<u>Fungi…So We Don't Die!</u>

Proposal for the Network for the Advancement of Sustainable Mycology (NASM)

EE538 – Professor Reibstein

Written and researched by: Olivia L. Rollins

Abstract: Fungi have natural abilities as decomposers and recyclers that allow them to remediate polluted soil, water, debris, they can even restore land ruined by wildfires through processes called myco-remediation for land pollution and myco-filtration for water pollution. Mushroom cultivation is an inherently sustainable practice requiring low capital while also using agricultural and industrial waste to initiate growth. Research in fungi has also led to developments and innovation in biotechnology including the creation of alternatives to Styrofoam, plastic packaging, leather and building materials. Across science, into engineering, through agriculture, and also education, fungi have something to add. I propose the Network for the Advancement of Sustainable Mycology (NASM) to better integrate and coordinate these various sectors to disseminate these sustainable solutions and alternatives to more people in the region.

So, the title may be a bit hyperbolic…but I do mean what I say! For centuries, mushrooms and their health benefits have been used to heal and nourish civilizations. Proven health benefits and their nutrient dense composition make them a sought-after product in culinary institutes, but also for supplementary purposes. Some are called to mushrooms for their psychedelic effects. Psychotropic mushrooms, like psilocybin, have proven to help people suffering from addiction, post-traumatic stress disorder, severe depression and anxiety, and other chronic psychiatric conditions (1). Others are called to mushrooms for their health benefits, both nutritionally and mentally. There has been a recent surge in awareness of the medicinal properties present in mushrooms like Lion's Mane, Cordyceps, Reishi, and many others. Lion's Mane alone has been shown to have potential as a neuroprotective therapeutic agent for those suffering from Alzheimer's Disease, Parkinson's Disease, and other impaired cognitive functions (2). But this knowledge is not even new. Hippocrates, the great Greek physician used mushrooms and their anti-inflammatory properties for sterilizing wounds (2). And that was as early as 450 BCE. Not to mention, one of the hallmark inventions of great modern medicine, penicillin, was discovered by Alexander Fleming in 1929 and was derived from the Penicillium fungi.

Beyond just their human health benefits, fungi are an integral part of forest and ecosystem health. A mycorrhizal network depends on soil fungi, or mycorrhizae, and their extensive network of mycelium that branches throughout the soil. Mycelium is what allows the fungi to provide nutrients like phosphorus or nitrogen to the trees and nutrition and water for the plants. In exchange, the fungi receive sugars. This symbiotic relationship is what allows trees to grow tall and plants to grow at all. Beyond the normal functions of fungi, they also have abilities to remediate pollution and toxins from the soil and their mycelial networks can serve as filters for water pollution.

For this paper I will begin by highlighting the ways fungi can be used to remediate and treat waste in the forms of myco-remediation and myco-filtration. I then discuss mushroom cultivation and the inherently sustainable nature of harvesting mushrooms. I had the honor of speaking with three people who own mushroom companies. I spoke with John Michelotti (founder of Catskill Fungi), Dylan Goodwin (founder of Cleveland Fungi), and Eric Milligan (owner of New Hampshire Mushroom Company). I asked what their purpose for growing mushrooms and educating people on mushrooms was, as well as their opinions on people's perceptions of fungi and what would be necessary for wider scale use of their remediating properties. I also had the amazing opportunity to talk with Christopher Maurer of redhouse studio, an architecture firm located in Cleveland, Ohio that uses mycelium to design remediation technology. I am very grateful to have had the opportunity to speak with them and was incredibly encouraged by their openness and perspective – my paper is far more fruitful because of their help and points of view.

I found myself increasingly more interested in different aspects of fungi and their abilities, leading me to branch my paper from its original purpose of researching mushroom cultivation as a model for sustainable development, to instead including biotechnology, myco-remediation, as well as discussing Fungi Foundation and the brilliant work being done at the NGO. I was so inspired by the intersections and branches of work being done in mycology and microbiology research that I found there was a need for even deeper cooperation and integration of these differing interests. To finish my paper, I propose the need for the Network for the Advancement of Sustainable Mycology (NASM). Much like the paradigm shift we need for developing sustainable solutions, I believe wider cooperation and greater information sharing is necessary to be able to develop these solutions for larger scale use and access.

NASM will hopefully be the impetus to a much larger, growing concern in international relations. I'm graduating this month with a degree in International Relations that specializes in environment and development and I recently read a paper by researcher Joana Castro Pereira on the intersection of environmental issues and international relations, and she wrote something that really struck me:

> "This is [a] challenge for International Relations' scholars, given that, in this discipline, one finds the prevalence of a paradigm that does not link human society with its biological basis, which is considered infinite. The truth is that the essential holistic paradigm still lies in the sideline of the discipline. However, because the protection of the environment constitutes a civilizational imperative, this paradigm must become predominant, in other words, International Relations' scholars have to develop this area towards a view which takes into account planetary boundaries (3)."

Pereira's paper articulated the anxiety I had during all my courses at university: how can we prepare and develop sustainable solutions if the world order does not account for them? It requires a paradigm shift. I believe fungi and their ability to remediate, nourish, and sustain the planet are the revolutionary innovations necessary for that push. Scientists and researchers have long been calling for an immediate shift in the rate we have been polluting and using resources that contribute to climate change. Fungi research and development into alternatives for industrial, economic, and social sectors could be the paradigm shift necessary to go from creating sustainable alternatives to instead sustainable *solutions* to the problem. We focus on creating new systems to industrialize, modernize, and develop, but instead we should be focusing on developing research to help the systems already present function more efficiently – much in the same way natural ecosystems do. When we create more efficient systems, sustainability will be a natural byproduct.

Myco-remediation and Myco-filtration

What it is:

As we use, populate, and industrialize more of the planet, pollution only continues to become a more prevalent issue. Especially now that the environment is now forever burdened by “forever chemicals,” formally known as PFAS, or per- and polyfluoroalkyl substances. As pollution expands into more cracks of the planet, management of these chemical and solid wastes becomes increasingly more urgent, but also more precarious. A beam of light in an otherwise bleak landscape of polluted lands for miles and miles is bioremediation. By definition, bioremediation is a process of using suitable microbes in a polluted system that then uses its metabolism to degrade pollutants (4). Myco-remediation is a subset of bioremediation that focuses on the role of fungi to degrade or remove toxins from polluted environments. Fungi even have the ability to remediate pollutants like textile dyes, petroleum hydrocarbons, pulp and paper industry effluents, leather tanning effluents, and pesticides (4). Fungi removes heavy metals and toxins from land by breaking down plant materials by using plant cell wall degrading enzymes and then channeling the pollutants to the fruiting body, or the mushroom, for removal (5). To implement myco-restoration in practice involves mixing mycelium into contaminated soil, placing mycelial mats over toxic site, or a combination of both (5). Myco-remediation is a promising substitution for normal policy prescriptions of burning, hauling, or burying toxic waste to restore ecosystems which leaves the environment ecologically static (5).

So how can fungi do this? Fungi specialize in breaking down plant materials by way of a variety of plant cell wall degrading enzymes (6). There are enzymes in certain fungus that digest lignin and cellulose within their mycelium, which is the primary structure of wood, but toxins also have similar chemical bonds that can be broken down by the same enzymes. Lignin peroxidases dismantle chains of hydrogen and carbon to convert and decompose wood (7). These enzymes can also break apart hydrocarbons, oil structures, petroleum products, pesticides, and even PFAS. There are two subgroups of these kinds of fungi: brown rot fungi and white rot fungi. Both of these subgroups belong to mushroom-forming fungi group of phylum Basidiomycota. Brown rot fungus are fewer in population than white rot fungi, but they break down the pulpy cellulose, leaving behind a brownish lignin (5). White rot fungi produce enzymes that break down the brown fiber in wood and leaves cellulose intact (5). These are described as white rot because of the white cellulose-rich material that is left behind as they metabolize the lignin from the wood substrate (8). White rot produces lignin-degrading enzymes like laccase, lignin peroxidase, and manganese-dependent peroxidase that's necessary for mineralizing wood (9). This byproduct breaks down hydrogen-carbon bonds which then liberates the primary nonsolid by-products in the form of water and carbon dioxide (5). Several of the chemical degrading species also predate bacteria, produce antibiotic metabolites, and are commonly grown commercially because of the large variety of substrate materials possible (9). The curiosity was peaked in the mid-1980s when the white-rot basidiomycete *Phanerochaete chrysosporium* was found to have the catalyst lignin peroxidase (8). In 2004, *Phanerochaet chrysosporium* was sequenced to enhance the understanding of lignocellulose degradation, which is an important process in the carbon cycle (10). This was the first sequence of a basidiomycete phylum and it produced a framework that allowed for insight into these bioprocesses (10). Eventually after more observations, there were more basidiomycete species found and studied that had the same equipment. Even culinary basidiomycetes like the button mushroom (Agaricus brunnescens) and the oyster mushroom (Pleurotus ostreatus) were found to be capable of predating living colonies of bacteria and sought them out as sources of nutrition, even growing using only the killed bacteria for nutrients (9).

Myco-remediation works by denaturing toxins, like petroleum products, and absorbing heavy metals so when a habitat contains these two conditions, treatment for complex waste is possible (5). A study conducted by Paul Stamets showed that a strain of Oyster mushrooms could break down heavy oil (7). One experiment of his that shows the efficacy of myco-remediation took place at a vehicle storage center under the Washington State Department of Transportation.

Here, the soil was drenched with diesel with a concentration of 10,0000 ppm of polycyclic aromatic hydrocarbons (PAHs) (5). Stamets used mushroom spawn to inoculate[1] a pile of soil while other technicians tried different bacterial or chemical agents. When the tarp was removed from Stamets pile, the blackened soil suddenly had Oyster mushrooms "up to 12 inches in diameter" and more than "85% of many of the polycyclic aromatic hydrocarbons (PAH) were destroyed, reduced to non-toxic components, and the mushrooms were free of any petroleum products (7)." The mycelium of the Oyster mushrooms produce enzymes that break down hydrogen-carbon bonds, so then these enzymes reuse the hydrocarbons by turning these toxic petroleum contaminants into carbohydrates for nutrition (5). After two months, the mushrooms had rotted, but they had sporulated which attracted flies which brought other insects, which then brought birds who brought seeds leaving an oasis where a polluted environment once was.

Another successful review of the resistance of fungi studied their ability to expel polycyclic fragrant hydrocarbons (PAHs) from soil. PAHs occur naturally in coal, oil, and gasoline and result from the burning of these substances especially within the industrial sector. Theses toxins are cancer-causing, and very difficult to manage as they bind to or form small particles in the air, moving through terrestrial and aquatic environments, dispersing the pollution in its wake. This review concentrated on the species *Irpex lacteus* and *Pleurotus ostreatus* by monitoring their growth and expulsion of PAHS in two different soils, one a previous tar-delivering plant and another saved territory without the tar plant (8). These soils were set between two layers of mycelium on the substrate of straw and after fourteen weeks, *Irpex lacteus* had expelled more PAHS from the tar ridden soil (8). Both species displayed the capacity to degrade pollutants by emitting proteins through their hyphae to separate the contaminants (8).

But there's more! Myco-remediation is one subset of the larger heading under myco-restoration, which includes myco-filtration, myco-forestry, and myco-pesticides. For purposes of my research, I will only be explaining the myco-filtration process here, but myco-forestry and myco-pesticides require and deserve much more attention.

Myco-filtration is characterized as the intentional utilization of cultivated, developed systems of parasitic mycelium to encourage and facilitate water quality changes in biological

[1] **Inoculate** = to introduce something such as bacteria, a virus, or a fungus into an animal or plant as part of an experiment or to encourage it to grow there (Cambridge English Dictionary)
Inoculum = any part of pathogen that can initiate infection = spores, sclerotia (compact mass of mycelium) or fragments of mycelium

communities, and the term itself first shows up in 1993 in the literature of Paul Stamets (8). Mycelia is at the root of a mushroom's foundation, and are made out of thin, string structures called hyphae (8). The hyphae form massive systems underground, known as mycelium, and it absorb the nutrients from its surroundings to transport back to the fungus. The mycelia have filtration properties and is a technique used to sanitize storm water, graywater, and agricultural runoff. Mycelia are used as the biological filters. A myco-filter consists of the mycelium and a burlap sack layered with substrate, that then allows the mycelium to grow, creating the networks necessary for its use in remediation of the water (11).

An important practical application of this technique is for the presence of *E.coli* in water, which is a pointer for the presence of fecal defilement in water (8). E. coli is present in dairy runoff and in a study at a dairy farm in Vermont, they found even adaptive management approaches for the runoff were not able to consistently remove the bacteria from the water (12). In a review test set up for the efficacy of the myco-filtration process in reducing *E.coli*, there was a 20% reduction in *E.coli* with growth on 100% of the substrate (wood chips) showing that the mycelium of the species *Stropharia rugosoannulata* can successfully evacuate *E.coli* even in the most brutal of conditions (8).

Scalibility:

While these biological processes are incredible by their own merit, there is also an interest in making them scalable solutions. With water scarcity growing, and its impending continual growth in light of the climate crisis, water becomes a commodity for people whose survival depends on it. This, of course, requires immediate attention and sustainable solutions. Enter, Dr. John Todd whose Living Machine ® is an ecologically engineered system that operates as a wastewater treatment for municipal and some industrial wastewaters by mimicking a natural wetland. This is an example of biomimicry, by way of creating a system that is similar to that of a natural one. Later in this paper, we will talk with Christopher Maurer of redhouse studio who has developed incredible structures out of fungi that are able to take waste material and turn it into building materials and food. They even have innovations like the Biocycler that takes construction and demolition waste and converts it into new materials, both recycling and remediating at the same time. The question of scalability is still up for debate and requires further research and coordination to determine best practices for getting this kind of remediation technology into the hands of those they need it. Hopefully one day these innovations in bioremediation will become the default for cleaning up contaminated waste.

Mushroom Cultivation Businesses as Model for Sustainable Development

Fungi are the most sustainable living beings because of their saprophytic relationships between fungi and plants. Saprophytic means that fungi obtain its food and energy by absorbing dead, decaying, and dissolved organic matter. Without fungi, we would be sitting atop mountains of dead plant materials (13). Mycelial networks intersect and communicate through each other, and the mycelial links are at the foundation of soil. These interconnected bodies of mycelia react to the availability of plant and animal, as well as react to natural disasters by capturing and recycling debris. Saprophytic and parasitic fungi help create the components of topsoil in conjunction with bacteria, insects and other organisms (7). Primary, secondary, and tertiary saprophytic fungi even digest wood into the soil which then benefits the plant's ability to use photosynthesis for energy. Almost all plants join saprophytic and mycorrhizal fungi in the process of symbiosis. Fungi can also raise or lower soil pH to increase the usability of existing soils (7). Wild fungi support ecosystem services by recycling nutrients during decomposition allowing soil fertility to be maintained (14). Fungi also play a role in the "Wood Wide Web," Peter Wohlleben's term for the underground network linking trees and plants to one another, as fungi facilitate the uptake of nutrients and water in mycorrhizal associations between roots serving to store carbon within an ecosystem.

Mushrooms also transform agricultural and other organic wastes into a nutritious and marketable product (13). A study on the biodegradation of wheat straw by Oyster mushrooms and its use in cattle feeding found that the spent substrate of the mushroom had all the nutrients, proteins, and medicinal compounds that was found in the mushrooms themselves, making it an ideal feed product for livestock (15). The spent substrate can also be used as compost for other plant or vegetables crops which turns a waste product into a valuable, nutritious resource (13).

Mushroom cultivation often promotes itself given its low capital cost, high yield returns, and the rapidity with which it grows. For example, Oyster mushrooms usually fruit in one month and are able to be grown on materials like banana leaves, coffee waste, straw, cottonseed and cocoa hulls, as well as newspaper and cardboard (13). Using these materials as substrates to initiate mushroom growth further illuminates the sustainable nature of mushroom cultivation.

Growing houses or businesses can be locally managed by small communities and families and require small plots of land. Even when land availability is an especially limiting factor in certain areas, mushroom culture can be stacked using tray culture techniques (16). Mushrooms themselves are an attractive business also by way of being a precious commodity as the prices for mushrooms are much greater than other produce, and the demand for "gourmet" mushrooms has been increasing worldwide (13). They taste good too! Mushrooms are one of the best sources of vitamins, essential amino acids, and dietary fibers (17). What's more is that this agribusiness is not only an enterprise, but a tool for restoration. The presence of mushrooms in ecosystems serves as a food source for animals while also dispersing spores and mycelia to the benefit of the entire environment. This makes mushroom cultivation an attractive business not just for economical purposes, but also for conservation (17). When using mushrooms to recycle and generate food, it helps nature consciously use fungi to remediate (7).

Advanced mushroom cultivation facilities are widely utilized in wealthier, high resource settings like Europe and the United States Food insecurity, as well as financial insecurity, are major issues within the developing world. But mushroom cultivation is also a very promising intervention for the underdeveloped world or as a solution to extreme agricultural crisis. The low capital required for production, as well as the relatively quick harvests and abundance of agricultural biomass make mushroom cultivation an attractive option for rural, low-resource areas. It can also empower women and elderly in more rural areas to create localized cooperation to commercialize their harvest. In rural Tanzania and Mexico, women "represent between 76% and 90% of fungal gathers and vendors, respectively" making this a viable option for livelihood in rural areas with limited opportunities for women's personal growth and autonomy (14).

It's also very sustainable in practice. One prime example of this can be seen in the work conducted by Zero Emissions Research and Initiatives (ZERI), an international organization that uses the application of complex dynamic systems to design projects that uphold their philosophy that "zero emissions means zero waste" (13). The designs are modeled on the relationships amongst the natural world where waste, or even the toxin of one kingdom, is often the energy source and nutrients for a species in another kingdom. When the kingdoms of the natural world all work in harmony within a healthy ecosystem, the ecosystem can self-rely for endurance as they process matter in a way that maximizes productivity, resilience, and biodiversity. Sustainability in the natural world is found in this harmony where the resources do not become exhausted while the ecosystem itself does not pollute (13). One ZERI proposal for the potential application of mushroom cultivation in Brazil discussed the lignocellulosic waste production of cereal straws, wood sawdust chips, sugar cane bagasse, coffee wastes, and cotton seed hulls in Brazil and saw the potential to flip these by-products into raw materials for growing mushrooms (16). There would be no waste produced as the spent compost can be used for animal feed and their residues can be used as crop fertilizers, making this a great application for ZERI's principles and in the process addresses human health, poverty, and environmental challenges in Brazil (16). ZERI has numerous other projects using fungi as a sustainable solution or application.

Opinions from Mushroom Farmers in the Industry on Fungi Development

When talking with mushroom cultivators in the United States, I found myself increasingly more and more curious with every phone call as I realized that despite all growing mushrooms, everyone had different methods or purposes for doing so.

I first talked with John Michelotti, the founder of Catskill Fungi in the Catskills of New York. John was excited to share, and he gave enormous credence to his mentor, Gary Lincoff. It began a theme I would hear a lot, both in research but also conversation, regarding the importance of educators in mycology to pique the curiosity of people from all over. Catskill Fungi is also education based and holds workshops teaching mushroom cultivation as well as mushroom walks. I wondered how he gauged the audience's level of mushroom knowledge given the variability in age, skill level and experience in a group of people on a mushroom walk. "I try to tell a story that will be understandable for a little kid to a seasoned mycologist because everyone can learn something new," he replied.

Stories are an important technique as more often than not here in the US, people don't know how to treat a mushroom or have much interest in their importance. Even in my beginning fascination of mushrooms, my parents only warned me of the psychedelic and psychotropic "shrooms," despite my interests being entirely unrelated, rather centered on their remediating properties – though it is obvious that shrooms are a mystic being among the masses.

"Fungi just weren't apart of our culture for a very long time in a lot of Western cultures, so my own personal mission is to change the culture of North America to be more *fungiphyllic,*" John began, "we know less than 10% of the fungi on the planet, there's so much more to explore yet people don't even realize that. When people don't know something, they generally fear it, or have negative connotations, but as soon as they start to understand and learn about it – it becomes a friend."

John had experience in myco-remediation research, and when discussing its scalability, he emphasized the need for decentralization. "We don't have one massive plant to put together to do bioremediation, we can say we have different locations that are decentralized so it can be large in scale, but not just large in one place," said John, "it has more efficacy at the local level, and probably more potential. But here there needs to be a lot more research done with a definite need for microbiology. For example, with E. coli, you could try and remediate E. coli, but it's going to change the acidity in the water afterwards, and what's that going to do to the populations of creatures in the water that it's being introduced to? You have to have an understanding of an entire ecosystem and how things are going to be affected."

In terms of government funding and research, he referenced back to systems and decentralizing. "When I look at systems, we all have to get resources from somewhere, but I like creating systems that generate their own energy and this is where sustainability comes in. If your system relies on outside energy, in this case financial from the government, then as soon as that goes away the whole system doesn't run," said John, "there's no redundancy there."

"So, if we wanted to make remediation financially appealable to large businesses, corporations, and even the government, they will want to know how they can make money and turn a profit from it," said John. I thought back to the emphasis on local solutions and his ideas of decentralization, and it seemed to me that at the community level the profit wouldn't have to be monetary, it would be for the betterment of the community's environment. Sustainable solutions require systems that generate their own energy, just as John had said, and it piqued my curiosity for an alternative system that would assist in creating these local solutions.

I then spoke with Dylan Goodwin at Cleveland Fungi, who owns an urban mushroom farm that grows gourmet mushrooms in Westlake, OH, selling indoor grow kits and seasoning online while also creating partnerships with local restaurants for their mushroom supply. He was very health conscious, and his main focus was getting the nutrients from mushrooms into people's bodies.

"My indoor grow kits are really to expand awareness of gourmet mushrooms, and the countless medicinal aspects they provide, plus they taste great too! Cleveland Fungi is locally grown, organic, and a return back to small scale farming in light of the environmental impact of industrial scale agriculture."

Dylan saw mushrooms as a powerful tool in shifting people into a health-conscious lifestyle and told me the nutritional analyses of mushrooms like lion's mane and the oyster mushroom. He was also passionate about his company making mushroom products the right way.

"The concentration of medicinal compounds of mushrooms are lower in mycelia than in the fruiting body. To make myceliated grain powder, it costs a lot less and requires less time to make way much more of a product to sell. It's about corporations trying to sell a product and turn a profit instead of trying to get nutrition into people's bodies. There are other companies who extract the medicinal compounds from myceliated grain, but this added cost, which is passed to the consumer, is a marketing ploy from my perspective. Humans produce chitinase, an enzyme that breaks down chitin, which is what the cell wall of mushrooms are made of, and why the medicinal compounds within can be preserved indefinitely in the proper environment. Humans also produce chitinase like proteins, which do the same job. I believe utilizing those natural mechanisms of the human body in this regard, rather than outsourcing this metabolic process to a lab, is the sustainable way of taking a supplement like this for the long run. If the body realizes it doesn't need to produce chitinase anymore, would it? We are seeing 50% of kids without wisdom teeth these days due to change in diets, and without chitinase, your immune system will become compromised over time to some extent. Chitinase is required to fight off bacteria too."

Dylan has an online website available to buy mushroom seasoning for people located in Ohio, and indoor grow kits for anyone within the USA.

I also spoke with Eric Milligan at New Hampshire Mushroom Company located in Tamworth, New Hampshire. At NHMC, they sell a wide range of gourmet and medicinal mushrooms, both at their business but also in store around New Hampshire, online, and even some summer farmer's markets! More than just selling mushrooms, NHMC has a really amazing focus on spreading education on mushroom cultivation.

"One of my focuses is to get more people to eat mushrooms on a regular basis not only for nutrition, but for sustainability, specifically as an animal meat replacement," Eric said, "and if people want to do it themselves, they can follow us on our tours."

At NHMC every Sunday at noon, Eric gives a free mushroom farm tour where he shows people how he runs the farm. He also hosts “Forage Fridays” for observing mushrooms, identification classes, cooking classes, and at one point had the New Hampshire Mushroom School at NHMC which included a ten-day intensive on how to run a mushroom farm. Again, I realized the people who run these businesses have a strong commitment not just to selling mushrooms, but more importantly on spreading awareness and education to people on mushrooms and their abilities.

Innovation in Biotechnology using Mycelium

redhouse studio:

Cleveland is home for me, and it felt serendipitous that the breakthrough of my research would come when talking with a friendly face from my hometown. Christopher Maurer is the founder and principal architect of redhouse studio, an architecture firm based in Cleveland, Ohio that specializes in innovative research that invents new low impact material technologies, even building commissioning and net-zero retrofits. Redhouse has designed and built all over the world and even works with leading researchers at NASA and MIT on developing sustainable technologies. One catalyst that helps them in this feat is our friend, fungi!

“Fungi take dead matter and convert it into something new, a perfect opportunity for a circular supply chain or for regenerating new material from waste material,” began Christopher, “for example, in Namibia our bioHab makes food and buildings in the same process. We take waste resources and biomass and grow mushrooms on that, harvest it, and take the waste material from mushroom farming and turn that into something using waste to make good things.” Those good things made from the waste used in cultivation can even be strong carbon sequestering blocks used for building, while also creating food security and agricultural jobs.

And that’s not even the tip of the iceberg, as another project conducted at redhouse, known as their Biocycler, is another solution that remediates pollution to create something new and usable. “The Biocycler takes construction and demolition waste and converts it into new materials and not only recycles the material, but remediates it,” said Christopher, “if we can unequivocally prove that we can remediate lead poisoned environments, then we’d like to ask if we can mandate something like this to require that all lead poisoned homes be remediated and turned into healthy ones.”

I was interested in the biological process itself, because how the heck can fungi remediate a heavy metal like lead? Christopher describes the process like this:

> "There are long molecule chains of petrochemicals that are built in the environment, including things like asphalt, bitumen, polycyclic aromatic hydrocarbons (PAHs), and the enzymes from the mycelium break that down into smaller chains. With a heavy metal, since it's atomic, you can't break that down any further, so you have to do the opposite – you have to chelate by attaching it to long molecule chains that are biologically unavailable. When children are poisoned with lead, they go through lead exposure therapy, or chelation therapy, where they are given substances that actually latch onto the lead and make it so it can be flushed from the body and not embedded in the bones and blood. It's a similar thing here, we have biochelators that grab the heavy metals that form molecules. This gets lodged in the cell wall of the mycelium, which is chitin rich and double encapsulates with a very strong natural polymer like chitin. So, with the Biocycler material they don't digest the lead and it doesn't get into their bones."

Although this is a hypothesis at this point, it could have extremely promising potential for the future of sustainable development. Tests comparing baseline material with Biocycled material show that the ppm of lead in the baseline demolition waste was at a much higher level than the Biocycled material, but Christopher emphasizes "we want to get it down so its 0ppm in the Biocycled material and optimize this to the point where its untraceable."

Further testing and work need to be done but Christopher is hopeful, "we'd like to be able to prove that this process remediates all the lead in the construction and demolition waste, not only when we recycle it, but also in landfill, so the lead doesn't leach into the environment the same"

In terms of scalability, if they were to prove this process Christopher would want to have this mandated for handling construction and demolition waste. "If you mandate that this material can't go directly to the landfill anymore because it poisons the earth and the water supply, then we can mandate that there becomes some sort of payment for ecosystem service," said Christopher, "so, if it can't go to the landfill then all of the sudden, we have tipping fees to take that waste and process it into something different. It changes the financial model because there's no way we can compete making these materials at a price point against new, virgin materials like wood, steel, concrete unless there was this other income that was generated from doing the remediation work."

In my research I was curious about the financial aspect as I'm aware of the economy we live in and that innovation is great, but even greater when someone is getting paid. "We don't have any way of getting paid for that remediation at this point, so if there was an incentive or mandate that said you had to take this material and process it in some way, and there's one way that processes the waste into new materials, then not only could we get funds for doing that but we could license this technology to others that could find new and better ways to exploit the opportunity. We're getting to a point where we can set up a factory of this and when we reach that point, then we can start contacting manufacturers to use at a large scale. It's something I would want to hand off, from there I want to look solutions for disaster deployment crisis responses."

This begins at the community level too and the need for real solutions to problems that plague the people living in it. "Here in Cleveland, we tear down 175 homes every month that go into landfill, and we also have incidences of lead poisoning in our children that are 40 times the national average. When we were rejected in Cleveland, we took the Biocycler to Africa and tested it, proved it there and won awards, so I guess Cleveland just didn't believed it was possible, but we've worked with people at MIT and NASA that have proved this to be possible," Christopher began, "we're funded for our work in Africa, we're funded for our work in Mars, but we're not funded here in Cleveland. We pay for all the research on this ourselves alongside a group of lead advocates Robert Brown and Jennifer Lumpkin, as well as Black Environmental Leaders (BEL) in Cleveland."

"The same way the Cuyahoga River burning was the impetus for the Clean Water Act, we can look at this lead epidemic we have here in Cleveland and look at that as an impetus for doing something major for the built environment." If we recall the Clean Water Act, the inspiration for its passage of national water quality standards was the infamous Cuyahoga River fire in 1969 in none other than Cleveland, Ohio. It was Carl B. Stokes who became a national figure who advocated for the urban environment by giving a pollution tour of the river and the industrial sites and sewers that contributed to the fire. Stokes advocated at both the local and state level for funding for clean water, and this eventually formed the Ohio Environmental Protection Agency in 1972, and eventually the federal Clean Water Act in 1972. I mention all this because northeast Ohio historically can be used as a model for remediation. Even Cuyahoga Valley National Park successfully remediated the toxic soil and material at an unregulated industrial dump site known as the Krejci Dump that had been contaminated by auto industry titans like Ford, General Motors, chevron, and Chrysler. Another example of humans and the natural world working together to remediate can be seen at the parks Beaver Marsh, what once was an old dumpsite for cars and parts is now a wetland teeming with plant and animal life. The beavers returned to the valley in Ohio after the dumpsite was bought by the federal government, beavers had been absent from Ohio for over a century and gradually came back to build a system of dams that flooded this area into a wetland. Working with the animals, people in the park began cleaning up small dump sites in their marsh area removing trash and car parts to clean and preserve the land. Eventually the beavers restored natural water levels that allowed for wetland plants to grow and the seeds in the soil to grow creating an oasis for swallows, turtles. It's an example of allowing natural processes to occur, making space for natural remediation to take place. I tell these stories because hearing Christopher's vision of a Cleveland remediated from lead poisoning with new, sustainable structures in their place reminded me that it would not be the first time this area has served as a model for remediation where the community included ecosystems to encourage new growth and development in the area.

"Cleveland has been ground zero for this kind of action before, and with the lead pandemic and how its acutely bad here for poisoning young children, this could be another perfect example of ground zero for a demonstration level use of this process. Especially with the Biocycler, we are conscious of the obvious fact that there is racism around this, communities of color are disproportionately affected by the poisons of industry, city planning, banking, and it forces people into unsafe environments," said Christopher. With Justin Bibb, the new Mayor of Cleveland, he has a vision for Cleveland to become a national model for city management, police reform, and neighborhood revitalization. I can only assume he would be thrilled at the work Christopher and redhouse studio is doing, as a great way to begin the process of neighborhood revitalization would be remediating unhealthy, unsafe homes into clean ones using the Biocycler. I have faith in Cleveland's ability to remediate, and I think using the technology of the Biocycler to remediate lead would serve as the beginning of making Cleveland a model city for sustainability, just as it has before.

Developing Myco-technology for Wide Scale, Practical Use

Ecovative:

When I asked Christopher of scalability in biotechnology using mycelium, he pointed me in the direction of Ecovative. “They’re a good example of how scaling up can work, every five or so years they go up a decimal point with their investment and branch out into subsidiaries starting new projects,” he said, “at this point I think they’ve licensed their technology out to subsidiaries in four or five countries with new directions outside of packaging, like meat substitutes. They develop the technology and then license it out to people who want to take it from there, which is a good model.”

In fact, the book that introduced me to this wonderful world of mycology was Entangled Life by Merlin Sheldrake. I read this the summer of 2021 and was completely, utterly fascinated, particularly his chapter on Radical Mycology where Ecovative and their designs to replace plastics were first introduced to me. “Mycofabrication” recomposes types of materials we use to make them sustainable, compared to mycoremediation decomposition, “it is the yang to the yin of decomposition (18).”

Ecovative grows materials out of mycelium and by using agricultural waste streams to make a product, differing from the traditional manufacturing model that consumes materials and produces waste. The agricultural crop waste and mycelium work together to create their packaging and insulation in these steps (19):

1. Pasteurize feedstocks using pressurized steam.
    a. Feedstocks could include cottonseed hulls, rice hulls, corn stover, hemp hulls.
2. Inject sterile plant material with mycelia and shape into desired form
    a. The mycelia grows aseptically without any light, water, or petrochemicals necessary (19).
3. The mycelia fill into its form within five days.
4. Tests for biological quality are conduced to ensure the material is dead.

Even at the end of their life, or if defective packaging is accidentally made, these products can be broken down and composted, even used again. So, the final product is determined by however the mycelium is encouraged to grow, and afterwards these materials can be tanned to make leather or dried to make a foam able to be used for shoe insoles or dock floats (18). What makes this material so attractive for packaging is that the cell walls of mycelia are composed of chitin, which also makes up the exoskeletons of insects, spiders, and crustaceans making it an attractive source for tough, water-resistant material (19). The process itself can be adjusted based on the desired outcome as well, for example rice hulls would be the chosen feedstock to grow insulation because the silica composition in rice hulls makes it naturally flame retardant (19). Similar to myco-remediation, Ecovative grows primarily white rot fungi and the same variation in fungal strains and their ability to break down toxins applies to the variation in what material different fungal strains' mycelium will make (18).

Ecovative not only serves as a model of sustainable biotechnology innovations, it also can serve as a model of better, more sustainable business practices. The company itself is organized in a different, more equitable way while making an ethical product. This demonstrates a new model out of inspiration from the mycelial networks themselves, one that focuses on collaboration and not control. Ecovative has a State of Grace Contract that serves to focus on positive, meaningful collaboration by validating employees' personal and professional goals for development instead of the normal top-down approach to business (19). Even the way they've expanded and developed their business has a large emphasis on collaboration. By licensing their technology out to people who have new ideas of possible further developments, it creates a circular structure that is focused on the goal at hand: building sustainable alternatives.

Christopher Maurer agrees this is an optimal design in terms of scaling these biotechnology innovations. For his work on the Biocycler and its current research on the potential to remediate lead, he says, "We want to patent the process and then license it to anyone that finds new and better ways to exploit this opportunity," Christophers starts, "and it's about getting this into the hands of the captains of industry because they have the means of production to manufacture something like this at a larger scale."

<u>Fungi Foundation</u>

Giuliana Furci, who founded Fungi Foundation, the first non-governmental organization dedicated to fungi, and changed Chile and the role of fungi forever. One look at their website and anyone can tell this is the future of fungi. Their Fauna, Flora, Funga initiative aims to have the "Funga" kingdom of written into conservation laws and agricultural policy to protect it under international and domestic laws, and in doing this opening up lots of new opportunities for mycologists (20). Furci and the Fungi Foundation worked especially in Chile, and even wrote into Chilean law the recognition and protection of Fungi Kingdom. This makes Chile the only country ever to include fungi in their environmental legislation (21). The Chilean government and policymakers include fungi in their environmental impact evaluation assessments when undergoing new projects for economic development or industrialization. This spurred the rest of their work to increase mycological knowledge, opportunities in the field of mycology, and in education. The foundation also includes free Fungi Education with educational resources for kids K-12, as well as learning activities for kids K-5

John Michelloti from Catskill Fungi was the first person to tell me about Giuliana and her NGO. “She’s a hero, there is nobody else that is changing mycology more than her that is alive today. She lobbied the Chilean government to change environmental assessment impact to include fungi, meaning if you’re a developer and you want to clear a forest you have to get an environmental assessment impact report to see what they’re clearing in the forest and if anything is endangered or threatened. This means people have to study and understand fungi and rare fungi to pass environmental assessment impacts for development, creating jobs for mycologists and putting pressure on education institutions to study fungi and what’s rare, while *also* putting pressure on K-12 education to teach fungi so more people can graduate and study mycology” Another advocacy goal at the Fungi Foundation is to determine possible extinction of Fungi across the globe using the International Union for Conservation of Nature (IUCN) Redlist Criteria.

International meetings and conventions on climate change shape the conservation of biodiversity, yet the kingdom of Fungi is almost absent from their roadmaps and plans of action. For a conservative estimate, Fungi “include between 2.2 and 3.8 million species, possibly even 12 million” all playing unique, and critical roles in ecosystems and are also threatened by loss of habitat and effects of the climate crisis. In a white paper on growing a circular economy using fungal biotechnology, researchers found that the science they studied contributed to 10 out of the 17 United Nations Sustainable Development Goals (Figure 1) (22). International sustainability policy should include Fungi in their considerations, but this requires a paradigm shift in human thinking to accepting and understanding the value of fungi on ecosystem services. This requires collaboration and alliances among a wide range of experts in fields of policymaking, science, entrepreneurs, universities, biodiversity researchers, government agencies, educators, and indigenous peoples.

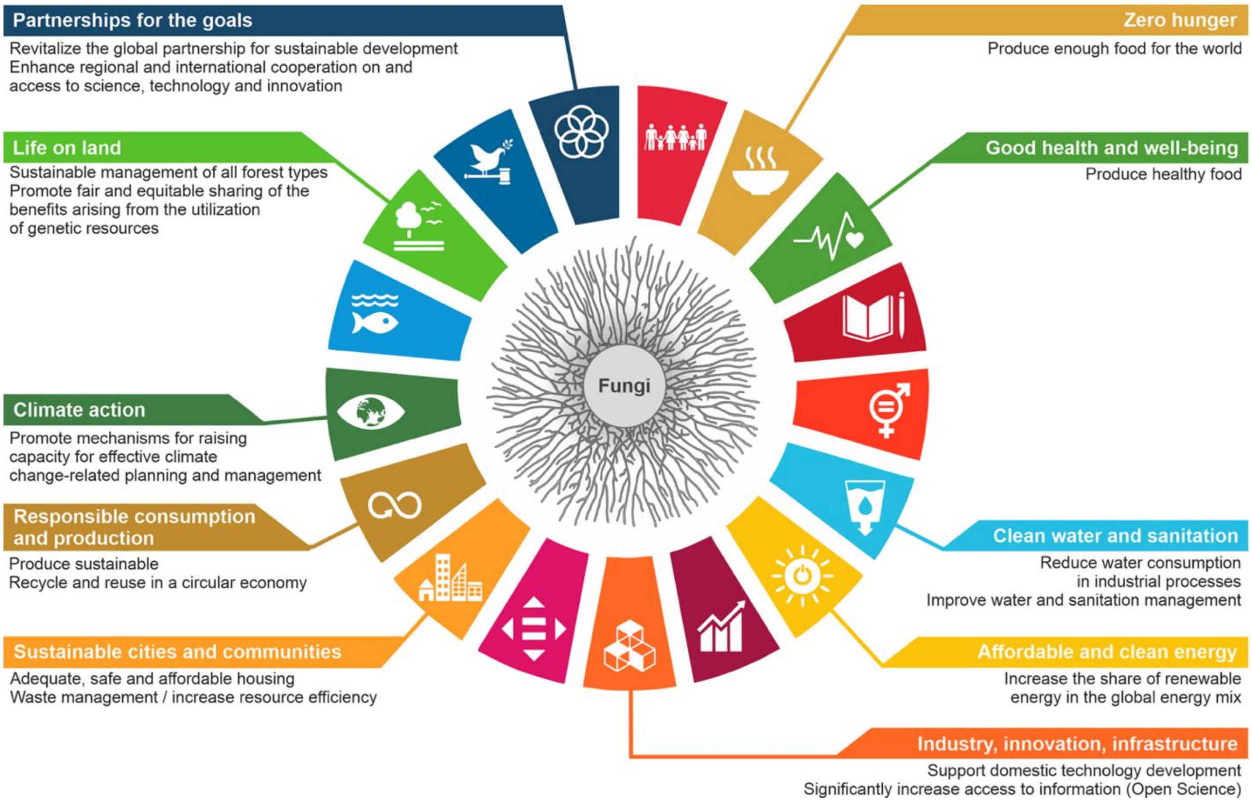

Figure 1 (22)

Proposal: Network for the Advancement of Sustainable Mycology (NASM)

A common thread I found throughout my research this semester was the number of different actors with different goals all working under this larger umbrella of fungi. People researched and developed for the purpose of remediating pollution, others harvested mushrooms for the health of people, others owned farms with the purpose of teaching others the mysterious beauty and nature of fungi, and others built new and innovative alternatives or machines out of mycelium. The list is endless. I started to wonder how all this information was shared amongst other mycologists, considering everyone had their own stake in it how did they hear about other uses or other alternatives?

So, I looked at mycology networks or meetings in the Conference Index, both nationally in the US and internationally. I found regional events for the North American Mycological

Association for over 90 mycological societies in the United States and Canada. I found the Mycological Society of America, which includes mycologists based in the US and Canada. Internationally, I found tons of conferences all with different specialties ranging from fungal diversity to veterinary bacteriology and mycology to pathogenic fungi and mycology and also applied mycology and biotechnology. The International Mycological Association is a nonprofit that represents interests of over 30,000 mycologists globally and hosts is hosting its twelfth International Mycological Congress in Maastricht in July of 2024.

Since I researched only in the United States and in Latin America, I was hoping to find a regional organization or conference that melded North American mycological interests or pursuits. The Latin American Association for Mycology was founded in Havana in 1990 with the aim to promote mycological studies in the region. Their last Congress in 2021 was headquartered in Paraguay, with ALAM congresses being held every two years consistently since the mid-1990s. Just a swift look at the list of themes presents at the XXV Latin American Congress of Microbiology and I saw microbiology in agriculture, industrial microbiology, environmental microbiology, along with fifteen other topics all under the umbrella of microbiology. I found the Society of Ethnobiology which has participants internationally including the US, Canada, Mexico, and Central and South America. Their Ethnobiology conference brings people together from all over to discuss the interactions of human cultures with the natural world (23). Of course, this includes more than just the field of mycology, but it still studies the importance of fungi on the natural world as a whole with an important emphasis on culture.

While the US and Chile, Colombia, and Brazil were a part of the tenth International Mycological Congress, I thought the US would do well to have the influence of Chile's environmental reforms that included fungi, but also have a way to streamline the biotechnology innovations being researched in the US to other areas in North America.

The United States would also do well to have a transfer of the education reforms in Chile's curriculum. In the United States, "there has never been a unit dedicated to Mycology at the equivalent of a department in US universities or colleges," it instead is included in applied sciences, plant pathology, or microbiology (14). This not only effects research and further development within the field of mycology, but also has consequences for grants and funding that rarely tailor to the very needed topic of fungal sustainability. And its effects on research can be seen in the lack of published articles mentioning fungi, with only 1-2% of articles indexed between 1991 and 2010 in the Web of Science including fungi (24).

There is a significant gap between what we know about fungi and their very obvious potential for sustainable solutions. This means that even when Funga are included as a kingdom in written laws, there has to be more than just an addition, it requires rethinking the way we have written sustainability indicators and targets. This will also require more mycologists and experts in different areas, meaning education should also be at the forefront of this shift in sustainable mycology.

Much like we cannot expect to understand organisms in isolation, we must work with one another to better understand the way forward. In order to effectively communicate and transfer education and innovation on mycology, I propose a regional, multilateral network that includes government agencies, policymakers, biotechnology industries, indigenous voices, mushroom cultivators, microbiologists, educators, and mycologists alike from the United States, Latin America, and Canada. My proposal is still preliminary, and I am hopeful that with a community effort we can all best learn how to enact this collaborative effort, together.

The purpose for the Network for Advancement of Sustainable Mycology (NASM) is to promote and organize research that focuses on creating and expanding sustainable alternatives or solutions based on microbiology/mycology. In doing this, NASM will raise awareness about fungi creating more of a need for education and curriculum about fungi in school – both at the primary and secondary level, but also at universities. With more education comes more research and collaboration on developing what we know about fungi, but also applying what we know to develop more sustainable solutions.

The Network for Advancement of Sustainable Mycology (NASM) has the following objectives:

1. Education: Collaboration between academics and industry is a primary goal of the network. Alongside this, one of the main purposes of NASM will be to create K-12 educational curriculum covering the study of fungi and its applications to be added onto current science education objectives and benchmarks. I believe Chile can serve as a model country in this respect as they have expanded the *need* for education in microbiology/mycology by including fungi in their environmental impact evaluations, and hopefully more countries can follow suit. The Fungi Foundation has also developed

their own Fungi Education curriculum. After all, isn’t the most sustainable model for an institution one that educates the people?

2. Coordination: Biotechnology innovations like replacing plastics, or remediating lead from construction waste as outlined in this paper are huge steps toward a more sustainable future. The question remains: how do we disseminate technology like this to make it available as a best practice for everyone? How do we make processes like myco-remediation and myco-filtration more accessible? I am hopeful that NASM could be the place where these questions of scalability and dissemination of information and technology are answered.
3. Information sharing: Similar to education, I propose there be an online database created for members of NASM to publish and share current research projects involving innovations in biotechnology, new remediation methods, research on health benefits of mushrooms, etc. I also propose that there be a specific focus on sharing information about opportunities for funding and current academic research, maybe even collaborations across universities. The network will also establish a collaborative publication that covers updates in biotechnology, sustainable development in mycology, news, research, available grants, job matching, and education opportunities. There also needs to be a particular emphasis on including voices in ethnomycological spots where mushroom harvesting practices and indigenous knowledge of management have been respected and widely used over millennia in Mexico and China. Their perspective on preservation and the way forward is crucial to our understanding.
4. Development: The technology and progress mean nothing if it’s not actively working to bring people together to advance sustainable solutions. A main pillar of NASM will be to disseminate best practices for sustainable development like climate-smart agriculture using mushroom cultivation, processes like myco-remediation and myco-filtration, and innovations like redhouse studio’s Biocycler to areas that need it most. A main goal in terms of development is making it so that these innovations and practices are the solution to waste treatment instead of just an alternative.

It’s no secret that we can derive inspiration from the mycelial network itself, as we’ve previously been inspired by its interconnection for major developments like the internet. When we realize how fungi work, we can better understand how fungi can influence our relationships and how we work with one another. This new collaborative will focus on sustainably sharing information about fungi from all different aspects (health, agriculture, education, etc.) so we can better understand how to make them all work together. The first meeting will be to develop a roadmap for fostering innovations and development while also determining best practices for integrating them into sustainable solutions. We must merge and foster technological innovations for sustainability to create a circular economy, but we cannot do this without including people from all over and in all sorts of industries. This technology should be actively working to advance sustainable solutions and by bringing people together from education sectors, tax experts, disaster relief, farmers, microbiologists we can all collaboratively determine how best to advance this, but also gain better understanding of what is needed. By forming a public-private partnership with industry sectors to discuss these issues, we can better coordinate expansion of research findings to a larger scale.

Below is an example, preliminary list of entities that would hopefully be involved in the network (plus many more!):

- NASA
- Defense Advanced Research Projects Agency (DARPA)
- South American Mycorrhizal Research Network
- Ibero-American Network of Researchers in Mycology (RIIMICO)
- US Department of Agriculture
- US Department of Commerce
- US Department of Education
- Environment and Climate Change Canada
- National Academy of Science
- IUCN Fungal Conservation Committee
- Organization of American States (OAS)
- US Environmental Protection Agency (EPA)
    - Office of Environmental Education
- Society of Ethnobiology
- Centre for Functional Ecology (University of Coimbra)
- National Collegiate Inventors and Innovators Alliances
- Environmental Company of the State of São Paulo (CETESB)
- Indigenous Environmental Network
- Fungal Diversity Survey (FunDis)
- North American Mycological Association (NAMA)
- Mycological Society of America (MSA)
- Science by Design
- Mycocycle
- Fungi Perfecti
- Catskill Fungi
- North Spore
- Fungi Foundation
- Smallhold
- New Hampshire Mushroom Company (NHMC)
- Cleveland Fungi
- Mycoworks
- Mylo-Unleather
- Ecovative Design
- redhouse studio
- NEFFA (MycoTEX)
- Mogu
- Saisei Foundation
- Marisla Foundation
- Weeden Foundation

- Global Biodiversity Information Facility (GBIF)
- Society for Protection of Underground Networks (SPUN)
- Wildlife Conservation Society
- Fungi Magazine
- Environmental Grantmakers Association
- The Sierra Club Foundation
- The Fungi Foundation of Argentina for Sustainability (FHAS)
- Ministry of the Environment and Sustainable Development of Argentina
- Ministry of Environment of Chile
- Ministry of Agriculture of Chile
- Ministry of Science, Technology, Knowledge, and Innovation of Chile
- Ministry of Environment and Sustainable Development of Colombia
- Ministry of Environment and Energy of Costa Rice
- Fundación Mar Adentro (FMA)
- National Science Foundation (NSF)
- The Nature Conservancy
- GlobalFungi
- Biodiversity Funders Group
- Conservation International
- Alberta Native Plant Council
- Centre for Biodiversity Genomics
- Congress of Aboriginal Peoples
- Abya Yala Fund
- International Indian Treaty Council (IITC)
- The Latin American Network Information Center (LANIC)
- Climate Litigation Accelerator (CLX)
- US-Chile Science, Technology, and Innovation Council (STIC)

This list is by no means exhaustive, and only serves to show an example of the kinds of organizations that would benefit the network with their rich, unique insights. All these businesses, foundations, publications, and agencies would be working together to integrate their different areas of expertise into developing sustainable solutions and alternatives for the world at large. NASM will be a space for anyone who understands the need to address the climate crisis through tangible actions by developing a model for a more sustainable a future – with fungi being our principal architect. This includes universities, independent researchers, and many others who are not listed above, but are just as integral to the conversation.

One issue to mention that deserves special attention moving forward is intellectual property sharing and agreements. American companies have abused this process and patented ideas that were not theirs to begin with. I feel this is important to articulate especially as indigenous voices are an important, integral part to NASM and the conversation as a whole. As far as I know, there are two approaches:

1. A standard model for commercializing where if the government steps in and gives a grant to Company A allowing them to develop what taxpayers pay for

2. We work collaboratively in a public-private partnership using common property, knowing what we develop together will be shared collaboratively with shared intellectual property developed with common ownership

If we go with option two, we can create a group or an entity where the government gets together with the researchers, voices, and companies to work on mycological development. We create an entity or a trust that will own the shared work which will be under restrictions on how to license the intellectual property so that people can use it. There will be agreements for a reasonable license price, either set by the government who can own it and license out at a reasonable cost, or the government and people come together and form a group that incorporates to form an entity or trust that can own the property rights. The government can also influence this, but we would be able to build into the bylaws of the entity to determine a reasonable cost for best sharing practices. Of course, I've never done this before, and I am entirely open to the discussion of different approaches for best practices, but I am aware that the formation of this must be prepared to find a balance between acceptable use and not gauging the market with commercialization, so use is restricted.

The government will have a hand in this, but I am hopeful that it will be one of observation more than control – learning from mycologists and innovators and indigenous voices to better prepare for the climate crisis and implement sustainability practices. The emphasis of this will be on collaboration exclusively, there is no time for a competition when the future of the climate is on the clock.

The thought to propose a network like this came close to the end of my research this semester. Researching the ways fungi can remediate toxins from the earth, or the way mycelium can be used as building materials made me envision a future that wasn't fraught with environmental destruction. Which is impressive because the last four years (admittedly) I have not had much hope for the future of our climate! I think any student, especially those aiming for degrees in science/environmental issues, can relate to the angst that comes with learning about the climate crisis while also witnessing it firsthand in the magnified natural disasters or reading the increasingly desperate reports from scientists. But to me, and many others, fungi have shown the solution to this angst – that the world has everything we need, and we are – and have always been - only something the world wants. If we return back to the original way of nature, before industrialization and globalization, and we listen and observe how nature runs its course absent of our hand of it, I believe then we will be on our way to a sustainable future. Fungi are the first step to that understanding and education on this discipline is of the utmost importance. From there, greater coordination is necessary to begin further development of practices like myco-remediation or myco-filtration as well as deeper integration of sustainable materials like those made at Ecovative or redhouse studio.

To close, I thought I would share my journal entry from when I finished my first draft of this research and was stumped on the introduction. I would call it a poem, but I know it is nowhere near the correct format for one.

What is a fungus? What are fungi? What would I even begin to say…
They're one kingdom of the five
A fungus is not a plant, nor an animal, they have no nervous system, yet they're sensitive – are they conscious? Sentient?
Well, they are intelligent, we know this for certain.
Fungi are not conscious, no, but the mycelia that grounds them to Earth branches off to fulfill its role in distribution, aware of the availability of nutrients, the presence of other plants and organisms in its surroundings– and is awareness not consciousness? Is sensitivity consciousness?
They're connected in an integrated network throughout the soil,
They live off the dead and the dying – by way of eating the dead and dying!
It's the largest living organism on Earth.
And it's underneath every footprint we leave,
Some say they're mystic, some say they're dangerous, most say they're delicious!
They are not always for us to see but a fruiting body unexpectedly peeking through the soil on a walk in the forest does feel like serendipity,
To know their beauty is the byproduct of something long gone, as the cycle of life moves on and we ask does life stop at death? Not for the humble fungus it doesn't! And not for us either.
Fungi are a beacon of hope for renewal, repurpose, rebirth.
We know a lot less than they do; in fact, we don't even know how many there are,
We can learn a lot from them, though they're not very interested in teaching.
They share their resources, they communicate within their networks, they keep their neighbors alive, healthy, sustained,
If we listen close enough, we can understand how they heal the Earth.
And if we care enough, we learn that what makes them so special isn't their elusiveness, but their altruism. And that the world is a lot better for it.

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