

SCIVIEW

Fall 2014 | Science Journalism Project | University of Arizona



Lightning Strikes

One Tucsonan's "Shocking" Science **Page 20**

"B" is for Biosphere 2

Photo Essay: Still Full of Life **Page 8**

Constructing an Artificial Earth **Page 12**



VIEW FROM THE TOP

Mark Armao, a University of Arizona journalism senior, pauses to shoot a photograph from the top of the artificial mountain in the Biosphere 2 rainforest.

PHOTOGRAPH BY JESSICA BURKHART



An Oasis of Discovery

Science

Science is about inquiry. It investigates how things work in the world around us.

The University of Arizona and the surrounding city, desert and mountains are laboratories for inquiry. As soon as students step onto campus, they enter a world of cutting-edge research in astronomy, optics, geosciences, ecology, medicine, engineering and other specialties of the university.

And so, in Professor Carol Schwalbe's science journalism class in fall 2014, we inquired. Seventeen undergraduate and graduate students from different disciplines learned how to evaluate scientific research, find story ideas and interview scientists. We wrote and edited stories, took photographs, created information graphics and shot videos about science.

But we also experienced science. We held baby Sonoran desert tortoises as we interviewed a scientist who studies the species. We photographed Gila monsters, snakes, tortoises and caterpillars. We made an overnight field trip to the university's Biosphere 2. The site of a space age experiment in communal living, it is alive with new projects that study Earth's processes.

This is the world about which we inquired, and *SciView* is a journal of our experiences.

We hope you enjoy learning as much as we have.

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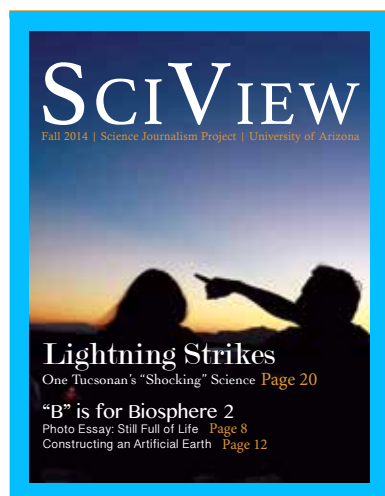
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FRONT COVER: Visitors watch the sunset from a ridge overlooking Biosphere 2.

PHOTOGRAPH BY TAYLOR SANDERS

COVER DESIGN BY ALAN SCOTT DAVIS

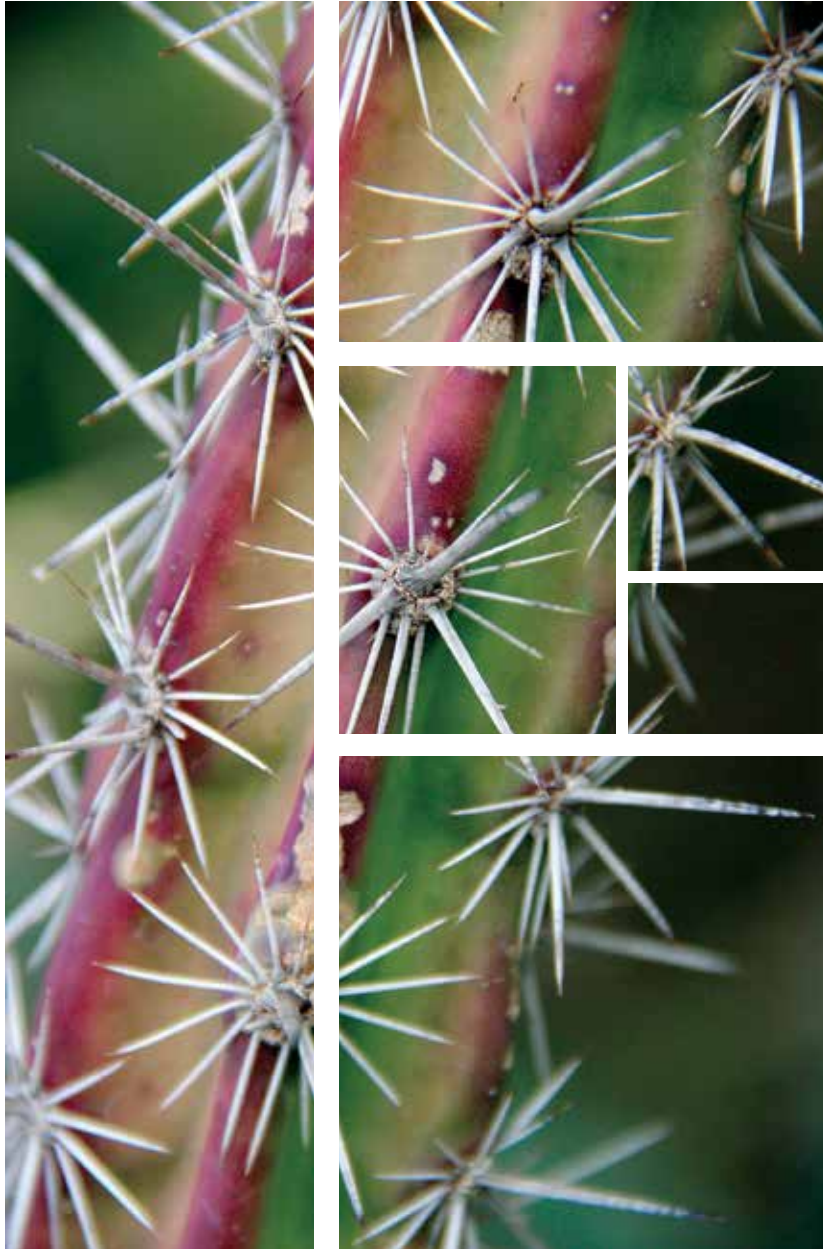
BACK COVER: Every year more than 100,000 visitors from all over the world flock to Biosphere 2, which was built to see how humans might survive in a self-sustaining colony on another planet.



MULTIMEDIA CONTENT: For videos and more photos, follow the group at [Facebook.com/SciCats](https://www.facebook.com/SciCats)

SCIENCE JOURNALISM: For more information about the science journalism program at the University of Arizona, please contact Professor Carol Schwalbe at cschwalbe@email.arizona.edu

Table of Contents



A young cactus grows outside Biosphere 2 near Oracle, Arizona.
PHOTOGRAPH BY VALERIE ROUNTREE

ACKNOWLEDGMENTS

The publication of SciView magazine would not have been possible without the generous support of the University of Arizona Confluentcenter for Creative Inquiry and the School of Journalism. Students in Gawain Douglas' Publication Design class at the School of Journalism laid out some of the stories.

6 | Reversing the Organ Shortage
By Patrick O'Connor

8 | Still Full of Life:
A Photo Essay
By SciView Staff

12 | Constructing
an Artificial Earth
By Mikayla Mace

20 | Sensing Light-
ning in Tucson
By Ann Posegate

26 | Edible Mush-
rooms from Trash
By Valerie Rountree

4 | My Tiny Creature
By Dieu My Nguyen

5 | Stars of Wonder
By Jordan Fowler

18 | Reptile Day: A Photo Essay
By SciView Staff

25 | Lighting a Beautiful Fire
By Jessica Burkhart



PHOTOGRAPH BY DIEU MY NGUYEN

My Tiny Creature

By Dieu My Nguyen

A CRICKET CANNOT BE TAMED. The tiny creature has been sitting next to me on a half-green grass field. Any moment now, he may hop away. He is so tiny, but his body is uncatchable when his skeletal muscles contract and relax at a speed faster than that of my *Homo sapiens* body. So I keep him in a Ziploc bag.

It is a Tucson kind of August. The heat manifests in the quick tanning of skin and the futility of deodorant. Surrounded by trees, I wonder: Without human care, would all the tall mesquites and acacias still give life to such vivacious green?

A dead, brown Shumard oak leaf falls beside my stretched-open legs. This quietness will be gone the moment I get up and walk toward the cars. Sit and sit and let the brain and limbs rest for a bit. The growing oak umbrellas me from the sun.

The sun is lowering, or am I merely rotating around it, sitting here so super-still? My hair is combed backward by a tiny breeze.

As if seeing that my ears are no longer

blocked by hair, my companion begins chirping for attention. New to chirpings of any kind, I cannot decode this auditory emission.

Since getting this tiny creature from PetSmart for 11 cents on a whim, I've researched crickets for the sake of feeling prepared. There are at least three types of cricket songs, sung by males (my cricket must be a male, then):

The loud calling song to attract females.

The quiet courting song to woo a sweetheart or two.

The aggressive song to intimidate other males.

Which is this one, or is my creature producing a new kind of song, yet to be discovered? A song of plea, perhaps? After all, a Ziploc bag must be a damned prison, especially for a hopper.

I hold him by the antenna. He is smaller than the top notch of my pinky. He has a body brown as the dry spot of grass ahead and eyes so black and legs so thin.

The wind sometimes gets so fierce I am afraid his little body will be blown away. The moment I detect the stillness of the branches, I set the cricket down on the oak leaf that has not left with the wind. He is stunned into stillness, defying my expectation of his escape on the first chance of freedom. I am stunned into stillness, glancing at him. His eyes won't meet mine.

We both face the sunset glow. The silence is like that of two lovers, or hateful enemies, crossing paths after a long

We both face the sunset glow. The silence is like that of two lovers.

absence. It's as if each has been floating elsewhere while in the same room, at the same dinner meal, on the same mattress every night.

But at the present moment, both our heads are clear, our lungs clean, our hearts wide as we lean back and anchor ourselves to the Earth. If we turn and look at each other, the silence might roar and soar. So I don't initiate any movement. I look at the pinkness of the sky.

Then, he is gone.

What shattered the unity? The end of the western sunset? My turning to glance at him?

Instinct must have yanked at him. My cricket has answered to the call of freedom, to the wind and maybe to a mate or pal. He has vanished into the grassy field, blending into the brown patches of dryness. I blink and touch my chest and lungs—he hasn't taken anything of me with him upon his departure.


I wait.

I remember *The Little Prince*: Just as the golden-haired prince tames a fox and becomes his friend for a while in the story, so the cricket has tamed me. But "I did not know how to reach him, how to catch up with him." I've given him a part of me, but he did not take it.

My mind suddenly runs again, toward "matters of consequences": the essay due in two days, the check for rent I have not sent, my bicycle's dry and oilless chain, a lover I am afraid of losing, the uncertainties of the future and all the life choices falling before me like ripe black figs as I sit and cannot choose and waste my time.

The sky has darkened in a blink. I shall no longer wait for the hopper. I shall walk away from this moment now, back to the cars and buildings. Pleasantly, though, in my lungs and limbs, a tune of quiescence begins to play, as if to say, "Slow down. You'll get there." ■

This essay appeared in the fall 2014 issue of The Blue Guitar magazine.



SciView staffers participated in an astrophotography workshop led by optical scientist and astrophotographer **Johnathan M. Davis at Biosphere 2.**
PHOTOGRAPH BY JOHNATHAN M. DAVIS

Stars of Wonder

By Jordan Fowler

IT WAS THE PERFECT NIGHT FOR STARGAZING—a cool breeze, no moon and not a cloud in sight. After a long day of hiking and dinner around the campfire, my dad and I walked over to the lake near our campsite and lay down on the pier. We had a 360-degree view of the wonders the sky held.

My dad began to speak, explaining the theories behind this great expanse in a way that I might understand at only 7 years old.

“See all these stars? They’re incredibly far away from us,” he told me, his voice low so as not to disturb the quiet of the night. “The light takes so long to reach us here on Earth that if we had a telescope powerful enough to view them up close, we’d be seeing them millions of years in the past.”

“Really?” I asked.

“Yes. And if there was someone on those stars looking at us, they might be seeing the dinosaurs right now.”

I stared up at the sky, amazed at what I was hearing. It wasn’t quite time travel, but it was close enough for me. I was hooked.

This was my first experience with the vast infinity of our universe and the immense smallness of the space we occupied. I struggled to understand the speed at which the stars’ light traveled and their distance from us, numbers too big for my young mind to grasp. I wanted to lie on that dock forever, wrapped in darkness and surrounded by the silence, picking out constellations and shooting stars.

This moment was by no means my first encounter with science. My father, a mechanical engineer turned pilot, had a passion for science. He took every opportunity to teach me and my brother about the inner workings of our universe, whether that meant trips to science museums or a crudely illustrated lecture about physics over dinner. This moment was, however, the first time I had encountered a topic grand enough to fill my mind.

My interest in the universe hasn’t waned since that evening on the dock. In the years to come I would sit outside at night with my father trying to focus a telescope, or I would stay awake long past my bedtime listening to an astronomer explain what we saw in the sky. I devoured Brian Greene’s writings on the origin and nature of our universe.

But many other interests have revealed themselves to me as well, as the stars do when your eyes adjust to the darkness. I’m sure my dad hoped I would follow in his footsteps and become a scientist myself, but my short attention span and desire to acknowledge my creative side led to a compromise: I would become a science writer. Instead of making my own scientific discoveries, I would explain those discoveries to others. In this way, I combined my two loves, writing and science, without having to sacrifice the passion I discovered that night on the dock. ■

This essay appeared in the fall 2014 issue of The Blue Guitar magazine.

Reversing the Organ Shortage

Patients in Arizona wait two to three years on average for a lung transplant. A University of Arizona associate professor of surgery is trying to shrink that wait time.

STORY AND PHOTOGRAPHS BY PATRICK O'CONNOR

DR. ZAIN KHALPEY STANDS next to a ghostly white lung pumping frantically on the table next to him. "That's pretty damn good, actually," Khalpey says as he gazes at the data recorded by the lung's ventilator.

The ventilator indicates that the pig lung is inflating and deflating like a normal lung. Experiments such as this bring research a step closer to the operating room.

An associate professor of surgery at the University of Arizona, Khalpey focuses his research on making more organs available to patients who need a transplant. Every day, 18 people on the transplant list die waiting for a new organ, according to the U.S. Department of Health and Human Services.

In Arizona patients have to wait two to three years for a lung transplant, according to the U.S. National Library of Medicine. This waiting period is emotionally and financially draining for patients.

Khalpey is trying to shrink the wait time. He is taking damaged organs and refurbishing them so they end up in a needy patient's body rather than a trash can. Other organs too damaged to be refurbished are stripped of their cells and used to grow new organs with the patient's own stem cells.

In the future, donor organs may not even be needed. Khalpey is working on hybrid organs that are 3-D printed from a patient's stem cells.

From London to Tucson

Khalpey's passion for transplant surgery started on a rainy day in 1990s London. A 16-year-old boy lay on the operating table about to undergo a heart-and-lung transplant. Cystic fibrosis had caused his lungs to become a breeding ground for infections that whittled away his ability to breathe.

A team of surgeons replaced the boy's lungs as well as his heart because he was more likely to survive with



An experiment with a pig lung brings laboratory research a step closer to the operating room.

donor organs. The medical team rushed the boy's viable heart to a second operating room, where it gave new life to another patient.

Both operations were a success—but at a cost. For the rest of their lives, both patients would need to take expensive medications that would prevent their immune system from rejecting the transplanted organs. Those lifelong medications also increased the likelihood that both patients might develop new afflictions, such as diabetes, osteoporosis, kidney damage and cancer.

A medical student in the operating room believed that trans-

plant surgery could be improved. That medical student was Zain Khalpey.

Born in Zimbabwe, Khalpey had traveled to England to study medicine. He completed his medical degree at the University of London and a doctorate in cardiothoracic surgery, bioenergetics and cardiac transplantation at London's Imperial College. Khalpey then trained at Harvard Medical School and the Mayo Clinic to master cardiothoracic surgery and transplant surgery. Inspired by UA's history with artificial heart transplants, Khalpey came to Tucson in 2013.

Saving organs from the dumpster

Hospitals throw out damaged organs every day, but recently some of these organs have found their way to Khalpey's lab in the Medical Research Building. Khalpey investigates ways to recondition lungs so they have the potential to save lives. "Reconditioning means that you have a lung that is marginally damaged that you want to optimize," he said.

Khalpey and his team preserve damaged lungs in a solution that slows the reactions going on inside the cell. The researchers then soak the lungs in a series of different solutions that reduce the damage. After the researchers test the lungs' performance, they are ready for transplant long after their traditional expiration date.

“Every test we do (on these organs) is translatable and exactly what we’d do in the operating room,” Khalpey said.

Khalpey hopes to test this technique in the next year through a clinical trial at the University of Arizona Medical Center.

“Our new therapies will provide more long-term benefits for lung transplant recipients,” said Anthony V. Louis, a research specialist and registered respiratory therapist in the Khalpey lab. “Patients on the lung transplant wait list will be transplanted quicker than current times because of the potential increase in the number of donor lungs qualifying for donation.”

Growing with ghosts

No matter how much work Khalpey and his team do, some organs will never be suitable for reconditioning. They are, however, useful to study. In these cases, the researchers strip the organ of its cells in a process known as decellularization.

“(Decellularization) entails washing out the lung with different solutions like detergents that take out all of the cellular matter,” said Destiny Lagrand, the cardiothoracic transplant research administrator in the Khalpey lab.

All that remains after the seven-hour process is the organ’s white bioskeleton. It is composed of the fibrous proteins that serve as a backbone for the organ’s cells.

Using a sterile, tightly controlled incubator called a bioreactor, Khalpey and his team are experimenting with reseeded the bioskeleton with stem cells from a patient who needs an organ. This new organ would be an instant match for the stem cell donor and would not require immunosuppressive medication after transplant.

The process is still experimental, but Khalpey is confident that it can be used in humans in the future. “(Previous efforts at reseeded) were more science fiction, and we need to bring it to reality,” he said. “Once I’m happy with reseeded and we have cellular integrity, I will put (reseeded lungs) in a pig.”

If tests in animals are successful, we may not be far off from having bioreac-



Dr. Zain Khalpey monitors data from the beating of a decellularized pig lung at his transplant surgery lab in the university’s Medical Research Building.

tors in hospitals all over the world.

The reseeded process is expensive and takes more than a month of work by trained scientists. “It takes a lot of resources,” Khalpey said, “but if you think about what it could do to people who are waiting for lung transplants, then you can’t put a price on that.”

Organs fresh off the presses

Reseeded organ bioskeletons may work for simple organs such as bladders, but it has been difficult to scale up to more complicated organs such as the heart and lungs. To bridge this gap, Khalpey and his team have recently begun using bio-inks made of living cells in 3-D printers to create new organs, cell by cell.

“What I see happening much quicker (than reseeded) is building bio-artificial organs,” Khalpey said. “This means using hybrid devices with human cells and matrices to work like a heart or a lung.”

These hybrid organs would not look like your traditional heart or lungs. By seamlessly melding tissue with tech-

nology, researchers could outsource some of the complicated physiological functions to machines.

Although these new hybrid organs might look strange, Khalpey believes that they are crucial to solving the organ shortage. 3-D printing has the potential to lower the cost of these custom organs and may be an easier technical problem to solve than reseeded.

“It’s not ambitious; it’s doable,” Khalpey said. “I think we can do it faster than we can reseed an organ.”

Located in the basement below Khalpey’s lab, the Cardiopulmonary Stem Cell Biobank contains a variety of tissues preserved in liquid nitrogen. Khalpey created this biobank after moving to Tucson because he wants to make it easier for other scientists and their students to find solutions for the organ shortage.

“I’ll never say “No” to students because I think it’s important to excite their minds,” Khalpey said. “That’s the reason why I’m in the academic environment: to share.” ■

Still

Biosphere 2 continues to conduct grand experiments



full of

LIFE



Biosphere 2, tucked in the foothills of the Santa Catalina Mountains, glows with energy-saving LED bulbs.

PHOTOGRAPH BY JESSICA BURKHART



Into the giant glass house



TOP LEFT: Cockroaches have populated Biosphere 2's rainforest ever since eight biospherians lived inside for two years with minimal assistance from the outside world. PHOTOGRAPH BY JESSICA BURKHART

TOP MIDDLE: Grasshoppers roam the grounds of Biosphere 2. PHOTOGRAPH BY MARK ARMAO

TOP RIGHT: In the 1990s the biospherians introduced about 300 types of plants. Fewer than a hundred species are left. PHOTOGRAPH BY JAMES KELLEY

ABOVE: A partly hidden hallway leads to an overlook above the ocean biome. The 676,000-gallon saltwater tank was originally designed as a coral reef. PHOTOGRAPH BY ALAN SCOTT DAVIS

ABOVE RIGHT: Plants grow in inhospitable-looking places inside Biosphere 2. PHOTOGRAPH BY TAYLOR SANDERS

RIGHT: The giant glass house glows in the sunset. PHOTOGRAPH BY ALEX MCINTYRE

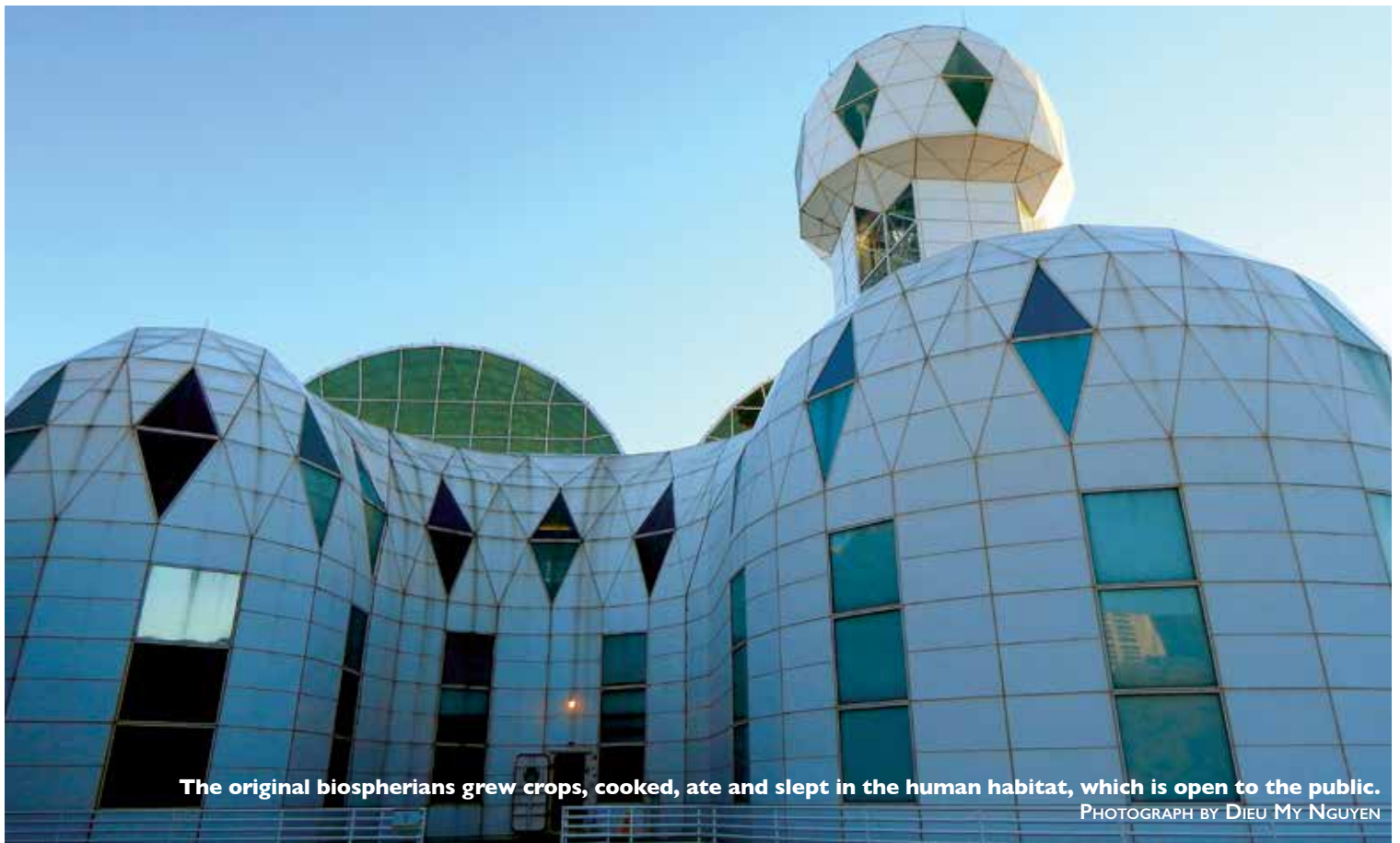




TOP: Biosphere 2 resembles a series of pyramids when viewed from the adjoining ranch of benefactor Ed Bass. PHOTOGRAPH BY PATRICK O'CONNOR

LEFT: Biosphere 2 is taking steps to transform the miniature ocean into a miniature Sea of Cortez under the lead of marine biologist Rafe Sagarin. He and his interns wear boots for their excursions in and out of the ocean. PHOTOGRAPH BY JOSH ROJAS

ABOVE: The Energy Center (far left) maintains power and controls the environments in the biomes. The two white-domed lungs, or expansion chambers, acted like giant diaphragms. Connected by underground tunnels, they maintained the pressure inside Biosphere 2 as the air warmed and cooled. PHOTOGRAPH BY ALAN SCOTT DAVIS



The original biospherians grew crops, cooked, ate and slept in the human habitat, which is open to the public.

PHOTOGRAPH BY DIEU MY NGUYEN

Biosphere 2: Constructing an Artificial Earth

By Mikayla Mace

IN DOUGLAS ADAMS' *The Hitchhiker's Guide to the Galaxy*, the protagonists stumble across an alien race that specializes in constructing planets. The planetary building company is commissioned by mice—yes, small white mice—to build Earth—yes, the entire Earth—in order to conduct their experiments on humans.

The construction of entire planets makes for a fun science-fiction read, but an artificial Earth is what Space Biospheres Ventures intended to simulate back in 1987, when the construction of Biosphere 2 began near Oracle, Arizona. Motivated by the Apollo missions to the moon, Space Biospheres Ventures also saw the potential for profit that space exploration promised. “(Humans) had made it to the moon, so the next step was to live in space,” said Meredith Sattler, an assistant professor of architecture at California Polytechnic State University in San Luis Obispo.

Biosphere 2 was a self-sustaining, closed ecosystem that housed eight

human crew members, known as biospherians, from 1991 to 1993. To create a variety of climates in this self-contained system, the designers and Space Biospheres Ventures incorporated five of Earth's biomes: rainforest, savanna, ocean, desert and marsh. Like rooms in a house, these biomes have distinctive characteristics but are still connected by the flow of air, water and energy.

And, like a house, every architectural choice made for Biosphere 2 was intentional—from the design of the struts to the shape of the biomes.

Space Biospheres Ventures planned to use Biosphere 2 as a model for human settlements on other planets. Unfortunately, an architectural blunder cut the mission short. Nevertheless, the team learned a lot, and, to this day, Biosphere 2 remains a monument to human innovation.

Constructing a giant greenhouse

Biosphere 2 sits on 40 acres near the base of the Santa Catalina Mountains, about 30 miles north of Tucson.

Arizona was the best choice for a

space-faring simulation for several reasons, said Matt Adamson, assistant to the director of Biosphere 2. First, because of the nearly constant clear skies, the plants growing in the biomes could perform photosynthesis year round. Second, the land is geologically stable. Third, Southern Arizona is free of extreme weather. And last, the land was serendipitously up for sale.

The construction project, which required 200 workers, cost more than \$150 million, Sattler said.

“It's remarkable how quickly they brought it into fruition,” Adamson said. “Nothing on this scale has been or is being done right now.”

A snug fit

Head architect Peter Pearce designed the envelope enclosing Biosphere 2, which is called the space frame. He used about 76,000 white steel struts intersecting in repeated geometric shapes. The space frame was strong and did not need to be supported by internal columns, which made it easy

for the eight biospherians to farm in the open space below.

Pearce had studied with the legendary architect Buckminster Fuller and found inspiration in his work with space frames, Sattler said. Fuller's method of assembling a space frame was to connect a separate node and module. Pearce, on the other hand, developed a single steel strut that included both pieces in one.

As a result, the architects had to be precise when assembling Biosphere 2 to ensure a snug fit between the pieces, Sattler said. Measurements could not be off by more than one thousandth of an inch, or the error would be compounded by the time the builders reached the outside of the structure, skewing the entire building.

Each windowpane consisted of three layers—inner, outer and, between the two, a bonding film made of polyvinyl butyral. Unfortunately, the panels blocked incoming ultraviolet light, interfering with the vision of the bees that were brought in as pollinators. The bees could not navigate and pollinate plants. They died soon after.

A silicon seal was engineered to close any gaps between the glass panels and the steel struts. The silicon was strong yet elastic, allowing the Biosphere to expand and contract with changing air pressure caused by temperature fluctuations.

The silicon seal made Biosphere 2 the most tightly sealed envelope on Earth... or in space. The Space Shuttle loses 10 percent of its atmosphere in a matter of days, Sattler said. Biosphere 2, on the other hand, lost less than 10 percent of its air each year when it was sealed.

The breathing Biosphere

The shape of the envelope was planned to let air circulate naturally, said John Adams, deputy director of Biosphere 2.

The hottest rooms in a house are typically those that face south because



LEFT: A prickly pear cactus grows outside Biosphere 2. MIDDLE: A cactus thrives in the desert biome. RIGHT: Broad leaves capture light in the rainforest. PHOTOGRAPHS BY VALERIE ROUNTREE

they receive the most sunlight. Likewise, Biosphere 2 is oriented so the desert biome faces south and sits at the lowest elevation.

The rest of the Biosphere slopes up and north from this point. After the sun heats the desert biome, the warm air travels up into the moist mangrove swamp, ocean and savanna. The air continues to collect moisture as it rises into the rainforest biome, at 91 feet the highest point in Biosphere 2. There, the hot, moist air condenses and rains down onto the plants and trees, completing the cycle.

The orientation of Biosphere 2 was controversial, Sattler said. The architects had to determine the *quality* of light (morning or afternoon) and the *quantity* of light the plants would receive. Some architects thought the Biosphere should have been oriented east and west, but this wouldn't expose enough plants to essential sunlight.

Instead, Biosphere 2 is oriented north and south on its long axis. This trade-off allows plants and trees to absorb the most sunlight, with the intensity shifting from weak morning light to bright afternoon sunshine.

The concrete conundrum

During the two-year manned mission, the oxygen levels in Biosphere 2 plummeted to dangerously low levels. The eight biospherians soon realized the cause of the problem—the concrete base of the building.

The architects knew that it takes 28 days for concrete to cure enough to begin construction, Sattler said. But they didn't realize that it could take years for the concrete to finish curing. Most other construction projects are exposed to outside air circulation, but Biosphere 2's atmosphere was sealed off, leaving the air trapped inside to cure the concrete.

Carbon atoms in the compost generated by the biospherians' waste broke down in the soil. The carbon combined with the oxygen in the atmosphere to form carbon dioxide, which was absorbed into the concrete as it cured, Sattler said. Since there are twice as many oxygen atoms as carbon atoms in carbon dioxide (CO₂), the level of breathable oxygen fell quickly. Oxygen had to be pumped in, bringing the level from 14.2 percent to 20.9 percent. (The Earth's atmosphere is around 21 percent oxygen.)

The eight biospherians emerged from Biosphere 2 on schedule, two years after they had entered.

The second mission, in 1994, lasted only six months. During this time the goal of Biosphere 2 began to change from an artificial habitat for space explorers to a large-scale research facility focused on Earth systems. Improvements and upgrades were made.

Today, researchers use Biosphere 2 as a "scaling tool," Adams said. It's the perfect intermediary between the controlled conditions of a laboratory and the uncertainty of fieldwork. Tourists can walk through the giant greenhouse and see science at work while learning about Biosphere 2's past flawed experiments as well as its groundbreaking innovations. ■

When Biosphere 2 was sealed, this large geodesic dome was one of two lungs that kept the structure from exploding or imploding.
PHOTOGRAPH BY ALAN SCOTT DAVIS



1984

Land Purchased
by Space Biospheres
Ventures (2,000 acres)

1987-1991

Construction

1991-1994

Closed Mission Era
First mission lasted
until 1993

1996-2003

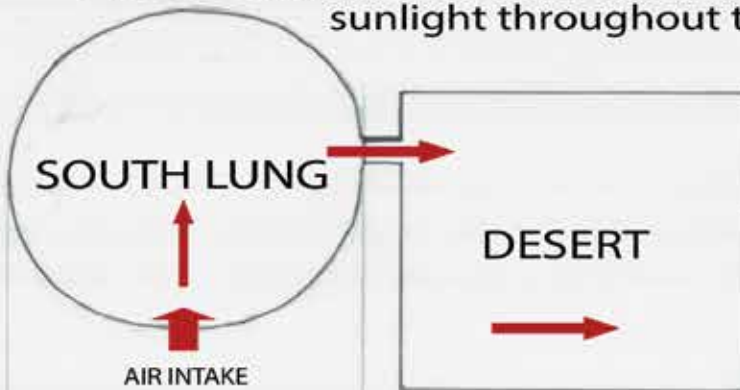
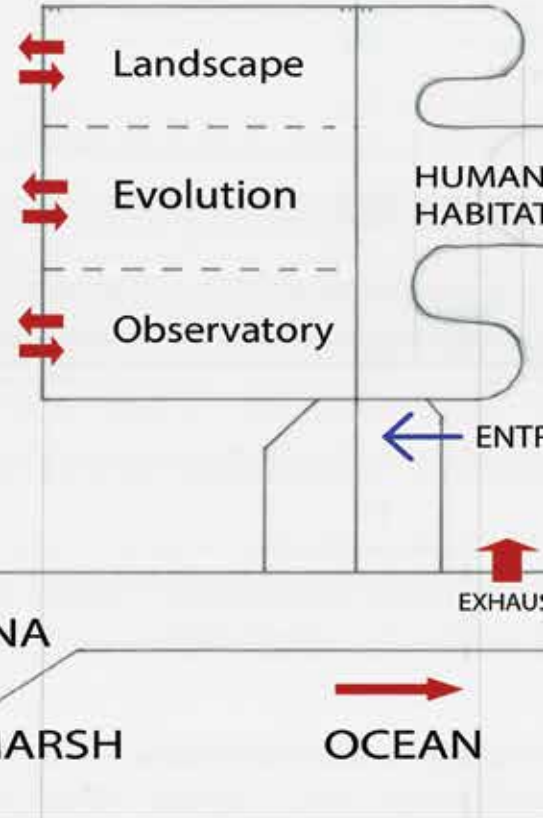
Columbia University
Experiments about
effects of atmospheric

LOCATION & ORIENTATION

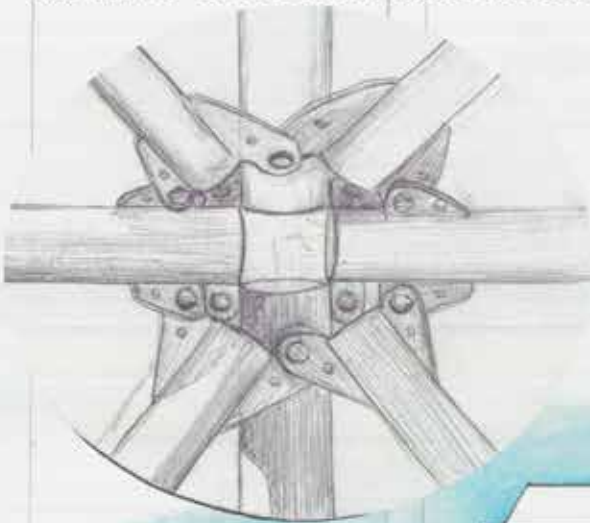
30 miles north of Tucson, Arizona

An ideal location:

- Geologically stable land.
- Nearly clear skies for plant photosynthesis.
- Free of extreme weather.
- Land for sale.
- North-south orientation to allow the most sunlight throughout the day.

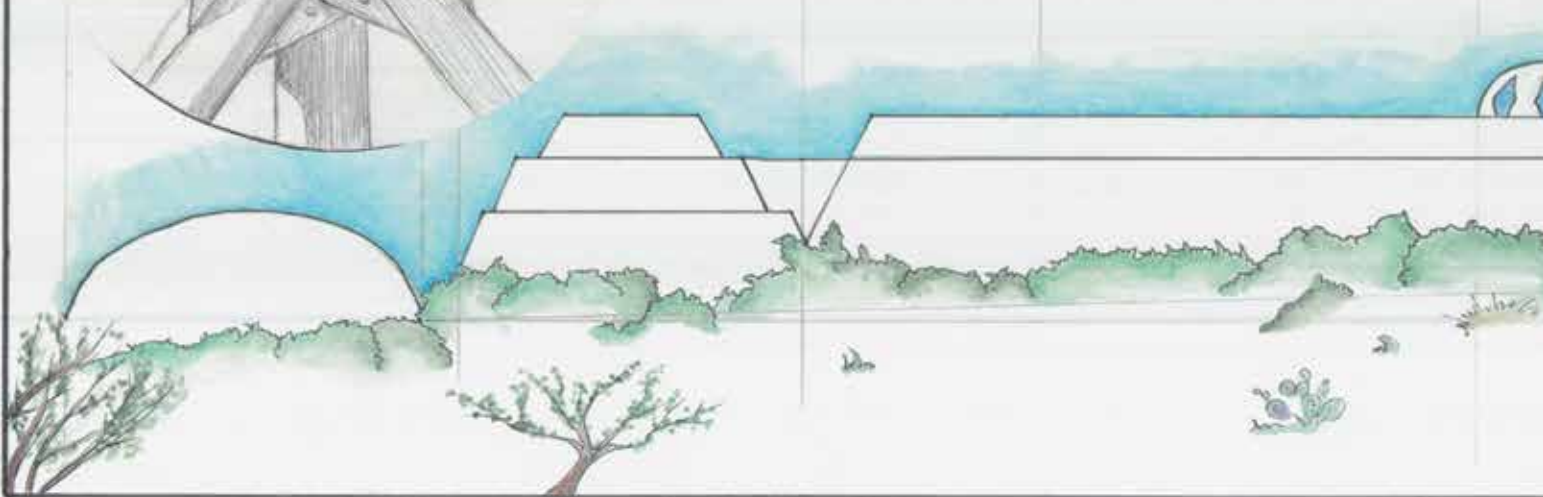


CLOSE-UP OF STRUT CONNECTIONS



MATERIALS & RESOURCES

- ~76,000 steel struts with aluminum coating
- ~6,500 panels of glass x 3 layers each
- 3.14 acres under glass
- 2 acres of basement
- ~\$150 million to build
- ~200 construction workers



Era
CO₂

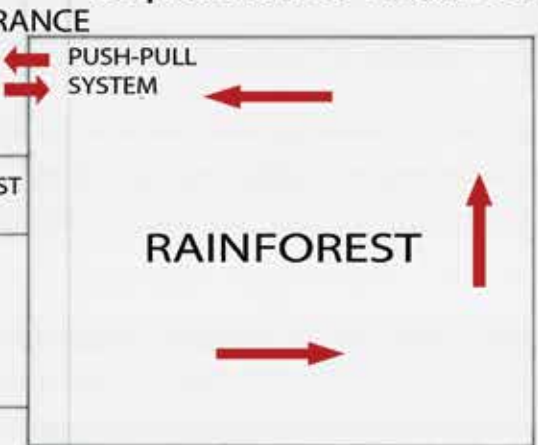
2007-present
University of Arizona Era
UA conducts environmental
research and hosts public tours

BUILDING B2

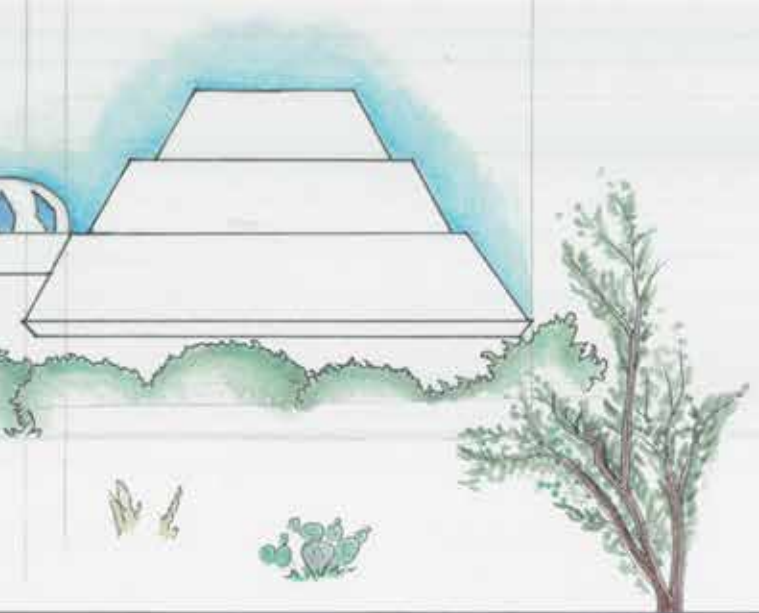
BY: MIKAYLAMACE
SOURCES:
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MATTADAMSON
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A SNUG FIT

A silicon seal closed gaps between glass and steel, making Biosphere 2 the most tightly sealed envelope on Earth. . . or in space. The Space Shuttle loses 10 percent of its atmosphere in a few days. When sealed, Biosphere 2 lost 10 percent of its air each year



ating



INSPIRATION

Head architect: Peter Pearce
A student of Buckminster Fuller, he further developed the space frame design.

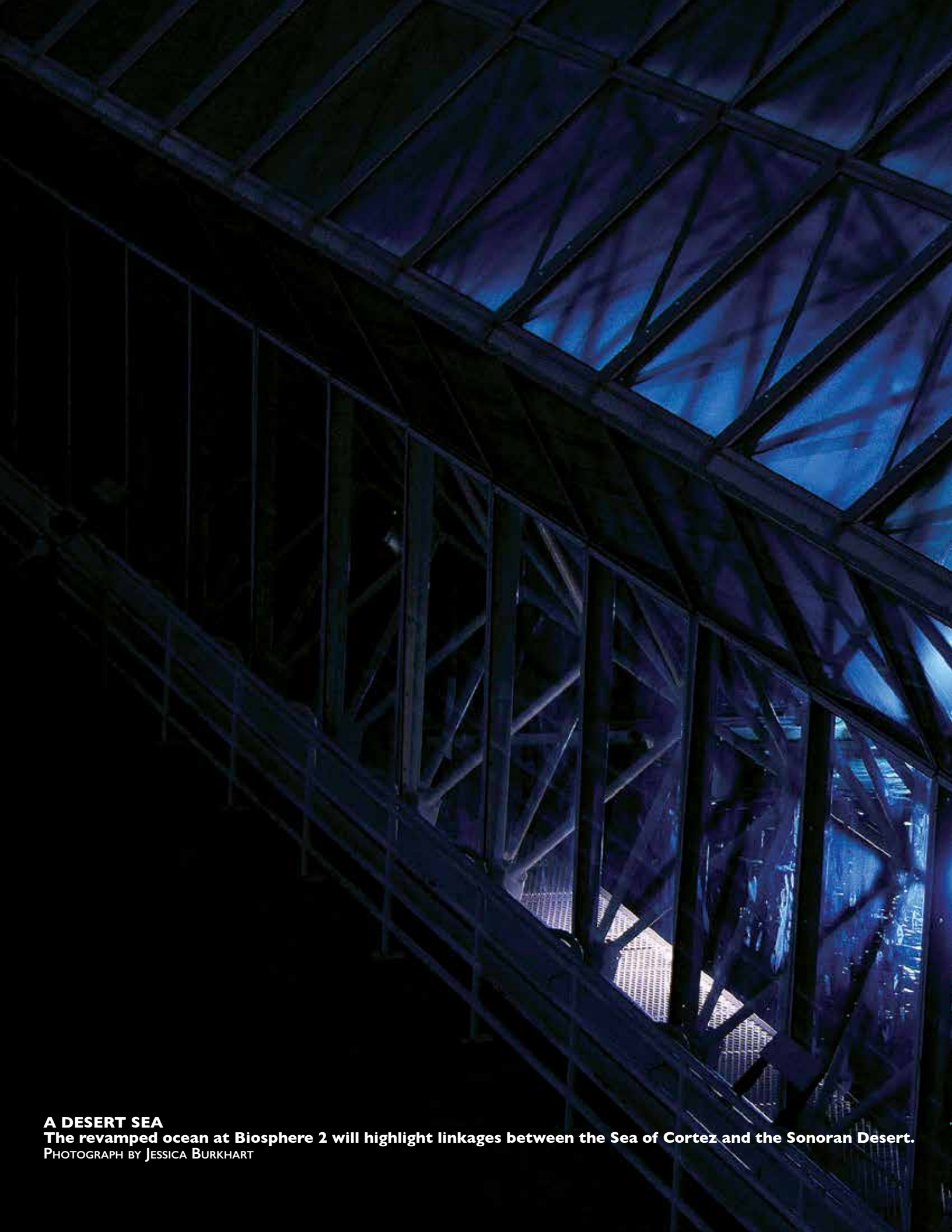
THE BREATHING BIOSPHERE

The shape of Biosphere 2 allows for natural air flow from the low, hot desert to the high, moist rainforest.

The highest point in Biosphere 2 is the top of the rainforest—at 91 feet.

THE CONCRETE CONUNDRUM

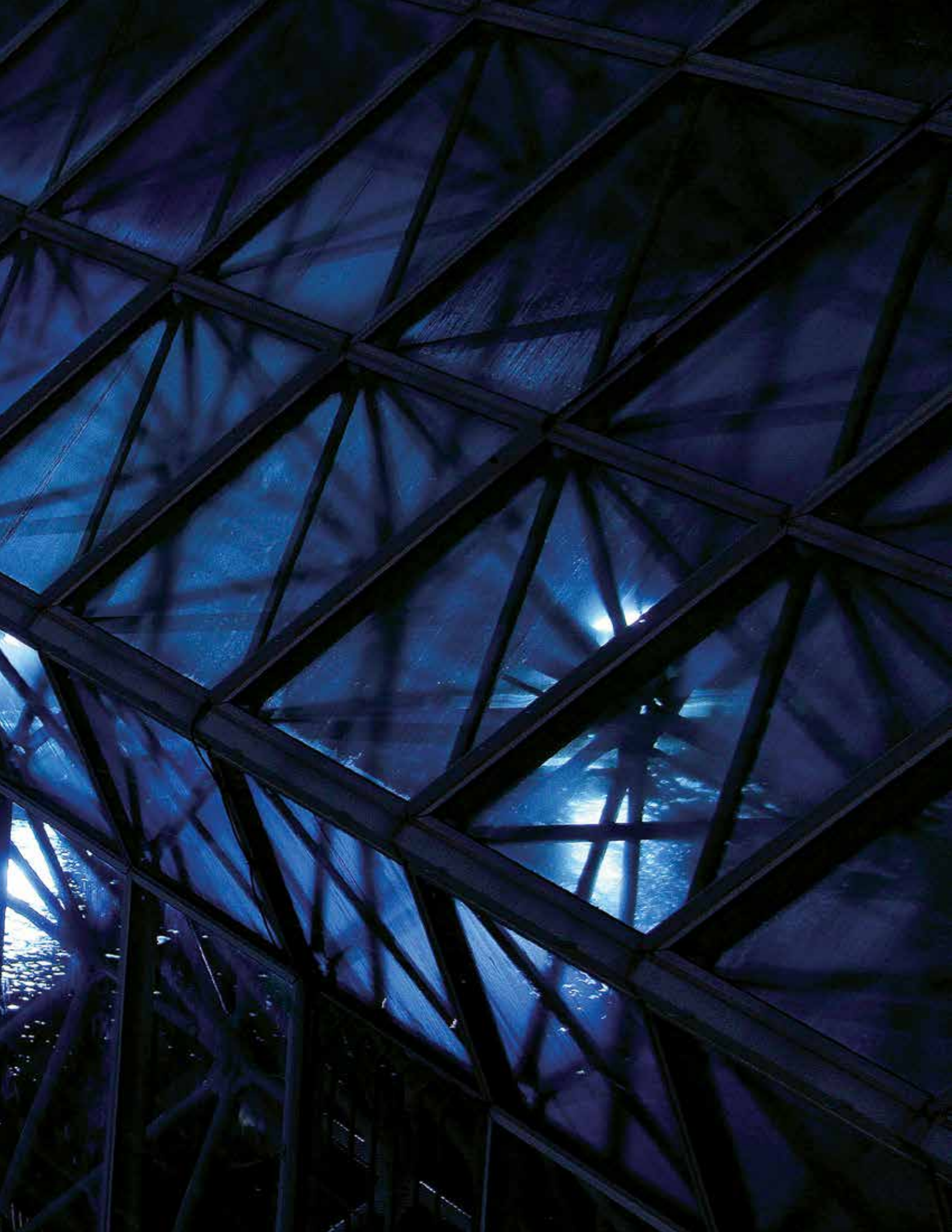
Concrete takes 28 days to cure enough for construction to begin. The builders of Biosphere 2 didn't realize that it could take years for the concrete to finish curing. Most other construction projects are exposed to outside air circulation, but Biosphere 2's atmosphere was sealed off, leaving the air trapped inside to cure the concrete.



A DESERT SEA

The revamped ocean at Biosphere 2 will highlight linkages between the Sea of Cortez and the Sonoran Desert.

PHOTOGRAPH BY JESSICA BURKHART





Reptile Day



The SciView staff participated in a wildlife photography workshop led by Cecil Schwalbe, an ecologist emeritus with the U.S. Geological Survey and affiliate faculty at the University of Arizona. He was Arizona's first state herpetologist. Assisting the students were Susan Swanberg, a science journalist and former geneticist, and John de Dios, a freelance video producer for National Geographic News and UA News at the University of Arizona.

STORY DESIGN BY JUSTIN SAYERS



1 The Sonoran desert tortoise (*Gopherus morafkai*), a protected species, consumes more than 200 species of plants. Its favorites are grasses, mallows and desert vine.

PHOTOGRAPH BY MARK ARMAO



2 SciView staffers, composed of students from journalism and the sciences, photograph Pancho Gila (not pictured) in the rocks. Pancho and other Gila monsters (*Heloderma suspectum*) feed on the eggs and young of birds, mammals and reptiles. PHOTOGRAPH BY ALEX MCINTYRE



3 Honors student Dieu My Nguyen prepares to photograph reptiles and insects. PHOTOGRAPH BY ALAN SCOTT DAVIS

4 The California kingsnake (*Lampropeltis californiae*) preys on rattlesnakes and many other vertebrates. PHOTOGRAPH BY JOSH ROJAS

5 The larva of a five-spotted hawkmoth (*Manduca quinquemaculata*) feeds on tomatoes, potatoes, tobacco and other plants in the nightshade family. PHOTOGRAPH BY VALERIE ROUNTREE

6 A rosy boa (*Lichanura trivirgata*) gets up close and personal with a camera. PHOTOGRAPH BY ALEX MCINTYRE

Sensing Lightning in Tucson



By Ann Posegate

Lightning strikes Tucson, Arizona, in August 2012. PHOTOGRAPH BY ADAM BLOCK

STORY DESIGN BY ANN POSEGATE

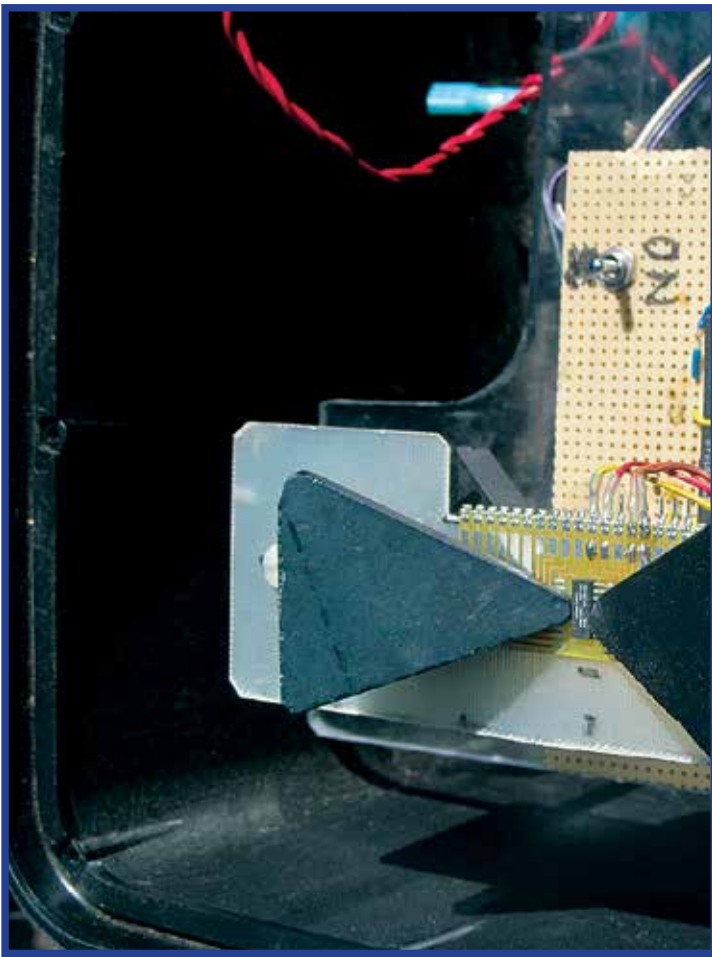


Carl Noggle stands beside his custom-built lightning sensors in Tucson. The sensors detect fast, high-current lightning as well as slow, low-current lightning. The latter has been known to start forest fires.

PHOTOGRAPH BY ANN POSEGATE

CARL NOGGLE KNOWS LIGHTNING. He studied it for more than 40 years as a student and staff member at the University of Arizona and in the private sector. As an engineer, he created lightning sensors and helped to form the U.S. National Lightning Detection Network. His work has helped prevent human deaths, power outages, airport disruptions and other damage caused by lightning. Since retiring, he has worked as a consultant in Tucson, Arizona, and still monitors local strikes.

To many lightning researchers, Noggle is known as a creative engineer who has contributed to global research and safety. But today, Noggle, now in his 70s, is still a kid at heart who likes to tinker with gadgets.



In this lightning sensor the two triangular pieces of iron act as magnets for the electricity, funneling it down to a computer chip.

PHOTOGRAPH BY ANN POSEGATE

NOGGLE STOPS HIS OLD GRAY STATION WAGON, rolls down the window and makes the sign of the cross as he looks out at a statue of Our Lady of Guadalupe—the Virgin Mary—on the side of a house. An arch of deep blue mosaic tiles sparkles on the wall behind it, and several items have been placed on a small table beneath it.

For the past three or four years, Noggle has made this Roman Catholic gesture toward the shrine every time he drives up and down Tumamoc Hill, just west of downtown Tucson, although he does not practice the religion.

“I’ve almost decided that it works because nothing bad has ever happened” during his trips up the hill, he says.

He drives up the 1.5-mile desert road to a group of small research buildings managed by the University of Arizona and parks in front of a one-story, sand-colored metal building. He unlocks the gate and enters.

Noggle and his fellow lightning researchers in Tucson have developed technology used to detect lightning throughout the United States and even around the world. Although by looking at his modest equipment setup in a nearly empty, 8-foot-by-8-foot corner room, one might not know it.

A video camera points toward one window. Two insulated wires thread in through another wire, and a few pieces of electronic equipment sit on a desk and the floor. A fan blows toward them.

* * * * *

The goals of Noggle’s research on Tumamoc Hill are twofold. First, he hopes to record an upward lightning bolt using the video camera that points toward a metal tower on top of the hill. He collaborates with University of Arizona researcher Kenneth Cummins on this project.

Most lightning travels from a cloud to the ground. But there is such a thing as ground-to-cloud lightning, which starts from very tall objects on the ground and moves up toward a cloud.

“This actually happens quite a bit, like if you’re in New York during a storm,” Noggle says. “If you watch the Empire State Building, you can see it create 50 of these in a storm, 50 of these upward lightning (bolts).” Television towers scattered throughout the Midwest tend to start them too, he says.

He holds his hand up and spreads out his fingers. “The way you can tell it’s upward lightning is that it branches out like this,” he says. The branches go up like tree limbs. “The usual lightning branches down” like tree roots.

The second goal involves the two black wires exiting the other window. They connect to a small box standing on a platform about 30 feet from the building.

“If you look out there, you can see a little black box that looks kind of like a hibachi,” Noggle says.

A hibachi? As in a type of charcoal barbecue grill?

He is 6-foot-2 and serious, though his eyes say he is smiling.

“That’s what it looks like to me anyway,” he says.

He walks outside to check on the box.

* * * * *

As a powerful type of electricity, lightning strikes can disrupt man-made electrical systems, such as airport towers, cell phone towers and utility lines. A lot of research goes into mitigating those effects.

“Lightning has enormous economic impact,” said Ronald Holle, a meteorologist for Vaisala, the company that runs the U.S. National Lightning Detection Network, which monitors strikes throughout the country.

In fact, lightning causes about 30 percent of U.S. power outages and nearly \$1 billion in damages per year, according to the Vaisala website.

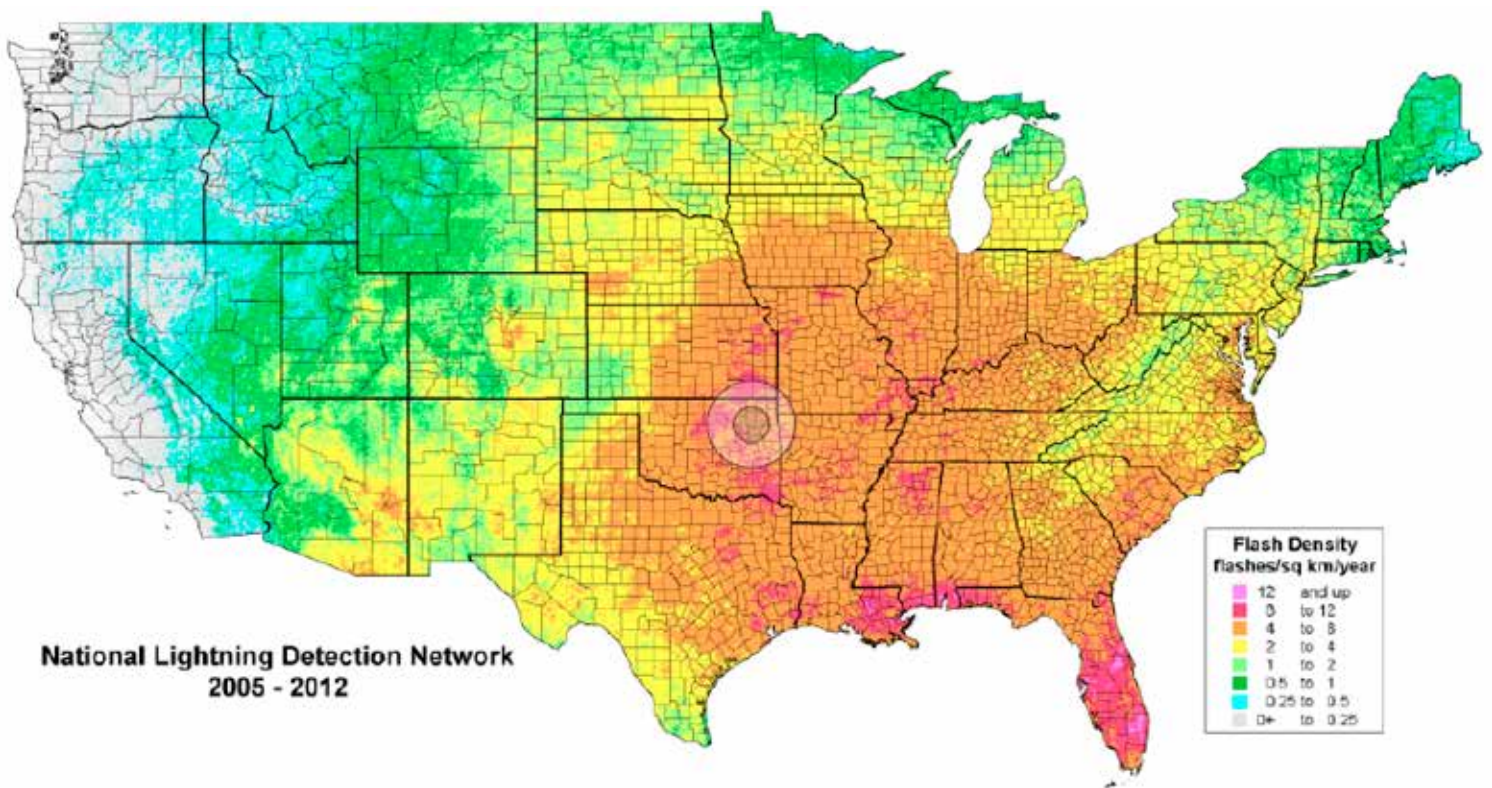
When it comes to human life, lightning can also pose a danger. National Weather Service statistics show that 23 people were killed by lightning in the United States in 2013. From 2004 to 2013, 329 people in the United States died from lightning strikes, according to the Vaisala website.

In addition, about a third of the business of the U.S. National Lightning Detection Network involves assisting insurance companies who receive fraudulent lightning insurance claims, Noggle says.

“Who knew insurance had anything to do with lightning?”

* * * * *

From the research compound on Tumamoc Hill, the view of Tucson sprawls to the east, ending with the Santa Catalina and Rincon Mountains rising up dramatically from the valley floor. The temperature is 96 degrees on this sunny day in late September. The last few cumulus clouds of monsoon



Based on data from the U.S. National Lightning Detection Network, the Southeast and Midwest received the most lightning strikes per square kilometer from 2005 to 2012. Carl Noggle helped to form the network, which is now made up of about 200 lightning sensors throughout the continental United States and southern Canada. IMAGE COURTESY OF VAISALA

As a powerful type of electricity, lightning can disrupt man-made electrical systems.

season, the three-month period in mid- to late summer that brings most of Arizona's annual rainfall, hover above the mountains, but no lightning is in sight.

The black box stands just above Noggle's knee. It does look like a grill, though it is actually a portable electronics case.

A white circle of reflective material is bolted to the top to reflect sunlight and prevent the sensors inside from overheating.

Noggle opens the box.

Inside are two sensors, each about the size of a fist, that Noggle built using computer chips and a few other pieces of electronic equipment. The one on the right picks up nearby signals from fast, high-current lightning that "tends to act like dynamite and blow things up that it hits," Noggle says. "It will blow a tree into smithereens, and (the tree) won't catch fire."

The second sensor has two triangular pieces of iron on top of it, pointing toward each other. These pieces funnel electromagnetic signals from nearby lightning down to the sensor below so it can pick up smaller signals than the first sensor, Noggle explains. The longer-lasting, low-current lightning the second chip senses is "much more likely to catch things on fire."

Noggle's second research goal is to monitor this lingering type of lightning around Tucson.

The sensors connect to the equipment back in the room that records the data and digitizes the signals so a computer can read them, he says.

* * * * *

Noggle's lightning research in Tucson goes back to his days as an engineer and electricity enthusiast. A native of Michigan and northern

Arizona, Noggle earned a bachelor's degree in physics at the University of Arizona. He enrolled in graduate classes and began working as an engineer for the atmospheric physics department, but he enjoyed his job so much that he decided to keep working instead of finishing a graduate degree. He continued his career as an engineer at the university and later in the private sector.

At first, Noggle designed ways to test the vulnerability of aircraft, utilities and other systems to high jolts of electricity.

In the mid-1970s, after lightning had struck and damaged rockets such as Apollo 12, Noggle and two other colleagues recognized a need for better detection of lightning strikes in real time to avoid damage such as this, said Holle, a meteorologist at Vaisala and long-time colleague of Noggle.

Soon after, the U.S. National Lightning Detection Network was born.

The network was a project of the university and later spun off into its own company, Noggle says.

The network is now operated by Vaisala, a larger company, and has grown to include about 200 manufactured ground-based sensors. Spread across the contiguous United States and southern Canada, the sensors pick up the electromagnetic field around lightning when it hits the ground. When a sensor detects the electricity, a signal is sent to a satellite, then relayed to the network's headquarters in Tucson within seconds of the strike. Together with GPS data from each site, this information gives researchers the time and location of lightning strikes.

Signals from more than 20 million flashes per year are picked up around the United States, though this number increases to about 100 million if one includes the return strokes that travel up and down the same channel as an initial flash, Holle said. In 2013 the network detected 574,477 downward flashes in Arizona alone, according to the Vaisala website.

Vaisala also operates a global lightning detection network,

Holle said. "We're picking up about 1 million strokes per day worldwide."

This number accounts for more than two-thirds of the lightning flashes around the world, according to the Vaisala website. Most are cloud-to-ground lightning strikes, Holle said.

* * * * *

Noggle closes the lid of the black box. "This is sort of a kludge, but I think it's kind of a nice kludge," he says. "A kludge is something you kind of just throw together to get it to work without worrying about what it looks like or anything."

During the nine or so months of the year when lightning does not strike often in Arizona, Noggle works on other projects, such as studying the effects of lightning strikes on saguaro cactuses and improving his lightning sensors. A few years ago, he also started his own electrical circus show called Circus Amperean, where performers don custom-made suits invented by Noggle and a friend. They climb on top of an electricity generator called a Tesla coil, and 4-foot bolts of lightning fly out from their hats and hands as they dance around.

The day is heating up, and Noggle needs to get out of the sun. He has recently been diagnosed with skin cancer on his arm and will soon have the spot removed through surgery.

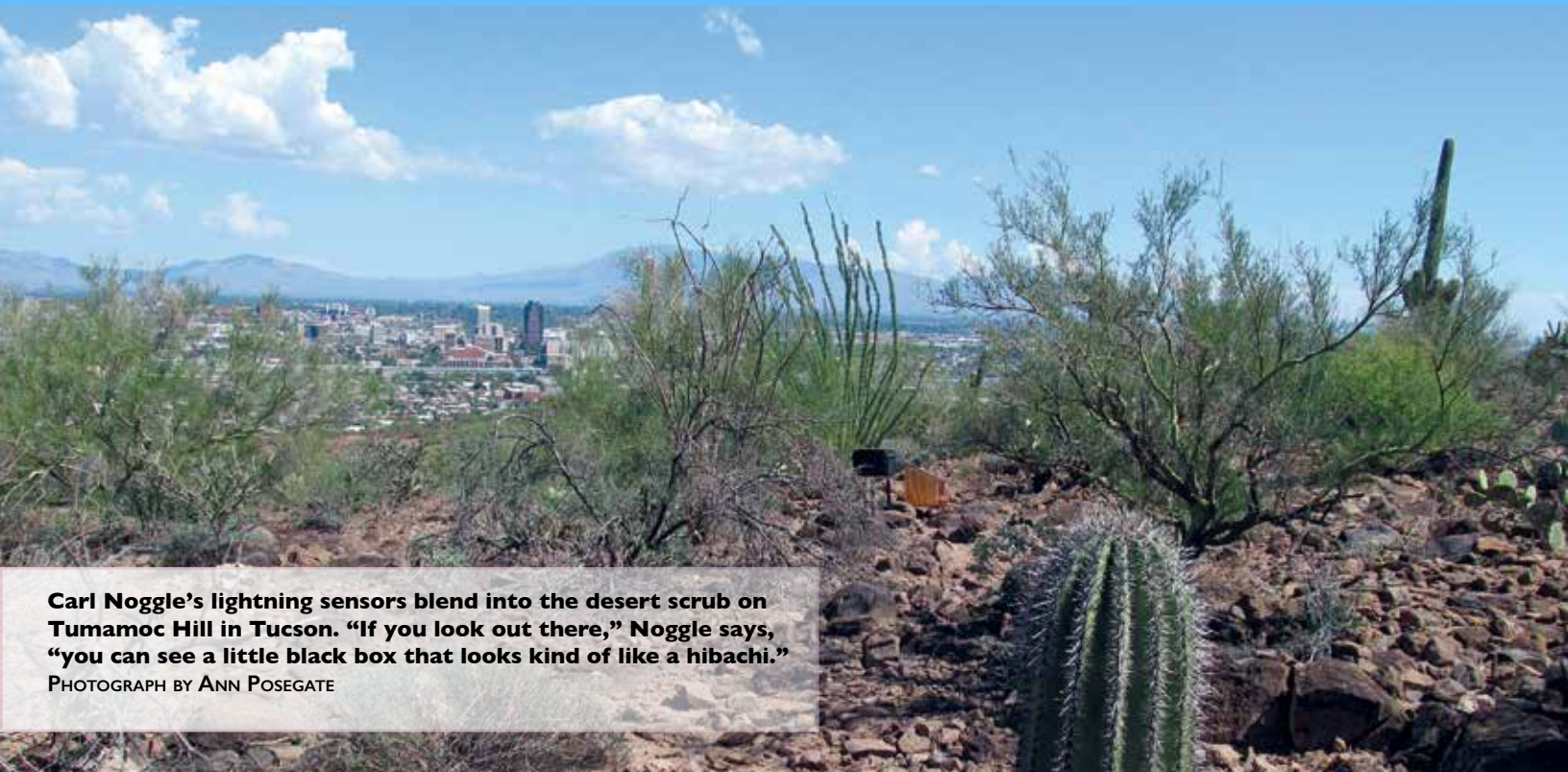
He drives back down the winding, paved road through the thick desert scrub to the bottom of the hill. He stops the car and rolls down his window.

"I better say 'Hi' to the Virgin Mary again," he says. He looks toward the shrine and makes the sign of the cross.

"It's funny. Even though I don't believe in that, I've been coming up here for three or four years, and I would not go up there without doing it."

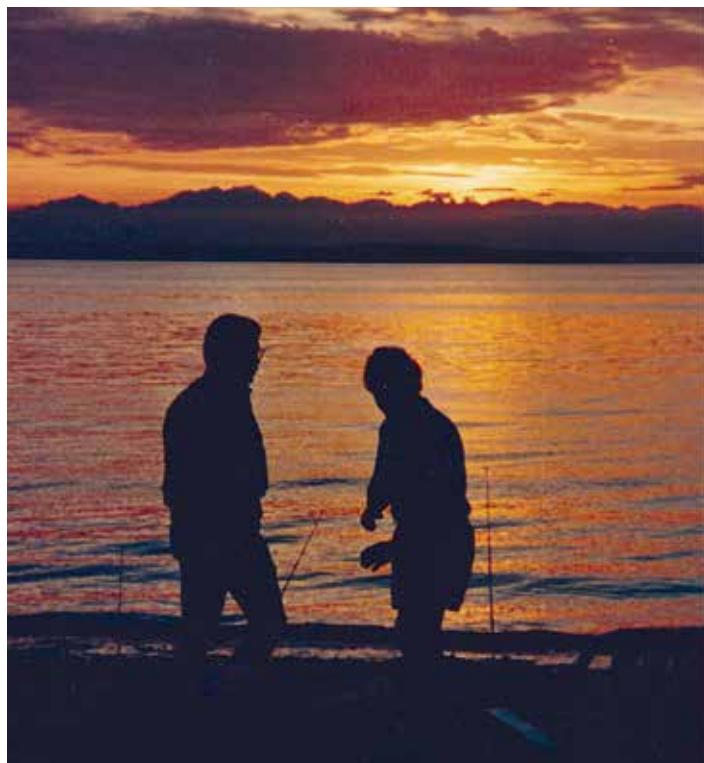
As far as he knows, no one has been struck by lightning on Tumamoc Hill.

Maybe his little gesture works. ■



Carl Noggle's lightning sensors blend into the desert scrub on Tumamoc Hill in Tucson. "If you look out there," Noggle says, "you can see a little black box that looks kind of like a hibachi."

PHOTOGRAPH BY ANN POSEGATE



PHOTOGRAPHS COURTESY OF JESSICA BURKHART

Lighting a Beautiful Fire

BY JESSICA BURKHART

It wasn't until I was 19 that I faced the ultimate question. It changed my life and my family forever.

THEY SAY I WAS A DIFFICULT CHILD, always asking questions. "What if...?" and "What if...?" and "What if...?" Was I difficult, or did they just not have answers?

My wonderful parents were high school sweethearts from a small town in Alaska. Intelligent and witty, to say the least, but neither was able to pursue a college education. My father, an Alaskan outdoorsman, had mastered essential techniques like how to fish and build a beautiful fire, but he couldn't begin to explain that fish scales felt slimy because of an antiparasitic glycol-protein or that the incandescence of the flame was a chemical release of carbon and other molecules.

I was always asking questions. My dad would become exhausted from time to time. "Stop saying, 'What if!'"

But I couldn't stop. My inner scientist had begun to emerge. This is what scientists do. They inquire in order to solve problems.

It wasn't until I was 19 that I faced the ultimate question. It changed my life and my family forever.

Dad got sick, very sick. He began to lose control of his muscles, starting with his throat. He could not speak or eat. The disease spread throughout his entire motor system with all the fury of a raging fire. Total paralysis at the age of 43.

The doctors told us that his brain was deteriorating, and they didn't know why. I asked the neurologists "What if...?" and "What if...?"

They didn't have answers. "There is so much more about the brain that we don't know than what we do." This response from one doctor was not enough for me. I wanted to know more.

After nine acute care facilities in three states, and three years of paralysis and agonizing confusion, we lost my dad to this mysterious degenerative disease when he was only 45.

With so many questions left unanswered, it's only natural that I have dedicated my life to seeking solutions. As I work toward my doctorate in neuroscience, I will ask more informed questions to seek informed answers.

Even in death, my father has again managed to light a beautiful fire. ■

Growing Edible Mushrooms at UA

Story and photograph by
Valerie Rountree

FUNGI ARE THE GREAT RECYCLERS of the world. Their cobweb-like mass, individually called hyphae and in mass called mycelium, break down organic matter and absorb nutrients. Mushrooms are the fruiting, reproductive bodies of some fungi.

Mycelium can be undetectably small, or they can form colonies immensely larger than any other organism on Earth. A single 2,200-year-old colony in eastern Oregon once covered 2,384 acres—that's equal to 1,802 football fields. The mycelium can break down just about anything, including plastics, pesticides and petroleum.

There are millions of species of fungi, yet we don't hear much about them. Perhaps that's because fungi don't cause many diseases in humans, although they account for nearly 70 percent of plant diseases, says Dr. Barry Pryor, a professor of plant pathology at the University of Arizona.

Pryor is a world-renowned specialist in *Alternaria*, a genus of ascomycete fungi that include yeasts, molds and the edible fungi morels and truffles. *Alternaria* is a major plant pathogen that commonly causes leaf spots and other damage to crops.

Twenty years ago, Pryor never dreamed he'd be studying fungi. His love has always been plants. While working as



Mushrooms grown in the lab using campus waste eventually make it to catering as part of popular dishes.

a microbiologist in the food-processing industry, he became interested in pest management. Pryor went back to school for a master's degree in integrated pest management at the University of California Davis, and before he knew it, he was on an academic track. He continued into a Ph.D. program at Davis and started learning about plant pathology and fungi for the first time. Then, the whole mycological world opened up.

Now Pryor, along with two graduate students and a handful of undergraduate students, is exploring the multitude of benefits of growing gourmet oyster mushrooms: They are nutritious, they are local and they help break down the waste they're grown on.

Packed with nutrition

Pryor's office is small, with ceiling-high shelves overflowing with books. Most of the floor is covered by textbooks, stacks of flyers advertising various mycology courses and a diorama of lifelike mushrooms made by some of Pryor's students.

"Every day our lives intersect with fungi, and people don't even know it," Pryor says. Some of the most well-known foods in the world come from fungi.

Pryor takes two examples out of the cupboard: Vegemite and Quorn. Both are high in protein and many other nutrients. The Australian-made Vegemite is the salty cousin of the British Marmite and is made from leftover brewer's yeast extract and various spices.

Quorn is the leading meat substitute in the United Kingdom. It is made from a mycoprotein ("myco" refers to fungus) derived from a microfungus and combined with egg white, then pressed into various meat-like forms. Quorn was introduced in the United Kingdom in 1985 to help feed the growing global demand for protein. The company claims the carbon footprint of the product is 70 percent less than that of beef.

As part of a class, Pryor and some of his students are trying to calculate the land, water and energy required to grow mushrooms compared with traditional sources of protein, such as beef, pork,

chicken and eggs. Pryor predicts that mushrooms will be among the least resource intensive of all these foods.

Repurposing trash

Pryor shares a passion for sustainability with graduate students Lauren Jackson and Parker Evans. About three years ago they saw an announcement that the UA's Green Fund was accepting proposals for projects that would make the university "a more sustainable place to live, work and learn."

"We had a vision of recycling UA waste products, especially waste produced by students," Evans says.

The trio secured funding to start MycoCats and grow edible mushrooms from waste produced on the UA campus. Their project integrates research, student engagement and a positive environmental impact.

"The benefits (of our project) are that we recycle, and we can eat the product," Pryor says. The project supports the broader mission of the MycoCats: "We want to reduce the ecological footprint of the UA."

Currently, the MycoCats grow four varieties of oyster mushrooms (*Pleurotus ostreatus*). The group also tried raising enoki, maitake, shiitake and reishi mushrooms, but with less success. "Oyster (mushrooms) are forgiving," Pryor says. "We don't need the best facilities or the best equipment to grow them, and we can grow large quantities of high-quality oysters."

In the wild, oyster mushrooms grow on decaying logs. In the lab, Pryor and his students create a similar environment. They grow the mushrooms in a variety of substrates, which are like airy soil that is high in organic matter and nutrients. The substrate must be moist and not too dense so the mycelium's delicate hyphae can easily penetrate through it.

The group is experimenting with different combinations of substrate and adjusting the carbon and nitrogen ratios to recycle as much campus waste as possible while increasing the mushroom yield. Some of the materials for the substrate come from campus, including pizza boxes, coffee grounds and mesquite pods. The straw is purchased from local companies.

Although the straw is not a waste product, Pryor and his students have found

that it creates an airy texture for the substrate and enhances the mushroom yield. The cellulose in the straw is also a food source for the fungus. "The fungus uses enzymes to break down the cellulose and then absorbs the nutrients like a sponge," Jackson says.

Other researchers have successfully grown edible mushrooms on spent beer grain, which is obtained for free from breweries that would otherwise have to pay for additional waste removal. Pryor and his students have looked into using spent beer grain in their substrate, but right now they're not equipped to handle the large volume that Tucson breweries want to give them.

Their project has been operating for about a year and a half now, and they estimate that they've already recycled about 480 pizza boxes collected from student clubs and about 110 pounds of coffee grounds from local cafés.

When the substrate is no longer usable, the MycoCats donate it to Compost Cats. This UA student organization reduces waste by composting landscape clippings and food scraps from campus and the surrounding community.

Growing gourmet

The MycoCats team members grow the mushrooms in four stages. First, they inoculate a Petri dish of culture with fungal spores. Once the fungus starts to grow, it appears white and fuzzy, like mold growing on bread. The long, white branching structures that make up the fuzz are the mycelium.

After about seven days, Pryor and his students sprinkle the mycelium into a bag of cracked corn to "spawn" or spread out the fungus to enhance growth. The spawn stage is not required to grow mushrooms, but Pryor and his students have found that by including this stage, they can increase the size and number of the mushrooms they produce.

After another seven days they transfer the spawn to a bag of substrate made from various combinations of straw, coffee grounds, shredded pizza boxes and mesquite pods. There, the fungus grows for about three weeks, consuming oxygen and producing carbon dioxide.

In the final stage the fungus produces mushrooms, which are the reproductive "fruit" of the organism. The bags of substrate, which are firm and almost entirely

white at this point, are put in glass refrigerator-like cases. Slits are cut around each bag, allowing the fungus to breathe and providing space for the mushrooms to grow outside of the bags.

The fungus needs fresh, cool air and high humidity to fruit, Pryor says. He keeps the cases at 95 to 97 percent humidity to maximize the mushroom yield. It takes about ten days for mushrooms to grow large enough to harvest.

Pryor and the MycoCats sell about 40 pounds of oyster mushrooms to UA's dining services every week and donate extra mushrooms to food banks in Tucson. They don't sell their mushrooms at farmers markets, though. "There are other startup mushroom productions in Tucson that we don't want to compete with," Pryor says.

Instead, the MycoCats sell the spawn grown from pure cultures in their clean facilities to local growers and thus support rather than compete with local businesses. "Mushrooms are well suited for small growers, not large companies," Pryor says. The best mushrooms come from local producers because the quality deteriorates with lengthy transportation.

Michael Omo, the senior executive chef of the UA dining services, admires the high quality of the oyster mushrooms he buys from Pryor. "The mushrooms have a great perfume, and the taste is phenomenal," Omo says. He attributes this in part to the mushrooms being freshly picked and delivered twice a week.

Omo has been buying the mushrooms for about two months now, and the new dishes that incorporate them are a big hit. He recently tested mushroom lasagna at the Cactus Grill. It sold out quickly.

Another popular dish is farfallini pasta with roasted oyster mushrooms and tomatoes. "We roast the mushrooms, which dehydrates them," Omo says. "Then they get rehydrated when we mix them into the sauce, and the flavor is intensified. It permeates the whole dish with a rich mushroom aroma."

As far as Omo is concerned, he'll take as many mushrooms from MycoCats as he can.

The MycoCats hope to expand their mushroom production and sales to UA's dining services. In the meantime, Pryor, Jackson, Evans and the rest of the MycoCats are redefining what it means to recycle on a university campus. ■

Trash to Table

Growing gourmet mushrooms in a University of Arizona lab

Story and photographs by Valerie Rountree

The University of Arizona's MycoCats, run by Dr. Barry Pryor and two of his graduate students, Parker Evans and Lauren Jackson, raise four varieties of oyster mushrooms from waste produced on the university campus. The mushrooms are grown in a variety of substrates, which resemble airy soil that is high in organic matter and nutrients. Some of the materials for the substrate come from the UA campus, including shredded pizza boxes, used coffee grounds and mesquite pods. The MycoCats have been operating for about a year and a half now, and they estimate that they've recycled about 480 pizza boxes collected from student clubs and an equal weight (about 110 pounds) in used coffee grounds from local cafés. When the substrate is no longer usable, it is donated to Compost Cats, a UA organization that reduces waste by composting landscape clippings and food scraps from campus and the surrounding community.



The white, branching fuzz in the inoculated Petri dish is mycelium, the vegetative growth of the fungus. It takes about a week to culture.



By day seven, the bag is firm and almost fully white with fungus.



Slits are cut into the bags, which are placed in a humid, climate-controlled case to fruit.

Mushrooms are harvested twice a week. About 40 pounds a week are sold to UA dining services, and the rest are donated to local food banks.

The fungus is then sprinkled into a bag of cracked corn, where it grows in the high-nutrient environment.



The spawn is transferred to a bag of substrate (soil) made from straw and campus waste, including pizza boxes, coffee grounds and mesquite pods.



Michael Omo, the senior executive chef of the UA dining services, uses the MycoCats' oyster mushrooms whenever he can. One of his favorite dishes is farfallini pasta with roasted oyster mushrooms and tomatoes. PHOTOGRAPH BY IMIPOLEXG/Flickr



Mesquite seed pods collected from around campus add nitrogen and cellulose to the substrate. PHOTOGRAPH BY KEN BOSMA/FICKR



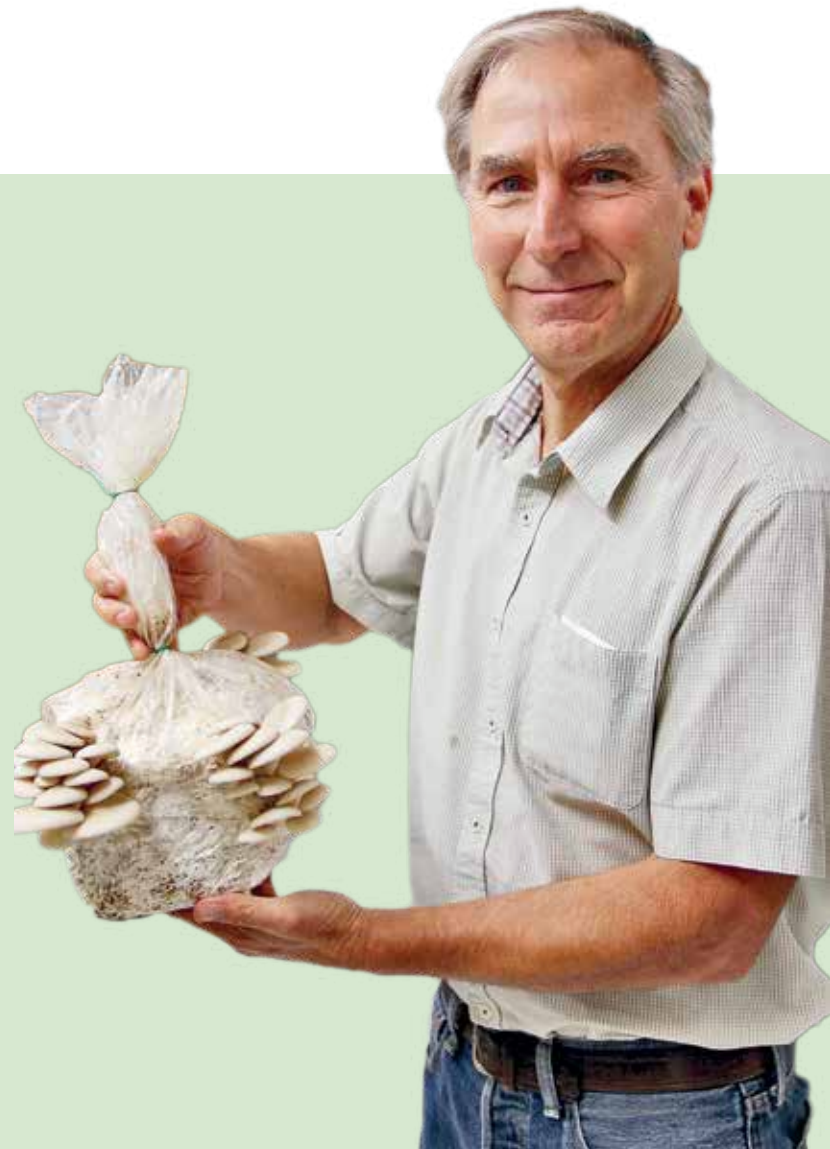
Pizza boxes are collected from student clubs, shredded and added to the soil. This organic matter serves as a food source for the fungus. PHOTOGRAPH BY ALAN SCOTT DAVIS



Used coffee grounds add phosphorus, potassium, magnesium, copper and nitrogen to the soil, considerably improving its quality.

“Mushrooms are incredibly nutritious. They’re a complete source of protein, comparable to eggs.”

~ Dr. Barry Pryor, professor
School of Plant Sciences
University of Arizona



THEN & NOW



PHOTOGRAPH COURTESY OF BIOSPHERE 2

Construction of Biosphere 2 began in 1987. Two missions were launched between 1991 and 1994 to see if humans could live in a sealed habitat without physical contact with the outside world.



PHOTOGRAPH BY JAMES KELLEY

The University of Arizona, which took over operation of Biosphere 2 in 2007, uses the structure and surrounding campus as a laboratory for large-scale research projects, including water, climate, energy and sustainability.



PHOTOGRAPH COURTESY OF BIOSPHERE 2

The eight original biospherians tested their grand vision by spending up to three weeks inside this one-person test module, which contained plants, wastewater recycling and all the biomes of its future big brother.



PHOTOGRAPH BY JAMES KELLEY

After successful research in the prototype test module, the eight biospherians moved into the main Biosphere. They were sealed inside for two years, growing their own food and running environmental experiments.