Witness Testimony of Eric Hegg
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Before the House Science, Space & Technology
Subcommittee on Research & Technology
Hearing on
Engineering Our Way to a Sustainable Bioeconomy
March 12, 2019

Chairwoman Stevens, Ranking Member Baird, thank you for the invitation to testify today. It is my great pleasure to contribute to the ongoing discussion of the opportunities and challenges of new and emerging technologies in the biological sciences, with key applications in agriculture, energy, and manufacturing. I look forward to today's review of the role of the federal government in research and development, the oversight of this critical area of science and technology, and the status of U.S. leadership in engineering biology. I am representing myself at today's hearing. The views I express are my own. To best serve the goals of the subcommittee, I have broken my written testimony into answers to the questions previously submitted to me and my fellow witnesses.

1. **Please provide an overview of your research and its potential applications, as well as which federal programs support your research. To what extent is your research shaped by consideration of potential applications?**

   I serve as both a Professor in the Department of Biochemistry & Molecular Biology at MSU and as the MSU Subcontract Lead for the Great Lakes Bioenergy Research Center (GLBRC). In both of these roles I have observed and experienced the critical collaborative partnerships that exist between the federal government and universities. At MSU alone, support from the Department of Energy (DOE) and the National Science Foundation (NSF) each make up approximately 25 percent of its total federal research funding. These funds provide vital support for cutting-edge fundamental research, for the training of future leaders in science and technology, and for the development of new sectors of our economy. MSU itself is part of the University Research Corridor, an alliance of MSU, the University of Michigan, and Wayne State University, whose mission is to strengthen innovation and economic growth in Michigan. Together, the three institutions – one of the top eight academic clusters in America – contributed an estimated $18.7 billion to our state's economy in 2017.

   My own personal research focuses on the role of metal ions in biological systems, and more specifically, on understanding how nature uses metal ions to perform difficult and important chemical transformations. Obtaining a deeper understanding of the strategies used by nature may enable us to mimic these processes and produce better catalytic systems for industrial processes, or potentially harness the power of enzymes directly. Over the years, I have used this approach to study cellular respiration, O_2 activation, biological H_2 production, enzymes involved in the global nitrogen cycle, and biomass deconstruction and conversion to biofuels and bioproducts.

In each of these cases, there are clear and timely potential applications in bioenergy, environmental research, and human health, among others. I have been fortunate to work with the MSU Technologies office, which facilitates commercialization of faculty members' research with the goal of moving new technologies out of the lab and into the marketplace, contributing to the strengthening of Michigan's economy and communities as well as the solidification of U.S. leadership in innovation worldwide.

In addition, it is imperative to remember that in basic research, discoveries made in one field can provide profound and unexpected benefits in other research areas, often many years later. It is therefore nearly impossible to overestimate or predict the full impact of basic research on the economy or quality of life. Over the years, my research has been funded by the National Institutes of Health (NIH), the NSF, the United States Air Force (AFOSR), the United States Department of Agriculture (USDA), and three different agencies within the DOE, including Basic Energy Sciences (BES) and Biological and Environmental Research (BER) from the Office of Science, and the Bioenergy Technologies Office (BETO) from the Office of Energy Efficiency & Renewable Energy. I am very grateful to these funding agencies. The contributions to society that I have had the opportunity to make both directly through my own research and indirectly via the GLBRC is a direct result of the financial support of these agencies.

The GLBRC is administered by the University of Wisconsin-Madison with MSU as a major partner. It is one of four bioenergy research centers established by the Office of Biological and Environmental Research Program within the DOE's Office of Science. The mission of the GLBRC is to perform the basic research needed to enable an economically viable and environmentally sustainable biofuel and bioproducts industry derived from dedicated energy crops. Success in this area has the potential to boost future U.S. energy security, lower greenhouse gas emissions, and create jobs in rural areas in Michigan, the Midwest, and throughout the country.

To accomplish this mission, the GLBRC performs a broad range of research, including (1) engineering dedicated bioenergy cropping systems with improved value and sustainability, (2) engineering microbes to enhance the efficient conversion of biomass into biofuels and bioproducts, and (3) optimizing field-to-product integration that will be crucial to the economic and environmental success of the emerging biofuels industry. Within that context, essentially all of the GLBRC research is focused either directly or indirectly on potential applications, and a large fraction of our research relates to engineering biology, whereby we harness the power of nature to improve a process or a desirable plant or microbe trait.

Important new technologies where plants or microbes have been engineered to contain desirable traits have led to the development of improved organisms, including: (1) trees with accelerated growth, increased density, and tunable energy content, (2) trees with modified lignin (a complex structural compound in plant cell walls) that enhances deconstruction, facilitating both biofuel and paper production, (3) plants with enhanced oil content in leaves to improve the energy density of both forage and bioenergy crops, (4) plants capable of producing oils with unique and desirable properties or co-producing oils and specialty biofuels and bioproducts, (5) forage and bioenergy crops with increased biomass yield and digestibility, (6) microbes with enhanced stress tolerance, sugar consumption, and biofuel yield, (7) bacteria that can produce high quantities of desirable fatty acids, and (8) bacteria that can convert lignin into useful biofuels and bioproducts. In addition, new tools have also been developed, such as one that enables high throughput genome editing in fungi. In many of these cases, the technology has already been licensed or optioned. Since 2007, GLBRC research and technology has led to over 100 licenses or options, highlighting the industrial relevance of our bioengineering work and the impact it is having on the economy.

2. **How do you integrate ethical and security considerations into the design and conduct of your research? To what extent is ethics a focus of discussion in engineering biology classrooms and research labs? To what extent is security a focus?**

Ethical considerations are an important aspect of the research design and implementation for all of my teams and collaborations. While we comply with all university, state, and federal rules and regulations, such as those related to the responsible conduct of research and the use and release of genetically modified organisms, we also carefully consider the larger picture. For example, to avoid competing with food production, GLBRC researchers focus on dedicated bioenergy crops grown on marginal lands (*i.e.*, non-forested lands not currently used for farming food). This is a conscious and deliberate decision made to ensure that the production of biofuels does not adversely affect our regional and national food supply or impinge on conservation areas. The use of marginal lands for the production of dedicated bioenergy crops, however, could theoretically result in increased water and fertilizer use; increased fertilizer use is especially problematic because of it can lead to reduced water quality and increased greenhouse gas emissions. To address these and related concerns, a significant fraction of GLBRC research is dedicated to understanding carbon and nitrogen cycling and water use in marginal lands, mitigating potential negative impacts, and ensuring the environmental sustainability of our bioenergy cropping systems.

We are also motivated by the ethics and long-term costs of *not* doing this research. To stand by while the climate continues to warm or to produce biofuels in an unsustainable way is also an ethical consideration. It is worth noting, however, that performing research that enables the sustainable production of bioenergy crops does not necessarily guarantee that they will be grown in such a fashion. Ensuring sustainability requires sound policy, which this subcommittee could influence.

Similarly, we give significant consideration to the plants and microbes engineered, especially those that might get deployed or released into the environment. Key questions considered include the possibility of engineered plants and microbes outcompeting native plants and microbes, and the likelihood and potential ramifications of genes inadvertently being transferred to other organisms. Fortunately, many of the engineered traits we are introducing (*e.g.*, increasing the energy content and ease of degradation in plants or funneling carbon and energy from cell growth to biofuel production in microbes) are expected to make these engineered organisms less competitive with native organisms in natural, unmanaged conditions, thereby significantly limiting the concern. Nevertheless, potential off-target consequences are carefully considered and researched as appropriate.

As a whole, faculty at large land-grant institutions, such as MSU, take the teaching and outreach mission of their institution very seriously. Part of this mission, of course, involves ensuring that students and the community are educated about the important ethical considerations of our research. In my own personal experience, when I discuss biofuels in the classroom, we consider not only the need for biofuels and bioproducts, but also the challenges associated with producing them in an economically and environmentally sustainable manner. Ethical issues invariably arise, including not only the risks associated with engineering transgenic plants and microbes, but also the risks associated with doing nothing. As part of the GLBRC, I have also been involved both directly and indirectly with numerous outreach activities at MSU, explaining to the public what biofuels are, how they are produced, and how they can help both the environment and the community. Together with my colleagues, we explain what genetically modified organisms are and the different ways they can be engineered. When interacting with the public, my goal is to give them information that will enable them to make informed decisions about the risks versus benefits of using engineered biological systems.

3. **Are the nation's colleges and universities educating and training enough skilled technicians, scientists, and engineers in the field of engineering biology to maintain U.S. leadership in this area? If not, what recommendations do you have for additional actions by institutions of higher education, the private sector, and government?**

   Interest in the biological sciences at MSU has grown steadily, as has the number of undergraduate majors. My understanding is that other universities are seeing similar trends. In addition, the number of teams participating in the International Genetically Engineered Machine (iGEM) competition (where students engineer organisms to perform a new function or develop tools to enable genetic engineering) continues to rise, with nearly 80 U.S. teams competing in 2018. Thus, students are not only interested in subjects related to engineering biology, they also want to get into the lab and perform research, applying what they have learned in the classroom to real-world problems.

   This interest in hands on research can also be seen in the large number of applications to the many summer undergraduate research programs at MSU and other universities around the country. Competition for these summer research programs is typically intense. For many programs, including those that support the GLBRC, there are often far more qualified applicants than there is funding to support them. To help balance this mismatch, it would be helpful if the federal government provided additional new funding to help support these undergraduate research programs, including those that integrate both field and laboratory research. Meaningful research experiences that employ the scientific method help reinforce key concepts, teach critical thinking, and encourage creativity, thereby laying the groundwork for the skills and training needed for scientists, technicians, and engineers at all levels. Thus, investing in these relatively inexpensive summer research programs can significantly impact the quality of the future workforce engaged in engineering biology.

   Another initiative that universities themselves could do to improve education and training in STEM fields is to increase emphasis on writing. The ability to express oneself clearly and logically is critical to the dissemination of results, the transfer of knowledge, and the exchange of ideas. In addition, clear writing encourages critical thinking. Simply put, communication is critical in science, but this is an area that is too often underemphasized at the undergraduate level. This is perhaps especially true at large universities, due at least in part to the expense of the one-on-one instruction necessary to train effective writers. Thankfully, I believe this is changing, and university science departments are beginning to put more emphasis on written and oral communication skills. This is encouraging, and I hope the resources are available to keep this trend going in the right direction.

4. **What recommendations, if any, do you have for improvements to the Engineering Biology Act? What additional recommendations, if any, do you have for Congress or for federal science agencies that fund engineering biology research, including any recommendations for improving interdisciplinary and interagency funding mechanisms?**

   The proposed Engineering Biology Act has a number of key compelling aspects. Enhancing the country's competitive advantage in engineering biology by increased support for research and education and accelerated commercialization is vital. These fields are likely to continue growing in global economic importance in the coming decades. Likewise, obtaining a better understanding of the factors that lead to societal acceptance and adoption of new products, processes, and technologies based on engineering biology will ensure a steady consumer base. Increased coordination among the agencies under the purvey of the House Science, Space, and Technology Committee will help accomplish these goals. This coordination could be especially powerful if expanded to include other federal agencies that fund engineering biology research, including the National institutes of Health, the Department of Defense, and the U.S. Department of Agriculture. I am confident in the Committee's longstanding leadership in working to achieve this goal with the other committees that have jurisdiction over these agencies. As these discussions move forward, however, it is imperative that any new initiatives be supported with a commensurate level of new funding. In times of tight fiscal budgets, it is essential that both single-investigator and center-level efforts be encouraged. Single-investigator research encourages the creativity that has been the hallmark of U.S. innovation leadership and can lead to profound and unexpected breakthroughs. Center-level research provides synergies with similar benefits. It is important to maintain a healthy balance between these two broad funding models.

Thank you for the opportunity to appear before the Subcommittee. I welcome the opportunity to address any questions.

ERIC HEGG

Biography
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Dr. Hegg is a professor of biochemistry and molecular biology at Michigan State University (MSU). He received his B.A. in Chemistry and History in 1991 from Kalamazoo College and a Ph.D. in 1996 from the University of Wisconsin–Madison. It was during his time at Wisconsin that he became interested in metalloenzymology, studying the role of metal ions in enzymes that hydrolyze DNA, RNA, and proteins. After receiving his Ph.D., Dr. Hegg completed a National Institutes of Health postdoctoral fellowship at the University of Minnesota where he studied non-heme iron dioxygenases and established his long-standing interest in understanding how nature synthesizes and activates small molecules such as H_2 and O_2. Following his postdoctoral work, Dr. Hegg and his family moved to Salt Lake City in 1999 where he joined the faculty of the University of Utah and began his independent research career. He received a National Science Foundation Career Award in 2004 and the Cottrell Scholars Award in 2002. When the opportunity arose, Dr. Hegg and his wife returned to the northern Midwest to join the faculty at MSU in 2006 where he is a professor of biochemistry & molecular biology and the MSU Subcontract Lead for the Great Lakes Bioenergy Research Center. In addition to studying heme biosynthesis and O_2utilization, he is involved in developing renewable bioenergy, converting biomass into ethanol and other transportation fuels as wells as using microbes to generate H_2. Dr. Hegg has recently participated in two leadership activities at MSU. In 2016, he was a Big Ten Academic Alliance Leadership Program Fellow and in 2017, was an Academic Advancement Network Leadership Fellow. When Dr. Hegg is not busy in the lab, he enjoys running, hiking, and most outdoor activities.