DRAFT Recommendation for Repurposing a BRC or Establishing a New DOE Center Focused on Improving the Energy Efficiency of Plant Productivity

Brief recent historical perspective: focus of DOE/BER efforts on development of bioenergy crops and related processes

The DOE's Biological and Environmental Research (BER) has had a historically impactful role in shaping and nurturing the development of biotechnology and genomics-based systems biology. In support of renewable fuels and materials, three DOE Bioenergy Research Centers (BRCs) were established in 2007 and charged with addressing three grand challenges:

1- Development of next-generation bioenergy crops
2- Development of enzymes and microbes to efficiently degrade biomass into forms that can be converted to duel and materials
3- Develop microbial methods and strategies to enable advanced biofuels production.

The scientific rationale that drove the formation of the three BRCs was formed at a workshop held 7-9 December 2005 that generated a 2006 publication from the DOE's Office of Science summarizing the findings and challenges[1]. The focus of this report was ethanol production from biomass, particularly how to overcome the recalcitrant challenges breaking down a ligno-cellulosic feedstock to five and six carbon sugars that can then by converted to ethanol and/or other fuels or chemicals via microbial fermentation.

The research efforts conducted at the three BRCs have been successful in developing new plant varieties that have improved ability to be converted to sugars, improved enzymes and methodologies to break down ligno-cellulosic materials to fermentable sugars, and new microbial strains to more efficiently produce not only ethanol, but also other compounds such as terpenes and fatty acids that can be potentially used for drop-in fuels or chemical feedstocks. The BRCs have also advanced key enabling technologies so support the grand challenges including informatics and genetic tools for metabolic pathway modeling and engineering, high-throughput analytics and screening technologies, and computational tools for systems modeling, data analysis, and data visualization.

The United States is in a more advantageous position with respect to energy independence in 2014 than we were in 2005-2007 when the above-mentioned workshop was held, and the three BRCs were founded. This is due in part to novel and highly efficient means of oil and shale gas extraction, as well as increased efficiencies in the use of liquid transportation fuel, the U.S. Energy Information Administration (EIA)[2] reported that as of 2013 only about 33% of the crude oil consumed by the US was imported from foreign countries (the lowest level since 1985), with Mexico and Canada accounting for about 40% of net imports. The EIA's short-term forecasts[2] predict that total production of U.S. crude oil and liquid fuels will increase through 2015, and their longer term predictions[3] have scenarios that would drive U.S. net imports of petroleum and other liquids close to zero by about 2030.

Clearly, in 2014 there is not as strong a motivation for discovering new means of increasing the U.S.'s independence for fossil oil and gas as there was ten years ago. This is partly due to the increased production of natural gas and crude oil. And also due to the success of research and development by the BRCs and others to solve the recalcitrant steps in cellulosic ethanol production. Evidence for this includes three full-scale cellulosic ethanol plants coming on line starting in 2014[4], each with a capacity of 20 million gal/year (or more), and using corn stover or wheat straw as the feedstocks. DOE support for these first full-scale commercial plants has been critical, and these 'pioneer' plants are intended to prove economic production at commercial volumes. It is worth considering to what extent the challenges that the BRCs were set up to address have been accomplished sufficiently such that is is reasonable to expect that the commercial entities will continue to develop and refine the technologies.

There are critical energy-related challenges facing plant productivity in addition to those addressed by bioenergy crops

The FAO released an Issue Paper in 2011[5] that among other things estimates that about 30% of global energy is consumed by the agricultural and food sector including agricultural inputs, field production practices, and post-harvest downstream activities. The report also estimates greenhouse gas emissions from the various aspects of agriculture and its associated value chains, and seeks to describe how agriculture needs to become more 'energy-smart', and what innovations and transformations will be required. Key is that the global agriculture and food sector is highly dependent upon energy inputs, and that this will become even more critical as population increases.

Agriculture itself is facing major challenges; a 2012 Revision to the FAO's *World Agriculture Towards 2030/2050* report[6] reported projections of how world agriculture may need to develop to accommodate needs by 2050. Key drivers for the challenges are population increase, and per capita income increase. Demand for food, and other uses of agricultural products will require markedly improved productivity per unit of cultivated land, while challenges of water availability, shifts in climate (and the associated many affects on agricultural production), and crop nutrition remain to be solved. It is likely that rapidly changing climate between now and 2050 may also result in significant shifts in what can be considered 'prime land' vs. 'good', 'marginal', or 'unsuitable' for production agriculture.

In September 2011 under the auspices of the American Society of Plant Biologists (ASPB) a Plant Science Research Summit was convened and included a diverse group of 75 plant scientists along with representatives from federal agencies, professional societies, and other stakeholders. Insights, conclusions, and debates from that meeting were compiled into a position paper released 2012[7]. The report was broadly accepted by the plant science community and a number of research institutes, scientific societies, grower organizations, and plant biotechnology/seed companies all wrote letters of support for the overall conclusions.

The report communicated the unanimous opinion of the Summit participants that that there will be required a sustained and interdisciplinary approach to research and development to identify effective solutions to four 'societal grand challenges' based in plant science:

- Assuring nourishment for all
- Seek innovations from a better understanding of nature's ecosystem that will benefit agriculture
- Improve biofuels technologies including crops and processes
- Develop effective agriculture methods that are sustainable economically, socially, and environmentally

The ASPB revisited and refreshed the conclusions from the 2011 meeting by convening a meeting in January 2013 of seventeen diverse plant scientists with the charge to develop a consensus plan to guide plant science over the next decade. The report from this meeting was released in July 2013[8], and builds on the previous on the 2012 position paper to posit that the challenges in plant science are urgent, and meeting them will provide multiple societal benefits.

- Agricultural productivity must increase by 2050
- In the U.S.; increasing severe weather including drought significantly impacts agriculture
- The world depends on U.S. agriculture; but, we are not prepared for future agricultural challenges
- The U.S. is in a good position to implement agricultural innovations at a scale that is meaningful and relevant to the U.S. and world economy and need.

Recommendation that a working group be established and charged with drafting a specific plan for a DOE BER focus on improving the energy efficiency and greenhouse gas footprint of sustainable plant production

The DOE through efforts of BER and its BRCs has been effective as both an organizing principle and direct research sponsor to surmount key recalcitrant challenges. There are additional challenges in plant production that have a distinct connection to energy and greenhouse gas balance, and to the extent that they can be solved will result in potentially large impacts to the U.S. economy and environment, and also have global impact. Successes addressing these challenges will likely result in multiple direct and indirect economic benefits to the U.S. economy, and also serve to maintain and expand the global preeminent status of U.S. plant science.

We recommend that a small working group comprised of world class plant scientists with representation from National Labs, crop organizations, and key industry stakeholders be formed to further explore, debate, and deliver a detailed recommendation for the scope, magnitude, and overall attractiveness of a DOE-BER effort focused on improving the energy efficiency of crop production. This would be complementary to a number of extant BER efforts, but distinct in focus as contrasted with the energy-crop orientation of the current BRCs.

We expect that this effort would focus on a systems approach, with the goal to translate cutting edge science into tangible technologies that can be deployed as rapidly as possible to improve U.S. and world agricultural efficiency. Note that the focus areas that are not relying on plant breeding or engineering may have a more rapid translation to commercial reality. Areas would likely include:

- Field phenotyping and sensing of water/nutrients/plant health focusing on technologies that can be adapted to the economics and realities of production agriculture
- Improving the efficiencies of agricultural inputs including plant nutrition to reduce undesired losses (and the associated negative environmental impacts), and improve the net greenhouse gas footprint for major row crops
- Develop production practices and associated downstream technologies for crops that will increase efficiency and also significantly sequester CO_2.
- Provide a central organizing principle cross the plant science community to develop and encourage standards of data and metadata collection, management, analysis and sharing.
- Provide mechanism where users outside the EECP Center's staff can access key facilities such as advanced controlled environment and field-based phenotyping sites. Develop a new paradigm for effective and transformative engagement of the plant science community

We expect that a number of the challenges that would be engaged by will be augmented by other technologies and competencies extant at other DOE labs. For instance, one means to improve agricultural efficiency will require improved remote and local sensing of water, nutrients, pathogens & pests, and plant health & status. To make this relevant for something other than just R&D, will need to potentially develop sensors, algorithms, and means to economically deploy them cross tens of millions of acres. Obviously, a number of DOE labs are expert in sensor, imaging, and computing technologies that likely can impact.

Other competency areas currently within DOE will likely also prove crucial in making the research goals of this new focus including various molecular analysis capabilities of a variety of labs, the genomics capabilities of JGI, and systems biology and plant genome editing at a number of labs. To effectively pursue this broader plant science initiative, a case could be made to repurpose one or more of the existing BRCs, and/or establish a new center to provide the required focus. The recommendation made here to establish a working group to further explore and develop the concept would provide clarity and a well supported conclusion.

In conclusion, agriculture is of critical importance to the U.S. economy, and because of the productivity of American farmers, we are critical to feeding the world. Besides the major efforts that DOE has been actively engaged with to develop specific crops that can be transformed into sugars and then fuels or chemicals, there are a significant set of challenges that well fit the global challenges that are important to BER, including redesign of crop plants and/or cropping systems to better manage energy and have positive impacts on the Earth's climate. A focused approach to critical agricultural challenges by BER would be beneficial and likely transformative to the Plant Science Community. And, given the nature of the challenges and some of the potential solutions, it seems likely that many may have a shorter ramp to making a significant impact outside of R&D than other more long-scale research approaches.

References:

1- U.S. DOE. 2006. Breaking the Biological barriers to Cellulosic Ethanol: A Joint Research Agenda, DOE/SC-0095, U.S. Department of Energy office of Science and Office of Energy Efficiency and Renewable Energy. http://genomicscience.energy.gov/biofuels/2005workshop/b2blowres63006.pdf
2- EIA. Short-term Energy Outlook. September 2014. http://www.eia.gov/forecasts/steo/pdf/steo_full.pdf
3- EIA. Annual Energy Outlook 2014 (with projections to 2040). http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf
4- Fuels America. Four Commercial Scale Cellulosic Ethanol Biorefineries to Enter Production This Year. 29 April 2014. http://www.fuelsamerica.org/blog/entry/four-commercial-scale-cellulosic-ethanol-biorefineries-to-enter-production
5- FAO. Energy Smart Food for People and Climate; Issue Paper. 2011. http://www.fao.org/docrep/014/i2454e/i2454e00.pdf
6- Alexandratos, N. and J. Bruinsma. 2012. World agriculture towards 2030/2050: the 2012 revision. ESA Working paper No. 12-03. Rome, FAO. http://www.fao.org/docrep/016/ap106e/ap106e.pdf
7- ASPB: The Green Frontier; A Unified Vision for Plant Research http://c.ymcdn.com/sites/my.aspb.org/resource/group/b1d27bb1-ad1a-49ae-9150-f9f931246ba3/docs/121105_final_summit_report_p.pdf
8- ASPB: Plant Science Decadal Vision-urgent call to action. 2013 http://plantsummit.files.wordpress.com/2013/07/plantsciencedecadalvision10-18-13.pdf