile industry (11). This loss of material during the manufacturing process results in a loss in economic potential and actions to alleviate the shedding of microplastics during this process would be beneficial for companies. A Mckinsey report analyzed the potential economic benefit of recycling for Denmark and found that, "Capturing the full economic potential of our plastics waste stream could save Denmark over DKK 1.6 billion a year in saved costs from importing virgin plastics rather than recycling domestic plastics waste" (10). This analysis also did not account for the money saved per year in environmental cleanup from plastic waste. Although this analysis was specific to Denmark, the possible economic benefit of reusing plastic or using plastic alternatives could be achieved by any country.

There has been a variety of life cycle assessments of plastics but a lack of research into the fate of microplastics. Microplastics are generally considered one of the environmental byproducts of plastics that shed towards the end of the life cycle. The recycling phase and later stages of the plastic product's use involve the shedding of microplastics. (136) After this point, the process following the microplastics themselves has not been closely researched. A material flow analysis of microplastics could help determine the ability of incorporating microplastics into a circular economy and alleviating some of the wasted financial potential. One study attempted to analyze the natural degradation of plastics compared to engineered microplastic degradation. Natural degradation products typically result in breaking down plastics into smaller pieces of microplastics and eventually nano plastics, but they do not disappear from the environment. Typically, degradation is measured through mass loss, but this does accurately measure degradation as the plastic could simply be fragmented to a point where it is no longer detected but it is still an environmental or health concern. A solution to this could be intentional degradation methods that result in mineralization of plastics into molecules that could be used to create other products (98). This process of recycling microplastics provides an opportunity to limit the waste of materials in the current process of plastic consumption. It would contribute to a circular economy that results in less money wasted in the material collection process. A circular economy could result in less microplastic contamination into the environment and provide an economic incentive for less plastic production. Microplastics are released during a product's use phase and end of life phase and applying concepts of a circular economy could address this problem. One research report proposed some of these concepts as solutions. These concepts

included: creating more durable polymers for longer use in the value chain, creating polymers with shorter environmental turnover times, use recycling methods for macroplastics that do not create more microplastics, and design plastics with the intent to be easily recycled (97). All of these solutions would shift away from the current linear plastic stream toward a circular economy that would limit microplastic production.

4.4.3) Inefficiencies of Recycling in America

To understand the monetary inefficiency of recycling microplastics, first a grasp on the failure of the American recycling industry must first be addressed. In short, recycling in the US does not work; inefficient is the kindest word to describe the American recycling industry. There are several reasons for this failure. First, most Americans are confused on what materials to recycle and how to recycle them. This confusion induces high levels of contamination in the recycling process which can prevent batches of recycled material from being repurposed (213, 214). A staggering 32.1% of waste was recycled or composted in 2023, so it can be deduced that much recycled material does not end up being recycled at all (214, 215). According to Forbes, contamination increases cost all around: to the recycling facility, the ratepayers, and the government or collector of the recycled material (213). In fact, contamination is such a large issue that it costs the average recycling facility around three-hundred million dollars per year (215). Another factor that might contribute to the American public's confusion is that there are geographical inconsistencies for which items should be or are not allowed to be recycled, a prime example being pizza boxes (215). These inconsistencies can also elicit sorting errors and contamination.

An incentive to recycle is that this process is "green" and environmentally friendly, no doubt an important reason. However, in capitalist America where the dollar reigns supreme over any great or friendly idea, recycling is failing because of the financial burden this industry causes. Ultimately, the monetary and physical inefficiency of recycling has provoked underinvestment in the industry as a whole, because the environmental benefits of this process are not reflected in their economics (213). Another consequence of this non-market based practice is the failure to create more incentive which conclusively encourages under-participation. With no economic gain, there is no motivation for companies to reconsider using more environmentally friendly packaging or contemplate adjusting product designs. These

considerations will take intentional time on a company or organization's behalf; this time spent costs money, the commodity this organization is already losing by attempting to be more environmentally conscious. Years ago, the recycling industry thrived in America, but today the industry loses so much money that the local and federal governments abide by cost-sharing agreements and need to pay for these facilities, because the total amount of revenue generated does not cover the operational expenses (220).

Present day solid-waste management legislation was established in 1976, the Resource Conservation and Recovery Act, designating that solid-waste management regulations have not been edited or updated for almost fifty years (215, 216, 217, 218). Current recycling and waste technology greatly exceeds the technologies available in the mid 1970s. These antiquated regulations could also potentially add towards the ease of contamination in the recycling process: the American processes and organizational efforts specifically for waste management and recycling are too out-dated.

Chapter 5: General Public's Perception and Sentiment of Microplastics

5.1) Past Qualitative Studies of Public Perception and Sentiment

Several surveys have been conducted to evaluate the general public's knowledge and sentiments towards macro and microplastics utilizing both quantitative and qualitative methods. Qualitative methods. For instance, a study from 2022 involved a qualitative survey of a representative sample of the Norwegian population with ~2700 participants adjusted for sampling bias (55). The survey was not anonymous and participation was voluntary with a lottery-system reward incentive for participation. The survey involved a personal values assessment and a microplastics short answer question. A coding scheme was developed and results were analyzed to determine correlations and relationships between sociodemographics, personal values, and awareness of microplastics. The majority of responses from participants (47.9%) discussed the environmental effects of microplastics while only 2.4% of responses were concerned with the personal health effects of microplastics, showing that the public is largely unaware of the possible health effects of microplastics.

Additionally, by correlating results from the personal value assessment and the survey results, they revealed that there is correlation between education level and responses indicating possible solutions to microplastics. People who value openness to change were also more likely

to think of solutions.This is useful information as it indicates that there is a correlation between awareness and knowledge of microplastics to a willingness to think of and indulge in solutions.

Another qualitative survey (57) was conducted focussing on analyzing cross cultural sentiments via survey on 15 Germans and 15 Italians using face-to-face interviews. Results generally showed that the public still has low knowledge on microplastics and generally tried to extrapolate information about microplastics based on knowledge of macroplastics. Results collaborate the findings from the Norwegian study; the public's overwhelming concern about the environmental effects of microplastics as seen in both this study and in the Norwegian study likely is explained by the tendency to extrapolate information about microplastics from information about macroplastics. Given that media coverage and campaigns surrounding macroplastics generally revolve around the environmental effects of macroplastics, this seems to explain the overwhelming concern about environmental effects of microplastics in participants. Additionally, the German-Italian study revealed a significant difference between microplastic risk perception depending on nationality, which could be due to a variety of factors. Some are cultural, some could be due to recent issues each country is facing and media coverage of said issues, etc. This should be taken into account in education campaigns.

5.2) Past Quantitative Studies of Public Perception and Sentiment

On the quantitative side of surveys, a 437 participant survey conducted in Shanghai revealed interesting insights (56). The survey involved random face-to-face short interviews conducted on passersby in public spaces. Participants were generally uninformed of microplastics and only ~26% of participants had heard of microplastics prior to the study. After informing participants of the characteristics and basic background information of microplastics participants were asked "which news headline would attract their attention about microplastics, the most frequently selected were "microplastics exist in daily drinking water and food" (47.7%), followed by "microplastics will damage marine life" (19.2%) and "microplastics will result in environmental pollution" (16.7%)." This result is incredibly interesting. Both the Norwegian and the German-Italian study suggests that of those surveyed without being briefed on the effects of microplastics, the biggest point of discussion was of the environment effects. But in a sample where participants are more informed such as in the Shanghai study, participants were immediately more concerned about the health effects of microplastics. This suggests that the general public is generally unaware of microplastics and is only concerned about the

environmental effects of microplastics because they are extrapolating macroplastics to microplastics, but when more informed of the microplastics issue, personal health becomes the primary concern. Alternatively, there is a significant cultural difference between the Shanghai study and European studies which could also account for the difference in sentiment.

Overall, the results showed that people tended towards the more negative possibilities when facing unknown substances and were pessimistic. This could work in favor of education campaigns, but could as easily cause public panic. The Shanghai study also postulates that the public generally responds more to issues which are more readily detectable to the five senses—this is a significant issue due to the microscopic nature of microplastics. An education campaign should take this into account and frame microplastics in a way that makes the issue feel more tangible and perceptible.

5.3) Past Characteristics of Misinformation Campaigns by Ill-Intentioned Sources and Anticipating Opposition

Plastics are a product of the oil and gas industry. Therefore, if plastics production were to slow down, the oil and gas industry would see a decrease in bottom line. Hence, there is an incentive for the fossil fuel industry to maintain the production of plastics or further increase it—leading to a conflict of interest. Therefore, a successful education campaign must anticipate misinformation campaigns spread by the fossil fuel industry and address them before they grow out of control. We aim to accomplish this by using how the fossil fuel industry has responded to the on-going global warming disaster as a case study.

The US fossil fuel industry has been aware of the global warming issue from as early as the 1950s as evidenced from their internal research notes (116). The industry's internal predictive models for global warming projections were validated and deemed reliable, accurately predicting temperature increases to within a respectable degree of accuracy. On the other hand, the fossil fuel industry repeatedly denied these claims. The principal strategy used was to "emphasize the uncertainty in scientific conclusions regarding the potential enhanced greenhouse effect." Indeed, there are countless examples of public statements given by oil companies which make claims that suggest explicitly and implicitly that the models are prone to error or that the evident warming effect is natural and not due to human activities. Republican political strategist and consultant Frank Luntz put it best. "Facts only become relevant when the public is receptive and willing to listen" (118). On global warming, Luntz advised "continue to make the lack of

scientific certainty a primary issue…emphasize the importance of acting only with all the facts…the scientific debate is closing [against us] but there is still a window of opportunity to challenge the science." Luntz was correct in his prediction that raising doubt in science would be successful at delaying action against global warming—coining the term "sound science" to imply that global warming is"unsound science" despite the obvious oxymoron of science being unsound. Science is science because it is sound. There is no rectangular circle and unrectangular circle. 'Sound science' became the primary rebuttal used to delay action against global warming until it was no longer possible to deny the evident increase in global temperatures. As Luntz correctly evaluated, the scientific debate did eventually close against global warming. It was no longer possible to deny its existence. Thus ended the first primary disinformation strategy used to delay action: denial of science.

Shortly after, disinformation campaign strategies pivoted from denying the existence and scientific legitimacy of climate science, to delaying public action via distractions. For instance, a 2005 advertisement campaign sponsored by British Petroleum introduced the idea of a 'personal carbon footprint' (117). At surface level this seems like a well-intentioned education campaign to push for reduction of emissions. In truth, the campaign functioned to redirect attention from the fossil fuel industry onto individuals, placing responsibility on the people and implying that the solution to global warming is for individuals to bike, eat less food, and travel less. As opposed to actually effective actions like lobbying to hold the fossil fuel industry accountable for massive oil spills, disinformation campaigns, and unsustainable practices. The campaign was an effective propaganda piece that straw-manned the issue of global warming as being the fault of the public. Many other examples of similar propaganda pieces exist which can all be characterized as part of a strategy aimed at distracting from the issue.

Other strategies used to delay public action was to downplay the impact of global warming. For instance, the term 'climate change' was coined by Luntz which he correctly asserted "is less frightening than global warming...climate change sounds like you're going from Pittsburgh to Fort Lauderdale…global warming has catastrophic connotations attached to it" (118). Alternatively, the impact of global warming was made to seem less than the impact of acting against global warming. A primary talking point against global warming for a long time was the loss of "American jobs." even though there would be a lot more "American jobs" lost when drought leads to massive global famine. The problem is that the threat of global warming

has been downplayed to the point where the impact is less perceptible than the immediate, hypothetical issue of an economic downturn. This strategy is best summarized as downplaying the effects of the issue.

When it was no longer practical to deny that global warming will have disastrous effects for humans, disinformation strategy pivoted to emphasizing that there is no longer any action that can be taken to stop global warming—that the ship has sailed and that it is now too late. Indeed, if you take a look at a global survey of young adult sentiments towards climate anxiety (n=10000), more than half reported feeling "sad, anxious, angry, powerless, helpless, and guilty" (120). This is a massive problem for taking action against global warming. Hopeless, powerless, guilty feeling people do not attend protests. People do not fight wars they feel are already lost. The point is to lower morale and raise apathetic sentiments towards global warming to delay action. This strategy which we are continuing to witness can best be described as destruction of morale.

To summarize, we see denial of science, disputing the scientific validity of the issue and/or raising credibility in its scientific representatives, distracting from the issue—propaganda pieces designed to distract from primary culprits and/or from solutions, downplaying the effects of the issue—campaigns designed to make the issue seem trivial, and destruction of morale—raising hopelessness and despair to discourage activism.

These were strategies that were sequentially used by the fossil fuel industry in the past and unfortunately are highly likely to be effective against microplastics as well should countermeasures not be taken beforehand. Based on our own survey of WPI students alone, we already see that a portion of educated young adults feel uncertainty about the effects of microplastics and how much microplastics will actually impact human health. Keep in mind that our sample are college educated, technical school students with significant scientific education not to mention the likely self-selection sampling bias which means our sample is even more aware of microplastics than the true population. Even with this sample we see significant uncertainty in the effects of microplastics—a disinformation campaign strategy such as denial of science or downplaying the effects of the issue would be extremely effective at delaying action unless intercepted.

Further, within our survey we see feelings of hopelessness over the abundance and ubiquity of microplastics expressed in many responses. For instance, one respondent when asked

“what is most concerning to you about microplastics” replied with “That they are everywhere and you cannot have complete control over stopping them. It feels like it is too late at this point.” This indicates that morale is already quite low within the sample. Hence an oppositional disinformation campaign designed to raise hopelessness in tackling the microplastics issue by making the issue seem impossible to solve or that ‘it is already too late’ is likely to be highly effective as well.

Either we will be the first to address these concerns in education campaigns, or the opposition will be. This cannot be allowed to happen. It is not enough that the general public become aware of the existence of the issue or even educated about the issue. The general public must care about the issue and not be distracted or misled or convinced of inevitable doom.

5.4) Studying Perception and Sentiment of Microplastics at Worcester Polytechnic Institute

Results from our survey suggests three things: (1) young-adult college students are aware of the existence of microplastics and their prevalence, (2) young-adult college students express uncertainty and distress about the possible effects of microplastics and their ubiquity, (3) young-adult college students overwhelmingly underestimate the general public’s perception and sentiment surrounding microplastic. To put differently: the vast majority of the people surveyed were very concerned about microplastics and simultaneously believed that no one else does. This is expanded upon in 5.4.3.

5.4.1) Demographic Information

Before we discuss this contradiction—some expansion on the demographic. In regards to demographic information, our sample is close to balanced. The distribution of participant age ranges mostly from 18-22 and follows a roughly normal distribution centered at 20.

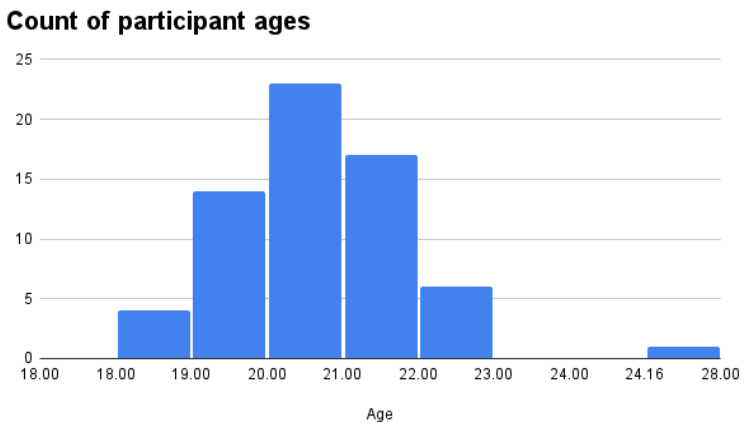

Figure 3: Distribution of participant ages. Mostly normal with a mean centered around ~20 years old, though with one outlier at the 28 year mark.

Around 38.5% of participants identified as male, 60% identified as female, with a single non-binary participant. This imbalance is because the survey links sent through sorority channels were more effective than expected. Unfortunately, there is no way to stratify participants based on how they found the survey. In spite of this, we believe the difference between the average student at WPI and the average student at WPI who is also in a sorority to be minor enough that the claims present later in this report to be meaningfully representative. Even discounting this issue, the imbalance might still remain as an effect of self-selection sampling bias. Survey participation was done online, where links to the survey were sent out through various student channels and through posters posted around campus. In general, those socialized as women are more likely to care about environmental and ecological issues than men (136), most likely as a result of differences in gender norms and expectations. Hence, without other incentives, women are also more likely to participate in surveys such as these than men, however, this imbalance in and of itself does provide the valuable insight that this issue resonates weaker with men than women.

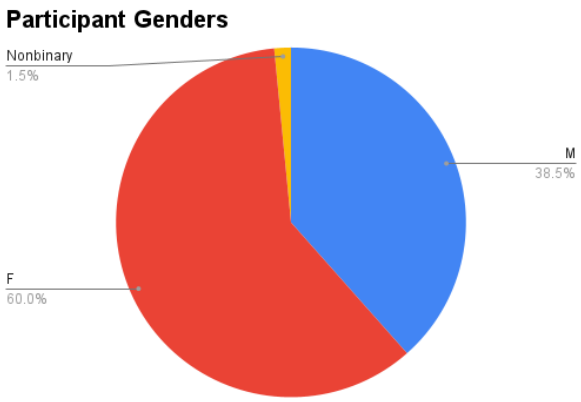

Figure 4: Majority of participants identified as women.

5.4.2 Microplastic Perception

In terms of perception of microplastics, young-adult college students are generally aware of surface level information involving the ubiquity of microplastics. When prompted to answer "What do you know about microplastics," most were able to state a basic fact about microplastics such as their presence in the human body (21.9%), ubiquity (14.8%), or presence in food (12.9%) which were the top three most common topics of their answers. Notably, all of these answers suggest the sampled population are most cognizant of issues immediately impacting human health, which itself tied for third most commonly mentioned topic at (12.9%).

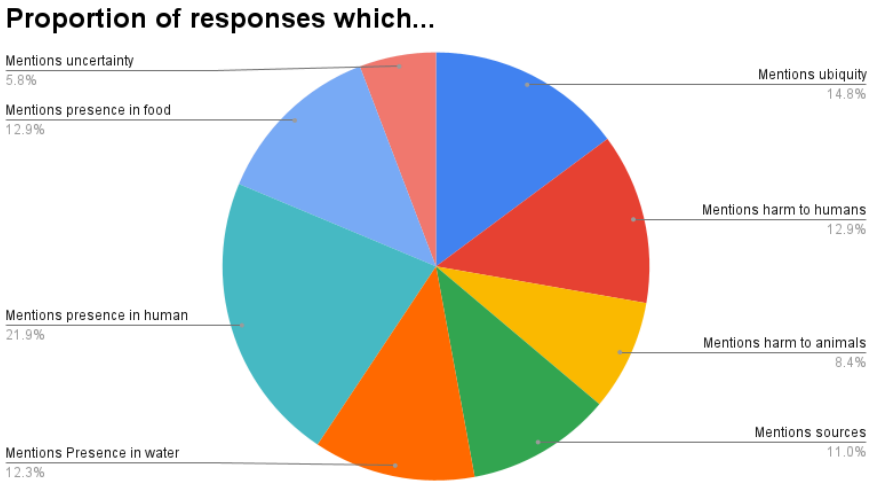

Figure 5: From the question: 'What do you know about Microplastics?' Proportions of how often a certain topic was mentioned in comparison to other topics. Each time a topic is mentioned in a response, a counter is incremented. A response can mention multiple topics, but for each

mentioned topic is only incremented once per response. The pie chart illustrates the proportions of each topic counter as a ratio of total counts.

Based on these results, we can stipulate three super categories which these topics belong to: (1) Direct human impact, (2) Non-human impact, (3) Non-impact topics.

Direct human impact encompasses mentions of presence in food, presence in humans, harm to humans, and ubiquity. Together these topics comprise 62.5% of all mentions. The common denominator between these topics is that they are all directly related to humans. Because the nature of knowledge in this category is most readily comprehensible and apparently relevant, it is most commonly known. IE: saying there is so much microplastics everywhere that the average person consumes ~a credit card's worth of microplastic every week is a very easy way to illustrate the scale of the microplastic issue that is also likely to resonate with the audience.

Non-human impact encompasses mentions of less commonly known pieces of knowledge regarding microplastics which are represented in the survey as mentions of presence in water and harm to animals. Together these topics comprise (20.7%) of all mentions. This broadly encompasses environmental and ecological impacts of microplastic which are not immediately human adjacent. Because of their degree of separation from day-to-day human activities and less apparent relevance on human life, these topics are less commonly known. IE: explaining that certain species of microscopic marine organisms are threatened by microplastics is less likely to resonate with people than saying we ingest microplastics, even though the issues caused by said ecological impact might be as great if not greater than that of ingestion.

Non-impact topics encompasses mentions of topics that are not related to any impact of microplastics, These are responses which mentions sources of microplastics or mentions uncertainty of some kind. Together they comprise 16.8% of all mentions. To elaborate on uncertainty: these are responses which either indicate lack of confidence in their knowledge or indicate that more research needs to be done in this topic. In other words, evaluations of current knowledge held by self or others as being lacking. The fact that these mentions only comprise 5.8% of all mentions is interesting. One hypothesis is that this is an example of Dunning-Kruger bias where people generally overestimate their own knowledge, and these 5.8% of respondents are actually quite knowledgeable. Alternatively, these responses are to be taken at face value as genuinely lacking knowledge in microplastics. Unfortunately, the number of respondents

mentioning this topic does not constitute a statistically significant sample size and thus we are not able to make statistically sound extrapolations from them.

What do you know about microplastics?
I know that they are tiny plastic particles that can either be made that way or broken off from larger plastics. I also know that they get into some of our foods such as seafood and negatively impact ocean ecosystems. I also know that they don't readily break down and I think they build up over time.
They can disrupt your endocrine system, they can be in food, on clothes, and many other things
they are in literally basically everything
more research needs to be done on how harmful they are, they are incredibly difficult to clean up and they are everywhere
Not too much, but I do know it's causing harm to the ecosystem, animals, and humans
They are tiny plastics that are w bad for the enviroment
They are materials generated from emissions where the breakdown of plastics gets so extreme that they can end up in the body. They are toxic materials that harm the body, especially in large quantities
They pose a threat to our health and the health of nature in general.
How they are abundant in the environment.
It is in everything, and it's also a concern in our food currently. They are also the "building block" (for lack of a better word) of plastic and when you heat them up, they break down and can blend in with your food. Which is why we are advised not to reuse/heat plastic containers
Not much. Everything I've heard is negative

Figure 6: Responses are a mixture of ones which contain an elaborate list of microplastics knowledge unexpected of a lay audience as well as ones which are lacking in any real description of microplastics knowledge. Most likely representative of two ends of the MP knowledge bell curve.

5.4.3) Microplastic Sentiment

Our sampled population of young adults expresses uncertainty and distress about the possible effects of microplastics and their ubiquity. The prevailing concern seems to be over the health effects of microplastics and unknown, long term effects of microplastics. Many responses share a common sentiment: a low sense of morale and hopelessness: "That they are everywhere and you cannot have complete control over stopping them. It feels like it is too late at this point.", "I guess that if they are an extinction level threat it's probably too late to prevent massive amounts of damage, since they are already so prevalent.", "It is so hard to avoid them. If I wanted to avoid them it is basically impossible". The most common topic mentioned in responses seem to be concerns regarding potential harm to human health and/or ingestion at 35.2% of all responses, followed by environmental concerns atAS 14.3%, and concerns over potential long term impact at 16.5%. To elaborate, long term impact here qualifies all responses which mention any possible impact implicitly or explicitly occurring not in the immediate present. IE: cancer and infertility are two commonly mentioned concerns which relate to health; uncertainty over possible unforeseen future impacts are often also mentioned.

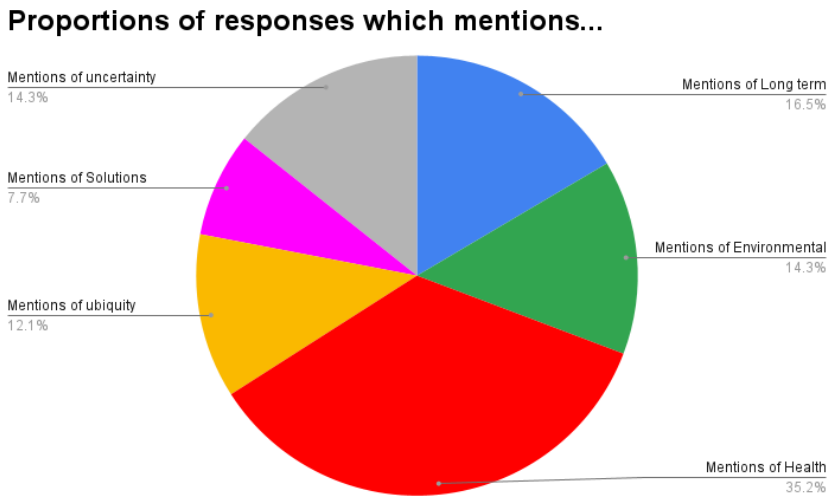

Figure 7:From the question: 'What is most concerning to you about Microplastics?' Proportions of how often a certain topic was mentioned in comparison to other topics. Each time a topic is mentioned in a response, a counter is incremented. A response can mention multiple topics, but for each mentioned topic is only incremented once per response. The pie chart illustrates the proportions of each topic counter as a ratio of total counts

Some insights can be gained from these results. Health, being the most commonly mentioned topic suggests concerns such as environmental, economic, or ecological are secondary. These results mostly corroborate findings from (56). Though there is some discrepancy in the exact proportion of participants citing health as being the primary concern, which we found is smaller at 35.2% as opposed to the 47.7% found in the aforementioned study. The discrepancy could be due to the difference in the underlying demographic—the sampled population of students are from WPI, a private institution in New England where the population primarily leans left politically and technically educated. Hence, they are more likely to be aware of as well as care about environmental issues. Regardless, in both surveys: impacts to human health was by far the largest concern and the exact proportion difference is negligible.

Moreover, while the vast majority of students in the survey were very concerned about microplastics, they simultaneously believed that they are in the minority in this sentiment. When prompted "How concerned are you about microplastics" the vast majority of students indicated they felt Microplastics are a high priority urgent issue, with the second largest group indicating that microplastics are an issue, but a lower priority one. On the other hand, when prompted "How concerned do you think the general public is about microplastics," this distribution shifts

completely with the vast majority of students indicating that they believe the general public at large regard microplastics as either a low-priority issue or a non-issue.

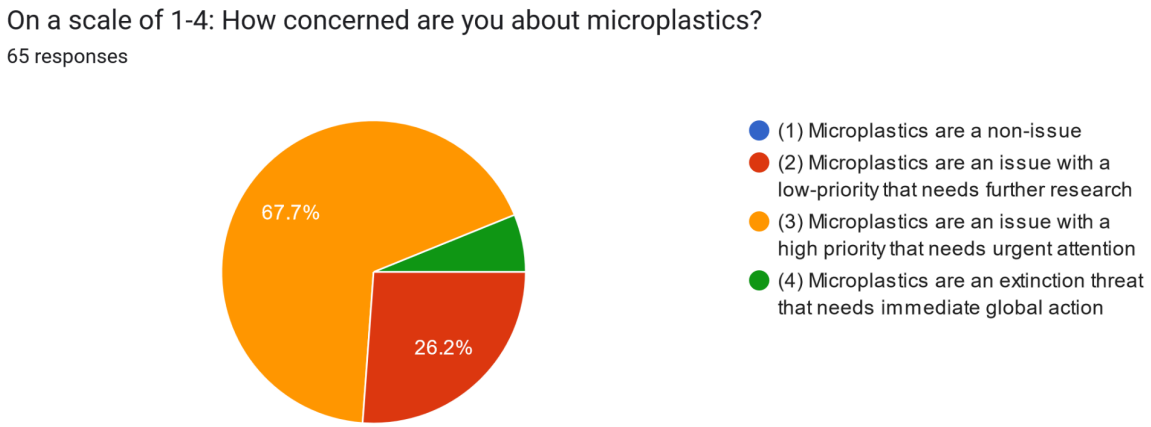

Figure 8

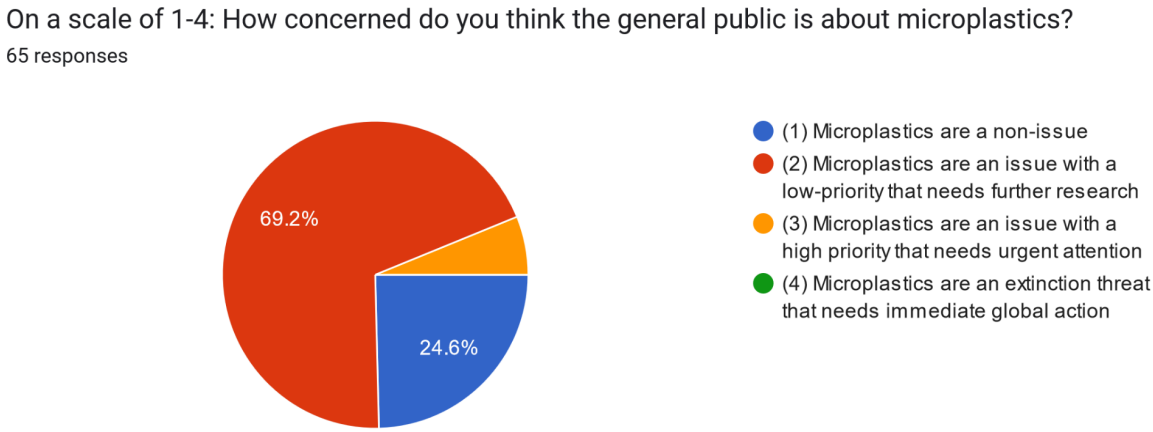

Figure 9:Proportions of participants estimating how concerned they are versus how concerned the public is about microplastics issue. Notably, while 6.1% of participants believe microplastics are an extinction threat and no participants believed microplastics are a non-issue, up to a quarter of participants believe the public views microplastics as a non-issue and up to 69.2% believed the public views microplastics as a low-priority issue.

This is further collaborated by our sets of questions designed to gauge how willing students were to take actions against microplastics. The following questions were asked to each participant: one version had the participant estimate their own willingness to perform the action given in the question, the other version had the participant estimate the willingness of others' to

perform the action given in the question. Notably—some of the actions proposed in these questions do not actually contribute much in combating microplastic, but this does not matter for our purpose as people generally believe these actions to be effective. Therefore, asking them if they would be willing to take these actions serves as a good estimator for how willing they are to take action against microplastics.

On a scale of 1-10: How often do YOU bring your own bag to the grocery store?
On a scale of 1-10: How often do you think OTHERS bring their own bag to the grocery store?
On a scale of 1-10: How often do YOU reuse plastic containers instead of throwing them away?
On a scale of 1-10: How often do you think OTHERS reuse plastic containers instead of throwing them away
On a scale of 1-10: How often do YOU do volunteer work for a cause out of your own volition. IE: Not for some requirement or because you needed to
On a scale of 1-10: How often do you think OTHERS do volunteer work for a cause out of their own volition. IE: not for some requirement or because they needed to
On a scale of 1-10: How often have YOU participated in a protest, boycott, and/or strike?
On a scale of 1-10: How often do you think OTHERS participate in a protest, boycott, and/or strike?

Figure 10

Another characteristic to these questions is that all of them describe actions which are otherwise meaningless unless others are willing to take the same action (i.e. a protest of one person scarcely accomplishes anything).

In general, all questions collaborate the idea that participants believe others are taking less action/are less willing to take action than they are and that they are in the minority of people. Below is a visualization of the results based on the grocery bag question.

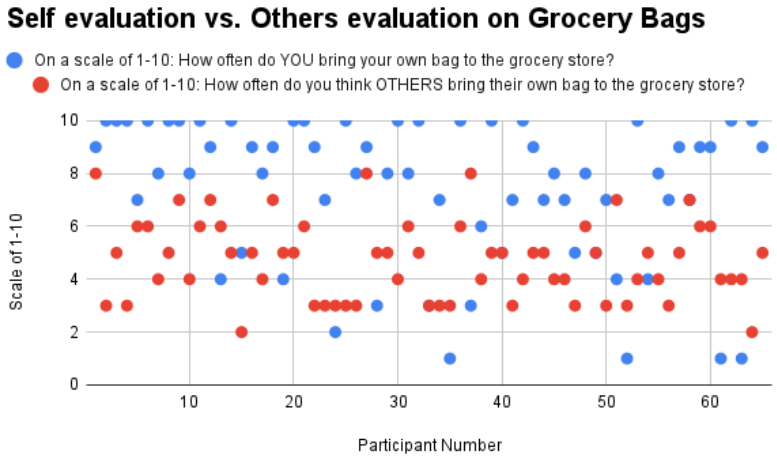

Figure 11:Scatterplot of answers to evaluation on grocery bag questions by participants—notably self-evaluations are consistently higher than evaluations of others.

Another thing of note here is that while self-evaluation for this question ranges from 0-10, evaluation of others ranges only from two to eight, a significantly smaller variance. This could indicate that as a whole participants are less certain about making claims about others and tend towards making 'moderate' claims (rating closer to the middle point of 5) as opposed to more 'extreme' claims (rating closer to the edge of 0 and 10). This is significant because even while attempting to be moderate, participants still consistently underestimate others.

To statistically prove this, we set a null hypothesis of "the mean of how people rate themselves is equal to or less than the mean of how they rate others" and an alpha value of 0.05. We then ran a paired, one-tail t-test for significance. The results are consistent for all questions with the sole exception of the protest question, participants consistently rate others as lower than themselves.

	On a scale of 1-10: How often do YOU bring your own bag to the grocery store?	On a scale of 1-10: How often do you think OTHERS bring their own bag to the grocery store?	On a scale of 1-10: How often do YOU reuse plastic containers instead of throwing them away?	On a scale of 1-10: How often do you think OTHERS reuse plastic containers instead of throwing them away
AVG	7.4	4.692307692	6.492307692	3.953846154
STDEV	2.748863401	1.488739787	2.795772908	2.079894598
P-value	0		0.000000005852993197	

Figure 12

	On a scale of 1-10: How of often do YOU do volunteer work for a cause out of your own volition. IE: Not for some requirement or because you needed to	On a scale of 1-10: How often do you think OTHERS do volunteer work for a cause out of their own volition. IE: not for some requirement or because they needed to	On a scale of 1-10: How often have YOU participated in a protest, boycott, and/or strike?	On a scale of 1-10: How often do you think OTHERS participate in a protest, boycott, and/or strike?
AVG	4.076923077	3.215384615	3	3.446153846
STDEV	2.464166266	1.57611377	2.41091269	1.811687484
P-value	0.00240348547		0.08649716767	

Figure 13:The average participant rating for all questions is lower for evaluations of others than for evaluations of the participants' self with the exception of the protest, boycott, and/or strike question. Additionally, all questions pertaining to evaluations of others had a lower variance than evaluations of the self.

Chapter 6: Solutions

6.1) Education campaign

Based on all information discussed in chapter 5, we believe a strong education campaign will focus not only on providing information about microplastics. There is an implicit assumption in the idea that once people become educated about a problem, they naturally begin to look for solutions—the assumption being that the former entails the latter. Hopefully this false assumption has become abundantly clear with the case study of the climate crisis.

Because of the success of the various misinformation campaigns and propagandas pieces disseminated by the fossil fuel industry over the years to delegitimize efforts to curb the climate crisis—many movements which broadly pertrain to any ecological or environmental issue will by proxy face the same oppositional schools of thoughts which faces climate crisis activists. This is likely to be the biggest threat to any education campaign. We therefore propose the following plan.

6.1.1) What to Say in the Campaign?

First, we must address the denial of science tactic which is the first line of opposition. With the case study of the climate crisis, it is not immediately apparent to a lay audience why rising temperatures is an issue. The true impact is abstract and not immediately tangible. It is much more difficult to explain to someone why they should care about the climate crisis than it is to convince someone why they should not.

- In order to convince someone that rising temperatures is a bad thing, the audience needs to be educated on the complex interplay between the environmental impact caused by the weather changes, then the cascading ecological disaster caused by habitats becoming unviable, then the resulting issue of drought, famine, plague etc caused by collapse of various food webs.

- In order to convince someone that rising temperatures is a good thing, the audience needs to be told it makes winters less cold so there is less snow to shovel.

This asymmetry in the climate debate is what allows denial of science to be especially effective especially with less educated audiences. This is the unfortunate reality that must be acknowledged. The goal then should be to design an idea which is intuitively true to any audience without significant scientific background, which will convince them of the legitimacy of the issue. Fortunately, this is not an issue with microplastics. Even without an elaborate understanding of health sciences, the image of eating plastic is universally recognizable to any audience as being bad for human health. In fact, based on the survey results we already see that this is the most effective image at attracting attention from people by a large margin. Again, this is corroborated by findings from (56) which found that the image of ingesting plastic particles is found to be the most striking to those surveyed. We believe that these concerns about impacts to human health should be heavily emphasized and exemplified first and foremost.

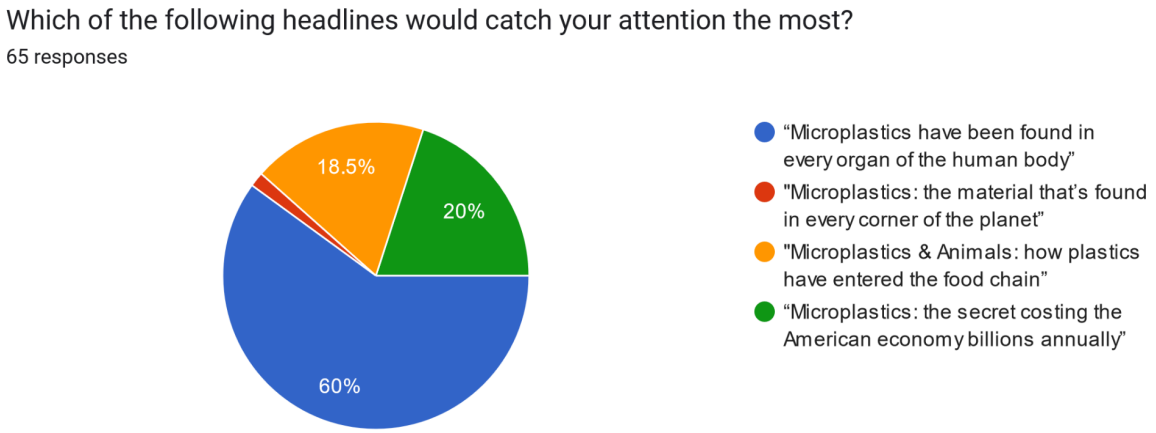

Figure 14:More than 60% indicates that "Microplastics have been found in every organ of the human body" as the most concerning headline—illustrating that the environmental, ecological, and economic impact of microplastics are far outweighed by the health concerns.

Environmental and ecological impact aspects of microplastics on the other hand should take a back seat in education campaigns. Yes. While equally concerning if not more, because of the past success of disinformation campaigns targeting climate crisis activists, any movement which aims to solve an environmental or ecological crisis faces the same vague obstacles. Like with the climate crisis, it is more difficult to convey the impact of environmental and ecological impacts due to the abstract and intangible nature of the issue. Rather, it is wiser to play to the strengths of the microplastics crisis which is the intuitive danger of ingesting invisible plastics that are everywhere and yet invisible. This is a highly provoking imagery that illustrates the severity of the issue well to all audiences regardless of education background. Less educated audiences will comprehend the severity of the issue even without any elaboration. More educated audiences naturally tend to fact check for sources and citations more often especially when presented with provoking headlines. A Germany-UK study analyzing the ability to detect fake news found that "older, male, high-income, and politically left-leaning respondents better detect fake news" (177). Given that income correlates with education level, it can also be said that ability to detect misinformation increases with education. The point is that in the process of detecting fake news and fact checking sources, these audiences are educating themselves on the impact of microplastics which is a desirable outcome regardless.

Although the simple image of 'eating plastics' is sufficient to tackle the issue of uneducated audiences and denial of science tactics, we believe that, left unaddressed, the disinformation strategy of downplaying the effects has the potential to hinder progress towards tackling the MP crisis. In our survey we see participants express doubts and uncertainty over the effects of microplastic. For instance, one participant wrote: "My main question is: 'okay what's so bad about this'. I would be in a state of denial if I ignored the fact that they are everywhere, but I'm far from convinced that they are having a significant harm anywhere. I do concede that I am not super informed on this issue and there could totally be something concrete that I'm missing, but I've seen so much on how microplastics are everywhere without really seeing how this is negatively impacting people or the environment, especially compared to more concrete issues like climate change or all the trash we make." This uncertainty over the actual impact of

microplastic is notably distinct from just a lack of awareness; this participant clearly indicates a basic understanding of the ubiquity of microplastic and the fact that they are in our bodies. The doubt here is instead if their presence is benign or not. In other words, doubting the actual effects of microplastics. This indicates that the image of eating plastics is not enough to convince everyone. Likely most people will take it as a given that ingesting plastic is likely to be unhealthy. Regardless, left unaddressed, this could become a talking point used by the opposition. While the image of ingestion of microplastic should be at the forefront of the education campaign used to draw attention to the issue, following waves should focus on providing factual, confident research that details negative impacts to human health due to microplastic ingestion.

Another point to address is the potential for distraction from the issue. It does not matter that people are aware of the issue and are willing to take action if those actions are being wasted where it does not matter. It should be made abundantly clear to all audiences where the primary source of microplastic is to eliminate the possibility of attempts at distractions as seen with the personal carbon footprint propaganda. This is an especially concerning risk in the case of microplastics. We have already begun to see examples of this issue crop up with news cycles and misleading headlines painting bottled water as being a big source of microplastics. It is a fact that microplastics have been found in high concentrations in bottled water (153, 178). However, as opposed to the factual statement of "microplastics have been found in high concentrations in bottled water" the overwhelmingly coverage of microplastic presence in bottled water runs the risk of disseminating the incorrect notion that "microplastics mostly come from bottled water." This would be analogous to insinuating that global warming is an issue of individually selfish decisions (i.e. not walking to work, taking vacations, etc.) as opposed to a systemic issue of over-dependence on fossil fuels as an energy source and unsustainable industry practices.

This is dangerous. Even if the public is swayed by the microplastic crisis, if they are focussed on a relatively trivial aspect of the crisis such as its presence in bottled water, then more pressing sources of the crisis will not get the needed attention. All attempts should be made to clearly establish the largest primary contributors of microplastics and reinforced as often as possible to avoid this.

6.1.2) Who to Talk About This to?

The education campaign of course should be tailored towards individual demographics. We believe the best demographic to focus on in the beginning is Gen Z. The demographic generally is more left leaning than previous generations and is hence more likely to resonate better with something like the microplastics issue. Additionally, young adults are an energetic, rebellious demographic; hence why they historically tend to be the demographic to initiate social movements.

Another reason is how Gen Z receives new information. By far, Gen Z spends the most amount of time than any other generation online (179), where information can spread virally for significantly less cost. Indeed, while information can spread virally, so can misinformation. In the case of microplastics, this is more likely to work in favor of the crisis than not. It is much easier to over exaggerate than it is to under-represent the impact of eating literal plastic and the provocative nature of the image is likely to grab attention. So any misinformation spread will likely revolve around exaggerated descriptions of microplastic impact, which while not factually accurate, will be effective at swaying people. Again, more educated audiences are more likely to detect misinformation and fact-check sources, which actually works to our favor as they are educating themselves further on the complete microplastic picture in the process of doing so. The problem is that while this will work on the short term at quickly getting peoples' attention, predicting how information mutates over time as they are shared is difficult. But given the choice between a select few possessing accurate information about microplastics versus the general population possessing somewhat inaccurate information about microplastics, we believe the latter is still preferable.

One seemingly obvious concern with Gen Z as a demographic is the risk of low morale. Anecdotally, our generation is less hopeful about the future than predecessors. From 1995 to 2024, nominal wages in the US have doubled while the median nominal housing cost has quadrupled (180). The rise of generative AI is accompanied by employment anxieties. Moreover, a general awareness of the climate disaster and need for action is juxtaposed by an inability to effect meaningful change leaves many feeling hopeless, a sentiment echoed by Gen Z activists like Greta Thunberg. Many teens report feeling anxious, frustrated, and hopeless (120). Given all of this, it might seem that Gren Z would be highly vulnerable to a strategy like destruction of morale.

While it is true that Gen Z reports feelings of hopelessness, they also report feelings of anger. Out of all generations, even in spite of the low morale, Gen Z is by far the most concerned with long-term, global impact issues such as the climate crisis (154). As seen with the survey, the vast majority of the Gen Z participants survey results were opposite to our team's original predictions; we found that Gen Z actually is concerned, is already aware of microplastics, and they demonstrate a willingness to take action. Simultaneously, Gen Z is completely convinced that they are in the minority and alone in this belief. This behavior is unintuitive and irrational. If an action is only effective if others partake in the same action, then a person who does not believe others will take that action should not take that action themself. If I believe I will be the only one showing up to a party, then I would be less likely to attend. But this is not what we observed. Take for instance the simple act of bringing your own bag to the grocery store—a simple act designed to curb plastic waste which is only effective if the majority of people perform it. Therefore, if a person does not believe others will partake in this action, then intuitively they should not waste their own energy doing so futilely. In other words there should be a correlation between how likely a person is to bring their own bag to the grocery store and what they predict is how likely others bring their own bags. We built a regression model using how often a participant indicated they brought their own bag to the grocery store as the dependent variable and how often they think others do the same as the independent variable. We then performed two hypothesis tests for significance: the first setting the null hypothesis to be "population correlation coefficient = 0" and the second setting the null hypothesis to be "population regression coefficient = 0." For both tests we set the alpha value to be 0.05. We were unable to reject the null hypotheses for both tests. The former had a T-statistic of 1.41 at 63 degrees of freedom which equates to a p-value of 0.08. The latter had an F-statistic of 2.005 at df1 = 1 and df2 = 63, equating to a p-value of 0.16. These results illustrate perplexing behavior. An analogy would be if the vast majority of the sampled Gen Z participants were participating in a big game of *Prisoner's Dilemma*, indicated that they believe most other players are going to betray them, then decides to pick the cooperative option regardless.

Yet this unintuitive, irrational behavior is ideal in this exact scenario. To reiterate, destruction of morale works by convincing an audience in the futility of their actions and in the apathy of others to prevent action. Yet, here we see an audience which is utterly convinced they are in the minority of people who care about a gargantuan issue yet simultaneously demonstrates

the willingness to take action against the issue regardless of their conviction. Put differently, the sampled demographic of Gen Z demonstrated two qualities (1) they believe themself to be in the minority of people who care and are taking action against issues, (2) they do not seem to mind the first fact and are in fact the majority. Correcting the misconception that Gen Z are alone in their awareness and concern over these issues, would enable them to take individual activism and turn it into collective: organized activism setting disorganized steps into a purposeful march. We believe correcting this bias through presenting empirical research evidence will shine light on the fact that we are not alone in our feelings and actions and that this will serve to build morale and foster collective organization amongst our generation. Hence why we believe this demographic possesses the greatest potential to successfully push for solutions to the crisis.

It is important that the microplastics crisis does not turn into a partisan issue and get bogged down as has been with the climate crisis. In order to guarantee the greatest likelihood of passing microplastic legislation, bipartisan support must be achieved. While different parties may have different interests in tackling microplastics, there must be support from both sides. Exclusively focussing on the young-adult, Gen-Z audience will likely alienate rightwing audiences. We must also focus equally on swaying a right-leaning demographic. Our proposal for this demographic of choice are right-leaning adult women of ages 20-40. Which brings us to the reasoning behind why women of age range 25-45 in particular. As seen with both (56) which showed that "females' willingness to reduce emission was higher than males' willingness" and (135) which showed that women generally "show a more positive green consumption intention, consume less carbon, and purchase green products more frequently," we believe that the microplastic crisis is more likely to resonate with the adult women audience than adult men. Hence, we select women to be the gender demographic of choice for the reason that the campaign is more likely to succeed that way. This goes for the Gen Z focus as well.

This brings us to the question of why this specific age range in particular. This range is flexible but is generally intended to roughly correspond to the age range of mothers in right-leaning parts of the United States. Right-wing audiences generally value traditional lifestyles with emphasis on traditional feminine qualities, including motherhood for women. As a case study, we can look at the anti-vaccination movement which started out with the idea that vaccines cause autism in children. This myth is generally more prevalent amongst those holding right-wing populist beliefs and mothers generally care about the health and safety of their

children (152). It then stands to reason that information such as how microplastics have been found in the human placenta or that newborns are ingesting microplastic should resonate strongly with this demographic (151). Pushing for solutions and reforms to microplastics can be painted as a campaign for a "return to natural, traditional healthy living" as well.

6.2) Legislation

Along with an education campaign, we believe it is important that legislation to combat the microplastics issue is implemented as part of the solution. An effective education campaign as described in the previous section would ideally result in the general public being on board with changing consumer habits to alleviate the issue. This is an important first step to ensure businesses start moving towards more sustainable practices but proper regulation would be the next step in holding contributors to the microplastic issue responsible. This section will describe some of the already existing legislation involving plastics, different possible paths for future legislation, and what is involved for regulatory laws to become a reality.

6.2.1) Existing Legislation for Plastics

There have been various attempts to reduce plastic waste through legislation across the world and some legislation specifically tackling the issue of microplastics. Microplastic regulation started in the United States with the 2015, "Microbead Free Water Act," to ban the use of primary microplastics known as microbeads in personal care products. Several other countries also banned these around the same time including Canada, Australia, the UK and others (155). More recently, in October 2023, the EU issued regulation on synthetic polymers, expanding the ban of primary microplastics used in a variety of applications (174). One of these applications includes the agricultural industry, in which plastic mulch films and plastic seed coatings contribute to the microplastic pollution into soil. This regulation specifically for microplastics addresses a large source of pollution directly into the environment. Beyond regulations on microplastics specifically, there are few laws to monitor microplastic levels in water or air. A 2018 state law in California tried to tackle this issue by monitoring microplastic levels in drinking water over 4 years (175). The results of this law helped establish a possible baseline for future legislation to monitor microplastic levels. Although, the measured quantities do not

establish much on their own as there is no comparison to be made for other regions and a lack of knowledge for a direct health concern for the measured data.

6.2.2) Possible Future Legislation

There is currently a lack of legislation requiring monitoring for microplastics in the environment on a large scale. Before moving straight to legislation requiring microplastic cleanup and plastic bans, it is important to have a full understanding of the current state of microplastic waste in the environment. This would also help establish any connection with health concerns for populations exposed to higher concentrations of microplastics. Another possible type of legislation that could be pursued moving forward is the bans or regulations on plastic use. These regulations would result in less plastic production and subsequently less microplastic pollution but there are challenges that might not make this the ideal path. Plastic bans require sustainable alternatives that are economically feasible which are not fully available at this point. There is limited research to support that biodegradable plastics, commonly used in place of traditional polymers, are contributing any less to the microplastics issue. This means a path towards legislation banning plastic would first require more research on plastic alternatives and a solid solution to finding an alternative material to traditional plastic. A different legislative route that could result in positive change is regulation to clean up environmental microplastics. Cleaning up microplastics requires a large effort of various technical solutions that can work in combination to clean up microplastics in various aspects of the environment. The details on the possible technical solutions will be examined in further detail in section 6.3. Generally the legislation would require specific standards of acceptable microplastic levels in the environment, whether that is in the waterways, atmosphere, soil, etc. The responsibility of this clean up can fall onto the government imposing the regulation or the private corporations contributing to the microplastic issue. For this to happen there must be monitoring of microplastic shedding at each level of the plastic's lifecycle to determine what stages require clean up before the microplastics build up becomes unmanageable. This shift in responsibility to the private sector would likely result in a natural phase out of traditional plastics due to the long term cost that constant clean up efforts would take. Regulation to make sure plastic producers are producing plastic that has less toxic chemical makeup would also be a step in the right direction. This would not decrease the amount of microplastic pollution into the environment but it may lessen some of the harmful

effects current microplastics have towards humans and animals. A combination of these different paths for legislation is expected to lead to significantly less microplastic pollution and damage caused by it.

6.2.3) Pathway Towards New Legislation

The process of legislation becoming a reality would involve a joint effort between legislators, the general public, and private corporations. The first step towards pushing legislation involves getting the general public educated about the issue and on board for change. Changes in consumer habits pushes industries to move towards sustainable practices without legislation involved, but legislation would be the final push to ensure there is a standard of sustainability to follow. Legislation is also necessary to ensure that private corporations are using genuine sustainable practices instead of misleading consumers. Without regulations in law, "the concept of corporate sustainability remains vague and tools to measure if/when an impact has been successful—as opposed to greenwashing—are non-existent," (156). Non-governmental organizations have played an important role in pushing for environmental policy and are essential in the process of lobbying for government intervention. The UN Environment Programme also plays a major role in establishing clear guidelines across the world for countries to be held accountable to change over time. International treaties have proved effective in the past for environmental concerns such as the Montreal Protocol's success in repairing the ozone layer (157). International agreements to address the microplastics issue could prove useful and help governments work towards a unified standard of sustainability and support developing nations in meeting them as well. The UNEP is currently running campaigns to combat the microplastic issue, such as the Clean Seas campaign targeting microplastic pollution in the oceans (170). Once a country would pledge to an international agreement, it would need to establish its own laws through pre-established environmental agencies to meet the standards. Although international agreement and unity to solve the issue can be beneficial, it is not essential. Meaningful change can come from any level of government, and from any country. Government agencies such as the FDA and EPA in the US or REACH in the EU would be instrumental in implementing the necessary legislation with the best interest of the public.

These organizations and groups come together to work with politicians to create policy with the advice and support of scientists with expertise in the issue. In order for politicians to be

on board with devoting time to the microplastics issue, it must be clear that the general public wants change as well. There must also be some feasible technical solutions for plastic alternatives and clean up techniques that allow for the enforcement of the laws to be possible. This is how the legislation across the world banning microbeads in cosmetic products was made possible. The general public was concerned about the issue and there were easily accessible alternatives to the primarily microplastics used, which did not disrupt the cosmetic companies too much. It is more difficult for politicians to work on legislation involving secondary microplastics specifically because of the lack of clear alternatives and the lack of public knowledge about the issue (173).

6.3) Technical Solutions to Microplastics

The true "answer" to the microplastic issue is to get rid of plastics all together - this would keep microplastics from ever being produced. However, this is not a feasible solution and not remotely realistic, too much of our world today depends on plastic to continue operating. Even if microplastic pollution or production immediately and entirely stopped, it has been predicted that there would still be an increase of microplastics, due to the macroplastics already existing in the environment which will fragment over time (195). Promoting a cyclical economy for the use of plastics and massively decreasing the production of plastics would significantly impact the microplastics issue in a positive way and would be the first step in truly attempting to remediate this problem. A true solution would need to be economically feasible, which will be very difficult because plastic is a cheap and super versatile commodity with massive production benefits. The initial stages of implementing any alternative might cost a little more because the production of safer alternatives might not be on as large a scale or as easily accessible both industrially or domestically. Additionally, when new technology is generated to pioneer plastic in a "greener" way, this does not necessarily mean that a solution is proposed. It is of the utmost importance to analyze the whole of the proposed solution when making coverall decisions about true cures to this problem.

6.3.1) Recycling: the Dangers and Alternatives

When investigating solutions to microplastics, the issue seemingly got worse when the news about recycling broke. According to contemporary research, technology used presently for

plastic recycling generates microplastics instead of actually recycling the material. It should be noted that most published studies encourage more research into this statement, but still conclusively produce evidence. In one pilot study, monitored microplastic pollution originating from a mixed plastics recycling facility in the UK to "receiving waters" (50). In this mostly controlled environment, the water contained ultra high concentrations of microplastics. This study also implemented a filtration system which filtered most but not all of the microplastics out of the contaminated water. In a similar study, the generation and fate of microplastics were examined from three different facilities that all create plastics out of PET (49). The microplastics were found in the respective facilities waste water, effluents, and sludge, the highest concentration of PET microplastics found in the sludge. Another study monitored three different recycling plants and their microplastic pollution and conclusively stated "plastic fragments are still likely released to the aquatic environment during mechanical recycling processes" (48). From just these three studies alone, it can be deduced that current recycling methods do not work well enough to eliminate plastic as an issue and these methods most definitely produce microplastics.

A researcher out of Glasgow, Scotland, Erina Brown, conducted a similar study as to the three discussed above and had similar results. When interviewed by a local newspaper, Erina Brown stressed the importance of how recycling is actually an issue which seems ironic considering "recycling has been designed in order to protect the environment" (46). After these findings, a certain question is asked: how will the microplastic issue as a whole be remediated if macroplastics can't be recycled? The short answer is to find a new solution or create a better recycling method. Luckily there are other ways macro, and micro, plastics can be broken down.

Recent investigations into chemical degradation processes, like advanced oxidation and photocatalysis, have proved promising as an alternative to traditional recycling. The goal of these chemical processes would be to wholly break down microplastics to their base nature and permanently eliminate microplastics as an issue. It should be noted that there is a barrier for these degradation chemical processes: critics who believe there is a lacking foundation in the chemical kinetics for the mineralization of macro and microplastics. However, there are case studies which prove these cutting edge chemical kinetics to be successful (211). First, advanced oxidation processes (AOPs) are mainly utilized to eliminate organic pollutants, i.e. sulfates (47). It has been proven that AOP effectively degrades and mineralizes not just microplastics but dyes

and antibiotics as well (211). Microplastics are not just a run-of-the-mill contaminate but instead are unique; microplastic particles have a much higher molecular weight which makes them more difficult to completely break down. The AOP process, however, degrades compounds with larger molecular weights with ease and most definitely is a viable option for true microplastic recycling (212). The second aforementioned recycling alternative is photocatalysis. Photocataylsis, a well known, environmentally friendly process, utilizes solar energy to degrade compounds. Currently this process is mostly used with water purification because, similar to AOP, antibiotics, pesticides, and dyes are effectively broken down in this process (47). The benefit to photocatalysis is that it is universally well received and is much more cost effective in comparison to other recycling methods (47).

Additionally, there is another form of recycling: sodium iodide recycling although this process is less permission than AOP or photocatalysis due to its high cost. Sodium iodide recycling is extremely environmentally friendly and is effective at procuring microplastics from physically similar substances like sand (70). However, the process is expensive which, as explained above, goes against the feasibility of this option. There are studies now that prove sodium iodide is recyclable, and using recycled sodium iodide works just as well as non recycled sodium iodide (70). If this technology made sodium iodide a cost effective enough option, this recycling technique deserves some consideration.

6.3.2) Plastic Alternatives

Completely ridding the world of macroplastic would in theory negate all the problems imposed from microplastics. However, this unrealistic theory is just not plausible, so looking into alternatives to plastic seems like a potential solution. The purpose these alternatives would serve is that there would be little to no impact on the environment in production process, use, and decomposition, and these alternatives can be fully implemented into society and nature without generating pollution. (167)

According to recent research, the alternative that holds the most promise are biopolymers. These biopolymers can be genetically engineered or naturally derived. There is a promising idea to use animal waste byproducts to create a biofilm alternative. In one study, animal waste was used to create a biopolymer out of whey protein which will degrade, as opposed to their plastic, petrochemical counterparts that do not degrade but instead create microplastics (140).

Similarly, the idea of bioplastics has surfaced as a potential solution. Bioplastics might sound similar to biopolymers, but make no mistake, there is a difference. Bioplastics are a "subset of biopolymers" which means that "all bioplastics are biopolymers, but not all biopolymers are bioplastics" (167). Renewable bioplastics are plastic polymers created from renewable organic compounds like starch, sugar, and natural fibers. (163) Further, bioplastics are classified on either their composition or biodegradability: there are bioplastics created from renewable and non fossil fuel sources (the starch, sugars, etc.) and are not biodegradable, there are bioplastics that are fabricated from carbon emission sources and are biodegradable, and there are bioplastics made with both renewable compositions and biodegradability (167). One study researched the effect of bioplastics on soil, using earthworms as a test study. Where microplastics restrict plant growth (83), this study found that bioplastics do not limit soil biota and encourages root growth (163).

Additionally, there is a movement to use chitin to alleviate this issue. Chitin, the second most abundant polymer on earth after cellulose, is the structural material in crustaceans and insects (144). From chitin, a polysaccharide called chitosan is derived by a low cost, simple partial deacetylation process (149). Chitosan is the real diamond of this process. This polysaccharide is already used in biopolymers commercially in industries ranging from waste water treatment plants, to photography, to electronics. (144) Both the short and long term effects have been studied extensively and there are no known hazards. Further, there was a study conducted to use the chitin from seafood waste to be used in a plastic alternative biopolymer in the future, specifically for food packaging applications. The drawback of chitosan is not mechanically sound enough to be used singularly, but rather should be mixed with other biopolymers or similar to create a stronger, more similar to plastic alternative. Scientists have attempted blending chitosan with other biopolymers, such as polyvinyl alcohol, to achieve a material akin to plastic. However, caution should be used when implementing other biofilms because these new polymers may not be as prime an example that chitosan is. Polyvinyl alcohol for example is one to research further because a "complete understanding of its fate in the environment and subsequent consequences is lacking" (142). In spite of this information, research has progressed in furthering establishing the PVA and chitosan polymer because PVA is a cheaper and easily accessible biopolymeric material.

Not only can chitosan be used to create a plastic-like material without creating microplastics and adding to the issue, but this material can be used to capture already existing microplastics. A study created biodegradable and reusable sponges that not only clean but remove microplastics from their environment. By combining chitosan, graphene oxide, and oxygen doped nitride, and a sponge was erected that was both strong and durable enough to withstand; this sponge is completely natural and truly biodegradable in the sense that it won't break down into worse materials that make the environment worse (144).

6.3.3) Filtration Systems

For research conducted, research about microplastic remediation solutions for water in general was the most abundant. Due to their unique and nonuniform shapes, existing filters needed to be modified or new filters needed to be created in order to strain microplastics out of our water. One study compared the implementation of different filters, their efficiencies, their cost, and more in relation to waste-water treatment systems. (104)

A widely known filtration technique is called Ultrafiltration, or UF. Membrane bioreactors show lots of promise. UF is a cleaning system that cleans and permits the reuse of waste-water and discharge waters with high levels of toxins in them; water from industries that deal with compounds like steels, plastics, resins, paper, pulp, food and beverage. UF is successful due to its high molecular weight cut off, a characterization method of a filter to describe pore size distribution and the capabilities of the internal membranes. UF is a potentially feasible option because this filtration system gets dirty water back to drinking water standards with a relatively low energy consumption, high separation efficiency of ninety to one-hundred percent removal, and compact plant size (104).

UF is just one removal and filtration technique developed that could potentially be implemented for microplastic remediation. Some of the others include, but are not limited to, granular activated carbon filters, carbon block filters, reverse osmosis filters, and then there are the membranes. Specifically membrane reactors, these biologically engineered and developed structurals might hold the most promise when wanting to solve truly clean microplastics from water in an environmentally friendly manner. There are many different types but the few this team studies are the following: Membrane BioReactor (MBR), Dynamic Membrane (DM), Biocatalytic Membrane Reactor (BMR), and an anaerobic membrane bioreactor (AnMBR).Of

the membranes researched, the MBR proves to be the most promising. An MBR might be implemented in systems in which catalysis is promoted by a biological catalyst, like bacteria or enzymes, and is paired to a separation process controlled by a membrane system, like UF. .

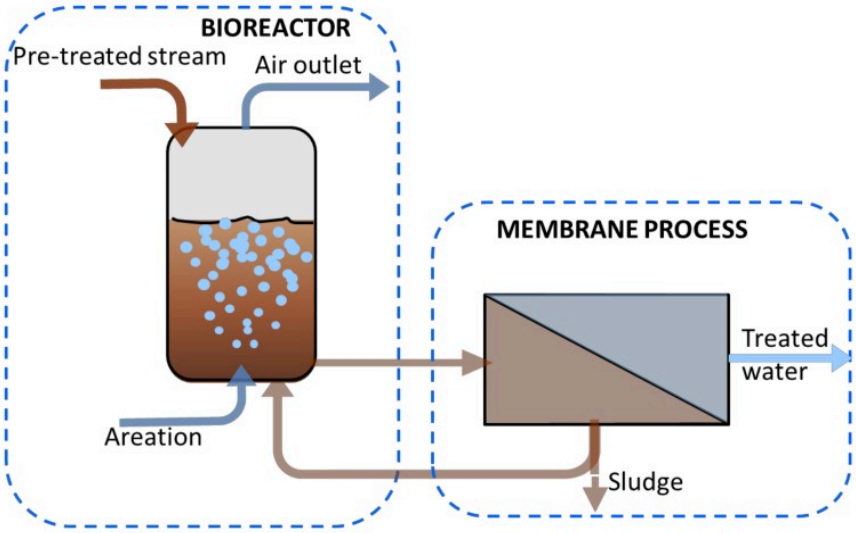

Figure 14: the role of MBR removal in wastewater treatment plants
Photo taken from (104)

MBRs are already involved in the experimentation processes for filtering microplastics, and have been performing well in not only the waste-water treatment industry, but food, pharmaceutical, biorefinery, and biodiesel production industries as well.

Intrinsically, when humans want to clean their water, their first thought is to filter or boil the dirty water first. Seeing as the entire ocean is unable to be boiled at once, filtration is left. While this idea of mass filtration of large bodies of water works in theory, to clean every drop of water on the planet, solely relying on filtration methods will ultimately fail. Decreasing generation of microplastics will be imperative to solving this facet of the microplastic issue. Additionally, a more proactive solution might be most beneficial in this case. Current remediation techniques are reactive - the microplastics come to the filter and the filter will react. The development of a technology that can navigate earth's aquatic environments and almost goes hunting for microplastics could potentially really start to help clean water.

6.3.4) Soil

The use of biopolymers and bioengineered plastics is substantially better for soil than the currently used plastic. (164, 167) Most bioplastics and biopolymers are not only renewable, but

are safe for the environment and surrounding world. Overarchingly, these materials would not cause further damage to the planet of the organisms living in and on it. Potentially using or developing a biopolymer or bioplastic to implement instead of using the plastic mulch films might go a long way in producing less microplastics. A couple years ago, plastic was mixed into asphalt to potentially increase economic benefit in the asphalt industry as well as determine a positive use for plastic waste. Some attempted to pawn this idea off as a way to keep plastics out of the environment. Obviously this design did not pan out, but instead produced microplastics releasing them back into the environment with vigor. The seasonally cold temperatures and consistent wear on the plastic filled asphalt from vehicles encouraged massive microplastic fragmentation. It can be argued that the soil, air, and nearby waterways were even more impacted because these roads brought microplastics closer to rural areas. This experiment should serve as a reminder: although some solutions might seem promising, caution and in depth testing will always produce the most effective results.

6.3.5) Atmosphere

There are not many methods humanity has for detoxifying and cleaning air. Presently, the most common removal strategy is filtration. Historically, air filters and solutions for air pollution are the trickiest to develop. Not only are these filters expensive but most don't work as well as originally planned. Perfect examples are air filters used for smog in large polluted cities or air filters used during the COVID-19 pandemic. Unfortunately for the microplastics cause, most air filters today are created with plastic somewhere in the apparatus: a film on or in the filter, the composition being made from another plastic derivative, etc. Contemporary filters, and most if not all are made from plastic, will only aid the generation of microplastics, completely defeating the purpose of a solution. Currently, the team did not ascertain a solution to remediate microplastics from the atmosphere. However, decreased macroplastic production and improving plastic recycling methods is sure to only benefit this issue.

6.3.6) Textiles

Textiles are one of the largest contributors to microplastics in the air and are the most likely reason that the concentration of microplastics inside is much larger than the concentration of microplastics outside. Refraining from producing fabrics with plastics in them, like microfiber

and polyester, would significantly decrease the microplastic contamination from this industry. Much of literature suggests that textiles composed of synthetic materials and fabrics are an enormous source of microplastics both indoors and doors (20). Using organic fiber fabric instead of plastic filled materials like microfiber or polyester will certainly assist in lowering concentrations of microplastics or even decreasing the amount of microplastics generated.

6.3.7) Rehabilitation Impediments

Recently, there have been many reports of cutting edge technology breaking into the macroplastic and microplastic spaces to create plastic in a "greener" way.. This is detrimental to the microplastic cause because this would serve as fuel for companies to continue to use plastic as opposed to using the alternative. For example, when a greener production method for creating isopropanol, a very common ingredient used to create plastics, is discovered and the process includes much smaller carbon emission productions that alternative isopropanol production methods, specifically for the creation of plastics, this incentivizes companies to still use new plastic as opposed to an alternative substance or implementing reused plastic (139). However, it should be noted that although new technology breakthroughs might decrease carbon emissions for a small part of the production of plastic, the end result of microplastics will still carry the same level of threat to the planet.

Chapter 7: Conclusion

Given our analyses and results, we believe that microplastics is a crucial area of research demanding an immediate global response. They are present everywhere from the stratosphere down to the ocean basin. Their presence in the human body has been linked to lung cancer, reproductive issues, and other diseases. In land and sea, their presence disrupts the food web through reproductive stress and more. All these issues contribute to losses in the economy. We believe the situation is dire and that an immediate, confident response from the international community is needed.

At the same time, while the scale of the crisis is undoubtedly gargantuan and the situation can appear dire and demoralizing, we should remind ourselves that we as a species are capable of more than we as individuals. The most productive place is in that balanced middle point between overconfident complacency and apathetic despair. A significant length of this paper discusses the detrimental effects of microplastics and our past history of failing to solve global

environmental/ecological crises. But there also exists past precedents of successes. We've plugged the ozone hole. We've brought species back from the brink of extinction. We've eradicated plagues. We are not alone. People care about this issue and they're willing to take action. Solutions do exist and everyday researchers all over the planet expand our understanding of the problem. What is important is to remind people and ourselves of these facts, to turn individual steps into a coordinated march, to chisel away at a gargantuan problem one by one until a mountain turns into a pebble, to never lose hope.

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