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Bio Styro
Revolutionizing Packaging through Mycelium

Abstract

This paper will discuss the comparison of polystyrene and mycelium in regards to how mycelium based packing peanuts would be a greener product than Styrofoam (polystyrene) packing peanuts through the design strategy of reformulation. It will also discuss how mycelium can not only be used as a medium for bioremediation through life cycle thinking and green chemistry but also a tool for a conceptually "closed-loop" product life cycle process instead of a linear product life cycle through minimizing hazardous impacts. Lastly, this paper will reflect on the challenges and opportunities that arose from designing a greener product through life cycle thinking.

key words: mycelium, bioremediation, renewable resources, feedstocks, life cycle thinking, green chemistry, biopolymers, polymers, monomers, biodegradable, fungi, plastic degradation, *Pleurotus ostreatus,* polystyrene, mycoremediation, recycle.

Styrofoam: Polluting the Planet

Styrofoam, a polystyrene foam product, has been mass produced over the course of the last 70 years.

300px-Polystyrene.svg.png

Polystyrene, $(C_8H_8)_n$ (1), (structural formula above) is a lightweight, soft, durable, and multi-use polymer made for thermal insulation, arts and crafts applications, disposable eating utensils, and packaging. We specifically focus on packing peanuts in this paper; its function is to be a common loose-fill cushioning material used to prevent damage to fragile objects during shipping.

Annually, 1,885,200,000 pounds of styrofoam are produced in the US alone, and polystyrene takes up 30% of worldwide landfill space each year. (2). Combine the "Great Pacific Garbage Patch" floating in the Pacific ocean, which is now twice the size of Texas (3), with that 30%, and we simply do not have the space to properly dispose of polystyrene products in a sustainable manner.

Furthermore, polystyrene is not recyclable. It's too lightweight and bulky, making it difficult to transport, and very few recycling facilities will accept it. It's even more challenging because any polystyrene products that come into contact with food cannot be reused. However, packing peanuts can be collected and reused; rigid packaging can be chopped up into loose packaging. A few manufacturing plants exist that take polystyrene with the intent to essentially melt the polymer down and use it for new products. While it

is well-meaning, this poses a whole new set of risks that include many carcinogens being released in the air during the melting process as well as massive amounts of energy used in the separation, grinding and melting processes.

Additionally, polystyrene lacks biodegradability. Each styrofoam product being produced takes a minimum of 500 years to degrade organically, thus polluting the planet faster than humanly possible to clean up (4).

An Unsustainable Life Cycle

The hazards associated with the life cycle of polystyrene are widespread across its life. In regard to life cycle thinking, polystyrene feedstock is petroleum, which is a hazardous chemical to work with in a production setting. By inhaling petroleum in small quantities, it is possible to develop respiratory irritation, headaches, dizziness and nausea symptoms. Breathing it in large quantities can cause coma and death (5).

Manufacturing of the polystyrene has multiple steps.

benzene.png | styrene.gif

First, benzene, C_6H_6 (6) (structural formula above left, 31) is extracted from coal and gasoline, and styrene, C_8H_8 (7), (structural formula pictured above right, 32) is extracted from petroleum. Then, blowing agents such as HFC (hydrochlorofluorocarbons) are implemented to make the compound 30x lighter than its original weight (8).

The impacts from manufacturing can be incredibly severe, as both styrene and benzene are hazardous substances to work with. Benzene comes from coal, which is a nonrenewable resource. This poses health risks to the miners extracting it by exposing them to conditions that will give the workers high risk of respiratory damage from excessive amounts of dust and pollutants (4).

Both the EPA and the International Agency for Research on Cancer has identified styrene as a carcinogen. For those exposed regularly during the manufacturing process, acute health effects can include irritation of the skin, eyes and upper respiratory tract, as well as gastrointestinal effects. Chronic exposure can lead to depression, headaches, fatigue, and minor kidney problems (9).

Distribution of the partnering companies' polystyrene products would be done by freight trucks which use diesel fuel originating from crude oil and then polystyrene is used for packing peanuts or more commonly known as, "packing popcorn." Although in theory polystyrene can be reused for beanbag chairs and packaging fillers, more often than not the hazardous polymer ends up in landfills, floating in oceans across the world, and within incineration facilities. These factors cause negative impacts to human beings through chemical exposure and creates unforeseeable amounts of environmental damage (8).

Styrofoam (polystyrene) packing peanuts are not sustainable because of their lack of biodegradability and non-recyclability. Since the chain lengths in polystyrene are very long, the bonds are stronger which increase the degradation time. By using the design method of Reformulation, which is the process of taking an original product and modifying it to make it better but "identical," we can replace the polymer polystyrene

with the renewable biopolymer mycelium, extracted from the fungi *Pleurotus ostreatus*. This material would replace Styrofoam packing peanuts with a greener solution by reducing its life cycle impacts to create a future of sustainability (10).

Mycelium: Finding a Solution

Before explaining how mycelium has a greener life cycle process, it's important to explain what it is exactly and how it functions as a replacement for polystyrene. As Paul Stamets famously said in his Ted Talk, "mycelium is the Earth's natural Internet" (11).

Mycelium is made up of multitudes of hyphae, which are a system of interconnected filamentous cells; tubular, thread-like structures that can grow to be several centimeters in length. Hyphae generally grow at the tips of single hypha. This dense web of cells creates an organic underground network (the "Internet" of the Earth) that can digest and recycle debris and decay of past living matter. It is often referred to as the vegetative component of a fungus (12) and can hold up to 30x its mass (11). Because of its digestible decomposing properties, it arranges and nourishes a platform on which life can continue to exist. (13)

440px-Chitin.svg.png

The cell walls of mycelium are made of a polymer called chitin, pictured above, $(C_8H_{13}O_5N)_n$ (14). Chitin can be paralleled to the polysaccharide cellulose that is the fundamental component of plant walls. Chitin has a similar structure, but it has nitrogen-containing side branches. Because of the nitrogen, it makes the chitin stronger by cross-linking nitrogen to the chitin polymer. This allows for extra structural strength, opening up innovation for product design (13).

400px-N-Acetylglucosamine.svg.png

The monomer in chitin is *N*-acetylglucosamine, $C_8H_{15}NO_6$, (pictured above, 33) a derivative of glucose and also a monosaccharide, which is the simplest unit of carbohydrates. (15).

Mycelium is an ideal candidate for replacing polystyrene in packing peanuts because it is a bio-based polymer, therefore it is organic in nature. It is compostable and biodegradable at the end of its life and its applicable properties allow it to be utilized for bioremediation through mycoremediation (16). Bioremediation is a technique that incorporates living organisms in the process of degradation of hazardous pollutants (17). Mycoremediation is a form of bioremediation, but is specifically the process of fungi degrading environmental pollutants (18).

Since mycelium is 100% biodegradable, it has potential to be a biological filter by removing chemicals and harmful microorganisms from soil and water as well as transferring nutrients to where they are needed. The biopolymer takes three to five days to grow and can be made into materials that are both absorbent and flame retardant (19).

In this particular case, we will be using the fungi *Pleurotus ostreatus,* more commonly known as the Oyster Mushroom. Fungi were the first organisms to inhabit land over 1.3 billion years ago because of their ability to acclimate to unwelcoming

environments by using mycoremediation (11). This particular fungi, the Oyster Mushroom, is ideal for this product because of its ability to thrive in a multitude of temperatures and climates all over the world, making it easily accessible to produce. It is also a carnivorous fungi; its mycelia can kill and digest roundworms (20).

BioStyro: Using Mycelium for Sustainability

The product we are creating to replace Styrofoam packing peanuts is called BioStyro. This paper will conduct a conceptual product life cycle since this product does not currently exist. There are products that are similar in nature through different points in the life cycle such as Ecovative (21) and Livin Studio (22), but these companies are not replicas of BioStyro. When we came up with BioStyro, the concept was to minimize or ideally eliminate impacts across the life cycle from polystyrene. The impacts include polystyrene not being able to be recycled due to its lightweight nature from the petroleum base, which causes a high economic cost in transportation. Twenty-five to 30 percent of landfills are also dedicated to plastics, including Styrofoam. Additionally, polystyrene takes at least 500 years to decompose, is a source of urban litter, is the main pollutant of oceans, bays, and other United States water sources, and can cause starvation and/or choking in wildlife (34). The idea is to make BioStyro in a closed-looplosed-loop life cycle process rather than a linear life cycle process, which will be further expanded on later in this paper.

Because fossil fuels are composed of polycyclic aromatic hydrocarbons (PAHs), and PAHs are very common organically, they are being used as the hydrocarbon sources for plastic manufacturing. The Oyster Mushroom has been found to be a PAH degrader and has the potential to degrade 80-95% of all PAHs in soil after 80 days (16). This is vital information for mycoremediation because it does this process through "lignin metabolization," which secretes enzymes in order to break down the PAHs into carbon dioxide (23). As a result, this white rot basidiomycete- capillaceous fungi composed of hyphae- (24) can break down plastic polymers as they do with lignin polymers, specifically polyurethane (16).

Since the Oyster Mushroom's mycelium can degrade polyurethane, we can use recycled polyurethane as the renewable resource for creating the feedstock for BioStyro. This eliminates impacts from a potential partnering company's polyurethane products by taking out the impacts of the products' end of life as well as BioStyro's impacts from extracting raw materials for feedstocks.

With the mycelium using polyurethane as a carbon source, with limited amount of oxygen required, controlled and sterilized facilities would be required to grow the feedstock without interfering bacterias at its beginning stages of growth. As a result, the mycelium grown from recycled polyurethane is now applicable to be used in manufacturing. Another minimizing impact would be implicated by creating a partnership with local farmers around the manufacturing facilities to use their agricultural waste as a substrate for the mycelium.

The Process:

During manufacturing, the mycelium is extracted from the fungi and mixed with agricultural waste; for example, the by-products from harvesting corn. Then the mycelium/agricultural waste mixture is put into recycled plastic molds shaped like packaging peanuts to grow for 3-4 days depending on how fast the mycelium expands. Then, the mixture is put under heat until it's 30% of its original weight to stop the mycelium growth. Now that the mycelium/agricultural waste mixture is completed, the packaging peanuts are ready to leave the manufacturing plants (21). This completes the "cradle-to-gate" part of the life cycle.

Another way to reduce impacts would be by continuing the partnership with companies that use polyurethane products by proposal/agreement such as using BioStyro packing peanuts to ship their products. In exchange, BioStyro would use the company's recycled polyurethane as the product's renewable resource for feedstocks. A societal concern for transportation could potentially be a problem such as, "what if the product comes in contact with water, and would this make the product deteriorate?" This isn't a legitimate concern because there is a level of risk involved with transporting any product, regardless of what shipping materials are being used.

Distribution of BioStyro would be through the third party, the partnering company. When the consumer opens their package with their product, our fungal biopolymer packing peanuts will be inside and include our mission statement as well as instructions on appropriate disposal of BioStyro.

Since the greener polymer is organic, it is also biodegradable. This consumer, through reading the instructions that came with their product, would know to break up the packaging peanuts to be used for compost. This incorporates not only the partnering companies, but the consumer as well by making BioStyro's life cycle closed-loop. In the case that the consumer does not compost the packaging peanuts and they end up in landfills, the negative effects would be minimal due to the biodegradable nature of this organic compound. This again successfully completes the closed-loop nature of its life cycle, instead of it being linear.

A potential societal concern is that the shelf life isn't as long as Styrofoam, so it could be argued that BioStyro isn't as "green." This arguably also isn't a legitimate concern, because the LCA has demonstrated that longer shelf life does not always equal a "greener" product. For example, in class when we looked at the LCA of both a Rubbermaid food container and a Glad food container, it was discovered that Glad had lower impacts but the Rubbermaid was thought to be the greener product based off of its visual durability to the class. This same principle can be applied with BioStyro and Styrofoam. Although it may appear that polystyrene is visually more durable than mycelium, because of the impacts discussed earlier in the life cycle, the mycelium would be greener since its production and end of life impacts are significantly less than polystyrene.

We emailed Ecovative a list of questions about their "Mycofoam" which is their alternative to Styrofoam (they do not create mycelium packing peanuts nor is their feedstock from recycled polyurethane). One of the questions we asked was, "how long does it take to biodegrade and are there any specific conditions that are required to activate the degradation process?" Our reply that we received a few days later was, "in ideal conditions (for instance in a compost bin), it will take around 3-4 months for it to

break down. Moisture levels, size of the product, density of the product, enzymes and bacteria it's exposed to, and a variety of other factors will affect the decomposition time." This concludes that in comparison to polystyrene, whose estimated time of degradation is over 500 years (4), mycelium is significantly greener since its end of life impact is shorter due to its degradation time.

Product Design: Envisioning BioStyro

Consumers in today's society are more likely to look for a product that is more environmentally friendly (29). According to an article from the news website Nielsen, "fifty-five percent of global online consumers across 60 countries say they are willing to pay more for products and service provided by companies that are committed to positive social and environmental impact." (29) Packing peanuts are used in huge amounts every day for shipping products; our product has significantly lower environmental impacts than Styrofoam. Its feedstock is renewable and does not need to be thrown away, and it can be thrown into a yard and will biodegrade within a year. Even if it's thrown away, it will still degrade in a landfill very fast. That alone will give producers initiative to choose our product over competitors, considering the environmental impacts.

The opportunities to improve the product's function/performance is the fact that it will be biodegradable and will degrade within a year if thrown into a yard or a trash can. The functionality will most likely stay the same considering the qualities of Styrofoam and our product are very similar. Styrofoam is squishy, light, and impact resistant. Our greener product has very similar, if not the same qualities of styrofoam peanuts, but will have the added benefit of being greener.

By creating a design that shows renewable and recycled materials used in our product, consumers will understand what we are trying to do. We can use earth toned colors and and a logo that motivates the consumer to look into the concept that our product is greener. Because we use a fungal biopolymer for our product, the logo will incorporate mushrooms and packaging, showing a direct correlation between the two and what we are trying to do. It may be a more direct approach to show what we are doing, but it gets the point across easily. Refer to the cover of this paper for our logo, and the back of the paper for our Mission Statement.

The Business Benefit

The incentives associated with partnering with BioStyro makes for a compelling argument that our product is the best way to ship a partnering company's product. The relationship benefits the environment and benefits both partnering companies through a symbiotic relationship, while meeting the growing consumer demand for sustainability.

In our modern society, people are tired of hearing about yet another preventable environmental disaster. They cringe in disgust knowing both natural flora and fauna are choking and dying out on the garbage we throw away. There is a widespread desire to see change through making our surroundings healthy again. By using BioStyro's packing peanuts and reading the mission statement explaining why we're sustainable (that we send out with the products that the consumers bought) people know that both companies care about the fate of our environment. This increases the partnering company's moral standing in the public eye while meeting consumer demand for greener products.

Advertising BioStyro as a sustainable company whose aim is to clean up plastic waste will create positive associations with the brand through its impact on the environment. Any company that uses BioStyro will create brand loyalty and praise among people, while benefitting the company shipping their products with it. Partnerships could be made with any company that uses plastic (specifically polyurethane) and is interested in recycling. In order to create that symbiotic relationship, a company can direct polyurethane product waste to a BioStyro facility to be recycled, and in return is compensated with packing peanuts to ship out products at a reduced rate. This would generate incentive to invest in a greener solution, despite the low cost of polystyrene.

Additionally, the desire to "go green" will inspire bright minds to innovate. Therefore, if a company tackles a significant issue, such as Styrofoam, those bright minds would gravitate towards that company because they would offer accessible and promising innovation opportunities through historical scientific discovery.

The natural regenerating properties of mycelia insures that there is little risk associated with the limitations of this resource. The only risk is not being able to grow mycelia fast enough to supply consumption needs and can be reduced by expanding the sites in which mycelium is grown. Using polyurethane as a nutrient base (a carbon source) for growing mycelia provides a new solution by integrating recycling. This method of recycling plastic could lead to new environmental legislation through the encouragement of new recycling processes. This proposal not only has the ability to recycle plastic but generate capital along the way through production of mycelium, as discussed in the mycelium life cycle process.

There are opportunities to decrease costs associated with regulatory compliance, energy, and limited resources through using mycelium. The cost associated with the "cradle to gate" process is miniscule; companies that specify in mycelium based products propagate select mycelia cultures from traditionally used mushrooms in multiple small batches allowing for a quality control rather than using a large fermentation process that cannot be overlooked upon. This process does increase labor because of the constant close watch, but it permits a consistent, contaminant free product (30). Mycelium needs a sterilized facility with controlled humidity, temperature, and requires inoculum (spawn or starter culture) and substrate (growth medium). In this case, the growth medium can be compiled of recycled polyurethane for the feedstocks renewable resource and agricultural waste during its manufacturing process (22). Using recycled materials as a growth medium allows for an unlimited influx of resources because of our capitalist economy's process. This helps overconsumption consequences as well as a reduction in energy for manufacturing.

The energy needed to grow mycelium is provided through recycled organic substrate and the energy needed for cultivation is minimal. Minimal energy is required for production of mycelium because most of the process is done organically through the mycelium growth. One of our questions we asked Ecovative was, "is there a lot of water used in manufacturing?" They replied, "we actually don't add any water in the process besides the water used to clean the molds after growth." This is very important because the costs of production are reduced substantially since energy costs are reduced.

Furthermore, implementing tax credit toward the partnering companies who give incentives to their customer to send polyurethane products back for recycling to be used

at BioStyro facilities would be an additional reason for companies to use BioStyro. Implementing tax credits for the consumers who recycle their polyurethane products they purchased through the company would increase brand loyalty, increase the amount of polyurethane recycled, and provide overall incentives to recycle. There is already a "Home Energy Improvement" tax credit in progress that encourages greener solutions. Tax crediting civilians and companies who choose to recycle would provide more startup materials (polyurethane) for production of mycelia, reducing overhead costs and creating brand loyalty as well as customer satisfaction (25). This also can reduce overhead costs of manufacturing through the influences of large companies investing in our recycling/production process. Overall costs are reduced through this production system of using a conceptual "closed-loop" life cycle process (26).

Companies who choose to invest in BioStyro as a method of recycling would have a competitive advantage over other companies. The more polyurethane recycled by a partnering company, the more packing peanuts produced for shipment. By using polyurethane as a renewable resource for BioStyro's feedstock, energy is saved where it normally would be used to process polyurethane recycling and turned into a new product sold back to manufacturing companies for profit as well as the energy to extract raw materials for BioStyro. BioStyro reduces the cost associated with the recycling process for a company by taking waste and turning it into a product associated with a company's overhead cost for a profit (27).

As a result of a relationship between a polyurethane producing company and BioStyro, positive public relations are enhanced by practicing honest incentive towards reducing impacts on the environment without greenwashing. This opportunity allows for consumer brand loyalty and interactive sustainability practices.

Inspiring the Consumer

We have discussed in detail about how the argument could be made to a company about the benefits of partnering with BioStyro to use mycelium packing peanuts, but we would also need to inspire the consumers to purchase our greener product over Styrofoam. The first step of this would be by creating awareness about the impacts. Raising awareness about the impact Styrofoam has on the environment, especially marine life, would inspire our society to take interest in our product by making the consumers feel like they are an active part of practicing sustainability. Raising awareness about the pros and cons of our product vs. the pros and cons of Styrofoam currently being produced would hopefully inspire consumers to become greener without the use of greenwashing.

This would be done by avoiding the seven sins of greenwashing through making our life cycle process transparent to the public and through active sustainability practices such as using recycled polyurethane as a renewable resource for growing mycelium as the product's feedstock.

A mission statement would be another way to engage consumers by making them feel fulfilled by helping make a difference through using our product and helping BioStyro have a beneficial end of life by composting the packing peanuts instead of throwing them away in a trash can. Through our mission statement, cooperative partnerships with other companies, and our transparency on focusing on a sustainable future, we could make a viable difference that would hopefully inspire others to innovate with a "closed-loop" life cycle thinking process in mind.

Conclusion

BioStyro's mission was to reinvent the packing peanut so that it is more sustainable and environmentally friendly in order to reduce the harmful impacts of Styrofoam. Mycelium is a fungal biopolymer that helps degrade substances that are harmful to our environment through mycoremediation. Inspiring our customers and compelling society to better understand the dangers of polystyrene as a whole will provide the incentive to become greener. People have shown a desire to become more environmentally conscious and by replacing Styrofoam packing peanuts with Mycelium, we are helping to get rid of 30% of what is clogging landfills today. By partnering with BioStyro, companies would appeal to a large market of consumers who hope to purchase greener products to help the environment. Through life cycle thinking and green chemistry, we have created a product that minimizes by-products, waste, and ultimately allows us to do our part to help better our planet. It is our only home after all.

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