LIVING IN A TIN CAN

By Jane Poynter

Biosphere 2 generated lots of jokes for late-night comedians, but the failure to create closed Earth-like ecosystems for long term space missions is no laughing matter.

Test Bed: Sally Silverstone, manager of the Biosphere 2 Food Systems, pictured on the inside of the Test Module—a test chamber 1/400th the size of Biosphere 2 where testing for the engineering and biological components of the structure took place.
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In 1991, I entered the sealed environment of Biosphere 2 with seven other people, intending for nothing material to enter or leave the three-acre steel and glass building for two whole years. Our life-support system of 3,800 species of plants and animals, along with bacteria and fungi, was supposed to produce everything we would need to live. In other words, it was meant to be the first self-sustaining fully bioregenerative life-support system—a giant leap toward enabling us to live on Mars.

But only a year into our stay, problems emerged: We moved in slow motion as we dug up our sweet-potato harvest. As we chatted, my fellow inmates and I couldn't finish a sentence without snatching a breath. Some of us barely slept, woken every few minutes by a sudden gasp for air. All of this was our bodies' reaction to low oxygen. Finally, when the oxygen plummeted to just over 14 percent—and our doctor couldn't add up a simple line of figures—we realized that our life support system had failed us, and it was time to pump oxygen into our prototype space base.

For us, this failure was not a matter of life and death. The safety valve for Biosphere 1, the Earth, was just a few millimeters away on the other side of our airlock door. Even for those in low-Earth orbit, the ground is only a couple of hours away. So while the life-support and thermal control system on the International Space Station has not run more than a matter of months without something breaking down, it's not life-threatening, albeit a strain on the already overburdened crew. Even a lifeboat from the Moon only need travel a few days to safety.

But for those on a minimum two-year mission to and from Mars, it will be an entirely different story. They will not be able to cry uncle and rush quickly home if their oxygen system breaks down.

Almost fifteen years have past since the eight of us walked into Biosphere 2. But have bioregenerative systems advanced since then? Unfortunately, not much.

True, we can grow more food on less area. Tomato plants now waste so little energy on growing stems and leaves that to call them green plants is almost a misnomer—they're practically entirely red with fruit. Utah State's Bruce Bugbee has developed the dwarf Apogee wheat, which pumps out fat kernels at an unprecedented rate. The plants grow 24 hours a day – reducing the time for the kernels to mature — and waste far less energy growing inedible stems and leaves than normal field wheat. Although the plants grow less inedible material, that material is still a roadblock to recycling everything. The nutrients locked in the vegetation cannot be reused within NASA's hydroponics plant-growth system, so they must be replaced with nutrients brought from Earth.

At Biosphere 2 we did figure out what the oxygen problem was—interactions with materials that had not previously been tested together—and how to fix it. But we have not retested it. Since then, the folks at Johnson Space Center have run experiments with up to four people sealed for 91 days in a 20-foot-diameter chamber with air and water recycled by a combination of biological and physicochemical means.

So, no system has yet been made that provides all the necessities of life through biological means, nor one that is entirely self-sustaining over the long haul.

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The other painful truth for those of us entranced by the romantic notion of a living home-away-from-home is that self-sustaining bioregenerative systems really aren't cost-effective unless people are going to be living on the red planet for a long time.

Back when we were building Biosphere 2, the prevailing thought was that fully bioregenerative systems, which included growing all the astronauts' food, would pay for themselves on missions of between two to five years. Now, with large advances in regenerative physicochemical systems and slight advances in lighting and other heavy, energy-guzzling plant-growth system components and chambers, that has receded to closer to 15 years. So, we biophiles will have to make do with a small "salad machine" to grow occasional freshies, as those who winter over in the Antarctic call morale-boosting treats of fresh fruits and vegetables.

We already have all the basic technologies we need for a short two-year trip, and many of them have already been tested in space. We'll schlep mostly dehydrated food, and we'll dry and store our solid waste. But we'll recycle all our water and air. We'll be able to treat our water from washing and drinking with a range of technologies, including filtration, reverse osmosis and distillation. Johnson engineers have developed a biological means of getting rid of soaps and other organics in water—a bioreactor, whereby bacteria decompose the organics.

Scrubbing CO_2 from the air is well understood and has already been tested on ISS. Some of these systems can produce the feedstock for equipment like the Sabatier/electrolysis system, which uses hydrogen to regenerate the oxygen supply by converting the CO_2 to methane and water, and then extracting the oxygen from the water.

For operations on the surface of Mars, extracting water from the Martian permafrost is not much of a technical challenge. It's not a great idea to rely on it, though, as we don't know exactly where the permafrost is, or how much there is. We could, however, get oxygen from the CO_2 in the Martian atmosphere.

Another cost-cutting use of in situ resources is propellant production for the trip home. Several Sabatier-based systems suck in CO_2 from Mars' air, and with hydrogen brought from Earth, produce methane (the fuel) and oxygen (the oxidizer).

Despite NASA's Advanced Life Support program being under-funded, many technologies are under development to maximize efficiency to reduce launch mass and increase reliability. One technology, solid oxide electrolysis, promises to produce oxygen much more efficiently than the Sabatier/electrolysis system, does not require consumable hydrogen. It's simpler, and therefore inherently more reliable.

What is conspicuously missing from the Advanced Life Support Program, though, is testing suites of technologies together in integrated systems, including the biological component—humans.

We know from other space-systems experience that that's a potentially fatal omission. Some of the problems on ISS and at Biosphere 2 did not emerge during subsystem testing, and so were not anticipated. For example, CO_2 from the ISS cabin air permeated coolant loop piping and compromised the thermal control system. This disruption only became evident when the system was integrated on ISS with the crew.

Thus, Saturn V- and ISS-style all-up system testing might work for a trip to the Moon or in LEO, but a mission to Mars is more complex and longer than any mission humans have yet undertaken in space. What's more, improper testing is often cited as a cause of failure in much simpler robotic missions; the Mars '98 Lander failed due to no end-to-end test of entry, descent and landing.

Is it too early to start integrated-system testing? Consider this: It would take at least two years to prepare for a short two-year mission end-to-end test. The test itself would run for two years, followed by another couple of years of analysis and fixing things that didn't work the first time. Then another two-year test and a final year of analysis and refinement. That's about 10 years for two end-to-end mission tests. If we're really going to have anything reliable on the Martian surface by the early 2020s, we'd better get started soon.

I'll figure NASA's getting serious about going to Mars when full-up system testing gets underway, and people once again start living in prototype space bases or transit vehicles here on Earth.