June 13, 2014

Patricia M. Dehmer
Acting Director, Office of Science

Dear Dr. Dehmer,

We are writing in response to your charge letter of February 19, 2014 requesting that the Biological and Environmental Research Advisory Committee assess workforce development needs in Office of Science research disciplines. BERAC discussed this topic in some detail during the Spring, 2014 meeting. A subcommittee was developed that further discussed the topic in conference calls. Finally, the full BERAC was involved in a conference call on June 4, 2014. This letter presents the results of this process and the conclusions reached during our discussions. The text of this letter was approved by a unanimous vote of the BERAC.

BERAC members felt strongly that the DOE Office of Science should be engaged in education and workforce development that are pertinent to DOE-specific needs. While we are aware of opinions within government that such efforts should be limited to only specific agencies, we believe that such views are overly narrow and reflect a lack of understanding of the unique needs, resources and potential of DOE. For one, the Office of Science is perhaps unique in representing a convergence of engineering, physics, chemistry, biology, climate and ecology. As we amplify below, science of the 21st century will be interdisciplinary and, hence, given the unique breadth of DOE it is natural for the Office of Science to support training of the scientific workforce that is capable to meet future DOE missions. It is clear that the National Laboratories are grossly underutilized in their support of workforce development. These laboratories have unique capabilities, equipment and expertise that could be more actively engaged in education and training. The National Laboratories provide a centralized location where true interdisciplinary training could occur. The National Laboratories, therefore, can complement excellent interdisciplinary training programs arising at many Universities. Moreover, the DOE Office of Science clearly has unique needs in the area of workforce development and training, which are outlined below. It makes little sense to train a DOE-relevant workforce isolated from its facilities.

We have organized this letter around the four specific areas identified in your letter.

Disciplines not well represented in academic curricula? The wording of this question belies one of the big problems with current workforce development and educational activities extant in the US. That is, the workforce of tomorrow will have to be interdisciplinary. Evidence for this is easy to see; for example, all science is becoming ‘big data’ science, which requires that scientists are equally conversant in computational methods, statistical analysis and specific disciplines. It is also clear, as outlined in past BERAC reports (i.e., DOE/SC-0135, Grand Challenges in Biological and Environmental Research: A Long-Term Vision; DOE/SC-0156, BER Virtual Laboratory: Innovative framework for biological and environmental grand challenges), that the exciting challenges of the future involve the study of natural systems across spatial and temporal scales. We ultimately need to move from the microscopic to the global; for example, to truly understand the impacts and consequences of climate change. A new revolution is occurring in biology, synthetic biology. An operational definition of this new area is the application of engineering principles (e.g., systems engineering) to understanding and improving biological systems. Again, this new area demands expertise in engineering, genetics, molecular biology, chemistry, physics, enzymology and computer science. These are all areas that fall naturally under the umbrella of the Office of Science and represent areas well developed in the national laboratories.

While the overwhelming need is to train scientists and engineers with interdisciplinary skills, there are some specific subdisciplines that are also very important to our future and are currently not well supported by federal workforce and educational efforts. An example is physiology, such as the physiology of whole plants and the poorly understood system of microorganisms with which they symbiotically associate. This is an area that was developed in the early 20th century but slowly fell into decline as science followed the trends of molecular biology. However, 21st century science will be 'systems' science in which we try to understand whole systems, integrating the parts to ultimately predict system function and response. There is currently a real shortage of scientists trained in the ability to study, model and understand whole systems; a negative effect of our past focus on reductionist science. Of course, this is not an either/or decision-we need both holistic and reductionist approaches if we are going to gain the proper detailed understanding of the whole system.

The ultimate goal of systems science is to understand the system to the point that it can be modeled to a level that can accurately predict system-scale responses to specific change and ultimately mitigate any deleterious effects. Climate modeling is one such example where it would clearly be advantageous to model the effect of change accurately so that better public policies could be implemented. However, the same can be said of modeling efforts in microbiology, terrestrial ecology and a variety of other disciplines. Although there is now a growing recognition of the need for this type of work, efforts are still lagging to create a workforce capable of systems-level quantitative modeling. Mechanistic, multiscale modeling of complex biological and environmental systems is a crucial disciplinary curriculum gap.

Additionally, many of the controversies that now rage in our society can be, at least in part, attributed to a lack of understanding by the general public of science, its potential, contributions, as well as its limitations. While this has many causes, one is clearly the lack of effective communication by scientists to the general public. This exposes another curriculum gap in US academic training; that is, more needs to be done to train the scientific community with effective communication skills to properly engage and explain science to the broad public.

Disciplines in high demand, nationally and/or internationally, resulting in difficulties in recruitment and retention at U.S. universities and at the DOE

national laboratories: Again, the wording of this question, focused on specific 'disciplines' misses the point that interdisciplinary training is really the primary need for 21st century science. However, clearly the point is not to devalue the need for high level training in specific areas of expertise but, instead, to stress the need to be able to apply this expertise across the boundaries of areas that previously were considered distinct disciplines. We need to move away from the 'stovepipes' of traditional disciplines. Again, the Office of Science and associated national laboratories already represent structures where such cross-discipline and interdisciplinary efforts are underway. BERAC feels strongly that more emphasis should be placed on these efforts and that the Office of Science is uniquely positioned to do this in a way that will support the DOE mission.

However, to more specifically address this bullet point, we refer you to the discussion above where we stressed the need for more training in physiology, computational science, modeling and cross-disciplinary approaches that will more fully support the integration of 'big data'/ 'high throughput' approaches into all DOE relevant research areas.

Disciplines identified in the previous two bullets for which the DOE national laboratories may play a role in providing needed workforce development: The BERAC feels that the national laboratories are underutilized for workforce development and education. By their nature, the national laboratories represent unique environments where interdisciplinary science and collaborative research are possible and, indeed, essential to address critical national needs. Again, it is nonsensical to seek to develop such an environment de novo to support such interdisciplinary training, when the national laboratories already provide such an environment.

At a more specific level, the BERAC feels that more effort needs to be placed on educating the scientific community with regard to the design, construction, availability and utility of various instruments and resources uniquely available at the national laboratories. Although a majority of the community may be aware of various capabilities at the national laboratories, more needs to be done to demonstrate how these capabilities can be applied in the laboratories of potential collaborators. Exposing more students to training opportunities in the labs would address both interdisciplinary training needs, as well as the need to better demonstrate the capabilities of the labs' advanced instrumentation capacities. It is not enough just to advertise the capability-more needs to be done to actively recruit and educate potential users. This effort would extend the educational mission of the national laboratories and spur progress and innovation in American science.

Specific recommendations for programs at the graduate student or postdoc levels that can address discipline-specific workforce development needs: As might be expected, BERAC spent most of the time discussing specific recommendations to stimulate, expand and support a strong education and workforce development effort within the Office of Science. Again, we stress that it is nonsensical to think you could create a useful effort that could address DOE-relevant needs by limiting such efforts to agencies that lack an understanding of such needs and, more importantly, lack access to the resources, facilities and expertise that underpin the DOE mission. Our recommendations are listed below in bullet form in no particular order.

- Office of Science support for K-12 education. While your specific request deals with graduate and postdoctoral training, BERAC feels strongly that K-12 education cannot be omitted. Educational research reveals that choices between quantitative and non-quantitative careers are made at a very young age. Therefore, ignoring this age group is extremely counter-productive to the need to develop a modern workforce that is equally conversant with quantitative/ computational approaches and system-level studies of the natural world. By way of example, one of our members recalls a visit to the DOE Mound National Laboratory, Miamisburg, Ohio, as an elementary school student. They remember being very impressed with the facilities, the equipment and excited about the research taking place so close to their home. They felt that this exposure stimulated their overall interest in science. This is only a very small sample of how the national laboratories could be used more effectively to advance the nation's needs in STEM education.
- Office of Science supported graduate student and/or postdoctoral fellowships. In keeping with our stress on interdisciplinary training, BERAC proposes a program that would involve two mentors, one in the area of computational science, the other in a research area. The focus of the program would be on interdisciplinary training in BER-relevant science areas with a strong emphasis on computation.
- Office of Science supported graduate student and/or postdoctoral fellowships in the area of physiology. BERAC proposes a program that would address the lack of people in basic physiology, which is an area that has not seen significant growth in several years. Hence, people with this knowledge are few and far between but needed to support initiatives in ecophysiology, metagenomics, system design and molecular bioengineering (i.e., synthetic biology). This program could also address the identified need for people trained in enzymology, who are also currently rare but needed to support efforts in synthetic biology.
- Office of Science supported graduate student and/or postdoctoral fellowships in the area of instrument development and application. Instrument development is a common capability at national laboratories and is essential to DOE missions. Moreover, many scientists in this area are nearing the end of their careers and, hence, replacements are needed.
- Multiweek workshops: Anticipate summer long or perhaps semester long training workshops. These might be in several areas but should have as their purpose the idea of providing training in novel, multi scaled, integrative and multi-disciplinary approaches. For example, people with expertise in atmospheric chemistry or physics could gain a working knowledge of climate modeling during these workshops, or vice versa. Those focused primarily on terrestrial ecology could gain experience in genetics, etc. People with expertise in lab/field measurements can work with modelers for cross fertilization of ideas to integrate measurements and modeling better.
- Short term: 7-10 day workshops that would provide training in very specific areas. An example could be the week-long training in earth system modeling

offered at NCAR (https://www.regonline.com/Register/Checkin.aspx?EventID=1377494). Another is the training in stable isotope biogeochemistry and ecology offered at the University of Utah (http://stableisotopes.utah.edu). Again, the idea would be to facilitate the incorporation of new, interdisciplinary approaches into research programs where the new knowledge could be applied. These workshops could also be an excellent way to introduce potential collaborators to specific resources available at the national laboratories.

- Interdisciplinary Graduate Research and Training Program: A program that would fund institutions to develop novel, integrative and interdisciplinary degree programs in areas of BER-relevance. An example might be programs that support training in atmospheric chemistry, physics and modeling or programs that support the integration of ecophysiology, genetics, molecular biology and modeling, etc.

Finally, with the interest of the DOE and the National Labs on broader public-private partnerships, it would seem of great value to reach out to private industry for the same assessment of workforce development needs in the Office of Science research disciplines. As approximately half of the graduate students trained will also ultimately end up working in private industry, ensuring the appropriate capabilities are developed to meet these needs is also critical.

Sincerely,

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cc: Sharlene Weatherwax
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