Biosphere II Is Back: The perfect intermediary between nature and lab.
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Biosphere II Is Back

FRED POWLEDGE

The perfect intermediary between nature and lab.

Biosphere II, the futuristic-looking structure in Arizona's Sonoran Desert, has a habit of reinventing itself. First, it was a sealed system in which researchers—originally called *bionauts*—and later *biospherans*—grew their own food, generated their own oxygen, and conducted experiments in a variety of biomes, all with an eye toward understanding Earth's biosystems and preparing for space missions, perhaps to Mars (see box 1). Then it became a remote classroom operated by Columbia University. After its earliest years, Biosphere II operated much of the time under threat of being closed and sold to developers, its 6.5 square kilometers turned perhaps into a resort and golf course.

Scientific research remained the owners' chief hope, however, and the effort to save Biosphere II for science bore fruit in 2007 when the University of Arizona (UA) announced that it would take on part of the operation. The enormous laboratory was reborn with a brand-new mission.

UA, which moved to full ownership of Biosphere II in July 2011, designed a suite of projects that constitutes a mission more to Earth than to Mars. The big items in Biosphere II's portfolio now are the very real and present ones concerning climate change, water, soil, and energy. There is a strong focus, too, on fostering public understanding of science through tourism, teacher education, and art. UA also got rid of Biosphere II's old-fashioned Roman numerals and started calling it *Biosphere 2*, or *B2* for short. It even erected colorful billboards in nearby Tucson advertising B2 as the place "where science lives."

In its earlier days, Biosphere II, which lies isolated in the foothills of the Catalina Mountains near the village of Oracle, was marveled at and mocked in equal measure. After a history as a cattle ranch, then as a wintertime desert retreat for Margaret, Countess of Suffolk, the place became a conference and training center run by Motorola. An outfit named Space Biosphere Ventures took over and, in 1986, began construction on the roughly 200,000-cubic-meter glass-and-steel structure that still gleams today in the intense sunlight some 1200 meters above sea level. Biosphere II became an enormous scientific laboratory.

Very-large-scale science

That B2 is unique is obvious from a glance at its futuristic design, but

Biosphere 2, seen from the air. The two domes control air pressure inside the main structure, a collection of connected buildings that contains a large soil experiment, a rainforest, and a scale-model ocean. Photograph: Fred Powledge (with thanks to pilot Sandra Lanham, Environmental Flying Services).

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Box 1. From Biosphere II to Biosphere 2.

The first eight bionauts signed on for a 2-year hitch in Biosphere II's closed structure in September 1991. They grew their own food, recycled their own water, and tended to their own needs in what two of them—Abigail Alling and Mark Nelson—recounted in their book, *Life Under Glass* (Biosphere Press), as a "completely self-sustaining agricultural system." The idea was to measure the survivability of humans, potentially on other planets. They were supported on the outside by an array of scientific experts connected by telecommunications and on the inside by weed-loving goats, access to lots of computer technology, and a driving work ethic.

The first mission was followed by an abbreviated one that ended because of inadequate oxygen levels and operator disputes. New managers from Columbia University took over, but the financial problems continued. A potential buyer registered the name "Biosphere Estates" for a housing development. Articles about Biosphere II used terms such as "flop" and phrases such as "new-age drivel masquerading as science."

The effort to save Biosphere II for science was close to being called off when the University of Arizona announced in 2007 that it would take on part of the operation.

Alling, reached recently at her 111-year-old ketch anchored off Bali, where she works for the Biosphere Foundation (no relation to Biosphere 2), said that the new iteration of B2 is more like an open greenhouse with an experiment inside it than a self-contained system.

Much was lost, she thinks, when B2's present owners decided to open the doors. "By keeping Biosphere II sealed," she said in a Skype interview, "it was an unprecedented laboratory—the only one of its kind on the planet. It could look at what was happening in the larger picture, such as how do ecosystems evolve, and [could] also look at how parts-per-billion molecules move through air and water.

"[On one hand,] Biosphere II, as it was conceived, was a perfect laboratory to… seal up a large amount of complex living systems and learn from the systems how they were maintaining a healthy biosphere, how the various levels of lifeform interacted, how molecules move and help sustain a breathable atmosphere that is conducive to many life forms. And that has been lost. It's too bad. But on the other hand, at least it's being used for science."

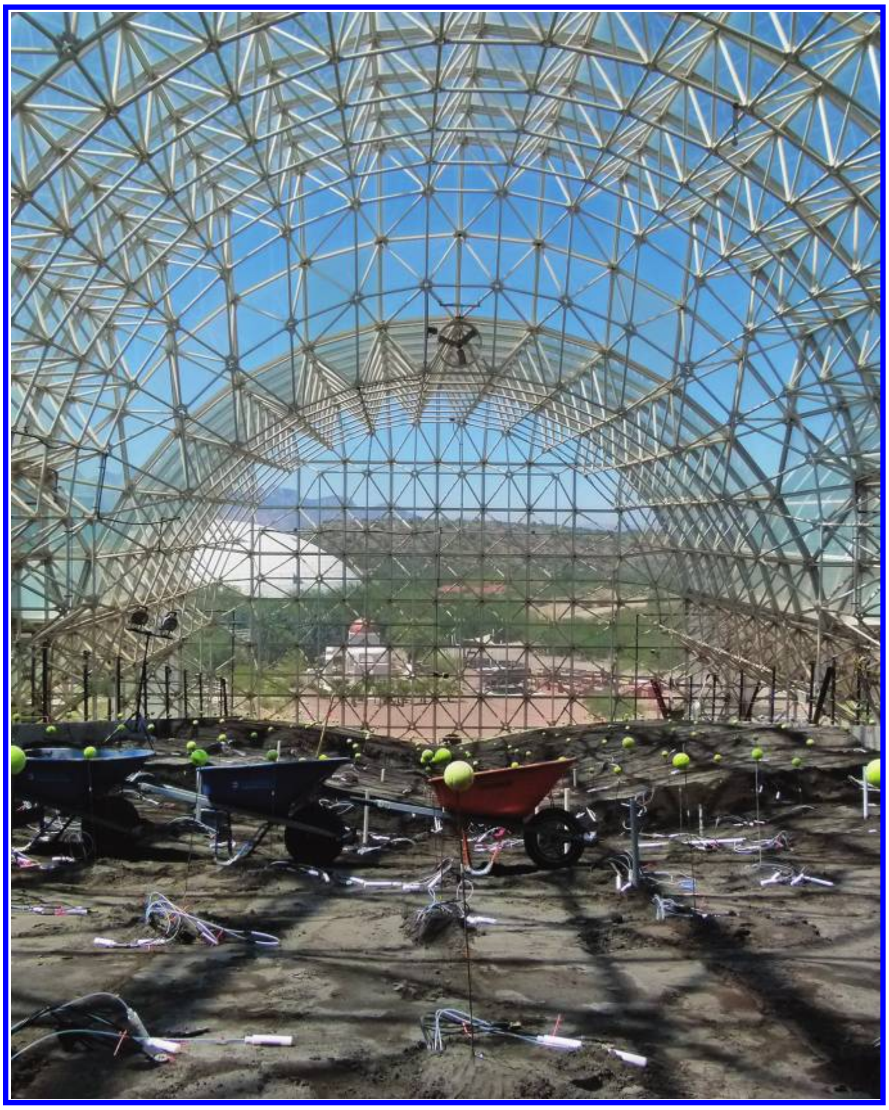
today's biospherans maintain that its uniqueness extends far beyond the architecture to the large and precise scale of the science that is conducted within it. Travis Huxman, an ecologist and evolutionary biologist who helped plan Biosphere 2 and directed it until his departure in the spring of 2012 for the University of California at Irvine, said B2's uniqueness "is the large-scale experimental work with fine-scale environmental measurements coupled to it. There are lots of incredibly well controlled, small-scale experiments throughout the nation, and there are many observatory systems of very large scale. But what there isn't is a bridge between these.… So that's the unique spot that we occupy." Only B2 allows biology, hydrology, and geology to interact while at the same time giving researchers environmental control, he explained.

B2's large scale is exemplified by LEO (the Landscape Evolution Observatory). Situated in the section of B2 that once grew peanuts, sweet potatoes, and rice, this flagship project of the new B2 consists of three enormous tilted platforms, each 30 meters × 12 meters, with slopes that vary from 10 to 17 degrees. Each slope, called a *watershed* by researchers, holds nearly 1.4 million kilograms of volcanic earth, and the whole apparatus will be used to measure—among other things—the effects of rainwater on soil. The "rain" will come from sprinklers in B2's tall glass-and-steel ceiling. Researchers can tend the slopes from movable gantries or cranes that glide above them. Some 3000 sensors and 2000 gas and water samplers embedded in the platforms will each calculate, on a near-continuous basis, the density, temperature, moisture, and carbon dioxide (CO_2) levels of the square-meter patch of soil in which it is set. Other devices will constantly track what the soil weighs. Those data will be fed to computers and on to researchers at B2 and back to the university in Tucson. After a period of basic observation, the slopes will receive plant life. One of the slopes is currently completed; LEO's designers hope to have all three running in November 2012.

It is the near-instantaneous nature of the data collection that fascinates Salim Hariri, director of the UA's branch of the National Science Foundation's Cloud and Autonomic Computing Center. Hariri said that the collection for a more typical process—one in which, say, the interactions of plant growth with the environment are studied—might take a year or more. "We're trying to collapse all of this in real time," he said. "While the data are [being] generated, we are building a model that captures it and ties it all together. With that integration, we could [better] understand… the right model and predict the behavior of the environment, and [we would] also be able to control the environment." With a large-scale project like LEO, researchers will be able to validate lab results from other experiments and do so speedily. And they can play what-if with their inputs as needed.

"With LEO, we can vary all the parameters," said Hariri, that currently preoccupy researchers in the desert Southwest—temperature, rainfall, CO_2 levels, humidity—"and let you have accurate modeling and simulation so you could project what happens a year from now and a hundred years from now. You could see if we are headed toward desertification of the land in the Southwest, or a drought; we'd be able to predict that. And, hopefully, we would be able to prevent that." Policymakers, who might be skeptical of climate change, could visit B2 and witness the experiments with their own eyes and even plug in their home-precinct data.

Stephen DeLong, a geologist who is LEO's lead scientist, sees the project as complementary to the many



One of the three large "landscapes" that constitute Biosphere 2's (B2's) Landscape Evolution Observatory. Dark volcanic soil covers the tilted platform. Sensors, their locations marked here by yellow tennis balls, will send data to B2's computers, where researchers can control inputs (rainwater, carbon dioxide, temperature) and measure the results. Photograph: Fred Powledge.

smaller-scale research efforts, run by land-grant colleges and federal agencies, in which the effects of water and CO_2 on soil are studied (see box 2). First, there will be a period of studying LEO's slopes in their relatively abiotic condition, DeLong said (although he acknowledges that soil microorganisms will be there from day one). "We really want to understand how these physical systems work: how the water moves, how the chemistry in the soil changes," he said. "[We'll] study that for a few years, and then we'll introduce plants. It'll be a very fundamental coevolution: How does life modify earth? How do the physical system and the biological system coevolve? That's something that's very interesting in a big-picture way because the surface of the Earth is this mosaic of physical systems that coevolve with biological systems. But it's very hard to study that, because it's hard to understand the history.… Here, we'll be able to actually watch the history proceed."

Grand challenges

One of B2's main contributions, its redesigners hope, will be its ability to bring together diverse scientific disciplines to try to solve big problems—what B2's promotional documents call *grand challenges*. When UA was figuring out what to do with the gleaming $200 million chunk of real estate it had acquired, it gathered scientists from many disciplines to offer advice and, later, to run the place. When LEO was in the design stage, recalls John Adams, the interim assistant director at B2, "you had modelers, you had hydrologists, and you had ecologists and geologists and atmospheric chemists. They were all put at a table to discuss 'Okay, if we're going to build the next generation of science instruments, and we have the space to do it in, what is it actually going to look like? And what components does it need to have?'" LEO, said Adams, is the outcome of that process.

Pierre Meystre, the director of the newly formed B2 Institute, one of UA's B2-related components, said that B2 "is more than just bio. The idea is that to deal with big problems—big challenges like global warming—you need to have everybody at the table. You need to have the engineers, you need to have the physicists, you need to have the social scientists, the educators. We are really trying to build a community."

Community building is difficult, he said, because the disciplines involved are so diverse. "I'm a physicist by training, so I don't really know the language of biologists. And they don't know the language of physicists and may not know the language of the engineers who are involved in energy development. [However], if you want to do energy, you need to understand water—especially in a place like Arizona, because most energy comes here from water. So you need to bring these people together, and you need to get them to listen to each other, and you need for them to understand the point of view of the other folks."

Another (and obvious) grand challenge is energy. "We are running out of oil," said Meystre, "maybe not tomorrow, maybe not in 50 years, but one of the challenges is renewable energy. If you want to get into renewable energy, you have to get into the other challenges. We are starting to think about B2 as a model city where we can do many interesting projects in renewable energy and smart monitoring." The B2 campus now includes a hillside garnished with solar panels that help to reduce B2's heavy power usage.

The original Biosphere II housed several biomes: the farming unit, a desert, a marsh, an ocean, a savanna, a tropical rainforest, a thornscrub, and a place for the biospherans to live and work. Beneath it all is a wealth of electrical and electronic cables, plumbing, and ventwork to support the activities above. Two huge domes, called *lungs*, moderated the fluctuating air pressure inside B2 when it was sealed shut. LEO is by far the top-ranked biome in the new B2, but the 850-square-meter ocean model and the 1900-square-meter rainforest remain important components. John Adams sees the rainforest as a prime example of one of B2's strengths: the opportunity to address "questions… that couldn't be [addressed] anywhere else."

"Specifically," he said, "what happens when you dry a rainforest out? What are the dynamic changes?"

Similarly, said Adams, B2's ocean offers the chance to "better understand the metagenomics" of a marine environment. Matthew B. Sullivan, of UA's ecology and evolutionary biology faculty, leads a laboratory devoted to studying the health of the fish in the ocean biome. Originally, the Biosphere II ocean was stocked with corals to emulate a Caribbean reef environment. Live corals perished, but the reef-dwelling fish species from the Atlantic and Pacific Oceans and from the Gulf of Mexico have survived because they feed on the ocean's algae, which grow on the surrounding rock installed during Biosphere II's construction.

Melissa Duhaime, research scientist at the University of Michigan, uses the B2 ocean to model the Great Pacific Garbage Patch, the gyre of marine trash trapped and circulated by ocean currents. Duhaime particularly wants to understand the role of microbes in connection with marine plastics. "The ocean at B2 is the perfect intermediary between nature and lab," she said in an e-mail. The community ecosystem in the B2 ocean is certainly infinitesimal compared with that of a real ocean, she said, "but it's much larger and more complex than what we could design in a lab setting and, in that way, better reflects a natural system. However, it benefits from being controlled and contained, sheltered from storms and other factors that can disrupt experimental deployments in nature. [Furthermore], we know from previous work that the members of the microbial community (the bacteria, Archaea, viruses) in

Part of the towers and rooms that make up Biosphere 2. Photograph: Fred Powledge.

Biosphere 2 contains a thriving rainforest. Photograph: Susan Swanberg.

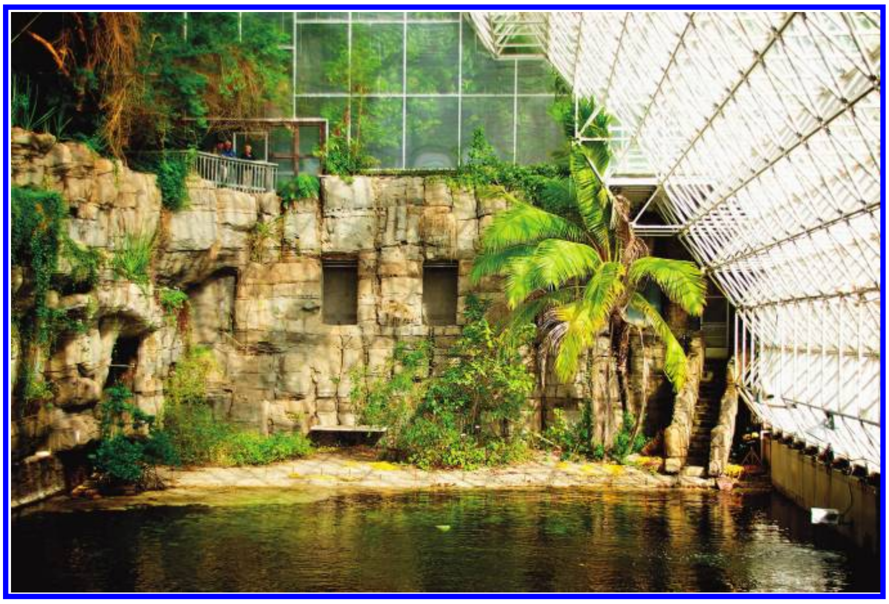
Box 2. Nails and soup cans.

The Landscape Evolution Observatory (LEO) project at Biosphere 2 may be unique among laboratories. Thousands of sensors embedded in the three fabricated slopes will transmit data about soil and how it reacts as rain tumbles down an incline, but a resourceful soil scientist conducted a smaller-scale version of the research on a steep hillside in Honduras, using a handful of 20-penny nails, an empty soup can, and a ruler.

Gaye Burpee, whose interest in agriculture might have been provoked by membership in the family that founded a mail-order seed company, was working several years ago for the Centro Internacional de Agricultura Tropical, seeking ways that poor Honduran farmers could best use their lands, which in Honduras are likely to be of marginal quality and steep. Armed with the nails and soup can, she showed farmers how they could measure soil quality and erosion.

Burpee sank the nails partway into the soil and measured the portion of nail remaining above land. After the next rain, the farmer could see just how much soil had washed away from his tomato and bean plants. She plunged the soup can, opened at both ends, into the soil and poured a measured amount of water into it. Then she and the farmer counted the seconds until the water had disappeared into the soil. The farmer could use the results of the experiments to decide whether to build terraces to slow down the erosion.

B2's $6 million LEO will do the same sort of research, writ very large. In addition to tracking water as it moves atop and through the bare soil, LEO's sensors will also constantly assess soil temperature, pH, carbon dioxide levels, overall moisture, and a number of other data points—far more than could be measured with nails and soup cans. In about a year, LEO's job will become even more complex; the Biosphere 2 scientists will add plants to the soil.



Biosphere 2's "ocean." In the original Biosphere II, corals were planted in the 700,000-gallon tank, but they failed to survive. Fish remain, however. Photograph: Paul M. Ingram.

Box 3. For more information.

www.b2science.org. The official Biosphere 2 (B2) site, published by the University of Arizona, contains links to many of B2's activities—for teachers, the B2 Institute, information on visiting the site, and on the flagship Landscape Evolution Observatory experiment. The site includes a brief history and a colorful time line.

www.biospherics.org. This site is about the original Biosphere II—its people, history, and publications. The chronology ends at September 2003, when Columbia University ended its relationship with the project. The site lists a number of publications that relate to the experiment's early years.

www.nytimes.com/1996/11/19/science/paradise-lost-biosphere-retooled-as-atmospheric-nightmare.html. This *New York Times* article, written by William Broad in 1996, is on Columbia University's attempts "to turn a utopian failure into scientific triumphs."

www.nsfcac.org. This page contains information on the National Science Foundation's Cloud and Autonomic Computing Center, the industry–academy collaboration that focuses on cloud computing, which plays a large part in B2's operations.

the [B2] ocean are very similar to the community makeup we see in natural coastal marine environments. We design our experiments with this confidence in mind."

Another B2 mission is education (see box 3). Scores of visitors arrive daily; they may come to see the amazing architecture, but once they are there, they are treated to tours led by guides well versed in the science of the place. They may go away with a better appreciation for the value and methods of science. Schoolteachers receive special treatment at B2. The facility has programs for educators in STEM fields (science, technology, engineering, and mathematics); teachers who enroll in B2's programs go home with complimentary computer tablets (they used to get laptops) and membership in a network of B2 information. B2 also offers conference-center facilities, as well as "exotic dinner event locations."

The ultimate driver and motivator

Behind most of the work that's being done at the newest edition of B2 are concerns that were far from utmost on the scientific agenda when the eight biospherans entered and sealed the door two decades ago: climate change and the closely associated issues of water. These will be studied and modeled in intricate detail once LEO finishes its shakedown cruise and receives its first plant life.

DeLong, LEO's supervisor, said, "Climate change is the ultimate driver and, really, the ultimate motivator in many ways. The plant physiological ecologists who work here want to understand how plants work, in detail. They want to understand how water moves through a plant. They want to understand how a plant responds to an intense rainfall, a long drought period, a light rainfall—different scenarios. And the reason they want to understand that is that they want to understand how things are going to change in the future. And also how things are currently changing. Things are changing very rapidly already in ecosystems and in landscapes."

He added, "You can't talk about climate change and impacts of climate change without eventually talking about population and about development and about land use. And about water. Water is the thing that really binds a lot of the research together out here. We need to think about how water resources are going to change in the future."

Mission to Earth and beyond

When Biosphere II was created, there was much talk about using its unique facilities to learn what was needed for planetary exploration, as well as for life on Earth. Mars was frequently mentioned, as was using Earth's Moon as a base for deeper probes. An official record of the early Biosphere II said that the experiment was scheduled to last 100 years and that it would produce research, education, and environmental technologies "for use on Earth and in outer space." Over the years, science and the decisionmakers who fund it seem to have set aside their passion for space colonization in favor of taking a more serious look at the home biosphere. Exploration of Earth now takes precedence over probes of the rest of the solar system. A study back in 1996 in *Science*, by Joel E. Cohen and David Tilman, challenged the Mars proposition. "At present," they wrote, "there is no demonstrated alternative to maintaining the viability of Earth.… Despite its mysteries and hazards, Earth remains the only known home that can sustain life."

Adams, B2's assistant director, thinks that "at least right now, technology doesn't lend itself to traveling to another planet. The one that we have is Earth. This is the first tool that was built to understand the functionality of Earth's systems. And now we have an opportunity to leverage it, to look at it with different eyes: How can we use these systems to understand the systems here on Earth?… This is the first really large-scale Earth science experiment."

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