EBRC Engineering Biology Research Consortium

To whom it may concern: August 28, 2020

The Engineering Biology Research Consortium (EBRC) is pleased to submit this response to the *National Defense Education Program Request for Information (RFI) from the Department of Defense for the Office of the Under Secretary of Defense (Research & Engineering)*. EBRC is a non-profit, public-private partnership dedicated to bringing together an inclusive community committed to advancing engineering biology to address national and global needs. EBRC members represent diverse perspectives of the engineering biology research community and include some of the nation's top scientists and engineers. At its core, EBRC's objective is to advance pre-competitive research in engineering biology through cross-sector coordination between industry, academia, and government.

The following is in response to the RFI **Focus Area II - Biotechnology Education and Workforce Development**.

1. *What is the current state of the biotechnology education and workforce in the US and what are the limits of the current practice?*

Current State of Biotechnology Education and Workforce: Currently, biotechnology education and workforce development is primarily concentrated in higher education, particularly in Masters and PhD programs, and within communities with the most resources, such as affluent high schools. Biotechnology is often taught as an application of traditional educational programs, such as chemical engineering and molecular biology.

The workforce itself is centered in the Boston, MA-area and the San Francisco, CA Bay Area, where the convergence of a high-density of research-intensive universities, technology industries, and investors have fostered a robust regional modern biotechnology enterprise. Biotechnology, however, has been a major U.S. industry for decades and several large scale companies with biotechnology interests exist outside these hubs, such as Bayer/Monsanto and Cargill.

Limits of Current Practice: A paucity of early educational opportunities, coupled with the speed with which biotechnology tools and the biotech industrial sector have advanced, has put significant limits on the development of a well-prepared biotechnology workforce. Biotechnology development has far outpaced the development of educational resources necessary to teach the cross-disciplinary concepts, technical skills, and critical thinking required for many biotech jobs. In particular, most educators in K-12 and community college programs are not aware of biotechnology career opportunities, much less receive training or education to stay up-to-date on advancements in biotechnology or to prepare their students for the applications and societal considerations associated with biotechnology.

One particular limitation of biotechnology education is a lack of hands-on training resources and opportunities for students and educators at all stages. Biotechnology inherently combines the application of tools and processes of chemistry, engineering, and data/computational science with the dynamics of biology, and thus requires agile and flexible skill development, including critical thinking, digital literacy, contextual integration of math and physical sciences, technologies such as robotics and machine learning, and real-time manipulation of biomolecules, cells, and organisms. Current curricula and educational tools rarely accommodate this intersection of fundamentals in a practical way necessary to develop the skills and techniques required for success in a biotechnology-based career.

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2. *What skill sets and capabilities are most important to foster in the future biotechnology workforce? Are there different skills and capability needs for different components of the biotechnology workforce?*

Interdisciplinary Training and Practical Application: Biotechnology is inherently interdisciplinary and as such, the biotechnology workforce must be able to integrate knowledge and skills of chemistry, engineering, mathematics, physical sciences, and computer science with a foundation in molecular biology. The future biotechnology workforce should be taught to translate theoretical understanding in these areas to experimental design, laboratory work, and/or data analysis; these skills need to be taught early and often and not relegated to advanced graduate education. Educational opportunities can be developed that begin with conceptual understanding and incorporate practical application, letting students not only conduct experiments, but over time become more independent and autonomous in *designing* experiments to address hypotheses and *engineering* biological solutions to meet societal needs. Outside of student training in research laboratories, these experiences are incredibly variable and available only to subsets of the biotechnology workforce trainees.

Computer Science: Of required skills for a robust biotechnology workforce, computer programming, data analysis, and basic statistics should be emphasized as they are necessary for success in many areas of the biotechnology workforce, including all aspects of the research life-cycle along with automation and robotics. Currently, this skill set is usually learned at the graduate level and, historically, is associated only at a very basic level with the biological sciences (e.g., analyzing experimental results in a spreadsheet). Integrating data analysis and statistical concepts into biology curricula starting in K-12 education and emphasizing computer programming and the use of computational tools at the undergraduate and community college levels will provide the background and formal educational experiences required to seamlessly enter the biotechnology workforce.

Similarly, creating programs at the high school or community college level that cover subsets of the above skills - automation coupled with cell biology laboratory experience, or bioprocessing techniques coupled with programming - would benefit the existing biotechnology companies as well as the myriad new startups to come. Experiential training for biotechnology jobs needs to also include all the steps of the industry process, such as hands-on work in pilot scale facilities. The workforce needs to develop expertise in competences that allow one to move from the bench to society-scale manufacturing.

Communication: Communication in cross-disciplinary teams is an essential skill for the biotechnology workforce, for those engaging in research and those that play other roles in the industry. Traditional STEM education is focused on facts, concepts, and information processing, leaving students underprepared for the cross-disciplinary, multifaceted biotechnology work environment which requires effective communication between team members with different skill sets and backgrounds. Emphasis needs to be placed, early and often, on effectively communicating scientific concepts, ideas and challenges, and the impacts, implications, and importance of biotechnology across audiences, settings, and platforms. Students and trainees need to be taught effective communication tools, and diverse communication strategies need to be inculcated into curricula and training programs.

ELSI Considerations: The success of the biotechnology workforce relies upon not only trained scientists and engineers, but knowledge and application of ethical, legal, social, environmental, regulatory, security, and safety considerations of biotechnology and the inherent tools and consequential products. Critical thinking in biotechnology education and careers requires students, educators, and members of the workforce to engage in these considerations and integrate these concepts into curricula, experimental design and practice, and industry.

3. *What existing biotech or non-biotech EWD programs, program elements, or models could be leveraged or applied to support biotechnology EWD? What are the strengths and/or weaknesses of these example(s)?*

Biotechnology education and workforce development programs are generally designed to create and support opportunities that are either geared toward individual students/trainees or toward classroom settings. Both of these approaches have different costs and benefits; training for individuals can be more tailored to the trainee's level of development and interests but generally comes at a higher per trainee cost while training at the classroom level is less individualized but can reach more people.

Internships, Fellowships, Apprenticeships, and Similar Programs: These programs give students opportunities to gain the practical, hands-on experiences that are crucial for success in biotechnology. These programs are most commonly available at the undergraduate level, and sometimes at the high-school or graduate level, but are not ubiquitous nationwide. Programs that provide this training include the National Science Foundation's Research Experiences for Undergraduates (REU) and Research Traineeship (NRT) programs, and individually-coordinated undergraduate research programs at universities across the country. Some biotechnology companies also support their own internship/externship programs, but these are not widespread and not often broadly advertised. EBRC administers a national biotechnology Internship Program, designed to place graduate students in 3-4 month internships with small- and medium-sized companies and research organizations (including Department of Energy National Laboratories and Department of Defense Research Laboratories). This program is just in its second year and is still growing, but was designed with input and feedback from university educators and the industry partners to best suit the needs and interests of the companies with the realities of student skill sets and expectations.

Such experiences are important for student/trainee learning, networking, and resume building and can be important or even essential for progressing through educational pipelines. A real limitation of many of these programs is that they are not funded at levels that support all interested and qualified individuals. Decisions as to how positions in these programs are allocated are made with variable criteria that are subject to bias. Additionally, the types of experiences a student can have in these programs vary widely from a semester or summer spent performing menial tasks to being guided by attentive mentors through experimental design and implementation. Programs may consider requiring training for mentors that articulates expectations for student/trainee learning and strategies for mentors to recognize implicit bias and minimize its impact on student/trainee selection.

Hands-On Learning: Building skills in classroom settings can give many more students access to biotechnology education. Classroom education should integrate conceptual learning with hands-on experience. Traditional approaches separate the lecture component from the laboratory component of a course. Successful examples for integrating conceptual learning with hands-on experiences include the development of "studio" classrooms in Chemistry, Physics, and Math that integrate lecture and lab modules into the same classroom and time slot. Implementation of such pedagogical changes into biotechnology education are limited by access to the hands-on, inquiry-based learning modules. Current hands-on biotechnology learning generally requires expensive equipment, including proprietary materials and lab technology. At the university and college levels, there are often laboratory fees on top of tuition to offset some of these costs, which can pose a financial barrier for students from gaining access to such courses, or to universities that offer such courses. Many community and technical colleges lack this infrastructure altogether. Where these resources do exist, faculty are constrained in their course design by the time limitations of laboratory sessions and protocols that require action at times or on days when students are not in class. Experiments should also, to the extent possible, have a high probability of success with built in room for student error and critical analysis. One solution to these issues is distilling biotechnology tools and techniques into affordable "kits" that can be broadly disseminated and integrated into existing curricula to foster the development of practical skills at a variety of educational levels from K-12 through college. Such kits should be designed with price, equipment, reproducibility, portability, and ease-of-use in mind.

At the high-school level, the expense of biotechnology hands-on experience can generally be covered only in schools from wealthy areas or in areas with support from the biotechnology industry and/or local universities. For example, Biotech Partners, a non-profit in the San Francisco Bay Area, creates opportunities for underserved youth to participate in specialized biotechnology high-school courses with hands-on training and professional internship and development programs. Scaling or replicating such educational opportunities may be more difficult outside of areas bolstered by a strong biotechnology presence. As a result, high-school students across the country or even across a given state lack similar access and opportunity to hands-on biotechnology education. The development of lower-cost, low-tech equipment and digital resources that can be distributed within schools or school districts might reduce the size of this barrier. Additionally, such activities should focus on cutting-edge research tools and topics (e.g., CRISPR) that could bring new entrants to the field. Another solution is to support the development of interactive simulations, augmented reality, or hybrid approaches that eliminate the most expensive elements of a laboratory experience.

Teacher Training: Significant barriers remain with regards to teacher training at the high-school level. Indeed, implementation of the aforementioned kits and equipment still requires some degree of teacher education and training to make them most effective. Many science teachers may feel unprepared to develop and/or teach this type of curriculum because they were trained before modern biotechnology techniques were developed or were not trained at an institution that offered biotechnology skills in their curriculum. Additionally, some teachers may face resistance from students and/or their parents who are wary of biotechnology or are not yet aware of applications and impact of biotechnology opportunities and products. Educator training that keeps teachers up to date on the development of new technologies and their societal implications through partnerships between schools, biotech employers, and educational nonprofits may be necessary and sufficient to overcome these challenges. Some organizations, such as BioBuilder, exist to make this training and professional development possible but need more support and engagement to increase their impact.

Integration into Existing Curricula: While ideally biotechnology would be offered as an independent course that could truly emphasize its interdisciplinary nature, the reality is that biotechnology will need to be integrated into existing biology curricula. Top-down efforts will need to be made to better integrate conceptual, applied/practical, and critical thinking into biology education, leveraging new educational tools and improved teacher education and training to modernize existing curricula. This starts by recognizing and communicating the importance of biotechnology and the bioeconomy to national interests.

4. *At what educational level would future workforce benefit the most from EWD support?*

Secondary Education: Creating additional opportunities and hands-on experiences for junior-high and high-school students could significantly increase the number and types of students who choose to pursue biotechnology careers. At these ages, students are learning about the types of career opportunities that are available to them and beginning to consider which interests to pursue as adults. It is therefore a critical time to be exposed to biotechnology and the kinds of questions and problems it can address. Equally important is the hands-on, experimental practice that highlights the power of biotechnology and allows students to envision themselves in a biotechnology career.

Junior & Community Colleges: The junior college and community college levels could also see significant benefit from education and workforce development support. Students/trainees in these settings are often seeking practical skills that translate to the workforce more quickly, directly, and with less expense than university education. Training in these settings should focus on the integration of conceptual understanding with cross-disciplinary engineering biology skills and will be increasingly important as a source of new hires to operate the growing number of bio-based manufacturing facilities. Ideally, community/junior colleges in a given geographic area would network with regional industry professionals to identify directly translatable skills so that trainees are prepared to join the workforce. These connections should also increase the confidence of industry professionals in the training caliber of workers they might hire out of these programs and, for example, influence them to consider an individual with an associate's degree in biotechnology instead of requiring a bachelor's, master's, or doctoral degree.

Junior- and community colleges may also require assistance in developing curricula that effectively teach the in-demand skills required by a fast-moving biotechnology industry, and to offer courses available to high school students for college credit. The government should consider funding the creation of (and ongoing updates to) training materials and curricula for these newer programs.

5. *How can inclusion and participation of minority and under-represented groups be encouraged in biotechnology? What are the current barriers to increased minority and underrepresented group participation in biotechnology? How can these barriers be addressed and overcome?*

Opening the Pipeline: To encourage the participation of minority and under-represented groups in biotechnology, the field should support efforts that make the academic pipeline more welcoming and inclusive. The current biotechnology workforce includes a significant proportion of highly-trained professionals, often with masters and PhD degrees. We should strive to also identify areas of biotechnology that require less formalized training, thereby advancing the workforce development pipeline to provide many points of entry into biotechnology education, and outlets to the biotechnology workforce.

Barriers to Participation: Many barriers exist that, in effect, exclude underrepresented groups from graduate level education in preparation for careers in the biotechnology workforce. As an example, underrepresented groups might have employment and/or family responsibilities that preclude them from taking advantage of undergraduate research opportunities, internships, etc., which are essential for graduate school admission. One solution is to make sure that education and training opportunities are able to financially support students and that this financial support is clearly communicated in advertising materials. Underrepresented groups may also be unaware of the financial structure of graduate education in biotechnology fields, not realizing that students typically do not pay tuition and receive stipends to support their costs of living. Underrepresented groups might also feel uncomfortable, unwelcome, or a lack confidence in departments and locations without peers, advisors, and mentors who share their background and/or race or ethnicity. Overcoming these barriers requires work by departments and universities to value and build diversity in their faculty, staff, and student populations, and to communicate with students who may want to continue through the pipeline about the opportunities available to them.

Diversity of Careers: However, not everyone's situation and experience is best-suited to extensive formal education and training. Concurrently, not all work in biotechnology necessarily requires it. Students and trainees should be informed of the diverse career opportunities in biotechnology, and the associated levels of education or requisite training tied to these careers. In addition, funding for on-the-job training/apprenticeships that allows students with some background knowledge to build skills on the job can incentivize industry to hire capable individuals whose situations may not be best suited to extensive formal education.

6. *What metrics could be used to measure progress or success?*

Tracking Trends: Efforts to increase education and workforce development at all levels should incorporate evaluative measures of progress and success. Quantitatively, programs should track the number of students enrolled in courses and programs and track their outcomes over three to five years to better understand which types of education and workforce development are most effective for building a robust field of biotechnology professionals. Individual programs should produce metrics, such as through pre- and post-program surveys, to identify opportunities for improvement and assess interdisciplinary knowledge and ascertainment of concrete, transferable skills. Monitoring should also endeavor to track longer term employment trends (over 10 to 20 years, akin to the kinds of data collected by NSF on PhD holders by their Survey of Doctorate Recipients) among trained students to evaluate the impact of training on career mobility within biotechnology.

Needs of Industry: Simultaneously, metrics should be sought from industry that describe the education levels of their employees and their projected need for employees at different education levels and within different domains of expertise over five to ten years. This type of information, especially when collected on an ongoing basis, can inform future allocation of education and workforce development efforts towards training for anticipated industry needs.

7. *What level of investment would be meaningful?*

The level of investment required to generate meaningful development of biotechnology education and workforce development is proportional to the size of desired impact and is dependent on the types of programs being supported.

Small Investments: Grants to individual or small groups of faculty in the range of <$100,000 may be sufficient to provide a few students with training opportunities or to create new, limited-scope educational resources, but will not make a meaningful contribution to the development of a national biotechnology workforce.

Midsize Investments: Somewhat larger funding initiatives (i.e., totaling at least $20 million, with individual programs at $200,000-750,000 each) that can support the development of specific educational modules at a single university campus, or implementation at a set of community colleges, have the ability to meaningfully contribute to the biotechnology workforce of a given city or region with the potential to establish models that can be broadly adopted. Funding at this scale should consider the type of experience being offered (individual vs classroom) and the costs of equipment and qualified instructors that may be incurred above typical molecular biology laboratories and training.

Large Investments: Large funding investments granted to organizations with the capacity to design, build, and implement regional or national programs can impact the largest number of people, but also require multi-million dollar investments. Such programs may seek to establish biotechnology training programs across large networks of community or junior colleges, introduce specialized biotechnology education into K-12 settings, or create immersive training, re-training, or internship opportunities for individuals. These efforts will be more successful when industry partners are involved from the outset. Industry partners may find that supporting these education and workforce development efforts through financial contributions, in-kind donation of equipment, or hosting and mentoring of trainees/apprentices has a positive return on investment as they see a talented flow of qualified applicants to positions in their companies.

Respectfully Submitted,

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