Testimony

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Subcommittee on Research and Technology
Of the US House of Representatives

On

Engineering Our Way to a Sustainable Bioeconomy

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Chairwoman Stevens, Ranking Member Baird and Members of the Committee,

My name is Kevin Solomon and I am an Assistant Professor of Agricultural and Biological Engineering at Purdue University in West Lafayette, IN. Thank you for inviting me to speak to you today about my work at the intersection of engineering, synthetic biology, and the microbiome.

Historical context and potential of engineering biology

I have had the distinct privilege of being at the forefront of the emerging discipline of Engineering Biology for the past 13 years. I was in the inaugural class of trainees in the pioneering Synthetic Biology Engineering Research Center (SynBERC) funded by the National Science Foundation in 2006. This decade marked a transition in genetic engineering from an art to a rigorous engineering discipline. Precise genetic constructs could be developed for the first time. Quantitative models accurately predicted biological behavior and illustrated common biological design principles. More importantly, implementing seemingly simple designs based on these models replicated much of the rich complexity that we observe in biology, and also created novel behaviors never observed before. In other words, we were able to engineer biology for the first time.

Emboldened by this success, US researchers began to envision the ways in which we could apply these capabilities to solve grand societal challenges. Biological systems have remarkable biosynthetic capabilities that capture abundant CO_2 and transform it into myriads of chemical compounds with precise composition. These chemical compounds are frequently identical to those currently produced by traditional chemical industry. Moreover, biological systems more easily make complex molecules with higher purity than traditional synthesis, and can create novel materials with unique properties. That is, biological systems can be used as sustainable biomanufacturing platforms for medicines, fuels, materials, and other important molecules. Biological systems are also self-sustaining and responsive to their environment, and thus do not need traditional industrial infrastructure to perform specific actions. Systems can be decentralized to act only where needed to form truly innovative solutions to old problems

Envisioned applications include bacterial sentinels that detect and eradicate cancer in the body[1], gut health monitoring systems that cure infections before patients display symptoms of illness[2], and plant sentinels in public spaces that non-invasively sample the environment to detect and provide alerts for biological or bomb threats[3]. The genetic tools that allow the creation of these systems are valuable in their own right as they enable us to envision cures to "incurable" diseases such as cystic fibrosis[4]. This early work has led to hundreds of startups that have raised more than $5 billion domestically in investments in the last 4 years[5]. It has also led a renaissance in innovation at more mature companies in the biotechnology sector.

The rapid progress of the field has revealed a wealth of untapped biological potential. My lab aims to characterize the potential of novel microbes and develop them to address societal needs. Specifically, we focus on applications in bioenergy, biomanufacturing, nanomaterial synthesis, and agriculture. Our work is currently supported by the National Science Foundation (NSF), and we rely on user facilities of the Department of Energy's (DOE) Office of Science.

One specific example I would like to share from my work is about anaerobic fungi that are an essential part of the gut microbiome of cattle and other livestock. These fungi digest ingested plant material to provide nutrition to the host animal. They also secrete molecules that affect animal health and production. My lab uses cutting-edge mid-scale research infrastructure, provided by federally supported user facilities, to dissect the capabilities of these novel organisms and develops approaches to control them for biotechnology. For example, we are working to exploit the ability of anaerobic fungi to degrade crude plant material as it may advance bioenergy research by overcoming one of the most significant hurdles to economical biofuels: the ability to convert inexpensive, renewable biomass into sugars for fermentation. Similarly, we are trying to understand the biosynthetic capabilities of anaerobic fungi. Like penicillin from *Penicillium* fungus, the secreted compounds of anaerobic fungi may form the basis of powerful new medicines such as novel antibiotics, which are needed to combat drug-resistant infections. Finally, understanding and controlling these activities within the digestive tracts of animals may *naturally* enhance food production to meet a growing population while reducing the need for additives currently used to meet production demands.

Student training

Research integrity, ethics, and (bio)security are always of utmost concern when engineering biology. My lab's research complies with existing federal, state, and institutional guidelines and is subject to regular review. Beyond this, I train my students to consider the implications of their work. While our work does not currently suffer from the ethical dilemmas found in some aspects of the field, my students are sensitive to issues in this space. In my grad-level course on engineering biology, taken by upper-level undergraduates and all my graduate-level researchers, our lesson on Day 1 begins with a discussion on "Human Practices". Human Practices describe

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[1] Zhou S, Gravekamp, C, Bermudes, D. and Liu K. *Nature Reviews Cancer* **18**, 727–743 (2018)
[2] Claesen, J. and Fischbach, MA. *ACS Synthetic Biology* **4**, 358-364 (2014).
[3] Antunes, MS et al. *PLOS One,* **6,** e16292 (2011).
[4] https://labiotech.eu/tops/crispr-technology-cure-disease/
[5] SynbioBeta, Synthetic Biology Annual Investment Report, September 2018. https://synbiobeta.com/wp-content/uploads/2018/11/Synthetic-Biology-Annual-Investment-Report.pdf

how technological innovation serves society and how its development is informed by societal values. Students are trained to identify all possible stakeholders of new technologies (e.g. government, entrepreneurs, consumers, special intertest groups, etc) and discuss their different perspectives on safety, biosecurity, perceived risks, societal impact, and ethics. In so doing we not only determine *whether* a project should be undertaken, but *how* it should be executed. We identify valid concerns that should be addressed via design (e.g. a failsafe self-destruct to prevent environmental damage in case of accidental release) and discuss strategies to educate groups on the severity of a perceived technical risk.

Technicians, scientists and engineers that engineer biology come from a number of fields in the biological sciences, physical sciences, agricultural sciences, information sciences, and engineering. We bring unique disciplinary perspectives that are critical to the innovative advances of the field (e.g. quantitative models of emergent biological phenomena introduced by physicists and engineers). What unites us, however, is our shared desire to solve grand societal challenges, and our passion for the power of biological systems. While programs across the country, such as those at Purdue, offer specialized concentrations that focus on engineering biology within more traditional disciplines, most training is experiential. Students learn through authentic research projects in labs such as my own or in collective DIYBio[6] spaces. To increase the number of formal training opportunities for students, our community has developed and embraced educational programs such as iGEM, the International Genetically Engineered Machines competition, which has trained more than 40,000 high school, undergraduate and graduate students from across the globe in the past decade. I advise and mentor Purdue's team in this competition. Student-led teams engage in authentic research to solve societal problems, and develop critical soft skills in leadership, communication and entrepreneurship. Integrated in the design process is an explicit consideration of Human Practices. Projects are frequently ambitious in scope and have led to several startups with a total valuation in excess of $1 billion[7,8].

Recommendations

As a product of the federal government's initial investments in engineering biology, I am grateful for your renewed commitment to our field in the proposed *Engineering Biology Research and Development Act of 2019*. I benefited greatly from the interdisciplinary and forward-thinking approach of the Engineering Research Center (ERC) program and believe that centers such as these will continue to be key nexuses of American innovation and entrepreneurship. Your current investments in specialized facilities power my own research, and your funding support enables me to train future generations of scientists in this space. Please continue to support these initiatives.

From the ongoing research in my lab, we can see that tools that advance technological progress in bioenergy will be similar, if not identical, to those that would advance innovation in agriculture. Therefore, future advances in engineering biology will likely be cross-cutting with

[6] Do-It-Yourself Biology, a growing movement to democratize biotechnology research that supports the creation of open source equipment and the informal training of community members in engineering biology. https://diybio.org/
[7] iGEM, 2019, https://igem.org/Startups
[8] Bauhr, S, 2017, https://techcrunch.com/2017/12/14/gingko-bioworks-secures-275-million-in-series-d-valuing-the-company-at-over-1-billion/

significant impact to several agency missions. A coordinated federal research program for engineering biology as envisioned in the *Engineering Biology Research and Development Act of 2019* will provide long-term investments that recognize and support the fundamental basic science that drives American innovation in multiple areas, and continue its leadership in engineering biology. Given my experience with the current funding landscape and training programs, I share the following recommendations beyond the current bill provisions:

1. **Provide a forum for inter-agency collaboration and information sharing, as well as multi-agency funding mechanisms that enable game-changing technologies.** The current funding system is mission driven and relies on the ability of researchers to correctly match agency needs to their science, regardless of innovation. Just as proposals may be transferred intra-agency to more appropriate programs, mechanisms to transfer innovative high reward ideas across agencies for consideration are needed. Similarly, joint funding programs would accelerate innovation in multiple areas simultaneously. A coordinated framework should reduce artificial institutional barriers to funding by recognizing truly innovative and cross-cutting ideas that will maintain the preeminence of American technology and consider these ideas for funding from all relevant agencies.

2. **Ensure a variety of funding mechanisms to ensure a broad ecosystem of researchers along with focused multi-disciplinary centers.** Major center opportunities are an important component of the engineering biology ecosystem, as these act as nexuses for student training, interdisciplinary research, and commercialization of technology. It is also important that individual researchers have opportunities to contribute to ensure a broad and healthy ecosystem-that enables high-risk, high-reward research. Fundamental basic research that is needed to drive the next wave of innovation can be easily overlooked as the applications that meet agency needs may not occur within a standard grant timeline (< 5 years). To overcome this, more seed funding for high risk, high reward ideas and fundamental science that will enable game-changing technologies across missions is needed.

3. **Provide sustained research funding to critical federal programs in engineering biology at mission agencies**. Federal agencies such as the DOE, and NASA rotate their research topics for funding support in a cycle of 4 or more years. Similar topics may overlap at several agencies in a given year leading to lapses in funding in subsequent years. These gaps discourage young investigators and slow the development of emerging leaders with innovative ideas causing the US to follow, rather than lead, in these critical areas. This can lead to the permanent loss of talented researchers. Early success in the careers of academic researchers is a job requirement. Without federal support to catalyze these early successes, researchers may exit the field and be unable to contribute their innovative ideas over the standard 20-30 year period of an academic career. This loss has a multiplicative effect as it also includes the dozens of trainees that researcher would have gone on to influence and shape. A coordinated research framework will provide a sustained commitment to development in emerging areas by staggering rotation schedules or providing consistent (joint) funding to ensure American leadership in these areas.

4. **Increase US capacity and the number of people with skills in engineering biology by providing direct support for experiential training opportunities.** Student research is essential to prepare the emerging engineering biology workforce and train the researchers of the future. The premier experiential research training program in engineering biology is the iGEM competition. Students learn through experience by developing biological solutions to real problems. For example, Purdue's most recent entries have developed biological systems to capture phosphorus pollution from storm runoff to reduce damaging algal blooms, and envisioned using the natural microbiomes of our lungs to remove cancer-causing air pollutants. Our entry this year seeks to "vaccinate" plants with natural rhizobacteria to protect against crop pathogens. Students develop technical skills in the field, hone marketable soft skills, and consider ethics and security in their research. In a few cases, these projects bloom into exciting new commercial ventures. However, in recent years American entries have been eclipsed by European and Chinese teams that, unlike American teams, receive significant government support. Funding mechanisms for student-led research with significant budgets (~$50-100K/year/team) would improve the quality of this training and potentially enhance American innovation while encouraging the development of American industrial capacity.

Closing Remarks

Engineering biology is poised to form the basis of the next technological revolution with applications across diverse areas. To train skilled workers for this field, US universities have developed concentrations and certificates in engineering biology that complement rigorous training in more traditional disciplines. However, the most impactful training is experiential. The United States needs to invest in more basic research that will drive this revolution, in part through inter-agency consideration of proposals and more sustained funding in research areas, while providing direct funding for training opportunities. I am eager to see how the *Engineering Biology Research and Development Act of 2019* creates opportunities to enhance American competitiveness in this burgeoning area of possibilities. Thank you again for the opportunity to speak to you, and for your continued support of our field.

Dr. Kevin Solomon is an Assistant Professor of Agricultural and Biological Engineering at Purdue University. His work focuses on the development of sustainable microbial processes to supply the energy, materials, and medicines of tomorrow. He holds a bachelor's degree in Chemical Engineering and Bioengineering from McMaster University (Canada) and a PhD in Chemical Engineering from MIT. Dr. Solomon was part of the inaugural class of trainees in the National Science Foundation's Synthetic Biology Engineering Research Center (SynBERC), the first American interdisciplinary research center dedicated to engineering biology. As part of his graduate work, Dr. Solomon developed new tools to increase biomanufacturing efficiency. His research and mentorship, at the intersection of metabolic engineering and synthetic biology, were recognized with multiple awards including a Lemelson Presidential Fellowship, an NSERC Julie Payette Award, and a Science Education Leadership Award from SynBERC. As a postdoctoral fellow at UC Santa Barbara, he applied the latest advances in sequencing technologies to interrogate how microbes interact with their environment and identify new tools for synthetic biology. Using these techniques, he spearheaded efforts to molecularly characterize in depth a class of elusive microbes with tremendous potential for biofuel production, agriculture, and drug discovery. Dr. Solomon has published more than 20 peer-reviewed publications, is a holder of 1 US patent, and has several pending and provisional patents that are currently licensed to multinational corporations.