Ecovative's Breakthrough Biomaterials

by Penelope Zeller and Dena Zocher

Ecovative Design LLC (Ecovative) is a leading-edge biocomposite materials firm that employs the mushroom kingdom in an array of products, most of which supersede common uses of polystyrene and aldehydes. The company's grown (not manufactured) packaging products, trademarked EcoCradle®, are used by Dell Inc., Steelcase Inc. and Crate and Barrel. Ecovative's innovations are proving to be a powerful impact to the future of business, the environment and the field of mycology.

What does the Chief Mycologist Do at Ecovative?

"As Ecovative's chief mycologist, my primary role consists of procuring and preserving the strains of fungal species from the wild that we test and develop. I identify fungi in the field according to their ecological functions and roles in the environment – whether they are a white rot fungus, a brown rot fungus, or a mycorrhizal fungus. I harvest fungi and get them into pure culture in the laboratory. I also participate in the research and development of new products and new applications requested by our customers, and perform scientific overview. And, I serve in an evolving educational role, helping Ecovative employees at all levels learn to enjoy and respect the fungal kingdom."

Sue Van Hook, Chief Mycologist,
Ecovative Design, LLC

What a Long Strange (Career) Trip it was . . . . . How One of Our Own Became a Private Enterprise Mycologist

A dream workshop led former biology professor Sue Van Hook to her true calling as a mycologist – and a new career as an executive with biomaterials developer Ecovative.

A lifelong outdoor enthusiast, Van Hook discovered her passion for mycology as a botany student at Humboldt State University in California. "My Botany 101 professor, David Largent, convinced me to enroll in his Fleshy Fungi course. I did, and I fell in love with the fungal kingdom."

Van Hook's graduate studies in biology, also at Humboldt State, focused on the identification and ecology of macrofungi. Along the way, she and Largent helped found the Humboldt Bay Mycological Society. Van Hook's vocation led to stints with the Nature Conservancy and Maine Coast Heritage Trust, followed by a successful teaching career at Skidmore College in Saratoga Springs, New York.

One day in the summer of 2007 Van Hook came back to her office to find an article from the local paper pinned to her door: Eben Bayer and Gavin McIntyre, recent graduates of Rensselaer Polytechnic Institute (RPI) in Troy, New York were in the process of commercializing a new sustainable biomaterial they had developed using fungi.

CEO Eben Bayer and Chief Scientist Gavin MacIntyre.

"I ignored it for a few days, but I finally sat down to read it. Two RPI graduates had developed a mushroom-based insulation," says Van Hook. "As a mycologist, I was excited. I had to get in touch with them!"

"My first phone call with Eben lasted a few hours. I asked him if he or Gavin knew anything about fungi, and the answer was, 'Not that much.' I knew nothing about starting a business or filing patents.

But we agreed that our interests were complementary," says Van Hook.

Engineers and Mycomaterials Innovators

The company's co-founders, CEO Eben Bayer and Chief Scientist Gavin McIntyre, met while studying engineering and product design at RPI, and quickly realized their values, interests and career goals were in alignment. Like Van Hook, Bayer and McIntyre have deep, abiding respect for our planet and environment, and are committed to making a positive difference. They have also learned to be open to the unexpected, to see something that was always there suddenly pop into focus in a whole new way.

Growing up on the family farm in Vermont provided constant stimulation for Bayer's curiosity. "One of my jobs was shoveling the wood chips – lots and lots of wood chips – to fuel the gas fire to boil the sap for maple syrup," says Bayer. "I was fascinated by how mycelium would grow on that pile of wood chips, and how tenacious that material was."

McIntyre's background similarly prepared him to see unique opportunities in mycelium. "My mother is a biologist and my father is a mechanical engineer," he says. "As a kid, I had this happy

"It took two engineers to observe the tenacity of rhizomorphs and to see with new eyes what mycologists have known for centuries."
–Sue Van Hook

Celandine poppy growing in Ecocradle compost.

medium between the two, playing in the dirt with mom and building things in the garage with dad."

"Another major inspiration was a class at RPI called Inventor's Studio, where we were challenged to come up with socially responsible, unique, disruptive technologies," says Bayer.

At the end of the course, Bayer told his Inventor's Studio professor about his idea for 'grown' materials using mycelium as glue. "He basically flipped out about the concept of a grown material and urged me to pursue it," says Bayer.

Bayer's next big step was teaming up with McIntyre. Says McIntyre, "When Eben pitched the idea to me, I immediately saw the value. It was exciting for me."

"We both wanted to start a business, we both wanted to do something that would have a positive impact for our planet," says Bayer. "And we were presented with a core technology we knew could meet those goals. It was a matter of proving it wasn't going to work or making it happen."

Says McIntyre, "We bought some materials from Fungi Perfecti. We started with *Pleurotus ostreatus*, the common tree oyster. We initially tried concoctions of whole wheat flour and vermiculite as our substrate."

During a busy final semester at RPI, the two wrote a business plan, grew the first samples of an insulation material and tested them. They made over 100 samples in their home kitchens, drying them in toaster ovens. Bayer and McIntyre needed to test the sample materials to see how they stacked up against traditional, expanded polystyrene (EPS) foam, but didn't have money to spend on a testing facility. They decided to go out on a limb and cold call the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland.

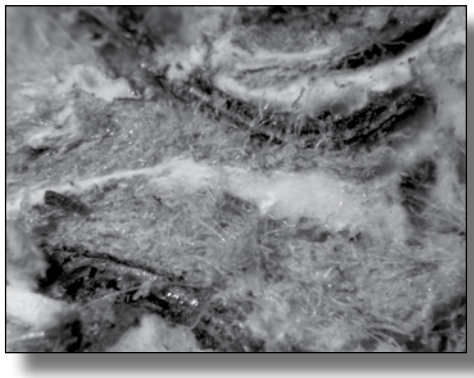
"NIST was very good to us. They offered us the use of their labs, along with training to use the equipment, so we could test the thermal, strength and fire-retardant qualities of our samples," says McIntyre.

The initial product benchmarked extremely well against foam. Not only did the material have thermal performance comparable to foam, but it also performed as a Class 1 firewall due to the mineral content of the substrate. The test results were the tipping point that convinced the two engineers they had a commercially viable concept.

"We both had job offers, but after graduation we realized we had to make a decision," says Bayer. "My first day working for a defense contractor I drove in and quit my job to go work on our idea."

"This was an opportunity to have a positive effect on the world by displacing synthetic materials," says McIntyre. "We really believed in the technology, and that's why we dove head-first into the company."

The two partners financed their start-up through business plan competitions,



Cellulose substrate with hyphae.

fully funding the company in its first year.

"Bootstrapping the company like we did allowed us to maintain control of the Firm and pursue our own ideals and goals for Ecovative as a triple-bottom-line business," says McIntyre.

When Van Hook called Bayer, the partners hadn't given much thought to the mycological aspect of their new venture.

"Sue came in and gave Eben and me a great gift. She taught us aseptic technique," says McIntyre. "As two engineers, it didn't occur to us to sterilize our substrate materials. We were extremely fortunate that our initial samples didn't get contaminated."

Bayer and McIntyre set up a lab in the Rensselaer Business Incubator in 2007, with Van Hook as their mycological consultant. Van Hook facilitated a Biological Materials Agreement with Skidmore College that gave the team access to spawn from multiple fungal strains.

"We were fortunate to have connected with Sue early on. Sue helped enhance the perspective Gavin and I have about treating our planet well," says Bayer. "Not only did she bring insight into the mycology, but also an appreciation of the mycological community and what fungi mean for our planet."

Winning the €500,000 Postcode Lottery Green Challenge[1] award in 2008 provided the financial boost needed to set up manufacturing facilities and ramp up production. In 2009, Ecovative moved to its current 10,000 square foot office and warehouse in Green Island, NY. In September 2010, Van Hook came on board as Ecovative's full time chief mycologist.

"I wound up creating a new job, but I didn't approach Eben and Gavin with that intention. I had a hunger for more fungi in my life. And this was the answer," says Van Hook.

"Sue was really phenomenal – without her it would have been more of a tortuous path," says McIntyre.

Says Van Hook, "It took two engineers to observe the tenacity of rhizomorphs and to see with new eyes what mycologists have known for centuries."

Ecovative Garners Global Recognition:

- ***Greener Package Innovator of the Year (non-FDA regulated packaging), 2011***
- ***World Economic Forum Technology Pioneer, Clean Tech category, 2011***
- ***DuPont Awards for Packaging Innovation, Diamond level, 2011***
- ***National Renewable Energy Laboratory (NREL) Clean Energy Ventures, Best Venture, 2009***
- ***Postcode Lottery Green Challenge, €500,000 winner, 2008***

Is The World Ready For Industrial Mushrooms?

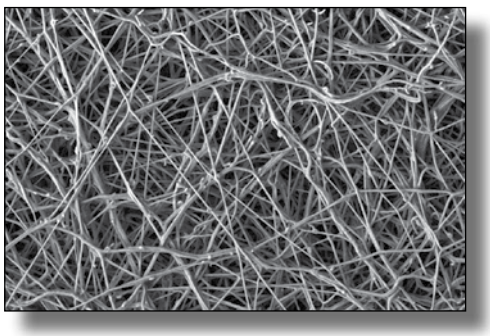
The archeological record of humans' use of mushrooms dates back thousands of years to the early Neolithic era. The tinder mushroom may have been used as early as 3,000 BCE. Archeologists believe rock paintings of mushroom effigies in the Sahara Desert – thought to have shamanic significance – may be 9,000 years old. Mushrooms have been used extensively as medicines and entheogens over thousands of years of human history, and are still an important part of the pharmacopeia today. While Bavarian felt hats made from Fomes[2] are still made in the traditional way, and *Ganoderma applanatum*[3] is a very popular art medium, mushrooms never really caught on as a material.

Until now. What Ecovative has done puts the mushroom kingdom in a new domain: materials science.

This fresh look at the binding properties of mycelium is a step in the right direction for the manufacturing economy. For example, traditional manufacturing processes consume raw materials to produce both a product stream and a waste stream. Ecovative procures someone else's low-value waste stream, and 100 percent of that waste stream will make it into a final product. Even if a packaging piece is defective, it can be broken down to use as substrate for more product or composted.

Bayer and McIntyre point out their goal is to produce materials that are not just green, but better – economically and in terms of performance.

"When you're introducing a new product, sustainable or otherwise, you can't make compromises in performance or cost. If you want the customer to easily adopt the technology, the biggest factors you can provide are a better product at a lower cost," says McIntyre.



Hyphae alone.

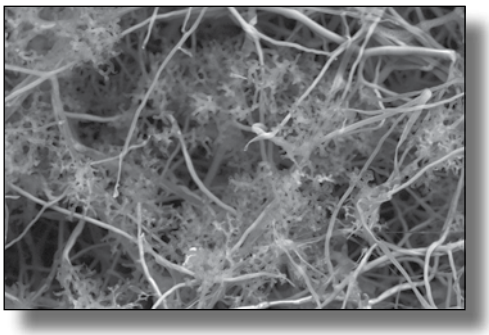
"We're letting the mycelium do the work – the fungus is our manufacturing system for the most part – and using agricultural waste, a low-value material, enables us to easily hit those metrics."

Every cubic inch of EcoCradle material grows a matrix of eight miles of tiny mycelial fibers.

Growing Industrial Materials: Mycelium Binding Technology

A finished Ecovative product for packaging or insulation requires two material inputs: agricultural crop waste and mycelium.

The first step in the production process is to pasteurize the feedstocks – such as cottonseed hulls, rice hulls, corn stover or hemp hulls – by way of a proprietary process that uses pressurized steam. Next, the sterile plant material is injected with mycelia and put into forms in which the mycelia will grow into the desired shape. The mycelia grows aseptically, completely filling a form in five days – without any need for light,



Binding hyphae.

watering or petrochemical inputs. At the end of the growth process, the product is dehydrated and heat-treated. The finished product then undergoes rigorous biological quality control to ensure that the material is completely dead.

"We work only with the vegetative mycelium; no spores are ever introduced," says Van Hook. "It is only when spores become involved that some molds might invoke toxicity."

The physiology of the mycelium is a key determinant of the strength and characteristics of the final product. The cell walls of mycelia are composed of chitin, the same biopolymer as insect bodies and lobster shells.

"That means this material is incredibly tough and also water resistant. It has unique characteristics you don't typically see in natural materials of this type," says McIntyre.

Ecovative Design LLC

Headquarters: *Green Island, NY*

Website: *www.ecovativedesign.com*

Industry: *Biomaterials and biocomposites research and development (R&D)*

Commitment to mycology: *Ecovative is committed to maintaining valuable fungus strains, ongoing research and development of mycelium-based biomaterials, and promoting opportunities for practitioners of the science of mycology. The company currently maintains over 70 strains in its strain library.*

Using different wild-type mushroom species, Ecovative's researchers promote the expression or operation of particular genes using phototropic organisms to drive specific gene expression. They can isolate strains that show the desired growth characteristics in different settings.

"There are ways of using the surrounding environment, chemotaxis – simple chemistry – to get these genes expressed," says McIntyre.

Different agricultural feedstocks in various mixtures are used to create diverse material properties. Ecovative's team can fine-tune the specifications for the application and adjust the density, strength, texture, appearance, and more, as needed by the customer. For example, Ecovative uses rice hulls in insulation products because the silica in the rice hulls is naturally fire retardant.

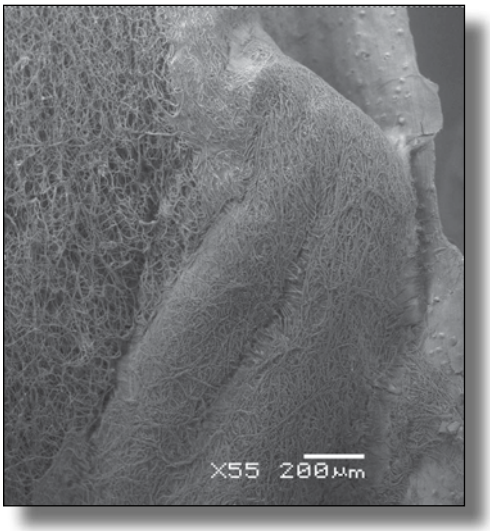
Mycelia binding technology also works with both natural and synthetic textiles. Materials like burlap, hemp, jute, wood veneers, fiberglass, and even carbon fiber can be adhered using mycelium instead of volatile chemical resins.

Replacing EPS: Conserving Precious Petro-molecules

The fact is, cheaply extracted petroleum supplies are a thing of the past – and it's more important than ever that every molecule of petroleum extracted is put to long-term productive use and not

consigned to a landfill.

Ecovative's grown materials use fully renewable resources, require very little energy to produce, and meet industrial and consumer needs. These mycomaterials can replace engineered woods, oriented strand-board (OSB) and medium-density fiberboard. While traditional, chemical adhesives produce a lot of volatile organic compounds



Substrate with hyphae.

(VOCs), Ecovative's products are VOC-neutral.

According to EPA data provided by Ecovative, plastics – especially plastics like EPS – take up 25 percent of US landfills by volume. Consumer recycling rates for EPS are less than 2 percent in the United States, primarily because the transportation costs and emissions make it not viable.

Walking the Sustainability Talk: Managing the Triple Bottom Line

"We're focused on our financial bottom line, but we're just as concerned with how people use these materials and how our materials affect society. And most importantly, how the materials return to the earth at the end of use," says McIntyre.

As product design engineers, Bayer and McIntyre want to develop materials that offer a positive environmental impact through their use. They also want to manage Ecovative using principles and practices based on managing the triple bottom line: people, planet, profit.

By their very nature, Ecovative's products are more environmentally sound than petroleum-based counterparts. But detailed analyses, performance measurement, accurate reporting and peer reviews help document that the company is truly meeting its people, planet and profit goals. That's why Ecovative is using Life Cycle Assessment (LCA) tools to optimize the design and operation of its new manufacturing facility and validate the sustainability of its products and practices.

A key outcome of the LCA process will be an embedded-energy comparison of EcoCradle with EPS, paper pulp and other protective packaging alternatives for which reliable published data are available.

Ecovative also has to be smart in sourcing the raw materials it purchases from farmers. The Firm utilizes many materials already collected in processing, such as cottonseed hulls and rice hulls. But not all agricultural waste that would be useful is readily accessible. Some viable materials are hard to come by because farmers don't normally collect them – they might be plowed under or disposed of. Hemp waste provides superior substrate materials, but can only be sourced from Canada. It's critical to ensure that raw materials and collection methods are consistent, reliable and trackable. Toward that end, the company has a cooperative research agreement in place with the US Department of Agriculture (USDA) and works closely with the agency to evaluate and develop new sources.

"We have a great relationship with the USDA," says McIntyre. "They help us determine which ag wastes are best for our needs. For example, we like the potential of corn stover as a substrate, but we need to work out collection and front-end logistics."

Still, Ecovative doesn't have to compete with other manufacturers or industries for resources. For example, feedstocks for biofuels require cellulose, and Ecovative uses materials high in lignin. And, its products don't impact food production. Because the company's materials are inherently cradle-to-cradle, any defective or excess product can be broken down and fed right back into Ecovative's own process.

"We don't want to compete for food-grade resources. We have a social obligation to the people using our products. They shouldn't have to pay more for food in order to use an ecologically viable, sustainable material," says McIntyre.

Just as important, using Ecovative's products helps customers validate their own sustainability initiatives.

"We do a great deal of education with clients to help them understand why it's important and how to communicate the benefits to their stakeholders," says Bayer.

The Hyphae That Bind: Sustainable Corporate Culture

"Ecovative is not only paving the way with new mycotechnology, but we are also changing how business is done," says Van Hook. "We are working as hard on creating our corporate culture as we are on our products. To help us maintain that commitment as we grow, we're incorporating a business model document called a State of Grace Contract into our policies."

The document validates personal and professional development goals, and helps employees focus on collaboration and positive outcomes. As engineers new to managing people and growing a business, Bayer and McIntyre see the State of Grace Contract as a powerful management tool to create and maintain a collaborative, sustainable company culture.

"It sets us apart from the top-down hierarchical business model. We function

Current Applications For Ecovative Products:

***Protective packaging:** packaging materials that are environmentally responsible, with equal performance at a similar cost*

***Building products:** insulation, structural insulating panels (SIPs), acoustical tiles*

***Automotive:** specially tuned materials replace foams found in bumpers, doors, roofs, engine bays, trunk liners, dashboards and seats*

***Home and garden:** containers, garden planters, wine shippers/ caddies, candle holders*

more like a mycelial network; with the nodes where the mycelia gather and exchange information, and the dendritic tendrils that go out and do the work," says Van Hook. "We've got less hierarchy, and a more interactive, collaborative model."

Mycelia Dancing: Advancing the Field of Mycology [4]

"Nanotechnology is moving toward complex microstructures that are assembled molecule-by-molecule, and are really efficient. Mycelia already do this, and it run on lignin and cellulose," says Bayer. "I'm in awe of them and the possibilities of their applications."

Says McIntyre, "We're measuring the structural integrity and physical aspects of fungal mycelia. But we're starting to learn there is little existing research into the physical characteristics and how tenacious fungal mycelia really is."

"Alongside Paul Stamets, we are

Ecocradle protective packaging corner block.

putting mycology on the map in the business world," says Van Hook.

In addition to sourcing their first mycelia from Fungi Perfecti, Bayer and McIntyre consulted with Stamets on building a business in the mycology space – and he continues to be an inspiration and a resource for Ecovative.

"We're looking at how we can partner with Paul's organization," says Bayer. "For example, giving our customers the option to use Fungi Perfecti's Life Box with EcoCradle protective packaging."[5]

Van Hook's team also works at preserving the strains of wild fungal species that the materials research team tests and develops. Today, Ecovative has approximately 70 strains selected from the northeastern United States in its strain library.

"The government agencies see value in this technology and material," says McIntyre. "In the past four years, we've brought in over $4 million in federal and state grants to continue to develop mycological materials."

"We are hoping our business venture will encourage students to go into mycology, knowing that there are jobs to be had," says Van Hook. "As Ecovative grows, we will need more mycologists trained in mycophysiology, molecular mycology and genetics, and mycochemistry to conduct our research. We'll also need technicians to handle culturing and inoculation procedures."

According to Van Hook, "Ecovative is already engaged with several universities as subcontractors for a percentage of their research and development grants. This trend will only increase as the demand for mycoproducts grows."

"When we started, we were pushing our concept and product into the industry, and having to educate the market," says Bayer. "But now we're seeing a shift, where customers are coming to us because they already get it, and they know why they want it and they're happy it's there. People in many industries are coming to us to solve sustainable materials challenges using mushrooms."

Breakthrough Mycotechnology Breaks Out: What's Next?

Ecovative remains focused on the vision of building a materials science company that grows sustainable materials for many industries and uses. Bayer says the company's success with its packaging products has provided freedom of movement to expand that vision.

"The core concept of our business model is growing materials, and we see this as a platform technology within that concept," says Bayer. "We're making it clear to industry that this underutilized kingdom is proving to have some good industrial applications."

Requests for new materials and applications come from all over the globe. Current projects include apparel fabrics, liquid-absorbing mats and a grown-materials process that can be replicated in developing nations. Ecovative and 3M are partnering on R&D to adapt the mycelium technology platform to new uses.

The company's strategy for US expansion incorporates a network of regional manufacturing facilities located to minimize the transportation miles and carbon dioxide emissions for transporting feedstocks and final products. Researchers are already testing a range of agricultural waste feedstocks, for future sourcing from within regions based on native fungi and the types of crop waste readily available. The fully optimized production facility that is scheduled to come on line in 2012 in Green Island will become the model for future regional sites.

Ecovative continues to develop advanced building materials and composites that offer the performance features of standard engineered products without the gas emissions. Products for the construction industry meet or exceed performance standards, and have the possibility to take LEED certification in commercial structures to new levels of healthy workspaces.

The automotive industry is also paying attention: Ecovative's biocomposites can replace polypropylene foams commonly used in cars. Specially tuned mycomaterials

What's your favorite mushroom?

Eben Bayer, co-founder and CEO, Ecovative; "We made our first prototypes with the common tree oyster, and it's still my favorite. I admire its tenacity to grow under any condition on almost any substrate."

Gavin McIntyre, co-founder and Chief Scientist, Ecovative: "I don't actually eat mushrooms. My favorite in terms of aesthetics is *Polyporus squamosus*, the dryad's saddle. It is just a beautiful mushroom, in every season."

Sue Van Hook, Chief Mycologist, Ecovative: "My favorite mushroom changes frequently as I gain new appreciation for their beauty, function, and spirit. My current favorite is Chaga, *Inonotus obliquus*."

Sustainable, Grown Mycomaterials Outperform Synthetic Alternatives		
	Ecovative Products	**Comparable 'mainstream' products**
Product Toxicity	Grown materials contain no toxic chemicals, emit no gasses, and are completely inert.	Polystyrene is made of chemicals suspected by the US government of being carcinogens; building materials like particleboard emit toxic gasses.
Raw Material Toxicity	Primary resources consumed are organic agricultural waste, steam-cleaned to remove any contamination; mycelium is grown aseptically.	Polystyrene is composed of highly toxic materials (like styrene and benzene); particleboard is made using formaldehyde adhesives.
Carbon Footprint	Low embodied-energy materials require minimal heat, water and light to produce. The process upcycles low value waste products like plant stalks and seed husks.	Raw material extraction and production processes leave a significant carbon footprint. The overall process requires supplementary nonrenewable resources to produce the finished product.
Compared to other Biomaterials	Feedstocks comprise parts of plants that cannot be used for food or feed and have limited economic value.	Feedstocks for most modern bioplastics are food crops with direct economic and commodity value.
Biodegradability	Finished products can be home-composted when no longer needed	Traditional plastic materials essentially never biodegrade. Proper recycling requires considerable energy to yield a lower grade material.
Sustainability	100% renewable cradle-to-cradle product, with expanding availability of raw materials.	Production relies on non-renewable resources, burdened with economic and ecological constraints.

can replace synthetic foams found in bumpers, doors, roofs, engine bays, trunk liners, dashboards and seats. The materials have the same or better ability to absorb impact, insulate, dampen sound, and provide lightweight structure within an automobile.

The patented pasteurization process Ecovative uses to sterilize the agricultural feedstocks ensures that the material meets International Safe Transit Association[6] standards for shipping agricultural products out of the country. And, Ecovative's insulation product already meets rigorous standards mandated by the European Union End Of Life Vehicle (ELV) Directive.[7]

An especially exciting new area of research is the field of self-repairing materials. Just as exciting, Ecovative is looking into creating a replacement for the ubiquitous Styrofoam™ clamshell used in the food service industry.

To aspiring mycomaterials innovators, Bayer says, "Make sure you're passionate about it, and make sure you're solving a real problem – there are plenty of real problems that require sustainable solutions."

McIntyre says his biggest lesson learned is, "Go out and do it: prototype, test, put the results in the hands of potential users and get feedback. Then go back and do it again. It's rare that your first iteration is the perfect solution."

Do try this at home! Ecovative is currently beta testing a simple Grow-It-Yourself (GIY) kit that skirts the need for aseptic technique, making it easy for budding mycomaterials enthusiasts to grow their own at home or in the classroom. Contact Ecovative at www.ecovativedesign.

"These materials help stimulate our manufacturing and farming industries," says McIntyre. "Ecovative has to take advantage of local waste streams to stay competitive. But it beats using extracted resources from half way around the world and transporting them with fossil fuels."

After spending most of her career in academia and non-governmental organizations, Van Hook comments: "I never imagined working in the business world. I'm at Ecovative for more than just my mycological knowledge, I'm here as a sort of mycelial glue. This is a break-through technology that has immense ramifications for our future on the planet. How can anyone not be excited about this?"

Author bios

Penelope Zeller is a project manager, business development specialist and passionate mycophile. Her favorite mushroom is any edible species of fungus. penelope@zellerdistrict8.com

Dena Zocher is an independent business writer, urban shaman and mother dedicated to leaving the planet better than she found it. Her favorite fungus is the fairy ring (*Marasmius oreades*). Dena.z@q.com

Acknowledgements

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Endnotes

[1] Postcode Lottery Green Challenge, a joint initiative of the Dutch Postcode Lottery and the Amsterdam based cross-media event PICNIC; http://www.greenchallenge.info/.

[2] *Fomes fomentarius*, commonly known as the Tinder Fungus, Hoof Fungus, Tinder Conk, Tinder Polypore or Ice Man Fungus.

[3] *Ganoderma applanatum*, commonly known as 'artist's conk'.

[4] Tip of the hat to Paul Stamets' *Mycelium Running*.

[5] The Life Box™ re-invents the cardboard box, implanting tree seeds and friendly spores of mycorrhizal fungi within its corrugations. Used boxes can be torn up and planted. http://lifeboxcompany.com/.

[6] International Safe Transit Association (ISTA) develops and delivers standards, educational programs and tools for the economic, social and environmental optimization of transport packaging systems.

[7] European Union Directive 2000/53/EC; http://ec.europa.eu/environment/waste/elv_index.htm.