# Witness Testimony of Eric L. Hegg
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## Before the House Committee on Science, Space, and Technology
## Subcommittee on Energy
## Hearing titled
## *Bioenergy Research and Development for Fuels and Chemicals of Tomorrow*
## March 16, 2022

Acting Chair Casten and Ranking Member Weber, thank you for the invitation to testify today. I am grateful to Rep. Meijer for his leadership and generous introduction. Also, I would like to thank Subcommittee member Rep. Stevens and full committee member Rep. Kildee, for their guidance of innovation in this critical area. I would like to commend the committee for its drafting of the DOE Science of the Futures Act and its inclusion into the America Competes Act. I understand that it authorizes two new Bioenergy Research Centers. Thank you for your leadership on this topic and for your continued advocacy as you go to conference with the Senate. It is my great pleasure to contribute to the ongoing discussion of the opportunities, challenges, and current status of bioenergy research, and how this research leads to both new technologies and a workforce prepared to address emerging grand challenges. I look forward to today's review of how current and future advancements in bioenergy and bioproduct research will help the United States and the world transition to cleaner forms of energy. 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 four key sections — (1) my professional experience and interest in bioenergy research; (2) the importance of supporting individual science projects, research centers, and scale-up and/or commercialization projects; (3) science and technology workforce development; and (4) opportunities for growth to improve the impact of future investment.

### 1. Overview of my professional experience and my interest in bioenergy research

I serve as both a Professor in the Department of Biochemistry & Molecular Biology at Michigan State University (MSU) and as the Associate Dean for Budget, Planning, Research, and Administration in the College of Natural Science. Prior to assuming my administrative duties in 2020, I was the MSU Subcontract Lead for the DOE-funded Great Lakes Bioenergy Research Center (GLBRC). In all three of these roles, I have observed and experienced the critical collaborative partnerships that exist between the federal government and universities. MSU ranks first nationally in Department of Energy (DOE) expenditures and ninth nationally for National Science Foundation (NSF) expenditures according to the NSF Higher Education Research and Development (HERD) 2020 data. Support from the DOE and the NSF each comprise approximately 25 percent of MSU's total federal research funding, while the United States

Department of Agriculture (USDA) accounts for an additional 10 percent (https://research.msu.edu/facts-figures). Together, these funds provide vital support for cutting-edge fundamental research, for the training of the future workforce and leaders in science and technology, and for the development of new sectors of our economy. Michigan State University is part of the University Research Corridor, an alliance between MSU, the University of Michigan, and Wayne State University, whose mission is to promote innovation and economic growth in Michigan. Together, these three institutions – one of the top eight academic clusters in America – contributed an estimated $19.3 billion to our state's economy in 2019 (https://www.urcmich.org/reports/urc-universities-contribute-193-billion-michigans-economy).

My 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. Because of their unique ability to attract, store, and transfer electrons, metal ions are vital in a number of biological pathways, including respiration, photosynthesis, carbon fixation, and nitrogen fixation, to name just a few. Obtaining a deeper understanding of the strategies used by nature may enable us to replicate these strategies and produce better catalytic systems for a variety of industrial processes.

Over the years, I have used this approach to study cellular respiration, oxygen ($O_2$) activation, biological hydrogen ($H_2$) production, biological global nitrogen cycling, and biomass deconstruction and conversion into biofuels and bioproducts. Several federal agencies have funded my research, including the National Institutes of Health (NIH), the NSF, the United States Air Force (AFOSR), the 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 grateful to these funding agencies, and the societal contributions I have made in my research is a direct result of the financial support of these agencies.

Much of my research has focused on bioenergy and environmental research. 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. Relevant to this hearing today, I am an inventor of patented technologies to (a) deconstruct biomass and separate the plant cell walls into their core components for conversion into biofuels and bioproducts, (b) depolymerize lignin (one of the key structural components found in plant cell walls) into its monomeric constituents, and (c) employ lignin in polyurethane applications. I am hopeful that these technologies will ultimately supply farmers and growers with additional revenue streams, provide industry with new or improved products, contribute to the strengthening of the Michigan and U.S. economies, and enable an environmentally and economically sustainable bioeconomy.

## 2. Importance of supporting large multidisciplinary research centers, individual science projects, and scale-up and/or commercialization projects

Center-level funding. Federal support of large, interdisciplinary research centers is critical to addressing society's grand challenges, including the transition from an economy based heavily on fossil fuels to a cleaner, more sustainable bio-based economy. Large research centers, such as the Bioenergy Research Centers, are uniquely positioned for this task. They bring together researchers from multiple fields to tackle complex and challenging problems in ways that are simply not possible with single-investigator or small group projects.

In the case of bioenergy research, this includes bringing together scientists from agronomy, genetics, plant biology, and plant biochemistry to develop and produce dedicated bioenergy crops with improved traits such as increased carbon fixation and greater biotic and abiotic stress tolerance. Simultaneously, soil scientists, biogeochemists, hydrologists, entomologists, and microbial ecologists are needed to understand the flow of nutrients and plant-microbe interactions, both of which are critical to plant and soil health as well as environmental sustainability. The expertise of microbiologists, synthetic and computational biologists, biochemists, chemists, and engineers are also required to deconstruct the biomass and convert it in an atom and energy efficient manner into biofuels and bioproducts. Overarching these areas is the work of computational modelers and those performing life-cycle analysis and techno-economic analysis to ensure that the strategies identified to generate biofuels are both economically and environmentally sustainable.

Finally, it is key to remember the human element. The best scientific solutions are useless if we ignore the key stakeholders. It is crucial for agriculture and economic extension services to engage with and obtain buy-in from landowners, farmers, industrial partners, and consumers to ensure that the solutions identified can be employed in the real world.

It is important to reiterate that in bioenergy research, small or even mid-sized projects cannot fully address the interdependent and expansive areas of feedstock production, sustainability, biomass deconstruction, and conversion into fuels and chemicals. Scientific breakthroughs and paradigm-shifting discoveries in one area can greatly impact both the challenges and solutions in other areas. In the absence of large, integrated centers, the new technologies and approaches developed for one area might not integrate across the entire pipeline, thus restricting their adoption and the creation of a sustainable bioeconomy.

As an example, new bioenergy crops designed for desirable characteristics such as altered lignin content can impact both the reaction conditions for the ideal biomass deconstruction process and some of the products that are formed. At the same time, deconstruction conditions affect the quality and quantity of the structural sugars and other cell wall components that are released during processing. Meanwhile, the microbial and chemical conversion of these biopolymers into biofuels and bioproducts can be significantly influenced by the specific composition of the solution following deconstruction. In addition, the biotic and abiotic stresses that the plants experience (*e.g.*, pathogens, pests, drought, nutrient deprivation, etc.) impact not only the biomass yield and composition, but also the range of plant secondary metabolites produced, all of which can dramatically impact downstream processes. In the absence of a large, integrated research center, it would be exceedingly difficult to identify and efficiently share solutions that can work together in a holistic, robust, and sustainable manner.

<u>Funding for individual research projects.</u> While large centers are essential to address today's societal grand challenges, it remains critical that we maintain and even increase funding for individual research projects. Single-investigator or small-group research projects encourage the essential creativity that has been the hallmark of U.S. innovation leadership and can lead to profound and unexpected breakthroughs. Although large centers also perform basic, transformative research, even large centers cannot have expertise and visionary insight in all relevant areas. In addition, smaller projects often adapt more quickly to changing conditions and exciting or unexpected results, thereby opening new avenues of inquiry. In fact, these individual breakthroughs are often the basis for the integrative

research performed by the centers. Single-investigator projects are therefore vital to the success of the scientific enterprise and, indeed, to the success of large research centers.

For example, pioneering work elucidating the pathways of lignin biosynthesis has led to the design and production of plants with altered lignin composition and more amenable to processing. This cutting-edge research has been incorporated into some of the bioenergy research centers, and these plants with unique traits are an important component of the research pipeline. In addition, the technology has been licensed to the private sector. Highlighting the complexity of integrating such developments into bioenergy solutions, this technology is first being applied in the pulp and paper industry, where it is expected to lower both energy and chemical usage.

As another example of the importance and creativity of small research projects, much of the essential biomass deconstruction research in the centers, including work in my own lab, is related either directly or indirectly to breakthroughs achieved as a result of single-investigator or small group projects.

Finally, 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.

Scale-up and/or pre-commercialization projects. Once promising new technologies have been proven to be compatible in an integrated system, they must then be scaled-up and de-risked to make them attractive to industry, especially when these new technologies are competing with established and highly optimized existing technologies. There are a number of federal programs and resources focused on this endeavor including, but not limited to, the Bioenergy Technologies Office (BETO) within the DOE Office of Energy Efficiency & Renewable Energy (EERE), the SCALEUP program (https://arpa-e.energy.gov/technologies/scaleup) initiated by the DOE's Advanced Research Projects Agency – Energy (ARPA-E), and the multiagency Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs. Key resources for scale-up demonstration include the DOE Advanced Biofuels and Bioproducts Process Development Unit (ABPDU) at Lawrence Berkeley National Laboratory (https://abpdu.lbl.gov/) and resources at the National Renewable Energy Laboratory (NREL).

Promising technologies established at the bench scale often encounter unanticipated challenges (*e.g.*, issues associated with mass flow and heat/chemical transfer) when they are moved to the industrial scale. Demonstrating that these challenges can be overcome is often key to obtaining significant industrial investment for disruptive technologies. In my own personal experience, BETO has been an important partner in advancing our deconstruction technology that was developed within the Great Lakes Bioenergy Research Center (https://www.glbrc.org/). With BETO funding, we have both optimized the technology and scaled the process from the initial bench scale by over a factor of 1000. The work has led to an additional patent and patent application, and an industrial partner is potentially interested in collaborating on further scale-up, de-risking, and expanded application of the technology. BETO funding was crucial in developing potential corporate interest despite the many advantages of our deconstruction process, and my experience with the challenges encountered at this stage of technology development is not unique. Thus, to take full advantage of federal research investment and ensure that new technologies can move from the bench into the private sector, BETO and similar scale-up and de-risking programs and resources should be continued and, as appropriate, expanded.

## 3. Workforce development in science and technology

Established in 1855 as the nation's first agricultural college, MSU proudly carries its responsibilities as a public, research-intensive, land-grant university. In addition to (a) conducting the research and outreach required to expand human understanding, (b) identifying solutions that positively impact society both locally and globally, and (c) serving as an engine for economic development, MSU is also deeply dedicated to "providing outstanding undergraduate, graduate, and professional education to promising, qualified students in order to prepare them to contribute fully to society as globally engaged citizen leaders" (https://trustees.msu.edu/about/mission.html). In the context of bioenergy research, this includes developing the workforce needed to support the growing bioenergy research and economic sector, thereby enabling the scientific breakthroughs and deployment needed for the United States to maintain its leading role in this area and to diversify its energy options.

At Michigan State University, and at many universities throughout the country, interest in science, technology, engineering, and mathematics (STEM) fields has risen considerably over the past 15 years. Authentic laboratory experiences that provide students the opportunity to participate in cutting-edge research to solve real-world problems are key components to preparing them to become practicing scientists. Opportunities such as the NSF's Research Experiences for Undergraduates (REU) program (https://www.nsf.gov/crssprgm/reu/) and the DOE's Science Undergraduate Laboratory Internships (SULI) program (https://science.osti.gov/wdts/suli) have been hugely successful and popular. In fact, competition for these summer research programs is typically intense. For many programs, there are often far more qualified applicants than there is funding to support them. To help balance this mismatch, additional federal funding to support these and new undergraduate research programs would have a significant impact.

Meaningful research experiences that employ the scientific method 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. Further, because many undergraduate students must choose between meaningful research experiences and working to afford tuition and/or living expenses, paid internships and summer research programs positively impact diversity, equity, and inclusion. As a result, investing in these relatively inexpensive summer research programs can significantly impact the quality, the quantity, and the diversity of the future workforce engaged in the bioenergy economy.

In addition to specialized undergraduate and post-baccalaureate research programs, students at all levels can also gain invaluable experience in the laboratory by participating in federally-funded research projects. Thus, investing in university-led research not only advances the scientific mission of the funding agencies, it also provides crucial educational opportunities and technical training.

Large integrated endeavors such as the Bioenergy Research Centers are especially ideal environments for educational development. Not only do they provide experience in cutting-edge research focused on real-world problems, they also expose students to integrative and multidisciplinary teams that are so vital in today's industrial research enterprise. To be optimally impactful, researchers need to communicate effectively with scientists outside of their specific discipline as well as to the broader public. Exposing undergraduates, graduate students, and postdoctoral students to the integrative environments found in large research centers prepares them for this important challenge.

## 4. Opportunities for growth to improve the impact of future investment

As we move forward in the coming decade, there are opportunities for growth that will increase the impact of federal investment in bioenergy research. The first of these is continued and/or expanded support for long-term studies. The significance of historical long-term data and its impact on multiple research areas cannot be overstated. An example directly relevant to bioenergy is NSF's Long-Term Ecological Research (LTER) program. MSU's LTER site (https://lter.kbs.msu.edu/) at the Kellogg Biological Station (KBS) was established in 1987 and provides critical data to understand the interactions among plants, microbes, and insects in cropping systems appropriate to the Midwest, including candidate bioenergy crops and their potential positive environmental impacts. The recently established Long-Term Agroecosystem Research (LTAR) site at KBS (https://www.canr.msu.edu/ltar/), funded by the USDA, is anticipated to provide synergistic insights to enhance the agricultural sector. Studies co-developed with stakeholders will provide farmers new approaches for sustainably intensifying the production of food and bioenergy while simultaneously delivering ecosystem services such as climate mitigation, clean water, and pollination.

A second potential growth area is increased coordination among the agencies under the purview of the House Science, Space, and Technology Committee, including the DOE and NSF. This coordination could be especially powerful if expanded to include other federal agencies that fund bioenergy related research, including the USDA.

One way to achieve improved inter-agency coordination is to increase funding for the development of large-scale centers that are supported by multiple agencies. Potential centers could be reviewed by and report to teams representing all of the participating funding agencies. Successful centers, by their very nature, would be interdisciplinary and cross-cutting as they must address key aspects of each agency's mission. This process would ensure highly integrative and synergistic research, reduce duplicative efforts, and promote coordination in tackling society's difficult and complex grand challenges.

Thank you for inviting me to appear before the Subcommittee. I welcome the opportunity to address any questions you may have.

**Eric Hegg** obtained his B.A. from Kalamazoo College and his Ph.D. from the University of Wisconsin under the direction of Professor Judith Burstyn. 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., Eric joined Larry Que's group at the University of Minnesota as an NIH postdoctoral fellow 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, Eric and his family moved to Salt Lake City where he joined the faculty of the University of Utah and began his independent research career. He received a Cottrell Scholars Award in 2002 and a National Science Foundation Career Award in 2004. When the opportunity arose, Eric and his wife eagerly returned to the northern Midwest to join the faculty at MSU, where Eric is a Professor in the Department of Biochemistry & Molecular Biology. Eric has served a variety of roles within the Great Lakes Bioenergy Center since its founding in 2007, and he served as the MSU Subcontract Lead for the GLBRC from 2013 through the end of 2019. In January 2020, Eric accepted the position to become the Associate Dean for Budget, Planning, Research, and Administration in the College of Natural Science. Eric has participated in two leadership activities at MSU; in 2016, he was a Big Ten Academic Alliance Leadership Program Fellow, and in 2017-2018 he was an Academic Advancement Network Leadership Fellow. In 2019, Eric was elected a Fellow in the American Association for the Advancement of Science (AAAS).

Research in the Hegg lab focuses on elucidating how microbes perform environmentally important reactions. In particular, they are studying various enzymes critical to the global nitrogen cycle, including an enzyme that converts the environmental contaminant nitrite into ammonia as well as enzymes that produce the potent greenhouse gas $N_2O$. The Hegg lab also studies how microbes break down biomass to release the sugars and lignin from the plant cell wall, and how these structural components of the plant cell wall can be used to form biofuels and bioproducts. Ultimately, they are interested in applying the knowledge gained from these studies to address real-world problems.