Bioenergy Innovator: A Talk With Clarke Prize Winner Bruce Logan
By Stephen Hochbrunn, NEIWPCC

The best ideas are not only brilliant in and of themselves, they also come along at the right time. In Bruce Logan's case, his timing could not have been better. Logan, a professor of environmental engineering at Pennsylvania State University, is renowned for his work on new technologies that tap into the energy in wastewater to generate electricity, produce hydrogen gas that can be used as an alternative fuel, and even desalinate salt water. And one more thing—the wastewater is also treated in the process. This remarkable research earned Logan the National Water Research Institute's 2009 Clarke Prize, which honors individuals for outstanding achievements in water science and technology. He spoke with us by phone on October 15 from his office at Penn State.

iWR: You are probably best known for your groundbreaking work on microbial fuel cells. Can you explain in the simplest terms possible what a microbial fuel cell does?

Logan: Sure. In a microbial fuel cell, bacteria break down organic matter just like you and I eat food. But unlike you and me, who release electrons from the food we eat to oxygen when we breathe, the bacteria in a microbial fuel cell release the electrons to an electrode. The electrons flow from one electrode to a counter-electrode, and at that electrode, the electrons combine with oxygen and protons in water and just form water. So it's a way for the cells to respire while degrading the food. But that flow of electrons creates current, and therefore it can be used for work. So you have essentially bacteria making electricity directly. It's kind of like in "The Matrix," where they hooked people up and got electricity from them. Except this isn't science fiction. It's science.

iWR: And you need a fuel for the bacteria to feed upon, and wastewater is ideal for that?

Logan: Well, the price is right. They'll certainly do better on different types of organic matter, but the organic matter in wastewater is free. So if you think of it in terms of being able to generate electricity, it's a free energy source for electrical current generation.

iWR: Did you invent this process?

Logan: No, people have known about microbial fuel cells for a long time, a few decades. But the power densities were very, very low, where they needed to add in other chemicals to make it work. It wasn't very practical. I think our main contribution has been to take what was a scientific curiosity and show that it really could be a practical method of wastewater treatment and power generation.

iWR: In the lecture you delivered when you received the Clarke Prize, you described the process as "thermodynamically favorable." What does that mean?

Logan: Look at it this way. If you want to get water uphill, you can pump it uphill. But that takes energy. If you want to get water downhill, it can just run downhill. So what "thermodynamically favorable" means is it's a self-sustaining reaction. It will undergo that process naturally. You don't have to put energy into it to make this electricity production happen. It's a scientific way of saying it naturally occurs.

iWR: And of course if you can generate electricity naturally, you don't have to pay to purchase it. Is the wastewater industry excited about the possibility of using wastewater to create the power needed for treatment plants?

Logan: I think that the industry is interested in the work. Companies are trying to decide if this is the right time to get into this technology. Some companies have already decided to do that, small start-up companies primarily. There are researchers at applied research institutes, universities, and frankly in high school and middle school who are working on this, all around the world, all different ages, all for different reasons.

I got into bioenergy production probably back in 1997, when I moved here to Penn State. I started to scientifically work in the area, and I did it because how we make energy can greatly affect the environment. However we choose in the future to make energy, whether it's burning every little last drop of oil or it's solar or nuclear, every single type of energy production method has an environmental impact. So what I wanted to do was to devise and develop new methods of making energy that would be more sustainable and have low environmental impact. That's why I got into this area. I think it has a natural application in wastewater treatment, and that's something I've worked in for a lot of years as well. So I'm very pleased about that.

iWR: Are microbial fuel cells actually in a wastewater treatment plant anywhere, at any scale, right now?

Logan: There have been three demonstrations ongoing that I know about. One was at the University of Queensland, in cooperation with Foster's, the brewery in Australia. They conducted tests over some months, and their system's now shut down. They haven't really written anything up about it yet, but I think it was not as successful as they'd hoped. But they tried a pretty novel design, and there are certain characteristics of the wastewater they just didn't expect until they were trying to run the plant 24/7. So it was successful in terms of what they learned, but I don't think they walked away saying "We have the system that we're going to build 1,000 times larger."

The University of Connecticut has worked with a few different agencies to pilot-scale a microbial fuel cell, and Penn State has been working with Brown and Caldwell, Air Products and Chemicals, and the Napa Wine Company on demonstrating the concept of a microbial electrolysis cell, which is a related technology that is used to make hydrogen. We have a pilot-scale reactor ongoing right now, and we hope to have a pilot-scale microbial fuel cell demonstration in the summer of 2010.

iWR: Can you explain what you mean by a microbial electrolysis cell?

Logan: An MEC is just like an MFC, except that a little bit of energy has to be put into the system. What happens is the bacteria break down the organic matter and they release electrons, but we take away the oxygen at the other electrode, so nothing happens there. Then we boost the voltage that the bacteria produce by just a little bit, and now, the current will flow because the electrons have enough energy to combine with protons in the water to make hydrogen. So we have two electrons and two protons, two H^{+}'s in the water, and that makes an H^2, which is hydrogen gas. The hydrogen's very insoluble in water, so it just bubbles right out of the water and it's easy to capture.

iWR: And that hydrogen can be used as a fuel for many things.

Logan: Absolutely.

iWR: And wastewater powers this system as well?

Logan: That's right, but you could do this with other things. You don't have to use wastewater. You could use cellulose, sawdust, whatever. But with wastewater, the process can successfully remove the organic matter, and it has the advantage of a very high energy capture. It does a very good job of capturing the energy in the wastewater. In fact, the electricity that you put in is many times less than you would need to just say electrolyze water. So you have the advantage of using less energy to make hydrogen compared to water electrolysis, and you get wastewater treatment. So double benefit.

iWR: And this process, you actually did invent, correct?

Logan: Yes. Well, actually, it was invented by two different groups. Us here in the U.S. and a group in the Netherlands came up with the idea at just about the same time.

iWR: When was that?

Logan: We came up with the idea in 2004, and published a paper on it in 2005. So it's a pretty new idea.

iWR: What needs to happen to take both these technologies—microbial fuel cells and microbial electrolysis cells—to the next level, to perhaps get adoption at the industrial level?

Logan: Any new technology has to go through various stages of development. First, you have to go in the laboratory and prove it works. They you have to take it out of the laboratory and prove it works there. You have to reduce the cost of the materials and determine how you're going to produce the materials in larger quantity. Because in the laboratory, the things that you can do to make an electrode, you just couldn't mass produce it that way. It would be too labor intensive. So we need to get the cost of the materials down. We need to figure out how to mass produce the components. We need to conduct field tests with these systems to show that they're working well. And then all the other engineering matters: you have to see how the systems respond to variations in temperature and wastewater composition—all that sort of thing.

iWR: It sounds like a lot of things that cost a lot of money. Would it help if government at any level got behind this with research dollars?

Logan: Oh, I just love it when you ask me questions like that [laughs]. Of course. One of the reasons I like to give talks on this and I talk to people like you is to help to spread this information. A lot of people don't know this technology even exists, that it's possible to do this. And of course, what we hope is [the exposure] leads to greater investment and funding so that we can get a lot more people and companies working in this area. Because it's really needed.

iWR: Going back to your Clarke Prize lecture, you mentioned another related technology you're working on—microbial desalination cells. How do these work?

Logan: It all goes back to the bacteria producing this electrical current. So they make these electrons, but when the bacteria release an election, they also have to release a proton because the charge has to balanced. So for every negative charge they release as an electron, they release a positive charge as well. So what we do is construct a microbial fuel cell that has three chambers. One chamber has the bacteria that are making these protons. The chamber on the far side has the other electrode, and then there's a chamber in the middle. And in that middle chamber we put salt water, sodium chloride. And we put two membranes in the system, very special membranes that are ion selective. So when the bacteria produce a proton into the water, that increases the positive charge. Now, either that charge has to leave or a negative charge has to balance it. And we put a membrane there so that the positive charge can't cross it. So what happens is a negative charge, which is a chloride ion, moves from that middle chamber over to where the bacteria are. At the other side, a positive charge proton gets consumed and then a sodium comes out of that middle chamber to balance the charge on the other side. So what you're doing is you're pulling the sodium and the chloride out of that middle chamber to balance the charge when protons are consumed at one electrode and produced at the other electrode. And that ends up desalinating the water.

iWR: This too is your invention?

Logan: Well, again, it was one of those very amazing things. I invented it at right around the same time that a group in China was working on it. And so we decided to collaborate on it, and we recently published a paper on this idea that we both quite independently came up with. It's amazing. You think you have this great idea, and then you find out, oh, somebody else has that idea too, and there are probably half a dozen more people that had the idea but didn't do anything about it.

iWR: Given that desalination's Achilles heel has always been its high energy costs, it sounds like this system has commercial potential. Does it?

Logan: Well, like anything else, it remains to be seen. The energy costs may be very low for our process, but you could argue, well, the engineering is so complex or the materials are too expensive. But I think it has a lot of promise, and we'll see. One of the things you can envision is that even if you don't completely desalinate the water [with this process], you can partially desalinate it. We've done some experiments where it's pretty easy to get about half the salt out of the salt water, which is good. Because if you can partially desalinate, you can greatly save the amount of energy needed downstream for reverse osmosis. It may just be a very simple, very inexpensive pretreatment method.

iWR: One last question: you've won this prominent award, what do you do for an encore? I presume you're not going to just rest on your laurels. You also have the matter of a little prize money to deal with too. [Clarke Prize winners receive a $50,000 award.]

Logan: [laughs] I haven't decided actually what I'm doing with that money yet. I did decide to put a little bit into my kids' college education. I'm thinking I'm going to give the rest to the research program [at Penn State], but I don't know yet. There's tons of research science and research engineering to be done here, but I'd like to see all three of these processes move into the practical arena. My goals are to continue to advance the technologies in ways that make them more efficient and more affordable but also to work on making them more practical and available.

iWR: So you envision a time when we'll see MFCs as standard equipment in wastewater treatment plants?

Logan: I sure hope so. If these tests work out, they say commercialization is about three to five years away. I don't think your local municipal wastewater treatment plant would probably adapt in three to five years just because they tend to be more conservative and have to answer to a lot more regulators.

Generally they want proven technologies. I think this is the case where industries can move a little bit faster. They can do things in-house, and if they make some money, that's great. They are willing to take a little bit of chance on that.

For more on Bruce Logan and his research, visit his Penn State home page and his MFC page. More information on MFCs can also be found at www.microbialfuelcell.org.