

A Multiphase Solution to Microplastic Pollution: Integrating Enzymatic Degradation, Density Separation, and Biodegradable Innovation

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ABSTRACT

Plastic pollution, especially microplastics, poses a growing threat to ecosystems, food safety, and human health. Since over half of global plastic production is single-use, these materials persist in the environment. Our proposed solution emphasizes enzymatic degradation and innovative filtration. Entropic Materials developed biodegradable chaperone proteins that safeguard enzymes during plastic production, enabling rapid breakdown without generating microplastics. We also propose: (1) density separation systems in water treatment plants, (2) genetically modified Honey Fungus Mycelium to degrade plastics in fertilizers, and (3) hybrid biodegradable packaging from bamboo, sugarcane, and Japanese knotweed. Together, these strategies could reduce microplastics by 80%.

Keywords: *Sodium polytungstate, density separation, hybrid, mycelium, microplastics, enzymatic degradation, water purification, bamboo, sugarcane, Japanese knotweed, environmental health, plastic pollution*

UNDERSTANDING THE PROBLEM: WHAT ARE WE REALLY SOLVING?

Microplastic pollution results from the degradation of plastic waste or the direct manufacturing of small plastic particles. These particles, less than 5 mm in diameter, are nearly impossible to detect and remove once released, making them particularly insidious (Microplastics, n.d.). Our work targets three interrelated issues: the accumulation of microplastics in water and soil, their slow rate of degradation, and the sheer volume of plastic being produced (Gerretsen, 2023).

Our research began by deepening our understanding of the two main types of microplastics: primary and secondary. Primary microplastics are particles designed for commercial use, like microfibers from clothing and other textiles (fishing nets, flags, outdoor furniture, etc.) (Gerretsen, 2023). Secondary microplastics are created as a result of the breakdown of larger plastic items, like water bottles and food packaging, caused by exposure to environmental factors such as sunlight and ocean currents (Are microplastics in our water becoming a macroproblem?, 2015). However, both of these types of microplastics do not readily break down into harmless molecules, resulting in their spread throughout the environment (A complete guide to extraction methods of microplastics from complex environmental matrices, 2023). This made us realize that a major way microplastics directly impact us is through the food and water we consume (Alexis, 2022; Francis, 2022).

On average, humans ingest around five grams of microplastics per week—about the size of a credit card (We ingest plastics every minute of the day, 2023). There are many ways microplastics enter our digestive system, such as plastic packaging and unfiltered drinking water

(Sieff, 2023). Microplastics ingested by aquatic life, which we in turn eat, and the fertilizers that help grow the plants we regularly consume, also contain many microplastics (Cusworth et al., 2024).

This can lead to many major health issues. Ingested microplastics can cause cell damage, leading to inflammation and allergic reactions, which, in turn, weaken gut health and the immune system (Yonsei Med J., 2023). This creates a direct route toward multiple cancers, low birth weight, immunotoxicity, and thyroid disease (Plastic particles in medicine, 2022). Previously conducted tests on animals have shown that fish that have ingested microplastics develop neurotoxicity and oxidative damage (Harmful effects of the microplastic pollution on animal health, 2022). A study on mouse reproduction has also shown negative effects (Takaki et al., 2019).

Microplastics are also toxicological vectors, meaning they can absorb additional chemicals on their surface before coming into contact with a human cell (Enders et al., 2020). Some of these chemicals, and others that microplastics already contain, are known endocrine-disrupting compounds. This means they can mimic and disrupt the natural functions of hormones such as estrogen, testosterone, and insulin, increasing the risk of health problems. Long-term exposure to these chemicals is extremely harmful (Levin et al., 2020).

In addition to these concerning effects, research has also shown that microplastics can stunt the growth of not only humans but also other organisms, like earthworms (Cusworth et al., n.d.). Though this may not seem to be an imminent threat, every form of life plays a vital role in maintaining the fragile balance of the global ecosystem, and the extinction of even one destabilizes this balance, threatening life on Earth and all of humankind (The hidden ocean

pollution killing marine mammals, 2020). Our research has dramatically revealed the importance of immediately addressing the issue of microplastics.

EXISTING AND EMERGING STRATEGIES

To ground our work in context, we analyzed current methods used to detect, separate, or degrade microplastics. These strategies, while promising, are limited by scalability, efficiency, or environmental side effects (A Complete Guide to Extraction Methods of Microplastics from Complex Environmental Matrices, 2023).

Our focus is to target the microplastics that enter our bloodstream directly through the water and food we consume every day. Currently, there are a variety of solutions available to solve this pressing issue. This ranges from simple resolutions, like avoiding plastic containers, to complex hypothetical inventions and models (Sieff, 2023). Numerous extraction methods are available today, such as density separation, oxidative, alkaline, acidic, and enzymatic digestion, oil-extraction protocol, magnetic and electrostatic separation, pressurized fluid extraction, and centrifuges (Centrifuges, n.d.; Enders et al., 2020).

Today, density separation is the most commonly used method to filter microplastics from sediments, whose difference in specific densities is utilized in this process (Zobkov et al., 2020). Some dense solutions used to separate microplastics from sediments include sodium polytungstate, zinc bromide, zinc chloride, and sodium iodide, all proven effective in laboratory testing (A Complete Guide to Extraction Methods of Microplastics from Complex Environmental Matrices, 2023). However, sodium polytungstate is the only salt-based solution that is aqueous, or dissolves in water

(Alvarez-Zeferino et al., 2019). These solutions have a higher density than most microplastics, allowing for easy separation, as the microplastics with decreased densities float to the top of the solution, while the denser sediment sinks to the bottom, eventually separating the microplastics altogether (A new small device made of glass for separating microplastics, 2019). The most common types of microplastics around the world are polyethylene (PE), polypropylene (PP), polystyrene (PS), polyamide (PA/nylon), polyester (PES), and acrylic (AC) (Microplastics, n.d.).

Another possible solution that is commonly used for the separation of microplastics from liquids is a centrifuge. These machines approximate gravity's ability to separate different components of a solution, and depending on what type is being used, centrifuges can even separate ribosomes, organelles found within cellular structures (Woodford, 2009/2018). This process occurs when a liquid is put in the container of a centrifuge and is spun at an extremely high speed, separating the components of the liquid. However, the reason this machine is not incorporated into our solution is that centrifuges are high energy consumers and are difficult to manufacture on a large scale (Centrifuges, n.d.; CentraSep, 2024). This makes them difficult to implement in mass quantities. In terms of danger, unbalanced centrifuge rotors can result in injury or death, and sample container breaks also release aerosols that may be extremely toxic when consumed (Woodford, 2009/2018).

Electrostatic separation, a process that relies on the distinct conductivity of sample particles, is another possible solution. Mineral particles are generally more conductive than plastics, so (to optimize the procedure by eliminating water content), the process begins by freeze-drying the sample. Subsequently, the dried sample is introduced into an electrostatic

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separation instrument, such as the Korona-Walzen-Scheider (Haldar, 2018; K.R., 2011). A vibrating conveyor plate directs the sample toward the Corona electrode system, creating a high-voltage electrical field between a grounded drum and a rake-shaped electrode mounted above, allowing the particles to become charged. More conductive mineral particles discharge rapidly and are guided by the diving flap to jump off the drum and into the “sediment container.” Particles adhering to the drum are mechanically removed by a scraping plate and put in a plastic container. Through recycling the content of the plastic container in repeated runs, the mineral fraction is further reduced, refining microplastics (Enders et al., 2020; Tilmatine et al., 2009).

However, it is crucial to note the drawbacks of electrostatic separation. There is a risk of fire or explosion due to static or sparks, particularly when processing flammable materials like coal, wood, or plastics (How do you deal with the environmental and safety issues of electrostatic separation?, n.d.). In terms of public welfare, the machine generates fine dust particles, which impact air quality and pose health risks to workers and nearby communities (What are the advantages and disadvantages of electrostatic separation compared to other methods?, 2024). Dust can also impede separator efficiency by interfering with the electric field and particle trajectories (Haldar, n.d.). Electrostatic separation also contributes to noise pollution due to the high levels of noise generated by the electric discharge, vibration of separators, and movement of material, thus posing further risks to people in the machine’s vicinity (Tilmatine et al., 2009). In addition to these risks, the process results in waste streams, including sludge and impractical microparticles, adding to environmental contamination if not properly disposed of (Haldar, 2018).

The high presence of microplastics in our environment can be attributed to both the durability of plastics and the substantial disposal of them by people. Over 50% of the plastic produced on Earth is solely designed for single-use purposes, rapidly contributing to the accumulation of slow-degrading plastic in our environment (YOU ARE WHAT YOU eat: PLASTICS IN OUR FOOD, 2023). While numerous methods exist for separating microplastics from the food and water we consume, or even breaking them down entirely, manufacturing companies can play a crucial role in addressing the pressing issue of the overabundance of plastic. This approach is known as enzymatic degradation, a process that rapidly breaks down plastics using enzymes (Microbial and Enzymatic Degradation of Synthetic Plastics, 2020; Chen et al., 2020).

This solution was discovered by Entropic Materials, a company working to create a better environment for future generations. To fully understand their research and the path leading to this conclusion, it is essential to delve into some background knowledge first. Plastics consist of repeating units of molecules known as monomers, which are bonded together to create long chains called polymers. Organisms around the world have the ability to produce enzymes that can break down these sturdy polymer chains; these enzymes possess a precise shape that allows them to fit into gaps within these polymers. As a result, they catalyze chemical reactions, breaking down the polymers into monomers again. This process can also be applied to synthetic polymers, including plastics, with the assistance of microbes. However, this process is relatively slow, and the microbes can only break down the surface of the plastic, not the entire material (Levin et al., 2020; Microbial and Enzymatic Degradation of Synthetic Plastics, 2020).

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A potential solution involves incorporating enzymes into plastic during the manufacturing process, enabling the plastic to undergo internal breakdown once its initial use is completed, which addresses the issue from within. Unfortunately, this solution is not feasible because the enzymes would undergo denaturation, or be rendered inactive, during the manufacturing process due to the intense heat and pressure they would be exposed to (Chen et al., 2020).

Scientists at Entropic Materials have discovered a solution to this challenge: biomimicry, a strategy that involves imitating natural processes. Some organisms naturally release chaperone proteins, which act as protective layers that seamlessly interact with enzymes, either activating them or guiding them to their intended locations. Entropic Materials has ingeniously replicated this mechanism and developed biodegradable covers that emulate these chaperone proteins. These covers keep the enzymes safe during the plastic production process, preventing denaturation. Consequently, the enzymes can efficiently break down the plastic within hours under proper composting conditions, avoiding the generation of microplastics. This disintegration process yields simpler molecules that can be reused to manufacture new products or be further broken down into natural biowaste by natural microbes in soil or water treatments (Sridhar et al., 2022; Chen et al., 2020). If plastic manufacturing companies utilize this in the future, there is a high probability of significantly decreasing microplastics by almost 80% within the next 15 years.

OUR SOLUTION

Microplastics contaminate what we consume in three primary aspects: water, fertilizer, and plastic packaging. The water we drink contains numerous microplastics that are

not properly filtered, and these tiny particles are abundant in fertilizers too, getting absorbed into the food we eat (Cusworth et al., 2024; Gerretsen, 2023). Plastic packaging used to store and transport food also poisons what we ingest through physical contact (Sieff, 2023). To address these aspects, we split our solution into three parts.

Part 1— Water: Our solution involves integrating a modified density separation system to filter microplastics from drinking water at water purification plants, targeting the root of the problem before it reaches consumers. Our solution includes 10 large vats of water, with each vat holding 70,773 L of water with a 4:1 water to sodium polytungstate powder ratio, meaning for every 56,000 L of water, there is 14,000 L of powder. The vats measure 64 feet in diameter and 22 feet in height, allowing for a 3/4th of a ton gap to avoid spillage. These vats effectively filter approximately 700,000 microplastics (there are approximately 0 - 10,000 microplastic particles in one liter of water). This process takes mere hours, effectively addressing the issue of contamination. Our procedure eliminates 1.5 lbs of plastic every 2 hours from all 10 vats, totaling 18 pounds daily, providing clean water for over 50 households. The size and number of vats will vary based on the local hydro-filtration plant's needs during implementation.

Part 2— Fertilizer: Research indicates that microplastics enter the food chain through fertilizers containing sewage sludge, which are known for their high nitrogen and phosphate content (Cusworth, 2024). However, inadequate filtration in wastewater treatment plants results in the sludge containing significant microplastic levels. To address this, we propose incorporating Honey Fungus Mycelium, the root structure of a mushroom, into all fertilizers. Independently, mycelium takes years to break down plastic, so our solution is to genetically modify the

mycelium with the *Ideonella Sakaiensis* bacteria, PETase, and MHETase enzymes by linking the amino acid chains of the enzymes through heating and cooling. This significantly decreases the time in which plastics are decomposed, and produces a biodegradable ‘waste’ that has been clinically proven to be beneficial for plants.

Part 3—Packaging: Microplastics also contaminate our food through plastic packaging, presenting a significant concern. Today, solutions consist of compostable and plant-based plastics. These plastics are made from materials like bagasse (a sugarcane juice extraction byproduct) and bamboo (its fibers have the greatest mechanical strength of all plants), which are both derived from the same plant family, Poaceae (A Complete, 2023). Pure, organic bamboo takes around a year to completely decompose, whereas bagasse takes a mere 2-3 months. Additionally, Japanese knotweed, a plant from the pseudocereal family, is known for its fast development, so fast that it commonly causes issues by growing on buildings and weakening central supports. We propose to hybridize these 3 plants—bamboo, sugarcane, and Japanese knotweed—to create a biodegradable packaging devoid of microplastics (Gao et al., 2022). This would utilize the rapid growth of the Japanese knotweed, creating a hybrid that can also grow quickly, making it a promising real-world implementation.

REAL-WORLD IMPLEMENTATION

Part 1—Water

1. A pipe carrying water fills the vat with 56,000 L of water.
2. 14,000 L of sodium polytungstate (in powder form) is dropped into the water via a retractable pipe from the ceiling. (Duration: **15 minutes**)
3. 2 mechanical claws will shake the vat, ensuring that the sodium polytungstate

powder effectively dissolves in the water to make sure the process works. (**15 min**)

4. The newly created solution rests, allowing microplastics to float to the top. (**60 min**)
5. Once the microplastics rise to the top, a metal plate is inserted at the top of the solution to separate the microplastics. A cellulose nitrate membrane, a microscopic mesh, is added to the top of this metal plate. This membrane has a pore size of 0.1 μm , allowing the filtration of these minuscule microplastics. In a circular motion, this membrane is pulled up through mechanical claws and contains all the microplastics.
6. This raised ‘bag’ will be suspended in the air to drain any remaining water. (**10-15 min**) Then it will be taken away to a recycling plant.
7. The metal plate will open, and the drained water will go back into the vat.
8. The bottom of the vat will open, and the solution will immediately go through a distillation process via a pipe attached to all 10 vats. The unfiltered water will flow through the pipes and be added to the vats for the cycle to start all over again.
9. Once the water has been through the distillation center, the powder and water will be separated. The sodium polytungstate will then be sent to chemists for observation on whether it can be used again. The now purified water, free of both sodium polytungstate and microplastics, is sent out to consumers. The whole process will take approximately 2 hours, which means 12 cycles per vat can take place every day (120 cycles total).

Note: Since microplastics contaminate agriculture and livestock, it is also necessary to ensure that microplastics are eliminated from irrigation water that directly impacts the entirety of the produce and animals on farms. Fortunately, the process above can be implemented with irrigation water as well, eliminating microplastics from contaminating meat and other food items.

Part 2—Fertilizer: All fertilizers will sit in a large warehouse for 6 months, where they will be introduced to the genetically modified mycelium. Within this time period the microplastics within the fertilizer will be broken down into biodegradable material. This byproduct will be kept in the fertilizers and used on plants and produce since it has been proven to be positive for plant development. The modified mycelium will be kept in the fertilizer when it is used, so that it can continue to break down the microplastics found in the soil and produce natural fertilizer for plants. Mycelium has been proven to be 100% harmless when introduced to new ecosystems, as it only breaks down substances, like plastic, that are foreign to the natural environment. Shipment of modified mycelium will be created in labs and distributed to farms every 6 months. This way, the solution also targets existing microplastics in soil.

Part 3—Packaging: Bamboo, sugar cane, and Japanese knotweed will be hybridized through asexual reproduction or vegetative propagation. Since sugarcane and bamboo fall under the same Poaceae family, and Japanese knotweed under the Polygonaceae family, both families are classified as grasses (Liu et al., n.d.). This makes them the prime candidates to be genetically cross-bred. Vegetative propagation works when new plants grow from grass seed structures called rhizomes. In a controlled lab environment, the rhizomes of these plants will be grafted together and grown, creating a hybrid where biodegradable and

microplastic-free packing can be made and implemented within the real world.

SUPPLEMENTARY INFORMATION - OUR SOLUTIONS TESTED PART 1:

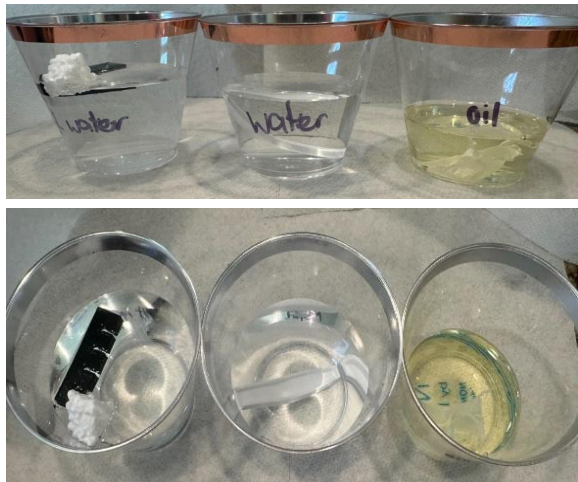
Testing Part 1— Water: Procedure, Results, and Explanation

Procedure

1. Prepare the 3 liquids: Salt Water (3 tbsp salt to 1 cup water), Tap Water (1 cup), Oil (1 cup) (in room temperature)
2. Obtain a number of different plastic types to test
3. Place the first plastic into the first solution
4. Agitate the mixture (mix it in) for 5 seconds
5. Record how long it takes (in seconds) for the plastic to rise in the water and become stagnant
6. Repeat steps 3-5 with each plastic for each solution and graph the results

This is the technique we have followed below in order to test the first part of our hypothetical solution. This procedure closely replicates the process of our density separation. We used salt water, because it has a higher density than water, and oil, because it has a lower density than water. This variety of solutions allows for an accurate depiction of the concept of density separation. Through the data results, it becomes quite clear that the plastics float faster when the density of the solution is higher. However, it is notable that Filament does not float regardless of which solution it is placed in. This is because the salt water merely has a density of 1.414 g/mL, which is smaller than the density of the Filament (1.700 g/mL). If the density of the solution had been higher, then the Filament would have risen to the top as well. This goes to prove that our hypothetical solution would have worked, as the density of Sodium

Polytungstate (a powder) is about 8 times that of water, making it 8.0 g/mL. It then decreases to about 3.1 g/mL when dissolved in water (GeoLiquids 3). This density is still larger than that of even the densest microplastics, meaning it is apt to raise all microplastics to the top of the water for filtration. Hence, our hypothetical solution is proven.



Figures 1-2. *Experimental setup* The set up of the experiment is presented.

Data Table 1: Salt Water			
Material	Trial 1 (\pm 0.01 s)	Trial 2 (\pm 0.01 s)	Trial 3 (\pm 0.01 s)
Styrofoam - Expanded Polystyrene Foam (0.032 g/mL)	10.34	11.56	8.37
Spoon - Polypropylene (0.920 g/mL)	16.54	19.56	11.23
Plastic Bag - Polyethylene Resin (HDPE) (1.12 g/mL)	30.82	34.48	29.51
Plaskolite - Transparent Thermoplastic Homopolymer (1.380 g/mL)	48.91	50.27	45.66
Filament (3D) - Polyurethane (1.700 g/mL)	Does not float	Does not float	Does not float

Data Table 2: Regular Water			
Material	Trial 1 (\pm 0.01 s)	Trial 2 (\pm 0.01 s)	Trial 3 (\pm 0.01 s)
Styrofoam - Expanded Polystyrene Foam (0.032 g/mL)	11.04	13.89	10.53
Spoon - Polypropylene (0.920 g/mL)	24.65	26.63	23.47
Plastic Bag - Polyethylene Resin (HDPE) (1.12 g/mL)	46.38	45.51	43.23
Plaskolite - Transparent Thermoplastic Homopolymer (1.380 g/mL)	Does not float	Does not float	Does not float
Filament (3D) - Polyurethane (1.700 g/mL)	Does not float	Does not float	Does not float

Data Table 3: Oil			
Material	Trial 1 (\pm 0.01 s)	Trial 2 (\pm 0.01 s)	Trial 3 (\pm 0.01 s)
Styrofoam - Expanded Polystyrene Foam (0.032 g/mL)	21.28	20.34	24.19
Spoon - Polypropylene (0.920 g/mL)	39.37	38.23	38.47
Plastic Bag - Polyethylene Resin (HDPE) (1.12 g/mL)	Does not float	Does not float	Does not float
Plaskolite - Transparent Thermoplastic Homopolymer (1.380 g/mL)	Does not float	Does not float	Does not float
Filament (3D) - Polyurethane (1.700 g/mL)	Does not float	Does not float	Does not float

Figures 4-6 . *Data Collection* All the data collected is presented.

SUPPLEMENTARY INFORMATION - OUR SOLUTIONS TESTED PART 2:

Procedure

1. Pour vinegar, water, glycerin (commonly found concentrated within vegetable oil), and tapioca starch into a pot
2. Stir over a medium flame until bubbling
3. Spread based on consistency desired, or pour into the mold
4. Cool and use

The main ingredient in this recipe is glycerin, a triol compound, commonly found in vegetable oil extracted from plants and skin care products. If this sample were to be truly created from our hypothetical solution, it would include glycerin and oil extracted from the plant hybrid between Japanese Knotweed, sugarcane, and bamboo (Zobkov et al., 2020). This product merely simulates the production of an alternative plastic and silicon, which has a variety of uses, from grocery bags to plastic bottles, all without harmful microplastics.



Figures 7-10. *Testing* These images are the documentation process of how the team executed this process. The solution starts off as a milky colored liquid. Then it turns into a sort of gel. Then it is spread on aluminum foil to dry for use. As shown above, this mixture can be spread thick or thin depending on the desired consistency. Food coloring can also be added to this process.

This is what our prototype looked like during the drying process. Please note that this is not what our actual packaging will look or feel like. In order to simulate the process of making eco-friendly packaging, we used glycerin (a type of concentrated vegetable oil) in order to make this prototype. However, in reality, our hypothetical solution uses oil extracted from our sugarcane, bamboo, and Japanese Knotweed hybrid plant (created within a lab), thus

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positively affecting both the quality and consistency of the resulting product. This ensures that the actual packaging is more durable and aesthetically pleasing.

CONCLUSION

This paper essentially presents a comprehensive, multiphase solution to microplastic pollution by integrating enzymatic degradation for plastic breakdown, a modified density separation system for water purification, and the development of biodegradable packaging from hybridized plants. This combined strategy offers a scalable and sustainable approach to significantly mitigate microplastic levels in water, soil, and food systems, paving the way for a healthier environment.

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