MUSHROOM

A crusading mycologist says fungi are key to human and environmental health –

by KENNETH MILLER

MANIFESTO

and can clean up everything from **OIL SPILLS** to **NUCLEAR MELTDOWNS**

Paul Stamets shows off mushrooms in a growing room at Fungi Perfecti, his family business and farm. Work done there has inspired potential solutions to such global problems as radioactive waste, global warming, oil spills and cancer.

Left: Pioppino mushrooms (*Agrocybe aegerita*) induced tumor regression, reversing cancer in lab mice. The species also controlled blood sugar in diabetic mice.

photography by STUART ISETT, *except where noted*

For Paul Stamets, the phrase "mushroom hunt" does not denote a leisurely stroll with a napkin-lined basket. This morning, a half-dozen of us are struggling to keep up with the mycologist as he charges through a fir-and-alder forest on Cortes Island, British Columbia. It's raining steadily, and the moss beneath our feet is slick, but Stamets, 57, barrels across it like a grizzly bear heading for a stump full of honey. He vaults over fallen trees, scrambles up muddy ravines, plows through shin-deep puddles in his rubber boots. He never slows down, but he halts abruptly whenever a specimen demands his attention.

This outing is part of a workshop on the fungi commonly known as mushrooms — a class of organisms whose cell walls are stiffened by a molecule called chitin instead of the cellulose found in plants, and whose most ardent scientific evangelist is the man ahead of us. Stamets is trying to find a patch of chanterelles, a variety known for its exquisite flavor. But the species that stop him in his tracks, and bring a look of bliss to his bushy-bearded face, possess qualities far beyond the culinary.

He points to a clutch of plump oyster mushrooms halfway up an alder trunk. "These could clean up oil spills all over the planet," he says. He ducks beneath a rotting log, where a rare, beehive-like Agarikon dangles. "This could provide a defense against weaponized smallpox." He plucks a tiny, gray *Mycena alcalina* from the soil and holds it under our noses. "Smell that? It seems to be outgassing chlorine." To Stamets, that suggests it can break down toxic chlorine-based polychlorinated biphenyls, or PCBs.

Most Americans think of mushrooms as ingredients in soup or intruders on a well-tended lawn. Stamets, however, cherishes a grander vision, one trumpeted in the subtitle of his 2005 book, *Mycelium Running: How Mushrooms Can Help Save the World*. Mushroom-producing fungi, he believes, can serve as game changers in fields as disparate as medicine, forestry, pesticides and pollution control. He has spent the past quarter-century preaching that gospel to anyone who will listen.

If his data were less persuasive, he might be dismissed as an eccentric myco-utopian. Stamets has no regular academic or institutional affiliation; his research is funded mostly by the profits from his private company, Fungi Perfecti, which sells gourmet and medicinal mushrooms (along with growing kits, mushroom-derived supplements and mushroom-related books and knickknacks) by mail order and at health food stores. With his Woodstockian hirsuteness and frank enthusiasm for mushrooms of the psychoactive sort, Stamets often comes across more as a hippie mystic than a dispassionate scientist. "Our bodies and our environs are habitats with immune systems," he writes in *Mycelium Running*, and fungi "are a common bridge between the two." He describes mycelium, the web of fibrous tissue from which mushrooms spring, as "the neurological network of nature," a "sentient membrane" that has "the long-term health of the host environment in mind." To some, such language seems uncomfortably metaphysical.

Mycelia change their behavior in response to the environment. When you walk through the forest, they leap up. They know you're there.

Yet Stamets' ideas have gained an expanding audience among mainstream scientists, environmental engineers, federal officials and Silicon Valley investors. His 2008 talk at the TED Conference, the annual hajj of tech barons and thought leaders, has snagged more than 1.5 million hits since it was posted online; it also earned Stamets invitations to brainstorming sessions with Bill Gates, Amazon CEO Jeff Bezos and the guys who run Google.

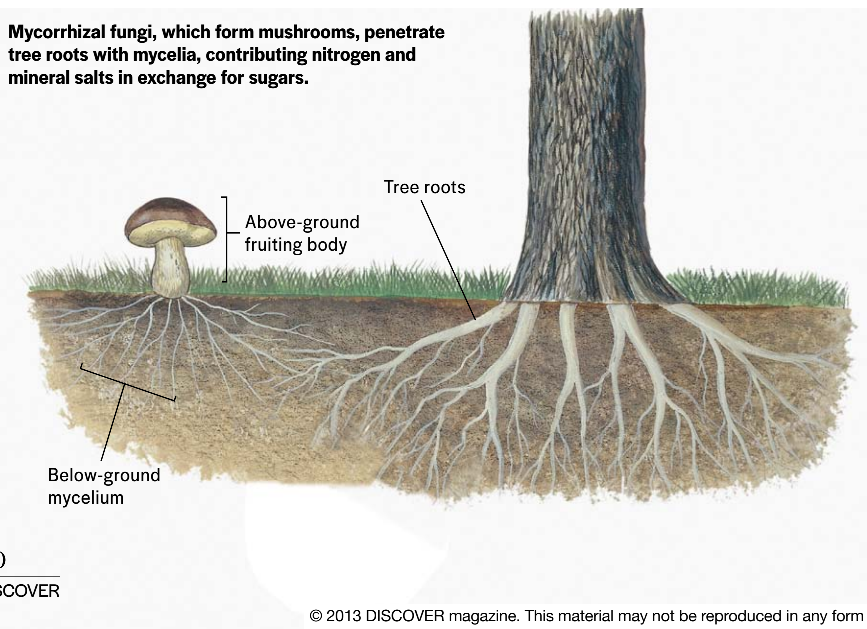
"It helps that he's brilliant," says Eric Rasmussen, a former Defense Department scientist and disaster expert collaborating with Stamets to decontaminate the zone around Japan's Fukushima nuclear reactor with mushrooms. Rasmussen compares Stamets to visionary entrepreneur-scientists like Thomas Edison or "some of the truly fine amateur naturalists or astronomers of the 17th and 18th centuries — people who were experts in their fields, but had other ways to occupy their days."

Stamets occupies some of his days teaching fungus aficionados and would-be mycotechnologists, both here at the eco-oriented Hollyhock Lifelong Learning Centre and at his mushroom farm in Washington state. He runs a business that has 47 employees and ships goods worldwide. Somehow, he also manages to juggle a diverse array of experiments — often in tandem with researchers at universities or nonprofit outfits — aimed at finding fungal solutions to global problems. "The path to the future," he likes to say, "is the path of the mycelium."

A PLANETARY WEB

However poetically expressed, Stamets' notion that mushrooms bridge human and environmental immune systems is grounded in solid biology. On the evolutionary tree, the animal and fungal kingdoms sprout from the same branch,

Mycorrhizal fungi, which form mushrooms, penetrate tree roots with mycelia, contributing nitrogen and mineral salts in exchange for sugars.



splitting from each other long after plants diverged. And fungi knit together the lives of plants, animals and the Earth itself in some very concrete ways.

There are an estimated 1.5 million species of fungi, comprising yeasts and molds along with mushroom-producing macrofungi. All these organisms share certain basic traits with animals: They inhale oxygen and exhale carbon dioxide, as we do, and they are susceptible to many of the same germs. Like us, they get their energy by consuming other life forms rather than by photosynthesis.

But a fungus's body is radically different from an animal's. Yeasts are unicellular, while molds and macrofungi take the form of mycelia, networks of threadlike membranes, each a single cell thick, that can infest a rotting orange, infiltrate acres of woodland or fuse together to make a mushroom. Mycelia absorb nutrients from their surroundings and can rapidly change their growth patterns and other behavior in response to the environment.

"They have cellular intelligence," Stamets says. "When you walk through the forest, they leap up in search of debris to feed on. They know you're there."

When fungi colonized land a billion years ago, some established a niche as Earth's great decomposers — key to the creation of soil. Their mycelia exude enzymes and acids that turn rock into biologically accessible minerals and unravel the long-chain molecules of organic matter into digestible form. Fungal mycelia hold soil together, help it retain water and make its nutrients available to vegetation. Species known as mycorrhizal fungi use their mycelia to envelop or penetrate plant roots, contributing nitrogen compounds and mineral salts in exchange for sugars from the host organism. (When a sapling is languishing in the shade of a larger tree, these fungi can sense the problem and send the youngster extra nourishment.) Mushroom-producing fungi feed animals; animals return the favor by spreading fungal spores.

To ward off pathogens, fungi have developed an arsenal of antibacterial and antiviral compounds — a resource that traditional peoples harnessed in the form of mushroom teas and foodstuffs. Alexander Fleming exploited them in more modern fashion when he isolated penicillin from the *Penicillium rubens* mold in 1929. Fungi can also parasitize and kill insects, including those troublesome to us.

For millennia, humans have exploited microfungi (molds and yeasts) to create edibles such as cheese, bread, beer and wine. But in Western culture, Stamets observes, the powers of macrofungi have been largely ignored, an attitude he refers to as "mycophobia" or "biological racism." Mushrooms were relegated to the Campbell's can, or outlawed when they blew too many minds. They were discounted, devalued, shunted aside.

Just as Paul Stamets was, before he found his own mycelial path.

THE MYCELIAL PATH

To understand how Stamets came to believe mushrooms could save the world, it helps to know how they saved Stamets.

He was born in 1955 in Salem, Ohio, one of four brothers. His father, an engineer, owned a firm that oversaw construction projects for the U.S. Army. Stamets was a shy kid with a crippling stutter who dreamed of becoming a trailblazing scientist. "We lived in a big house with a lab in the basement," he recalls, "and I looked up every experiment I could find." He nearly blew the place up on several occasions while tinkering with chemicals.

Then, when he was 12, his father's business failed and the family splintered. Stamets' mother decamped with him and his twin brother to a small apartment in Columbiana, Ohio, where they lived in poverty. Eventually, she moved with the boys to her own parents' vacation home near Seattle and sent them on scholarship to a boarding school in Pennsylvania. Stamets felt like a misfit among preppies. He threw himself into martial arts (later earning black belts in both tae kwon do and hwa rang do) and identified with the counterculture that was reaching its crest.

During his senior year, Stamets and his brother were expelled for selling marijuana to fellow students. They hitchhiked back to Seattle, where they finished high school at a public institution. Stamets spent a summer

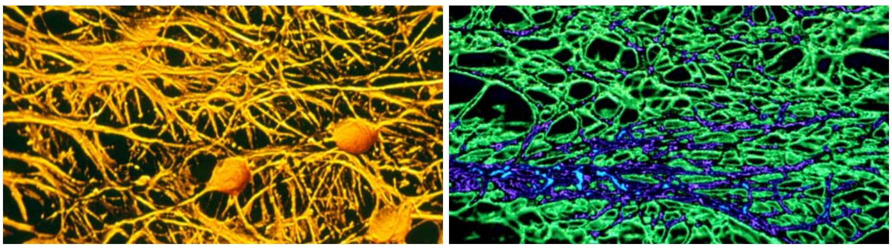
THE FUNGAL MIND

The cottony mycelium of a Garden Giant mushroom grows on fermented wood chips.

When you look at a mushroom, what you're seeing is a fungus's fruit. It emerges from a mass of fibrous tissue known as mycelium, which penetrates whatever material the mushroom is growing on. To the naked eye, mycelium resembles cottony fluff or cobwebs. Viewed through an electron microscope, however, it's an intricate weave of branching, threadlike membranes whose structure, Stamets notes, resembles a network of brain cells. And that, he argues, is evidence that fungi possess a kind of intelligence.

The analogies are striking. Brains and mycelia grow new connections, or prune existing ones, in response to environmental stimuli. Both use an array of chemical messengers to transmit signals throughout a cellular web. (One part of a mycelium, for example, can order another to send nutrients from hundreds of feet away.) The similar structures of fungal and neural networks, Stamets believes, reflect the fact that both systems evolved to do similar jobs — and do them with maximum efficiency.

But he doesn't stop there. Stamets perceives mycelium-like patterns in the information architecture of the Internet, in the matrices of string theory, in computer models of the web of dark matter suffusing the cosmos. Such recurrences, he believes, are signs of an evolutionary intelligence governing reality itself. "Nature tends to build on its successes," he writes in his book *Mycelium Running*. "The mycelial archetype can be seen throughout the universe." — KM



Scanning electron microscope images of human brain cells (left) and mushroom mycelium.

CLOCKWISE FROM BOTTOM LEFT: DE AGOSTINI/GETTY IMAGES; STUART ISETT; PAUL STAMETS; CNRI/SCIENCE SOURCE

Against a backdrop of evergreens in Shelton, Wash., Fungi Perfecti supplies mushrooms to a growing market.

toiling as a sawmill hand before enrolling at Kenyon College in Ohio. But he still felt out of place and spent hours wandering in the woods off campus.

That's where he headed the day he tried hallucinogenic psilocybin mushrooms for the first time. He climbed a tree, but was too intoxicated to climb down. Soon a thunderstorm blew in, and he was lashed by rain and wind. As lightning struck nearby, he realized he could die at any moment, yet the scene was overwhelmingly beautiful. He felt part of the forest and the universe as never before. He reflected on his life and how to change it. "Stop stuttering now, Paul," he told himself, repeating the phrase like a mantra.

When the weather calmed, he climbed down and hiked home. On his street, he ran into a neighbor whose attractiveness had always intensified his stammer. "Hi," she said. "How are you today?"

"Fine, thanks," he answered, with an ease that astonished him. "And you?"

From that moment, Stamets' tongue began to come untied, and he devoted himself to learning about the fungi that he credited with the change. With the help of a mushroom-identification book, he found psilocybes growing wherever he looked, and he began to probe the mysteries of other species as well.

The following summer, he dropped out and took a logging job. But the more fascinated he became with mushrooms (hallucinogenic and otherwise), the worse he felt about helping to destroy their habitat. After three crew buddies were killed in logging-related accidents, Stamets decided to try school again, this time at Evergreen State College in Olympia, Wash. He wanted to become a mycologist.

Evergreen didn't have a mycology department, but it encouraged independent study. An environmental chemist named Michael Beug offered a course on mushrooms, and Stamets badgered him into becoming his adviser. "I've never had a student who was more driven," says Beug, who intensified his mycology research to keep up with Stamets. (Beug also secured a license from the Drug Enforcement Administration allowing him and his students to work with psilocybin mushrooms.) Stamets learned to run the school's scanning electron microscope — a rarity in the 1970s — and was soon photographing the cell structures of mushrooms, mycelia and spores for scientists nationwide.

By the time he graduated in 1979, Stamets had been tutored by some of America's leading academic mycologists. He was an accomplished field scientist, laboratory researcher and taxonomist. He had discovered several new *Psilocybe* species and published a book on the genus. He was an expert cultivator, too. Yet grad school seemed economically out of reach. Stamets had recently married a woman with three kids of her own, and the couple's first child was on the way. To support his family, he remained at Evergreen as an adjunct professor and started a business with a research arm on the side.

Fungi Perfecti's first lab and grow room occupied the basement of Stamets' rented house. He began selling exotic culinary mushrooms and holding seminars for the paying public. Then, after a 1983 trip to China with two of his mentors (mycologist Gary Lincoff and physician Andrew Weil, on his way to fame as a natural-health guru), Stamets became one of the first U.S. cultivators to branch into Asian medicinal varieties. Later that year, he published *The Mushroom Cultivator*, a book still widely

THE MAN WHO MISTOOK HIS MUSHROOM FOR A HAT

Although he's obsessed with finding new uses for mushrooms, Stamets is also a passionate scholar of ancient mycotechnology. He often wears one example: a traditional Transylvanian hat made of amadou, the spongy inner layer of horse's hoof fungus (*Fomes fomentarius*), which can be processed into a warm, feltlike fabric. Highly flammable, amadou has also served as tinder for flintlock guns and prehistoric campfires. (Ötzi, the 5,000-year-old "ice man" found in an Alpine glacier, was carrying the stuff in his pouch.) Its absorbent and antimicrobial properties made it ideal for dressing wounds and preserving foods. And amadou was the first medicinal mushroom on record: "Hippocrates described it in 450 B.C. as an anti-inflammatory," Stamets notes. — KM

considered essential for home and commercial growers.

In 1984 Stamets dove into his business full time. Aided by loans from relatives, he bought a 20-acre farm on Kamilche Point, a few miles northwest of Olympia. And it was there where he began to discover the macrofungi's planet-changing powers.

THE FUNGI PERFECTI FARM

Stamets' land came with a sagging farmhouse, a half-dozen cows and 400 feet of waterfront overlooking Skookum Inlet off the Puget Sound. Soon after he moved in, the sheriff rang his doorbell. "I thought, that was quick, I haven't had a chance to do anything illegal yet," he recalls. The officer informed Stamets that *E. coli* from sewage runoff was contaminating the local oyster beds, and served him with a court order requiring landowners to install updated septic systems in two years.

Stamets couldn't afford a new system. But he had suspected that mushroom mycelium could function as a natural filter the first time he saw its microscopic structure. In college, he confirmed his theory by testing the mycelia of various common species for absorbency; they all beat cotton hands down. He also knew that mycelia exude antibacterial compounds. So he decided to conduct a (literal) field test.

Garden Giant mushroom: Mycelial wastewater filtration system and culinary delight.

A marshy depression called a swale followed the gentle slope of Stamets' property, running downhill for 800 feet and ending just above the inlet. At the top of the swale, he dumped several truckloads of wood chips, which he covered with mycelium-infused growing medium — known to cultivators as spawn. Within weeks, mycelia had fully enmeshed the bed. By summer, Stamets had his first harvest of tasty Garden Giant (*Stropharia rugosoannulata*) mushrooms. A year after the planting, when water quality inspectors checked his runoff, they found his septic system was no longer a source of pollution; fecal bacteria levels measured a hundred times less.

Technicians from a Seattle-based bioremediation company, Enviros, learned of Stamets' success and asked him for advice on using fungi to clean up oil-soaked soil. At the time, many experts were betting on hydrocarbon-eating bacteria as an eco-friendlier alternative to the conventional way of cleaning up such contamination — which was to truck the affected soil to a landfill and replace it with clean dirt. But bacteria can have trouble breaking down petroleum's largest molecules, and they're finicky about ambient temperature and oxygen levels.

A few researchers had begun experimenting with fungi instead. It had long been known that mold and mushroom species called "white rot" fungi could eat the lignin in wood, using enzymes to convert its complex hydrocarbons into nutritious carbohydrates. Molds also sometimes colonize fuel tanks, where they use those same enzymes to consume petroleum products. In the lab, a white-rot mold called *Phanerochaete chrysoporium* had shown particular thoroughness at digesting oil, but it often failed to perform under outdoor conditions. The Enviros staff hoped to find a hardier fungus, and Stamets suggested they try oyster mushrooms (*Pleurotus ostreatus)*, an aggressive white-rotter that could grow practically anywhere. He sent them some oyster mushroom spawn. The technicians covered it with oil, most of which was consumed within three weeks; mushrooms were popping up through the muck. But Enviros went bankrupt before the work could proceed further.

Meanwhile, Stamets began installing experimental mycelial wastewater filtration systems for other farmers (eventually with funding from the county and the state), improving on his initial design by encasing *Stropharia* spawn and wood chips in burlap sacks and packing them into ditches placed to catch maximum runoff. He began touting the method in environmental journals, and in 1996 he was approached by Pacific Northwest National Laboratory, operated by the Battelle Memorial Institute, known

Petroleum-eating oyster mushrooms resembling those above can remediate soil contaminated by oil spills.

for technological solutions to energy and environmental issues. Although initial interest was in Stamets' wastewater work, excitement grew when he mentioned his foray into oil-spill remediation.

Stamets and the Battelle team began lab work to maximize the mushroom's petroleum-eating efficacy. From his research on psilocybes, he knew that different strains of a single mushroom species can have wildly varying levels of chemical activity. So the team grew a few dozen strains of oyster mushroom, testing each for oil-digesting ability in petri dishes in the lab.

The strains that consumed oil fastest were selected for further trials, and in 1998, the team used the top performers in an experiment sponsored by the Washington State Department of Transportation at a maintenance yard in Bellingham. Soil at the site was contaminated with diesel fuel at up to 20,000 parts per million, similar to concentrations on Alaskan beaches after the Exxon Valdez oil spill. That spring, WSDOT scooped out four piles of dirt. Stamets' team added layers of myceliated wood chips to one pile and covered it with a shade cloth. Two of the piles were treated only with bacterial cultures or chemical fertilizers. One pile was left as a control.

Four weeks later, the myceliated sample was light brown, sweet-smelling and bursting with mushrooms — some more than 12 inches in diameter. Insects came to eat the fungi, and their larvae attracted birds, which likely deposited seeds. After nine weeks, the pile was covered with flourishing plants. Aromatic hydrocarbons had dropped to less than 200 ppm, suitable for freeway landscaping.

"The other piles," Stamets recalls, "remained dead, dark and stinky."

The mushrooms had won.

HOW MUSHROOMS CAN SAVE THE WORLD

By then, Stamets was obsessed with the possibilities of what he called "mycorestoration," a nascent field encompassing his own and other researchers' work in mycofiltration, mycoremediation, mycoforestry and mycopesticides (most of which are terms he coined). He began amassing a genetic library of hundreds of mushroom strains — gathered on hikes through the old-growth forests of the Northwest and on trips to Europe, Asia, South America and Australia — that could be used for environmental as well as medicinal healing.

The EPA asked Stamets to help the Coast Guard find ways to clean up waterborne oil spills. In response, he invented the mycoboom, a burlap tube filled with oyster mushrooms designed to break down petroleum while floating on a slick or barricading a beach. Battelle researchers tested his fungal strains against neurotoxins and found one potent variety of psilocybin mushroom highly effective at breaking down VX nerve gas. Stamets collaborated with the Washington State Department of Natural Resources on another successful field experiment, planting mushrooms on old logging roads to prevent silt and pollutants from clogging streams. He improved

Growing room manager Justin Tulloss inspects Lion's Mane mushrooms (***Hericium erinaceus***) at Fungi Perfecti. At right, mycorestoration project coordinator Katie Brownson works in the production facilities.

Mushroom cultures are propagated at the Fungi Perfecti farm and sold as part of its growing kits.

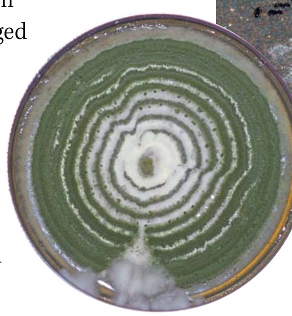
crop yields on farms and sped up reforestation in woodlands by adding mycorrhizal fungi to soil. In one case he planted broccoli together with elm oyster mushrooms; in another, he dipped Douglas fir seedlings into a slurry of puffball mushroom spores. He invented the Life Box, a cardboard carton impregnated with tree seeds and symbiotic fungi. After use (for shipping shoes bought online, for example), the box could be torn apart and planted to replace the trees used in its manufacture.

But the invention with the greatest immediate impact on Stamets' own environment grew out of his relationship with herbal medicine practitioner Carolyn "Dusty" Yao, which began in 1997 after his first marriage fell apart. (Stamets and Yao were married, with Andrew Weil officiating, four years later.) When Yao moved in, she was dismayed to find that Stamets' old farmhouse was infested with carpenter ants — attracted, ironically, by a white-rot fungus that was crumbling the floor joists. Stamets, who had ignored the problem for years, promised to take care of it.

He wanted to use a natural pesticide that was nontoxic to humans; unsurprisingly, he began looking for one derived from fungi. He knew that a few mold species could infect insects with their spores, killing them in the process. (In some cases, a tiny mushroom pops through the corpse's skull.) Yet existing mycopesticides worked poorly against social insects, which could smell the spores and stop workers carrying them from entering the nest.

Stamets smelled a challenge. He sent away for a sample of *Metarhizium anisopliae* mold, known to kill termites and carpenter ants when its spores are sprayed on them directly. His idea was to train the fungus, which normally produces spores nonstop, to hold off until the ants had carried it into the nest. In its presporulating form, he thought, the insects might be attracted to *Metarhizium* as a source of nutrition. Once they ate it, the mycelium would consume them in return.

When Stamets cultured the mold in his lab, a white circle of mycelium spread over the petri dish from the point of inoculation; it was soon covered with green spores. He transferred bits of the mold to other dishes, where they reproduced for several generations. Eventually, white stripes emerged amid the green in one dish, where the mycelium (perhaps due to a damaged gene) was lagging in its spore production. He then took some of the white material and cultured it over many more generations, breeding a mutant strain of *Metarhizium* whose sporulation cycle was delayed for days or longer.



Stamets grew his developmentally delayed mycelium on rice. When it was ready, he put a teaspoon of the spawn on a dollhouse dish belonging to his then-teenage daughter, LaDena, and placed it on the kitchen floor. That night, she ran to his bedroom yelling, "Wake up! You've got to see this!" The dish was swarming with ants, which were carrying grains of myceliated rice back inside the walls. Two weeks later, the house was ant-free, and remained that way from then on. After the insects died, Stamets hypothesized, the smell of their moldy bodies warned others away.

Further testing showed that other strains of *M. anisopliae* and another mold, *Beauvaria bassiana*, could also be modified to attract and then exterminate a wide variety of bugs. In 2003, Stamets patented

Ants succumb to the pesticide power of green *Metarhizium* fungus, grown in the petri dish at left and disguised as food.

BOTTOM RIGHT: PAUL STAMETS

Reishi mushrooms are used to produce the antibiotic ganomycin.

Lion's Mane mushrooms might be useful for regenerating nerves and treating Alzheimer's.

his method and licensed it to a company that planned to bring it to market.

He used the proceeds to tear down his decaying house and build a new one, with cedar walls, a soaring roofline and a geothermal heating system. A stained-glass window dominates the living room, depicting the cosmos entwined with a mycelium-like network of dark matter.

MUSHROOMS FOR HEALTH

Across the meadow from Stamets' home sits a cluster of hangar-size white metal sheds and Quonset huts: Fungi Perfecti's offices, labs and grow rooms. Inside, workers tend to fruiting maitake mushrooms for medicinal teas, stuff plastic bags with oyster mushroom spawn for home-growing kits, or propagate fungal cultures in clean rooms equipped with airlocks and laminar-flow benches. These days, however, the company's fastest-growing product line (co-created by Yao, now his partner in virtually all enterprises) is a line of nutraceutical mushroom extracts, sold through another facility a few miles away.

According to FDA regulations, a nutraceutical manufacturer can't claim its products are able to treat any particular illness. So Fungi Perfecti markets its tinctures as general immune-system boosters and antioxidants. But mushrooms are known to contain a host of proven disease-fighting chemicals, including polysaccharides, glycoproteins, ergosterols and triterpenoids, as well as antimicrobial and antiviral compounds, all varying according to species and strain. Indeed, a handful of pharmaceutical medications are derived from mushrooms, including the antibiotics ganomycin (from reishi mushrooms) and campestrin (from meadow mushrooms) and the chemotherapy drugs calvacin (from giant puffballs) and Illudin S (from the glow-in-the-dark jack-o'-lantern mushrooms).

Stamets is working aggressively to add to that list, and over the past decade, he has initiated or consulted on a dozen laboratory and clinical trials aimed at deriving novel mushroom-based drugs. After the 9/11 attacks, for example, he sent hundreds of samples to the federal Bioshield program, whose mission is to develop defenses against biological weapons. Several of his proprietary strains of Agarikon (*Fomitopsis officinalis*) showed strong activity against H1N1 swine flu and H5N1 bird flu, as well as viruses in the smallpox family. Stamets furnished capsules of freeze-dried fungus for a seven-year, NIH-funded study by Bastyr University and the University of Minnesota to determine whether turkey tail mushrooms could help breast cancer patients whose immune systems had been compromised by radiation therapy. Last year, the researchers announced that natural-killer cell activity, CD8 T-cell counts and other immune functions improved significantly with the treatment.

Stamets' mother, by coincidence, was diagnosed with stage IV metastatic breast cancer in 2009, at age 83. Although she was ineligible for the trial, he put her on turkey tail capsules to supplement her conventional chemotherapy drugs, Taxol and Herceptin. After six months, Patricia Stamets' tumor disappeared, and today she remains cancer-free. Though a single anecdote falls far short of proof, the deeply religious woman credits prayer as well as mushrooms for her return to health.

RENEWING A NUCLEAR FOREST

Divine intervention notwithstanding, progress toward Stamets' mycotechnological promised land has been slow. His

Turkey tail mushrooms: Stamets sent these to his mother when she was diagnosed with breast cancer.

medical research has yet to produce a marketable drug. His mycopesticides are held up in product development. His mycorenewal ideas still haven't been applied on a large-scale basis. When he proposed using mycobooms to battle the 2010 Deepwater Horizon oil spill, officials never even responded.

Yet momentum may be building. Last year, the EPA awarded Stamets $80,000 to design a mycofiltration system for managing storm water runoff. A global environmental consulting firm, New-Fields, has adapted some of the techniques Stamets pioneered to remediate polluted soil. In Ecuador, the nonprofit Amazon Mycorenewal Project, run by an alumna of Stamets' seminars, plans to use mushrooms to clean up oil waste left by drillers. In New York, another nonprofit is experimenting with mycobooms to help cleanse the Newtown Creek toxic-waste Superfund site. In Grafton, Mass., renowned environmental engineer John Todd is using a Stamets-designed mycofilter to scrub petrochemicals from an old mill canal.

And then there's Stamets' plan to redeem the devastated landscape around Fukushima. Shortly after the 2011 tsunami-driven meltdown, he posted an online manifesto called "The Nuclear Forest Recovery Zone," which was predicated on a little-known fact about mushrooms: Many species are able to remove and absorb heavy metals, including radioactive isotopes, from soil.

Stamets' proposal was simple. First, fence off the contaminated area around the reactors. Then chip the wood debris from ruined buildings and trees, and spread it over the area to make substrate. Replant native trees along with mycorrhizal fungi, which will help the trees grow while drawing radioactive material from the soil. Harvest the mushrooms as soon as they form, and dispose of them as nuclear waste. Repeat as necessary for several decades or even centuries until the Geiger counters stop screaming. The alternative, he pointed out, was to cart away millions of tons of soil and bury it as nuclear waste, taking up far more landfill space and depriving Japan of some of its best farmland and forestland forever.

The blog post went viral, although even many hardcore mycophiles assumed the plan was hypothetical. Eric Rasmussen, however, believed it was worth a try. The veteran disaster-relief coordinator had met Stamets nearly a decade earlier at a conference Rasmussen organized on environmental issues in refugee camps. "Paul had a lot of clever ideas that seemed both benign and effective, which is a rare combination," Rasmussen recalls. The two became close friends.

Last year, aiming to make the Nuclear Forest Recovery Zone a reality, Stamets partnered with Battelle researchers at the Energy Department's former nuclear production facility in Hanford, Wash., to test various mushroom species for their ability to take up cesium. Results are expected within the next few months.

Stamets, as usual, is optimistic. "I know some of my hypotheses sound rather extraordinary," he says. "I may be a little weird, but I'd rather be weird and right than normal and wrong."

Kenneth Miller is a Los Angeles freelance writer who contributes frequently to DISCOVER.

MUSHROOMS TO THE RESCUE

Stamets is researching a wide variety of ways in which fungi could help solve human problems. Here is a partial list:

Environmental cleanup Mushrooms could be used to break down petrochemicals or absorb radiation from contaminated soil and water.

Wastewater filtration Mushroom mycelia could cleanse runoff from storm drains, farms or logging roads. They could be used to filter out the nitrates, endocrine disrupters and pharmaceutical residues that disrupt ecosystems and damage human health.

Pesticides Fungal bug-killers could be used to target troublesome species while remaining nontoxic to others.

Medicines Mushrooms could provide new antibiotic, antiviral and immune-boosting compounds and even chemotherapies.

Forestry Planting symbiotic mushroom species could speed reforestation in clear-cut woodlands.

Agriculture Adding mycorrhizal fungi to soil could improve crop yields without the need for toxic chemical fertilizers.

Famine relief Mushrooms could be grown rapidly in refugee camps and disaster zones, using just wood chips or saltwater-soaked straw.

Biofuels Growing mushrooms for biodiesel could require far less soil and other resources than commonly cultivated fuel crops.

Space travel Because of their usefulness in soil creation, and the tolerance of many species for radiation, mushrooms could be grown by interstellar voyagers and used to terraform other worlds. —KM

Agarikon (*Fomitopsis officinalus)* mushrooms could protect against bird flu, swine flu and smallpox.

Slimy spike-cap mushrooms (*Gomphidius glutinosus)* can uptake radioactive cesium-137.

CLOCKWISE FROM BOTTOM LEFT: STUART ISETT (2); PAUL STAMETS (4)

See more pictures from the mushroom farm at **www.DiscoverMagazine.com/Mushrooms**