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Life Under the Bubble

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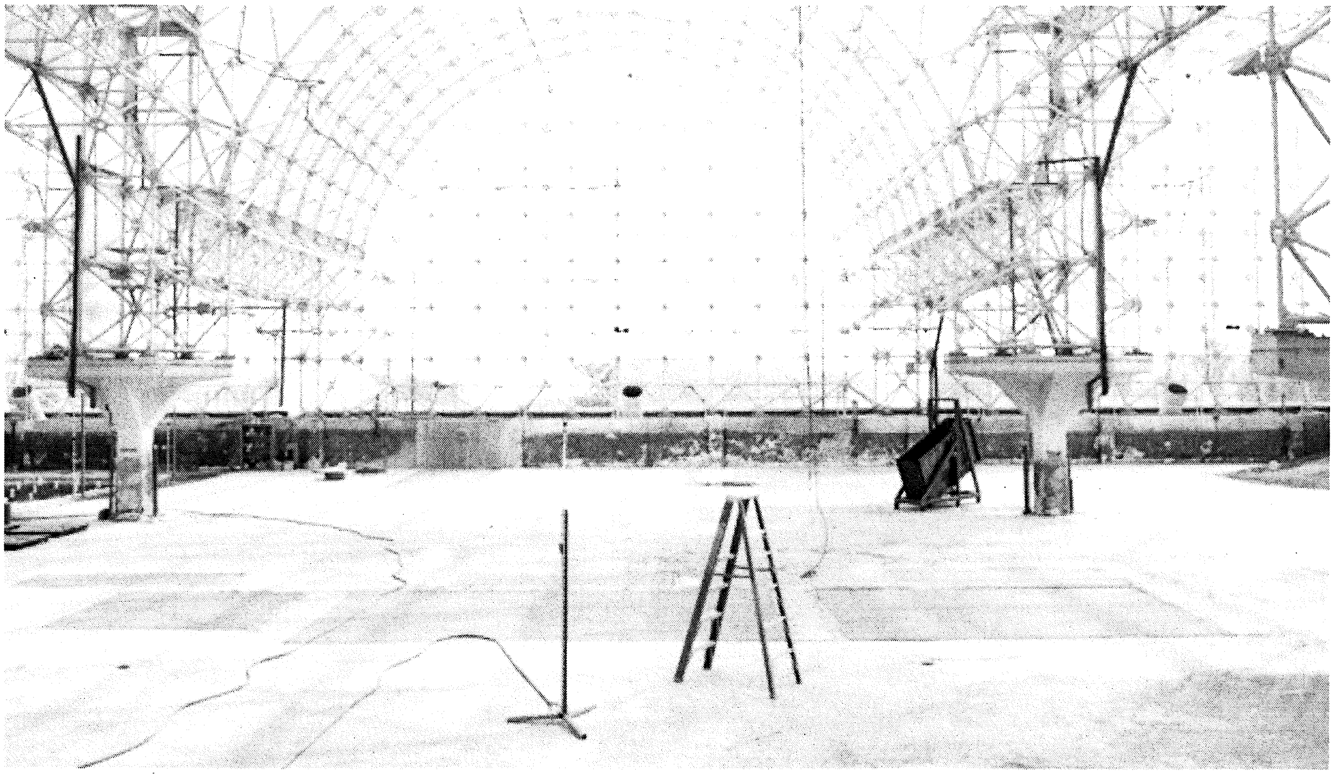
Biosphere 2 was one of the most lauded experiments of the 1990s, then one of the most ridiculed. Now it is back, offering a unique way to put theories about climate and environment to the test.

by Jordan Fisher Smith; Photographs by Douglas Adesko



Biosphere 2 has stood amid the paloverde, mesquite, and ocotillo southwest of Oracle, Arizona, for less than 20 years, yet it looks decidedly aged. Its skin is mostly glass and lacks window-washing tracks, so the hundreds of panes had to be cleaned by workers hanging on ropes like rock climbers. At one time seven people were employed to do this; today there are none. The desert wind deposits dust on the structure and the rain washes it downward, forming parallel streaks. The rain forest inside pushes against the glass. In 2003 there were about 150 employees on the site. Less than a third remain. Dry leaves collect against the air handlers by the main doorway; whiptail lizards skitter over the concrete paths, and javelinas trot around the grounds at night. A note on a whiteboard in the operating engineer's office tallies the number of poisonous reptiles encountered on the site, which is greater than the number of maintenance people left to encounter them: "Rattlesnakes: 17."

The café is closed, the mission control building deserted, and inside the row of clear plastic sheds where plants were readied for installation in the main structure, towering exotics—Panama hat palm, angel's trumpet—stand bleached and lifeless where they perished when the water was turned off. A monochrome monitor displays the last numbers it ever knew, burned into its dead screen. On the shelf below is the 1986 manual for the environmental monitoring system to which it was connected. Nothing ages faster than the future.

Constructed between 1987 and 1991, Biosphere 2 was a 3.14-acre sealed greenhouse containing a miniature rain forest, a desert, a little ocean, a mangrove swamp, a savanna, and a small farm. Its name gave homage to "Biosphere 1"—Earth—and signaled the project's audacious ambition: to copy our planet's life systems in a prototype for a future colony on Mars. A May 1987 article in DISCOVER called it "the most exciting scientific project to be undertaken in the U.S. since President Kennedy launched us toward the moon." In 1991 a crew of eight sealed themselves inside. Over the next two years they grew 80 percent of their food, something NASA has never attempted. They recycled their sewage and effluent, drinking the same water countless times, totally purified by their plants, soil, atmosphere, and machines. It wasn't until 18 years later, in 2009, that NASA announced total water recycling on the International Space Station. At the end of their stay, the Biospherians emerged thinner, but by a number of measures healthier.

Despite these successes, the media and the science establishment seized upon the ways in which the project had failed. Chief among these was an inability of Biosphere 2's atmosphere to sustain human life. As was true outside, the problem was signaled by rising carbon dioxide. By 1996 Biosphere 2 had passed into the hands of Columbia University, and later the University of Arizona took over. Both used it to run scenarios of global climate and atmospheric change. In its later life, "instead of trying to model utopia, Biosphere 2 would actually model *dystopia*—a future plagued by high carbon dioxide levels," wrote Rebecca Reider, author of a definitive history of the project. But while most research on impending environmental disaster relied on computer models, Biosphere 2 represented a fascinating alternative mode in which large-scale analog experiments employed real organisms, soil, seawater, and air.

The man behind Biosphere 2 was John Allen, a Colorado School of Mines–trained metallurgist and Harvard MBA. In 1963, after two hallucinogenic experiences on peyote, Allen looked out of the Manhattan office building in which he was working and realized he could not open the window. He felt trapped like a bug inside glass—an ironic epiphany for a man who would work so hard to seal up a handful of his followers three decades hence. So he sailed from New York aboard a freighter and traveled the world, seeking wisdom. By 1967 he had become a self-styled esoteric teacher in Haight-Ashbury-era San Francisco, delivering weekly lectures to a group of mostly younger followers and cohabitants. In 1968 he and his students went to New York to set up a theater company, and from there to New Mexico, where they started a commune near Santa Fe. If most such counterculture experiments yielded to entropy and poverty, Allen's Synergia Ranch is a notable exception. The Synergians were a very hardworking bunch.

In 1974 a lanky young Texan and Yale dropout named Ed Bass wandered up the driveway to Synergia Ranch. Like Allen, Bass had a strong interest in the environment. Unlike Allen, he was the billionaire heir to an oil fortune. Later that year Allen and his followers drove an old school bus to Berkeley, California, where they built an 82-foot sailboat. None of them had ever built even a rowboat. In 1975 they began sailing the Heraclitus around the world. They took her up the Amazon River, dove coral reefs in the tropics, and sailed her to Antarctica to do research on whales.

With John Allen's big dreams and Ed Bass's big money, the Synergians began taking on bigger things. They acquired a huge cattle ranch in Australia, started a sustainable forest in Puerto Rico, built a hotel and cultural center in Kathmandu, and took on other projects in Nepal, the United Kingdom, France, and the United States. Now calling themselves the Institute for Ecotechnics, they began hosting international meetings on ecology, sustainable development, and then space colonization. At a conference in Oracle in 1984, Allen announced his plan to build a prototype Mars colony on Earth before the decade was out. The destiny of human beings was to seed Earth's life into space, and the first stop would be a working colony on Mars.

The principals of the institute broke ground for Biosphere 2 in January 1987. If some of them lacked academic qualifications for the jobs they held, they enlisted real experts to execute the design. Walter Adey, a geologist at the Smithsonian Institution, was in charge of the ocean. The rain forest was the domain of Sir Ghillean Prance, then director of the New York Botanical Garden. These and other experts installed 3,800 species of life inside, even as cranes lifted great sections of white superstructure into place overhead. The majesty and complexity of the project entranced the press, touching on myth and religious narrative, Rebecca Reider wrote. *Time* called it "Noah's Ark: The Sequel." This created expectations that would be hard to meet.

Next page: A case of bad chemistry

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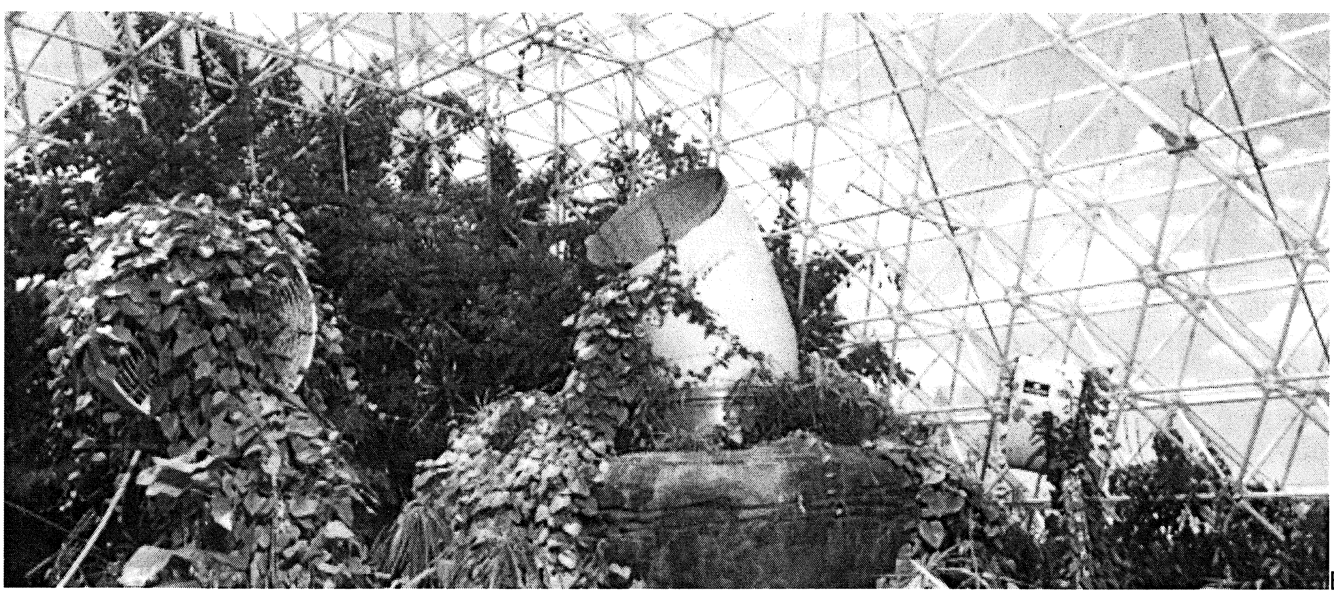

Biosphere 2's

91-foot-tall rain forest contains more than 150 plant species and now provides scientists a test ground for ecosystem experiments.

In September 1991, four women and four men in NASA-style jumpsuits entered the air lock of Biosphere 2. Twelve days into the mission, Jane Poynter, a young Englishwoman in charge of the farm, put her hand in a threshing machine while winnowing rice. The group's doctor sewed the tip of her middle finger back on, but the graft didn't take and she was evacuated for surgery. She returned in only a few hours to serve out the two-year mission, but when she reentered the air lock, a duffel bag was placed inside with her. It contained nothing of substance, Poynter said—some circuit boards and a planting plan for the rain forest—but the media had a field day with it, along with the fact that someone had left and then reentered, which couldn't have been done on Mars.

More ominous, signs of trouble with the internal atmosphere began within 24 hours. Each morning the crew had a breakfast meeting over bowls of home-grown porridge in *Star Trek*–style chairs around a polished black granite table. The morning after closure, the crew captain announced that carbon dioxide in Biosphere 2's atmosphere had risen to 521 parts per million, a 45 percent increase above levels outside at the time. By the following day, the lowest it went was 826. Over the months that followed, the news at the morning meetings got worse. Crew members were feeling tired and began to pant when they climbed stairs.

In May 1992 in Palisades, New York, geochemist Wally Broecker got a phone call from someone at Biosphere 2, asking if he would be willing to consult on their atmosphere. Since the late 1970s, when he became the Newberry Professor of Earth and Environmental Sciences at Columbia University's Lamont-Doherty Earth Observatory, Broecker had been sounding the alarm about a buildup of carbon dioxide in the big atmosphere. An elfish presence with a dried-apple-doll face and wild, tousled hair, he was already one of the great men of atmospheric-change research when he crossed the George Washington Bridge for dinner with John Allen at a Manhattan restaurant. The meeting had a cloak-and-dagger feel. Allen, a handsome, clean-shaven, broad-shouldered man who often wore a fedora, reminded Broecker of Indiana Jones. By Broecker's account, Allen proffered a graph of the gas composition of Biosphere 2's atmosphere, then nervously pulled it back, as if someone else might see it. A week later Broecker flew to Arizona and began collecting data.

Much attention had been focused on charismatic species when Biosphere 2 was put together. A biologist surveyed the world's hummingbirds to find one with a bill the right shape to pollinate a variety of plants inside the structure, and without a mating display predisposing it to fatal collisions with the glass. But Broecker and his graduate student Jeffrey Severinghaus discovered that the culprits in the carbon dioxide problem were the tiniest organisms on board: soil bacteria.

The process of their subversion was respiration, in which living things release carbon dioxide into the atmosphere. Green plants absorb sunlight and carbon dioxide during photosynthesis, making carbohydrates and releasing oxygen, but they also do the reverse: Plants, too, respire (or breathe), burning carbohydrates to do work like making branches and roots. In the soil around their roots, billions of fungi and soil bacteria respire as well. In fact, the greater part of all "breathing" in terrestrial systems goes on underground.

Ever grand in their ambitions, Allen and his people intended Biosphere 2 to be used by rotating crews for 100 years. Feeling they had one shot to invest their world with life-giving nutrients, they had loaded their soils with compost and rich muck from the bottom of a cattle pond. (Agricultural chemicals used inside might end up in their air and water.) When the air locks closed, soil bacteria had a massive party, exhaling carbon dioxide and tipping the balance the wrong way.

As oxygen was converted to carbon dioxide, free oxygen in the atmosphere declined. By January 1993, Biosphere 2's carbon dioxide levels were 12 times that of the outside, and oxygen levels were what mountaineers get at 17,000 feet. The crew's doctor was having trouble adding up simple figures and disqualified himself from duty. So, a year and four months into the mission, tank trucks containing 31,000 pounds of liquid oxygen started driving up the access road to the site.

The story of fresh-faced idealists getting taken down a notch played well in the media. For two years the glass walls of Biosphere 2 were lined with TV cameras and tourists. The crew's lives turned into reality TV. In fact, the producers of the world's first reality TV show, *Big Brother*, which aired in the Netherlands in 1999, acknowledged Biosphere 2 as their inspiration. True to reality TV's typical plotline, months cooped up together while struggling with their atmosphere and hunger and being filmed by well-fed people led to squabbles among the Biospherians. They emerged from the air lock in September 1993 in two groups of four who weren't speaking. Organizational cracks opened between them and their advisory scientists and extended into their relationship with Ed Bass. Originally budgeted at $30 million, Biosphere 2 had already cost a reported $200 million. By the time a second crew took its place inside, Bass had had enough. On April 1, 1994, his bankers, accompanied by carloads of armed federal marshals and sheriff's deputies, swept into the site with a restraining order. The second crew lingered inside Biosphere 2 for another five months and 16 days before terminating its mission.

Biosphere 2, it was widely reported, was a catastrophe. In 1999, when *Time* did its fin de siècle summary of the 20th century, it included Biosphere 2 in its list of the worst 100 ideas.

With the biospherians ejected from their eden, Bass's people began looking for a new entity to operate the facility. Eventually they struck a deal with Columbia University. The new director of research was Wally Broecker, who had coined the term "global warming" two decades earlier. Here was a gigantic laboratory flask with a whole tropical forest and an ocean inside it—models of what many scientists suspected were the two biggest carbon sinks in the world. By 1995, when the deal was closed, Broecker was not alone in his sense of urgency.

Next page: Hot research site in a warming world

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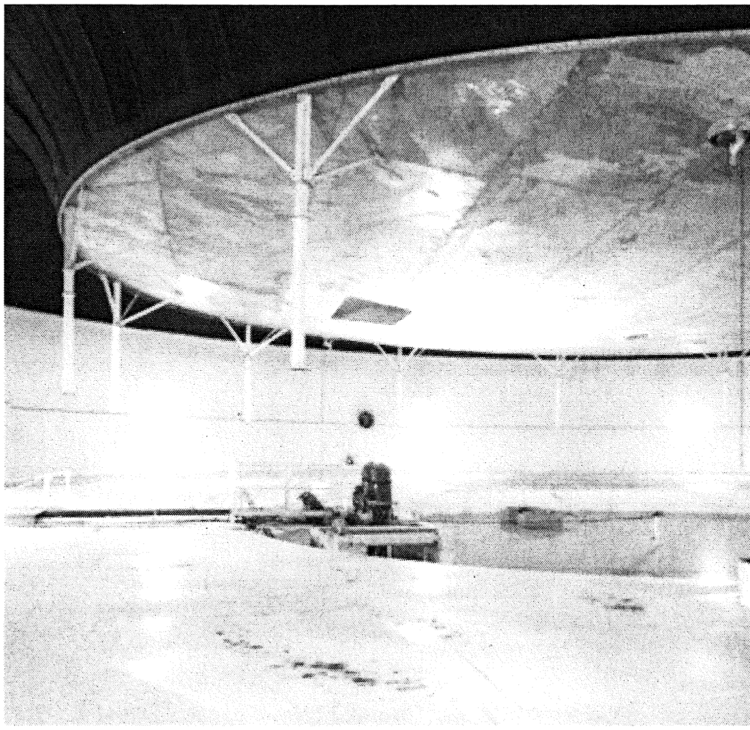

The "south lung" is one of two rooms that allowed Biosphere 2 to b
reathe— and not explode— during its former life as a closed structure.

That January, Rodolfo del Valle, chief of Antarctic earth sciences at the Argentine Antarctic Institute, received a distress call from colleagues at a research station adjoining the Larsen A ice shelf. The men were yelling, and in the background Del Valle could hear a roar. The Larsen A, a sheet of ice the size of Rhode Island and 500 feet thick, was collapsing into the Weddell Sea. The next day Del Valle called for an aircraft and flew over the area. All that was left of the massive ice shelf were small icebergs as far as the eye could see. "I cried because I could see the future," he said. That December, the Intergovernmental Panel on Climate Change reported that greenhouse gases were rising, with human activity the likely cause and dangerous changes in the earth's conditions a likely result.

Joe Berry, a plant physiologist at the Carnegie Institution for Science, came to work with Broecker at Biosphere 2 in 1996. Berry, Guanghui Lin, Kevin Griffin, Bruno Marini, Barry Osmond, and others began afflicting the little world with simulated droughts and a high-CO_2 atmosphere and measuring what happened in its rain forest and farm, now planted with rows of cottonwood and poplar trees to simulate a commercial forestry operation—a natural carbon sink.

As evidence of global warming increased, removing carbon from the air had become important in the world outside. Success hinged, in part, on understanding the feedback loops between photosynthesis and respiration on a global scale. As it stands, photosynthesis, which takes in carbon dioxide, only slightly outstrips respiration, which releases it again. The difference between intake and output—just 1 to 2 percent of the total carbon going into ecosystems—accounts for the amount of carbon fixed in things like the trunks of Biosphere 2's cottonwoods. What would happen to this relationship, Berry and his colleagues wondered, as the world grew warmer and more carbon dioxide was released? Photosynthesis was limited by the amount of carbon that green plants could scavenge out of the air. But with more carbon dioxide present, would photosynthesis speed up, saving us all by fixing more carbon?

What the scientists found inside Biosphere 2 was that when CO_2 was elevated, plants photosynthesized more, but their leaves and roots and the soil bacteria respired more as well. "Carbon just chased itself around the cycle faster," Berry says. There was no net benefit. Today soil respiration remains the wild card it was for the Biospherians. Known to increase with warmer temperatures, it could cut the carbon sequestration from tree-planting projects to zero as soils belch out more CO_2 than what is stored in tree trunks and the like.

Meanwhile, in 1996, Broecker invited Chris Langdon, a young marine ecologist at Columbia, to have a look at what could be done with the ocean. Langdon may have been the only person on his flight to Arizona with dive gear. He hadn't been spending much time in deserts; his research more typically had him on oceangoing research vessels. He showed up for work in sun-faded T-shirts, looking more like an extra for a Jimmy Buffett music video than a professor.

The first thing Langdon set out to do was balance the chemistry of Biosphere's ocean. It had gone acid, absorbing carbon dioxide from Biosphere 2's atmosphere and forming carbonic acid as a result. This was happening on the outside, too, although it was a phenomenon biologists had largely ignored until then. "Of the carbon dioxide human beings put into the atmosphere from the burning of fossil fuels and deforestation," Berry says, "roughly a third remains in the atmosphere, a third goes into terrestrial ecosystems, and a third goes into the ocean." As a result, Langdon says, the world's oceans have fallen one point in pH since the Industrial Revolution. That doesn't sound like much, but pH is logarithmic. Today's oceans are 30 percent more acid than they were a century ago.

Langdon worried about the effect on shellfish and coral. When seawater gets more acid, he explains, it holds fewer free carbonate ions. Corals and marine organisms that build shells rely on free carbonate for raw material. Biosphere 2 was the perfect lab; here was a little ocean in which, unlike the real one, acidity could be adjusted. By manipulating the acidity of the Biosphere 2 ocean and measuring the resulting growth rates in coral between 1996 and 2003, Langdon proved that ocean acidification from rising atmospheric carbon dioxide would radically affect calcium carbonate–shelled marine life (pdf). He forecast that by 2065, rates of growth in coral reefs would decline by 40 percent.

in experimental modeling of life systems and geochemistry, scale and complexity are important. In what are called microcosm experiments, plant physiologists study leaves in sealed containers so their gas exchange can be tracked, but that gives information only on the leaf's relationship to the atmosphere, not that of the whole plant, its soil, and other plants and animals. As the scale gets bigger, enclosed experiments are referred to as mesocosms. There has never been an experimental mesocosm as big as Biosphere 2.

However promising the facility was during the Columbia period, grant applications and submissions for publication from Biosphere 2 were undermined by the project's bad press. Like dog feces on a shoe, the project seemed to carry a whiff of something the big grantors did not want in their portfolios. Although it did get some small education grants from the National Science Foundation, major government research agencies generally wouldn't touch the place. "It was extremely unfair," Broecker says. In 2003 the situation led new Columbia University president Lee Bollinger to jettison the project. Staff were given pink slips, and filters were turned off in the ocean. Langdon's corals didn't survive. For a while it looked as if Biosphere 2 would become a theme park at the center of a housing development. After Columbia walked out of its lease, Ed Bass sold Biosphere 2 to the developer, and the University of Arizona in Tucson took over under a new lease.

Next page: Under-the-radar redemption

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Today Biosphere 2 is still open to visitors, a strange mixture of botanical garden, aquarium, and house museum about the lives of the early-1990s Biospherians with slightly big hair and loose-fitting clothes. Roy Walford, the first mission's doctor, described the place as "the Garden of Eden on top of an aircraft carrier" in Reider's book. Belowdecks are concrete galleries full of wind from rumbling air handlers, tanks, pumps, and miles of cable and pipe. But aircraft carriers have sailors with scrapers and paintbrushes. Biosphere 2 does not. Rust is becoming a problem.


Isabel Stubblefield was a cook during the first two-year mission at Biosphere 2. She still works there.

Down below there is also a cavelike aquarium with viewing windows into the Biosphere 2 ocean. Despite its murky appearance ("the last time we could see the opposite wall was 2004," my guide tells me), the ocean is not dead. Bright tropical fish appear out of the emerald gloom and flit along the glass: yellow tangs, sergeant majors, doctorfish. No one has been feeding them, says Matt Sullivan, the University of Arizona molecular and evolutionary biologist who now presides over the underwater portion of Biosphere 2.

Remarkably, after nearly two decades of separation from the Pacific, Biosphere 2's seawater still looks like living seawater under the microscope. "The chemistry and the microbes suggest that it's just another coastal ocean," Sullivan says. "I was shocked." His specialty is microbial life in oceans, and his particular interest is the way that viruses drive the evolution and regulate the activities of bacteria. If this seems like an obscure subject, it is of far more import to our future than it sounds. "Ocean microbial photosynthesis accounts for half the photosynthesis in the world," Sullivan notes. In May he landed a $600,000 grant from the National Science Foundation to study the role of viruses in an oxygen-starved region of the real ocean. Sullivan has been using the Biosphere 2 ocean to develop newer, more accurate sampling methods for this task.

From Sullivan's opaque tropical ocean, which still has a white-sand beach and palm trees at one end, I follow a path across the savanna and through the living quarters to what was once the farm. All its crops and earth are gone. Stripped to bare concrete, it resembles a glass-roofed aircraft hangar. It is now the domain of a red-haired University of Arizona geologist named Steve DeLong, who is working on a huge new mesocosm: three towering, sloping steel tables nearly 100 feet long and 60 wide, upon which will be constructed artificial landscapes with underlying soil and plants. Embedded in the supports will be the world's most accurate giant bathroom scale, capable of supporting 2 million pounds and sensing changes of less than half a percent. (At the time of my visit last spring, the technology didn't exist yet, and DeLong was working to develop it with manufacturers of scales that weigh jetliners.)

DeLong is trying to learn how to create realistic rain from a series of pipes and overhead sprinklers. That makes sense, since the university's new research focus for Biosphere 2 is water: not just rain but runoff, absorption by soil, use by plants, and evaporation. The scales under DeLong's tables will record real-time changes in water saturation while sensors in the air and the soil record humidity, chemistry, and gas exchange. Arizona no longer runs Biosphere 2 as a sealed facility. It now uses a "flow through" system, in which air exchange with the outside is allowed while sensors record the movement of moisture and gas, enabling accurate estimates of total mass exchange with the outside world. The reason for the change is the cost of energy. Biosphere 2 is a greenhouse in the desert, and Columbia was paying as much as $1.5 million a year to cool it. According to the University of Arizona, energy costs under the new system are less than a third of that.

Back in the 1990s, critics pointed to Biosphere 2 as an example of private philanthropy pushing science in wacky directions. But scientists who have worked in this product of Ed Bass's generosity see it another way. Wally Broecker, Joe Berry, and Chris Langdon, along with Columbia's last director of research, Barry Osmond, and the University of Arizona's present one, Travis Huxman, continue to believe in the potential of mesocosm research. In July 2010, Langdon was in Australia as an adviser on the Australian Tropical Ocean Simulator, currently in the works. The Simulator will allow marine biologists to put ocean life through conditions they hope they won't see outside, just as Langdon did at Biosphere 2. The University of Arizona, meanwhile, has linked research at Biosphere 2 with projects that operate in the outside world. For example, Sullivan's use of the facility was ancillary to the principal focus of his grant, which involves mapping ocean viruses around the world. His NSF grant might signal an end to Biosphere 2's big chill in academia. The university has put out 30 proposals in the last two years and believes some are recommended for funding. Now 81, John Allen still lives on Synergia Ranch in New Mexico with several of Biosphere 2's builders and at least one of its first crew, who fiercely defend their original vision for it. Their research yacht, Heraclitus, still plies the world's oceans. Jane Poynter, who lost the tip of her finger in a rice thresher, married a fellow crew member. They started a Tucson aerospace firm, a contractor on NASA's new Orion space capsule. Wally Broecker still goes to his office across the Hudson from Manhattan. After all Ed Bass gave away, in 2009 he was tied at number 236 in Fortune's list of the 400 richest Americans. He continues to fund research at Biosphere 2. And Matt Sullivan, the ocean microbe researcher, plans to run the lab while others collect viruses at sea for him. He suffers from terrible seasickness and thinks an ocean in Arizona is just fine.