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Engineering Report: Biodegradable Plastics

Element A: Presentation and Justification of the Problem

One of the major problems in our society is our overuse, and under-recycling, of plastic. Plastic is a very common commodity that has many uses. A few examples of these include: food and product packaging, household items such as CDs, utensils, light fixtures, and even in electronic devices such as cellphones and computers. According to Plastics Europe, plastics are composed of "natural materials such as cellulose, coal, natural gas, salt, and crude oil through a polymerisation or polycondensation process."[1] Raw materials are usually extracted from these matters and need to be processed for use in creating plastic. Specifically, crude oil is refined to create the main components of plastic: monomers such as ethylene, propylene, and butylene. Due to the many steps of this process that require energy, and the utilization of fossil fuels, plastic production not only creates waste but also contributes to pollution and global warming.

A reason why traditionally-manufactured plastic is not biodegradable is because, according to organic geochemist Kenneth Peters, "the carbon-carbon bonds in polypropylene require too much energy to make," therefore, "it's easier for organisms to synthesize peptide bonds (usually found in proteins and other organic molecules) than carbon-carbon bonds."[2] Currently, there are 8.3 billion tons of plastic in the world, and roughly 6.3 billion is in landfills, and only 8-10% of this actually ends up being recycled. Just over 1% of the world's plastics are biodegradable.

Element B: Documentation and Analysis or Prior Solution Attempts

There are two main types of bioplastic: PLA (Polylactic Acid) and PHA (Polyhydroxyalkanoate). Polylactic acid usually is made from the sugars found in sugarcane, cornstarch, and cassava roots. It is

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[1] Author Unknown. "How Plastics Are Made • Plastics Europe." Plastics Europe, 14 Jan. 2022
[2] Wolchover, Natalie. "Why Doesn't Plastic Biodegrade?" LiveScience, Purch, 2 Mar. 2011

biodegradable, carbon-neutral, and edible. According to the Columbia Climate School, "to transform corn into plastic, corn kernels are immersed in sulfur dioxide and hot water, where its components break down into starch, protein, and fiber. The starch is composed of long chains of carbon molecules, similar to the carbon chains in plastic from fossil fuels. PLA can look and behave like polyethylene (used in plastic films, packing, and bottles), polystyrene (styrofoam and plastic cutlery), or polypropylene (packaging, auto parts, textiles)."[3] On the other hand, Polyhydroxyalkanoate is made by microbes which intake large amounts of carbon as they are deprived of nutrients such as nitrogen, oxygen, and phosphorus. These microbes create PHA as a way to store their excess carbon, which can be harvested and used as a biodegradable plastic. This plastic is utilized in medical procedures (sutures, slings, bone plates, skin substitutes), as well as single-use food packaging.

There are a few esteemed companies that create biodegradable plastic, such as WorldCentric and Ecoware. WorldCentric has 510 biodegradable products in several different categories such as cutlery, take-out containers, plates, trays, catering pans, bags, and more. Their website states that the plastics are environmentally friendly because they use less energy to manufacture, as well as they are non-polluting, non-toxic, and break down in a commercial composting site. Ecoware is a sustainable packaging company based in India that has compostable and biodegradable plastic products made out of crop waste. Their products include an assortment of bowls, plates. takeout boxes, cups, and cutlery. Some companies that don't necessarily manufacture biodegradable plastic but use it in their products include Sweetgreen, Chipotle, Boss Foods, and Mindful Inc. Sweetgreen and Chipotle both use biodegradable plastic products, such as Chipotle's cutlery and Sweetgreen's lids. Some companies make it their goal to be as sustainable and environmentally friendly as possible, but biodegradable plastic for personal use isn't as widespread as one may imagine.

[3] Cho, Renee."The Truth about Bioplastics." State of the Planet, 13 Dec. 2017

For this research project, though, three other successful brands that have biodegradable plastic products will be used. These include an Earth Plus by Sysco straw, a Greenprint straw, and a Dixie Ultra Smartstock spoon. Each of the straws are agave based so they are naturally biofading. Each product has a ranging timezone of the length it will take for the products to biodegrade, the shortest time being roughly 240 days for Greenprint.

Element C: Presentation and Justification of Solution Design Requirements

While biodegradable plastic is an efficient substitute for traditional plastic, there are certain guidelines to follow when creating and using it. To produce a prototype with the best quality, the plastic must be able to withstand specific situations, such as varieties of temperatures and environments. When creating a new prototype, it must not easily break apart or crumble, as well as not degrade too soon before use by the consumer. To make sure the prototype doesn't biodegrade too quickly, yet isn't too strong to compost, a select list of ingredients was chosen with properties that would benefit this cause. These ingredients include glycerin, white vinegar, agar agar powder, and gelatin, as well as starch-based products such as cornstarch, potato starch, tapioca starch, and wheat flour. All plastics except one are also water-based. In addition to this, it is necessary that the product is non-toxic in case of accidental ingestion.

Element D: Design Concept Generation, Analysis, and Selection

My solution to the problem of the overuse of non-biodegradable plastic is: creating my own biodegradable plastic. I chose this solution of creating biodegradable plastic because it requires less energy and cost to produce, leading it to be a more eco-friendly product. Since it is more environmentally friendly, it is a safer prototype as well as desirable to those that are keen on improving the environment. The resources used to create it are cheap when bought in bulk, so the individual recipes for the bioplastics end up cheap as well. The most viable options ended up being recipes 6 and 8, the tapioca starch based and the gelatin based. Other options are still satisfactory nonetheless.

Element E: Application of STEM Principles and Practices

My brainstorming process included deciding to think of a large problem in the world that impacts a lot of people, as well as people in my community (both school and city). In order to reduce the amount of plastic used in my community, I came up with a possible solution: creating biodegradable plastic. After researching the problem and about biodegradable plastic in general, I decided to test out several recipes. Over 1-2 weeks, I successfully created 8 different prototypes based on 8 different recipes. While I completed all 8 recipes, not all proved to be desirable solutions to our problem. Once I was done with creating the plastic prototypes, I set each different prototype into three different water samples: a water sample from a saltwater tank in the Tennessee Aquarium, a water sample from a freshwater tank in the Tennessee Aquarium, and a water sample from the Tennessee River accessed by Coolidge Park (Chattanooga). In each sample jar was one flat, thin square and three small dense cubes in order to test different thicknesses, sizes, and concentrations of mass. Overall, using these test results, I came to a conclusion about which prototype would be the most viable and efficient solution.

As a side note, the reason I had two different freshwater samples is relatively simple. I really wanted to use water samples that contained wildlife so that they were samples from already existing habitats that maintained wildlife/ecosystems. The saltwater samples from the aquarium are acceptable because in Tennessee, we have no (close) access to any saltwater habitats, so, the saltwater tanks are a good replica of real saltwater habitats; carrying the same wildlife as oceans, salinity, and more. As for the freshwater, since we do have a freshwater source located near us, the sample from the aquarium isn't as acceptable because of that. Additionally, the freshwater in the Tennessee River tank in the aquarium is much cleaner and taken care of than the real river, though they share common wildlife. So that's why there's three samples instead of two; one from the Tennessee River tank in the Tennessee Aquarium (freshwater tank), one from the actual Tennessee River, and one from the largest saltwater tank in the Tennessee Aquarium (collected from Flower Gardens Bank National Marine Sanctuary in the Gulf of Mexico).

Element F: Consideration of Design Viability

I chose two different recipes to be my most viable solutions: recipe 6 and recipe 8. Recipe 6 would be great for products like food packaging, straws, and more plastics that are flimsy and thin. This prototype is durable yet flexible, transparent, and eventually biodegraded in each sample after tampering, which is also good because it doesn't biodegrade too fast. Recipe 8 would be helpful for products like storage containers and toys. It is extremely durable (the most durable of any prototype) and is quite transparent. Overall, recipe 8 is the best yet recipe 6 and recipe 8 cover two different products, soft and hard plastics.

Element G: Construction of Testable Prototype

I created each prototype using a similar style of heating and cooling. For each recipe, I would measure the different ingredients (using gram measurements for solids and milliliter measurements for liquids); all recipes had different amounts of different products. All recipes required heating by stovetop (reaching a peak temperature of 203° Fahrenheit), with the exception of recipe 3, which used a microwave for heating. After measuring the ingredients, I added them to a pot and stirred them together, and added food coloring to dye the plastics colors so I could easily identify each recipe once dried. Once the temperature reached 203° Fahrenheit, I removed the pot from the stovetop and poured the mixtures into molds.

For the testing processes, I had twelve jars for each water sample type and in each jar was roughly one ounce of whichever sample. In jars one through eight, I placed one square and three cubes of each recipe in one jar and in nine through eleven, I placed the already existing branded products.

Element H: Prototype Testing and Data Collection Plan

To test my design, I tested their biodegradability in two different freshwater samples and a saltwater sample. Besides their biodegradability, I did also take into account their flexibility and hardness/durability. As listed in the second paragraph of Element I, there were eleven jars of each water sample, all containing a different plastic product. Each jar sat for eight weeks, untampered, and monitored once a week where data would be collected at that time period. After the eight weeks passed, I would tamper/poke at each plastic to see if they'd dissolve more, break apart, test their softness, etc. to replicate what might actually happen in the wild/waves/current. The method I used for this tampering does not perfectly mimic what would happen to the plastics if they ended up in a water source by any means, but it shows that if nature did have some role in manipulating the plastics, the plastics degrading more is a potential result. Sitting in still water is not the same as moving bodies of water.

Each week when I checked on them, I would take a picture of each water "set" (three pictures total a week, each including the eleven jars opened) and would compare each three pictures from one week to the previous week to see if any changes have occurred. I would note size changes, splitting or points where splits were beginning, sometimes discoloration if it seemed prominent, and more.

Element I: Testing, Data Collection, and Analysis

Refer to the according documents.

Data collection over the eight week period plus after tampering… Testing Process.

Pros and Cons of Individual Plastics, Recipes by Plastic… Recipe Processes.

Images of Plastics during Testing Phase… Image Documentation.

All in all, recipes 6 and 8 end up being the best. While recipe 4's biodegradability is phenomenal, the texture of it after being dried isn't great. If recipe 6 were in an actual body of water, I believe it would biodegrade faster.

Element J: Documentation of External Evaluation

N/A at this time.

Element K: Reflection on the Design Project

This project made me realize that I, as any normal person, can help the community with something simple to improve such a large problem as overuse of non-biodegradable plastic. This project provided me with the knowledge that not all global improvements are costly, but require an investment of our time, effort, and care. Overall, I really enjoyed the project and if I were provided with more time, I would continue it again, a third time (project first ran in Spring 2022). Additionally, working with the Tennessee Aquarium on this project was incredibly insightful and if I continued the project locally again, I would be very interested in getting their hands on it with me.

Element L: Presentation of Designer's Recommendations

The biggest next step of mine would be to spend even more time degrading the plastic and monitoring how much more each degrades. From my first testing rounds being only two weeks, to this time being eight weeks, it is still not enough since most plastics need at least 10-12 weeks to fully biodegrade, most ranging closer to a 3-6 month period. Additionally, I would like to make all of the plastics uncolored, besides the beetroot since it could never be transparent. I did not do clear plastics this time around so that it would be easier to differentiate the samples when I had multiple recipes drying at the same time and limited mold space. Lastly, I made a mistake testing the thin squares and dense cubes in the same jars. When the budget is more flexible, I would need to purchase double the amount of jars so that the thin squares and dense cubes have their own jar. My plans of viewing the differentiation of biodegradability between different sizes/densities did not work when in the same jar.

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