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The Future of Bioengineering: An Interview with Professor Drew Endy

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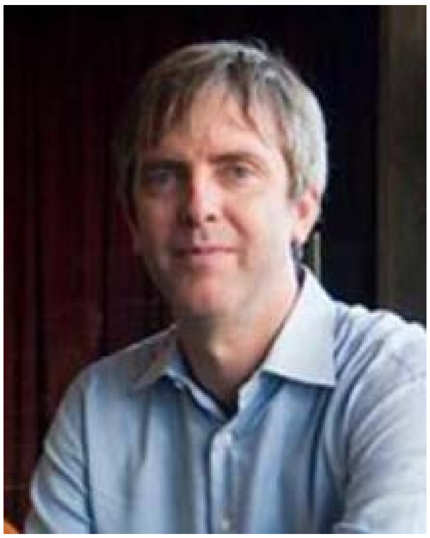

Drew Endy is a member of the bioengineering faculty at Stanford and BioBricks Foundation president. His teams pioneered amplifying genetic logic, rewritable DNA data storage, reliably-reuseable standard biological parts, and genome refactoring. Drew helped launch the new undergraduate majors in bioengineering at both MIT and Stanford; he also co-founded the iGEM competition, a global genetic engineering "olympics" now engaging over 6,000 students annually. The White House recognized Drew for his work on open-source biotechnology and, most recently, he received an honorary doctorate from the Technische Universiteit Delft. Drew served on the US National Science Advisory Board for Biosecurity and now serves on the World Health Organization's Smallpox Advisory Committee. He lives in Menlo Park, California with Christina Smolke (Stanford bioengineering professor & Antheia, Inc., CEO), their two boys, and three cats. Drew was a co-founder of Gen9, Inc.; he recently returned to serve as a director while Gen9 was successfully acquired. He worked briefly with the Rapid Evaluation team at Google [X] and also served on the core project team for the new Shriram Center at Stanford. He is a founding co-director of the Joint Initiative for Metrology in Biology (JIMB). Drew was recognized by Esquire magazine as one of the 75 most influential people of the 21st century.

Biography adapted from and photo from Drew Endy's profile at https://profiles.stanford.edu/drew-endy.

CL: In your research and work in synthetic biology, you've often described the potential to program living organisms to serve a variety of functions. What kinds of beneficial impacts can synthetic biology have on society, and where do you see the field headed in the future?

DE: Biology is itself a way of making stuff. It's the type of material that is all over the planet, for the most part, and wherever it is, it harvests local materials and energy and makes copies of itself: to the extent that we can advance our partnership with biology to make things, we can make a lot more. It's an understatement to say that we're very far along in doing this, and I think the way things are configured right now indicate how much upside there is. For example, in Menlo Park, where I live, we have garden clippings. Every Monday evening in my neighborhood, we have to take the bin of garden clippings out to the curb, and we pay a truck to come on Tuesday mornings and take it away. So, what's that all about? Well, apparently, there's a surplus manufacturing capacity in my yard, and this living material grows itself and with great abundance yet costs me money to get rid. This is a really baffling situation; I wonder how much that happens across all of Menlo Park. If you pull the data, the numbers were about the following: 500 pounds of garden clippings are carted away and composted for every person who lives in the town every year. If the town were 32 thousand people, that's 16 million pounds a year of stuff. That's the surplus manufacturing capacity of Menlo Park. Now we don't think of it like that; we think of it as "garden waste" or "compost." But, it is a self-assembling, state-of-the-art natural nanotechnology that builds itself in my yard, and I'm throwing it out? What could I do with 16 million pounds of state-of-the-art nanotechnology every year? A lot! Now, what do I do practically with it? The reason we compost it is we don't really know what else to do with it. It turns out there are organisms such as wood fungus—the mushrooms—that grow on cellulosic "waste" and companies now forming, like MycoWorks, that will grow a leather replacement using mushrooms and garden clippings. Not animal leather, mushroom leather, and in a few weeks, instead of a few years! And it's not constrained by the size of the animal, the hide you get.

We've got a functional, self-assembling, natural nanotechnology all over the earth, and we're just in the early days—one generation in—to programming it explicitly through engineering the DNA code, and you're sort of asking me, what's it good for? Basically, the answer is: anything that biology now does or anything you can imagine biology being tweaked to do. And it seems like if you do the back of the envelope, that you need energy for a civilization to work, and there’s reason to be optimistic about that, from photovoltaic, solar, or other, and you're going to need water and computation, and those are both more or less correlated or interconvertible with energy, and then we need atoms, we need matter, we need stuff, and biology is the way of wrangling atoms on a civilization/global/planetary scale. So, we need to make living matter fully engineerable. If we do this right, then all of humanity and nature can flourish and partner together. The example with the garden clippings from Menlo Park, as much as anything else, is meant to illustrate how poorly configured we are in partnership with biology. There actually should be an abundance of manufacturing capacity on Earth.

CL: You've mentioned how bioengineering can create tools and solutions, but you've also emphasized the potential ethical risks that can come with new biotechnologies. What are some of the biggest issues you foresee?

DE: The aspects of this that show up all the time and are important and powerful start with safety and security. Is working with biology safe? Most of the time, but not all the time. There are things that, if you get infected with, you're going to get sick and, worse case, die, and absolute worse case, infect other people. Zika, Ebola—in nature, there are biological things that hurt us and others. So safety has always been an issue with biology, and when you bring engineering into biology, safety remains an issue. Paul Berg, of Stanford, and colleagues a generation ago developed a framework for first-generation genetic engineering and how that should be handled from a biosafety perspective. That legacy of mitigating risks via containment and other approaches continues. Safety is important and is something that can be handled at a community level through best practice.

Then there's security—safety and security are different topics. You can think of a car: you've got a safety belt for accidents—you know something bad could happen, but you don't know exactly when, so you wear your safety belt. You've also got a lock on your door, a security lock, and that is for a different reason: you expect that there are people out there who wish you harm, directly or indirectly, so you have a security lock to secure what's inside the car. Mal-intentioned actors, in other words, and how you respond to that possibility, is not the same as how you handle safety. You've got new tools for building with biology, or tinkering with biology, and could people abuse or purposely misuse these tools to cause harm? The possibility is there. There are different schools of thought on how to approach it, and basically, at the end of the day, you have to have a very strong public health system, so that infectious diseases aren't a big deal. That's not the situation we're in. You also have to have the scientific knowledge and technical capacities, so if there's ever a new or emerging infectious outbreak, you can respond to it faster than airplanes travel. Note that we're going to need technology to do this: we're going to need to be able to do reading and writing of DNA in situ on a distributive basis to sequence, detect, and understand outbreaks where they arise and then implement solutions by transmitting the instructions as sequence information via the internet. So there's this strange coupling between: what are people's intentions, the emerging tools of biology and bioengineering, and how we get to a security strategy. It's a combination of culture and technology and good policy; for example, we should be having conversations around how do we minimize the number of people who might seek to actively cause harm with a technology that is a distributable technology—biology is distributive. So, security is a big topic.

Having opened with safety and security—I'm concerned about them, and I spend time on those—but they're actually not my primary concern. My primary concern is the concern having to do with literacy and citizenship. What does it mean to be a citizen in a world where living matter has been made fully engineerable? What does it mean to be a citizen of biotechnology? It seems like a strange word, but it didn't used to be. What does it mean to be a citizen of the United States today? Does it mean you vote? And if you vote in an election, then you're done? That's kind of the weakest and lamest form of citizenship. So, what does it mean to be a citizen of biotechnology? Are we citizens or consumers of our technology? Is this iPhone or Android device consumer electronics, or is it citizen electronics, and is there a difference? Or are those just words? Do we have a voice in biotechnology? When people, for example, think about and debate aspects of genetically modified food, are they really concerned about the safety of it? Or are they concerned about the equity and the fairness and the power relationships? Maybe all of the above. But to think that it's only a conversation about safety is naive. It's a conversation about many aspects. Thus, the big topic for me—the primary topic—is: what does it mean to be a citizen of the future? You're a citizen of the 21st century—it's not some arbitrary point in the future, it's a time that's emerging now. How does bioengineering and access to the tools of biotechnology fit into our future, along with tools of software and hardware?

CL: How do you think researchers and students should be better educated on the current risks and the idea of citizenship and the connections to society?

DE: We're really fortunate at Stanford in that we're a university, which means that, not only is there a still new Bioengineering Department, but there's an excellent law school and public policy program and anthropology department and classics and so on. As a university, I would simply point to the fact that there are amazing colleagues and professionals who are experts on topics related to how humans organize ourselves or fail to do so; how we choose to make decisions, or make bad decisions. A lot of these topics have nothing to do with the specifics of any one technology. They have to do with what it means to be a human and different ways of separating or recombining different practices and professions. There are very few places on Earth, regrettably, that are operating on the frontier of science and technology yet are embedded within a comprehensive university, and I think there's a tremendous amount of unfortunate naivete on the part of scientists and engineering professionals—including the engineering faculty at times— and working ignorance of these various other professions. From a student perspective, the opportunity is to really engage and immerse yourself in the humanities and all the associated human sciences in addition to the hard science and technology.

For example, what do you think of Huizinga, the Dutch cultural philosopher who, in the early 20th century, was interested in the culture of play? Instead of driving the development of technologies from the perspective of utility, maybe we should learn something about play and the role that play has in terms of contributing to a foundational culture that predates utility. Nobody is teaching animals in nature how to play. What if, in biotechnology, the original concerns around safety caused a reaction in the scientific community that overdrove the immediate deployment of the technology to solve problems right away, such that it became an esoteric technology that only people who were the “priests” who could treat it safely in a laboratory got access to it? Now they're controlling it all, and they're telling you it's safe, but nobody really got to play with it, so most are just not comfortable with it. If you were to go to the Cantor and look at a painting, and you were to do that with a friend, I bet you wouldn't expect you and your friend to have the same reaction to the painting, and that's because we have a type of sophistication and cultural maturity with respect to painting, usually. How come with biotechnology projects, people fall into the trap that everyone else must feel the same way as them—it's good, or it's not good? Biotechnology products can turn out to be very complicated artifacts that are multidimensional in their engagement. How do we learn to mature as individuals and as a collective culture around the future of biotechnology? Again, the opportunity, especially in the sciences and the engineering fields, as students, seems to be to learn about political theory, cultural traditions, anthropology, critique, and creative design. I've never been limited in my professional career by what we can imagine or do in the laboratory. I've always been limited by the cultural and political contexts within which I'm trying to do anything.

CL: You have also helped organize the iGEM competition, which brings students from around the world together to build their own synthetic biology systems and learn more about the field of bioengineering. What was the initial motivation behind the competition, and how has it influenced students?

DE: Healthy relationships are based on love and shared giving and getting. Biology is this framework within you can contribute to improbable patterns that exist throughout time and space. That's part of what it means, from my perspective, to be alive and be part of life. We can imagine that there's a massive, diverse future of who knows what biological things that can be realized. Let's say that I want all the good ones to come true. Not at some arbitrary point in the future, but in my lifetime. How do I actually get to that future? I'm going to have to work with other people. The computer scientist Bill Joy observed, to keep his observation short, that most people work for other people. Most of the people who discover biology or partner with biology, they aren't going to be me, they aren't even going to be my students—they're going to be all over the world! How do we create frameworks or platforms wherein people can both learn how to do stuff but also can work together, so everybody can work for everybody else? That's the type of coordination of labor, where what you do contributes to what I or somebody else might want to do somewhere else sometime else. If you can get to coordination of labor, then all of a sudden people will collectively pull off stuff that is otherwise impossible—like make of all good biotechnology come true. It's very selfish, in a way: I would like to make all of biotechnology to come true, not at some arbitrary point in the future, but as soon as possible, as soon as we can do a reasonably good job of it. That means that I have to enable people to work together. That's part of the motivation inside what becomes this global genetic engineering "olympics." There were around 6,000 students last year! The flipside of that is, how come it's so tiny? How come there's only 6,000 students? How would we make it a thousand times bigger? Could we do that? What would be needed to enable orders of magnitude more coordination of labor?

The flipside of it, from the students' perspective, you have to ask the students in iGEM. We never had a sales and marketing budget for iGEM, but it just kept getting bigger. The best way I can explain that is teenagers all over the world are "hungry" to learn about biology as a technology—not just as a science, but as a way of tinkering and making stuff. Some people like to learn by tinkering, as opposed to memorizing things other people tell you to memorize. Learning by building is very complementary. The world wasn't responding—people weren't satisfying that need—so, when we came up with something that was better than nothing and gave it away, then there was a type of synergy. People benefited from that: the students, it helped them learn and begin to work together. Consequently, actually learning to do things that are otherwise impossible. They're also given a blank slate: the iGEM competition isn't telling people what problem to solve specifically; instead, do something that's meaningful to you wherever you are and then tell everyone about it. Use some of the things people made before and give back some stuff you want to give back. It has this "give and get" philosophy that keeps it going. A lot of this came from Randy Rettberg, who runs the iGEM foundation now, and came out of the world of hardware and computing. Randy helped me learn some of those lessons from a scaling perspective and a community development perspective. I think all of iGEM benefits from the past history of seeing software and hardware develop—how the human cultures develop—along with the technology.