

Dr. Leslie Bebout, Microbial Ecologist, Ames Research Center, Moffett Field, CA

Dr. Leslie Bebout works as a microbial ecologist in the Exobiology Branch at NASA's Moffett Field, CA-based Ames Research Center. She and her colleagues study the complexities of carbon, nitrogen and hydrogen cycling in early Earth and Mars analog microbial systems. They concurrently are using this systems biology approach to work with engineers to design systems geared to optimize the use of water, light and nutrient resources relevant both to the development of new green technologies and space exploration capabilities.

NASA Tech Briefs: What does a microbial ecologist do?

Dr. Leslie Bebout: We started studying microbes because they are the earliest forms of life on planet Earth. They're also what we're looking for, either remnants of cells themselves or indicators that they were there on Mars. We also look at gases in the atmospheres of far distant planets to see if we get indications of life processes there. That's the historical basis for study of microbiology and microbial ecology at NASA.

On Earth, the many transformative properties of microbes are critical; one example is that the cyanobacteria developed the process of photosynthesis. People overlook how profound this is. Photosynthesis is the conduit by which a huge amount of solar energy hitting Earth gets transformed from electromagnetic energy into chemical energy. Basically, this is what makes Earth different from the other planets. It's the capture of light energy into chemical bonds that are continuously broken, reformed and transformed.

Microbes are fantastically diverse, and they carry out transformations that literally run the planet. All of our oxygen, all of our carbon, all of our nitrogen, all of our hydrogen goes through these microbial pathways, and it's a profound life support system. We wouldn't be here if it wasn't for these microbial processes.

In recent years, because of the transformative and pivotal roles of microbes, they've become increasingly interesting, especially in the field of green energy. They produce lipids, and the majority of our petroleum — diesel, kerosene, and gasoline — all have microbial origins. Microbes also produce hydrogen, oxygen and methane.

For space applications, about 20 or 30 years ago, there was a lot of emphasis on using this biological support to keep humans alive in space. However it was found to be challenging to do consistently. It was complicated, and similar to if you have a fish tank, things don't always go the way you want them to.

Therefore those biological system efforts were abandoned in favor of more short-term physical and chemical methods for life support, which had high reliability and were very well-defined, and those have worked really well. The problem there is re-support. It costs about \$10,000 to get a standard bottle of water into space. If you are going out longer than a year or more, you have to start recycling, as it will be difficult to even re-support your physical and chemical systems fully.

So, scientists are stepping back towards thinking about biology for life support; and now we have a lot more tools at our disposal to make biology work together with the engineering approaches. This is still in the distant future, but we have to start taking steps now to be ready for that scientific approach. Biological systems need to integrate with engineering to work well together.

NTB: Is that what you're working on now? Or is there more of an emphasis on green technology?

Bebout: Our day job is still the basic microbiology for astrobiology-exobiology; that's our core. But during these past few years, we've also been working with folks at Lawrence Livermore National Laboratory (LLNL), with funding from the Department of Energy, to look at hydrogen cycling in these microbial ecosystems. We were able to use their technologies and tools that we don't have at NASA, and that's been a really good partnership. That project is about a third of our time; exo-biology-based projects are still done about 50 percent of the time; and during the remaining time we want to reach out into these other areas, such as looking at modern-day fuel needs, and where NASA technologies or partnerships or basic biology knowledge could be useful.

NTB: Can you say more about the modern-day fuel needs?

Bebout: Five or six years ago, we began talking to people in the industry. We talked to as many commercial growers as we could, and as many people in different academic and federal labs. I think at that point there might have been a little perception of "Why is NASA interested in this? Is it jumping on the bandwagon?" Many times I said, "No, We've been studying these microbial transformations for a long time, and we want to use them eventually for space applications. So if there are things that we know that can be helpful, we want to provide that knowledge."

In the other sense, we want to see what is happening now that this area has exploded in the past 10-15 years, to see what developments have happened that we can pull back for NASA mission needs as well. Those contacts have remained viable, and we keep in touch with people in the industry and also at other federal labs. We're just keeping the awareness level up.

NTB: What is a typical day for you?

Bebout: It's kind of variable with time of year. There's always an emphasis on working on our funded projects and making progress on them. But at other times, we have to mix in a focus on proposals for new funding.

In the summer months, we have a lot of interns in the lab, 7 or more. We work with interns to either match them into ongoing projects, or in some cases, towards generating seed data in new areas that we might want to propose to in the future, but need preliminary data first.

Folks in our group also have a lot of emphasis in working with nanoSatellite platforms and looking at how you would study microbes in space, and their performance in space, so that we can use that data as we move towards applications.

NTB: What are the advantages of growing algae in space? How can the study of microbes help with future space missions?

Bebout: Microbes and microalgae could provide a lot of benefits, from being a food source to producing bioplastics or pharmaceuticals. They can use waste water, such as urea as a nutrient source, and also to absorb CO₂ and produce oxygen.

Conditions are different in space, though, as far as diffusion, convective flow, microgravity, and radiation. As we get better at using these microbes on Earth, we have to study these same functionalities in space platforms where the environment is a little bit different. It might take a survey of many different species to see which microbes are best adapted to that.

The other possibility is doing a slow adaptation or targeted directed evolution. Microbes in space will start to adapt to that environment. In fact, there is some talk that all the microbes on the International Space Station, which have been thriving for years, have probably undergone adaptations. that we should be studying even more actively.

NTB: Is that where the Space PAM technology comes in, as far as measuring the efficiency of the photosynthesis in different environments?

Bebout: [With Space PAM], or space platform adapted, Pulse Amplitude Modulated Fluorometry, you can non-invasively survey a cell and tell what proportion of the light is going into production of chemical energy, versus how much is just being dispensed as fluorescence and non-usable. If the cell is stressed in any way, it will very quickly lower its photosynthetic efficiency. If it's stressed by low nutrients or radiation damage or something like that, you could quickly see that, and as it recovers, you can non-invasively see that the cells are healthy. So it's a really quick monitor.

NTB: How does microbial research impact atmospheric studies?

Bebout: This is not really my area, but as I understand it, researchers will be looking at far-off atmospheres for the balance between certain gases like hydrogen, oxygen, water vapor, and other gases like methane; basically, you would expect a certain composition suite if there were only chemical processes going on. When things come to equilibrium, there's a certain proportion you would expect, and if there's a biological driver in the system, like on Earth, where [the bio-chemical processes are] getting sunlight, they're going to be tweaking the balance of those different molecules, in ways that don't make sense from a purely chemical basis. That is where you can get an indicator that there might be another process.

NTB: Will this kind of work be applicable to Mars missions as well?

Bebout: For the atmosphere, people have been looking for trace amounts of methane and trying to decipher what is going on there. But with Mars, I think the additional component is to look for what we call organic biomarkers, which are remnants of cells and cell walls in the sediment, or some of the minerals that might be influenced by microbes being there. As far as methane, there are folks in the group who are looking at the isotopes of the methane produced in extreme environments like Chile and hypersaline environments in Mexico. Isotopes can indicate that methane is formed by biological or chemical means, such as volcanic emissions. That also could have impacts on satellite monitoring of Earth's atmosphere, to look at methane balance, because it is an important greenhouse gas. Our group has worked with the Earth sciences group to help ground-test the JAXA satellite, that looks at methane hot spots.

That's kind of neat because you're looking at Earth from a mega-level in space, with satellites going over and looking at the gas emissions, and then going down to the intermediate level that you can do with UAVs, and then getting to the ground level, to see what is the actual biological, chemical, or geological signal, and interpret that data for the satellite.

NTB: What is RoboAlgae?

Bebout: RoboAlgae is something that came up when we were talking to all of these commercial growers — mostly in Imperial Valley, some in Hawaii, some other local ones. Raising algae for biofuels is rather new, but there have been people raising large algae farms for nutraceuticals like Spirulina or beta-carotene for decades. We asked those growers what their bottlenecks were to becoming more productive, or going to a larger scale. At those long term operations, they know exactly what they're doing. They know what to expect from the cells and what to watch for. They sample those systems, at rates determined from long time trial and error and get their data back in an hour to a couple of days,

which will tell them if they need to change a mixing rate, or add a different nutrient, to optimize their system. But using these systems for fuel production there is an absolute requirement to further lower operations cost, and the species for lipids don't have nearly as long of a history at mass culture, so there are still many challenges.

One of the problems for large operations is that things grow and change so fast. Imagine you had 50 acres of tomato plants, but those tomato plants grow from seed to produce full tomatoes in 4 days, and if something happened, like a pest, it could wipe out the crop in a matter of hours. And that's basically what the situation is with algae for fuel. It's a highly dynamic environment. It's affected by weather and things blowing in. You need to monitor the situation in real time to head off problems. Or if it's a situation where you can't fix it, then you need to know early on whether to crash the system, clean up, and start again, rather than waste your time on a dying crop.

The RoboAlgae concept is a very cheap and small wireless measuring device that can be designed with various sensors, and is based in part on space nanoSatellite design elements. It is designed to float through large or small raceways, giving you a lot of data, not just from one section of your growth system. It moves through the system to give you data from a lot of different areas, so that the growers can more quickly see what's going on in their ponds. We also have done some work with Kai Goebel and the Intelligent Systems Division, to develop prognostic algorithms, from actual trials in our greenhouse raceways. The hope would be that we could use the RoboAlgae data and prognostics algorithm software to design a useful system for growers. This would be useful because these larger operations for biofuels are newer than those traditional crops, and there are still a lot of unknowns. What you want to do is be able to head off problems down the line, and that's what NASA prognostics are very good at. One level is get the information to the growers quickly, the second is to build prognostic algorithms to help with management decision making and these are the same capabilities we will need for reliable space platforms.

NTB: Is that technology in use currently?

Bebout: No, that patent was awarded, and we hope to find partners to start using them to get further in-field testing. We would love to see that take off.

NTB: What other kinds of opportunities exist in the microbial ecology field? What gets you excited about the work and the future of this field?

Bebout: I just feel like there are so many opportunities. As an ecologist, it's exciting to see a systems biology approach that looks at the environment and the microbes together. For example, right now a typical method for raising algae in raceways is to link it to a coal-fired plant, or another power plant that captures CO₂. Actual CO₂ becomes limiting very quickly as the light comes on, the cells use it all, which then requires you to force CO₂ into the system. It's good to use those sources – that means carbon is used twice. But the tantalizing thing about algae is that it may help us with lowering CO₂ in the atmosphere, but if you're using fossil fuels CO₂ to feed your algae, then you're not getting to that second level.

Another way to approach this is the collaboration that we have with our colleagues at the University of Texas at Austin, (Drs Halil Berberoglu and Tom Murphy). Our Surface Attached Bioreactor (SABR) is a growing system where algal cells are attached to a substrate and have only a thin water film pulling through the system by evaporation. That way the cells can pull CO₂ directly from the atmosphere rather than having to pay for CO₂ to be bubbled in. SABR acts like an artificial leaf and supports high levels of growth with far less water, than conventional systems. Water is a precious commodity, and we've been excited about the SABR system that we have the patent application in on.

It's been shown, under best case conditions to date, to grow algae up to 4 times faster using 25 times less water. That's of interest for a space station because mass is a huge consideration, but we would like to see if that could also be useful for terrestrial applications for those same reasons, in that case, it would be a question of whether we could get it to the needed scale. The system is also appropriate for growth of a much wider variety of cell types, from fungi and bacteria to stem cells due to the specific environments it creates and the ability to have so much control over the rate of light, water and nutrients delivered to cells and the removal of wastes as well. Thinking this way about being more economical with our water, and other resource inputs and outputs will optimize for the cells and conserve resources, and so that's a perfect example to me of where understanding the biology and working with engineers to optimize that could have some really beneficial outcomes.

To learn more about Dr. Bebout's work with microbial ecology, read a full transcript, or listen to a downloadable podcast, visit www.techbriefs.com/podcast. For more information on licensing and partnering opportunities related to the technologies mentioned here, email sumedha.garud@nasa.gov, call 1-855-NASA-BIZ (1-855-627-2249), or visit <http://technology.arc.nasa.gov>.