Professional accomplishments

Calendar year 2015

Department of Biochemistry and Molecular Biology

for use in faculty reviews (including tenure and promotion considerations) and for determining raises

See the policy document at <http://www.bmb.msu.edu/dept/bylaws_policies.html> (attached)

Please provide

1. an up-to-date CV,

2. this form,

3. the NS Outside work for pay form

4. the completed Excel spreadsheet

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**Name:**

# Honors and Awards in 2015

Research2015 MSU Academy for Global Engagement

2015 White House Office of Science and Technology Policy (2015) Raising the Profile of Agriculture Panel member,

2015 MSU Global Innovation Fellow

## Description of major areas of research *(100 words or less)*

My research seeks to understand how plants convert light energy into forms usable for life, how these processes function at both molecular and physiological levels, how they are regulated and controlled in response to fluctuating environmental conditions, how they define the energy budget of plants and the ecosystem and how they might be improved to increase the efficiency and sustainability of agriculture. This work has led his research team to develop a series of novel spectroscopic tools for probing photosynthetic reactions both in vitro and in vivo. To disseminate these tools, he co-founded Phenometrics, Inc. PhotosynQ.org and the MSU Center for Advanced Algal and Plant Phenotyping.

## Goals and accomplishments in 2015

## Specific goals for 2016

**1) Tackle some of the most critical (but previously intractable) basic questions about energy transduction in photosynthesis.**

*Why is photosynthesis so sensitive to rapidly fluctuating light?*It is becoming clear that photosynthesis is highly sensitive to rapidly fluctuating environmental conditions, particularly light, and that this sensitivity probably represents a major limitation to crop and bioenergy yields. The mechanisms of this sensitivity are not yet understood, but our recent work strongly suggests that it reflects limitations in the rates of photosynthetic regulatory processes that result in either too low or excessive levels of the thylakoid proton motive force (a key intermediate in both photosynthetic energy transduction and feedback regulation). If our hypothesis is true, we will have not only identified an unexpected “Achilles heel” of photosynthesis, but also a way forward to detecting photosynthetic stress levels, with direct applications for crop monitoring and breeding.

*Is photosynthesis too conservative?*Over the past year, we have demonstrated both applied and basic applications for the PhotosynQ platform and the MultispeQ devices. *Is photosynthesis over-regulated or under-regulated?* Do plants lose productivity by dissipating more energy than they need to in order to avoid photodamage under rarely-seen fluctuating environmental conditions? NPQ and other regulatory processes act to protect photosynthetic organisms from photodamage, but at the cost of decreased photosynthetic efficiency. It has been proposed that photosynthesis is “over-regulated” and that increased energy conversion might be adjusting these controls under certain conditions. Until now, it has not been possible to directly test this fundamental question, but our new DEPI and PhotosynQ platform are allowing us to engage a broad community of researchers to assess the regulatory set points of a wide range of plants both under controlled conditions and around the world. Our preliminary data suggest that under many conditions photosynthesis is optimally regulated, but that deviations from this balance, particularly under environmental stresses, correlated strongly with photodamage and loss of crop yield (and biomass). If confirmed, these results could have profound impact on both our understanding of the importance of photosynthetic regulation as well as for practical applications for the detection of plant stress, predictions of yield etc.

*What do all the chloroplast genes do?*An astonishing finding from previous work was that systematically knocking out genes coding for chloroplast-targeted proteins resulted in only a small number of mutants with measurable photosynthetic phenotypes, in spite of the vast majority of these genes being well conserved. The development in the lab and CAAPP of a massive amount of background technologies, from the DEPI phenotyping platform to advanced visualization and statistical methods and software allowed us to show that under more natural-like conditions, the vast majority of chloroplast-targeted genes are, after all, critical for photosynthesis. The big questions we will address next are: how do we make sense of these wide range of effects? What are the basic mechanisms of these effects? What do all these genes do? How does this impact the concept of gene redundancy? We will approach these problems in highly collaborative way, involving a network of labs from PRL, MSU and around the world.

**2) Disseminate these tools to the world in innovative ways to impact science at broader scales.**

*Towards establishing MSU as the center of innovation consortium that will result in a large, open-source database of photosynthetic phenotypes. (see more details in Section f.)* We have already started this effort at MSU, by proposing to integrate our phenotyping platforms into existing MSU/AgBioResearch projects to enhance the capabilities of groups at MSU. For example, integration of PhotosynQ into these research projects will 1) empower AgBioResearch groups to collect high-throughput phenotyping data that will improve their understanding of plants’ status in response to local conditions; 2) validate the PhotosynQ platform’s capabilities in predicting yield and biotic and abiotic stresses; 3) lead to development of new phenotyping tools within the PhotosynQ platform; 4) expand and diversify use case’s where PhotosynQ can provide potentially actionable results through plant breeding, crop protection, and crop management studies. Once this effort is established, we hope to expand the effort broadly.

*Test if phenotyping tools can be applied to improve agriculture?*The PhotosynQ platform also has potential practical applications to agriculture, particularly in the developing world, which not only has the greatest food needs, but also lacks the sophisticated plant monitoring and analytical tools needed to apply cutting edge approaches to agricultural improvement. This past year, we demonstrated that local communities in Africa and the U.S. can effectively use the platform to take high quality phenotype measurements. Most exciting, by analyzing results from multiple MultispeQ field trials in both Africa and the U.S., we were able to develop methods that give early estimates of crop yield and the onset of diseases. Intriguingly, the parameters developed to measure regulation balance (see above) were by far the best correlated with disease or crop yield, suggesting a strong relationship between photosynthetic regulation and sustainable energy capture and storage.

## Funding in 2015

**MSU Center for Advanced Algal and Plant Phenotyping**

Michigan State funds

$5.0M (With 24 participants)

2012-2017

**The Energy Budget of Steady-State Photosynthesis**

U.S. Department of Energy (RC100185)

$690,000

9/1/12-8/31/15

**Exceeding Evolution in Photosynthesis (Photosynthesis Ideas Lab Meeting)**

National Science Foundation (RC102287)

$56,000

10/1/12-3/1/13

**Photosynthetic Energy Capture, Conversion and Storage: From Fundamental Mechanisms**

**to Modular Engineering**

U.S. Department of Energy, Basic Energy Sciences (RC063200)

Co-P.I. with ten others

$7.5M

4/1/14-3/30/17

**Center for Advanced Camelina Oil (CECO) (1-year extension)**

ARPA-E, U.S. Department of Energy (RC101328)

$1.4M (with 5 co-P.I.s, $860,000 to MSU)

1/1/14-12/31/15

**Collaborative Research:** **Plug and Play Photosynthesis for RuBisCO Independent Fuels**

National Science Foundation (RC103769) (Renewal)

$3.6M for 7 co-P.I.s, $459,999 to DMK

06/01/14-05/31/17

**2014 Photosynthesis Gordon Research Conference**

DOE Basic Energy Sciences

$10,000

8/2014

**2014 Photosynthesis Gordon Research Conference**

National Science Foundation

$14,060

8/2014

**2014 Photosynthesis Gordon Research Conference**

Funds from 10 Corporations and Societies (BASF, Inc.; LiCor, Inc.; Agrisera; Benson-Hill BioSystems, Inc.; BioChambers, Inc.; Elsevier Science, Ltd.; ExxonMobil Inc.; Geneva Scientific; International Society of Photosynthesis Research; Opotek, Inc.;

Total: $51,102

8/2014

**USAID Global Center for Food Systems Innovation: MultispeQ: A Deployable Sensor for the PhotosynQ Network to Enable Critical Plant and Soil Measurements for Breeders in East Africa** (RC102194-PHOTO)

Agency for International Development

$100,000

3/14-3/15

**MultispeQ: Photosynthetic Energy Capture, Conversion and Storage: From Fundamental Mechanisms to Modular Engineering** (RC104313)

McKnight Foundation

$300,000

09/01/14-08/30/16

**Realization of Algae Potential (REAP)**

U.S. Department of Energy, Advancements in Algal Biomass Yield (ABY) Program

(P. Lammers, NMSU, lead, (MSU project funded by sub-contract to DMK) (RC104632)

$120,000

9/14-8/15

**Venture Development Workshop**

VentureWell (RC104641)

$5,000

01/01/15-08/31/15

**MSU-EMRE Collaboration**

ExxonMobil Chemical Co. (RC104821)

$1,000,000

04/01/15-03/31/17

**ABI Innovation: A New Framework to Analyze Plant Energy-related Phenomics Data**

National Science Foundation (RC104995)

$641,429

10/01/15-09/30/18

**Scalable and Sustainable Biological Solutions for Pest Management of Insect Pests of Cowpea in Africa**

Agency for International Development

$498,108

3/10/15-09/30/17

# Teaching

## Formal course teaching in 2015

BMB864

BMB 960 Photosynthesis

## Post-docs mentored in 2015

7

## Grad students in your lab in 2015

4

## Specific goals for 2016

# Service

If you have any activities that can be considered service but is not captured in the spreadsheet, please describe them here. Include Journal editorships (decision making), chairing search committees, etc.

# Other

## Please describe any other activity you would like considered in the Academic Performance process.

Also provide information to support the numerical form if the numbers do not adequately describe the activity or for activities you would like to highlight.

**Phenotyping Innovation and Centers and dissemination of MSU technologies.** As a part of our efforts to establish MSU as a national/international center for innovation in plant phenotyping, I founded and direct the Center for Advanced Algal and Plant Phenotyping. I feel it is a reflection of my leadership abilities that CAAPP integrates such diverse disciplines and expertise, from engineering, computation and computer science, product development, biophysics and spectroscopy, biology genetics, field research and outreach and that this group has been very productive in catalyzing innovation (producing several product-ready and scientifically useful platforms) and applying them to solve important scientific questions.

**Broader impacts.** We have led thee way in translating our research and technologies to directly impact science, agriculture and bioenergy efforts and science education on the ground. First, we developed a unique photobioreactor platform that allowed us to study the photosynthetic and growth responses of algae and cyanobacteria under simulate d environmental conditions. To make these tools available to the broader community, we licensed the technology and spun off a company, Phenometrics, Inc., and consequently the ePBR is the most widely-used research photobioreactor in the world, is used in the workflow at several of the largest algal bioenergy companies, and is cited in over 50 publications. We are even more excited by the growing impact of the PhotosynQ.org project (describe above), which is currently allowing us to directly impact international outreach and research, in particular in developing countries in Africa and Central America, which is leading to a new approach to both basic research and improvements to plant breeding and crop management. We are currently leading a new effort to make all CAAPP-developed technologies as widely used.

**Classroom Instruction at MSU.** While only 10% of my appointment is for teaching, I participate in both classroom and one-on-one graduate education. I teach in the graduate-level Plant Biochemistry course (BMB864), in which I cover the basics of photosynthesis. To prepare advanced students graduate students whose research involves photosynthesis and photosynthetic measurements, I developed a 3-credit interactive special topics course (BMB 960-Photosynthesis), which debuted in 2015, and directly addresses fundamental and current thinking in all areas of photosynthesis. A part of the course uses the PhotosynQ platform to enable students to make their own measurements, the interpretations of which are then discussed as a group and presented in a public poster session. The feedback on this course has been very favorable and I am pleased that the majority of the students who took the class are using the concepts, methods and tools directly in their on-going research.

**Outreach impact on education.** My lab and the CAAPP are providing innovative educational tools to the MSU and international communities: 1) CAAPP has held a series of workshops on plant phenotyping that have been attended by participants across campus; 2) The PhotosynQ platform is particularly well suited for educational applications, potentially to teach both specific concepts and the scientific method. I use the platform in my Photosynthesis class (see above), but also distribute the devices freely to graduate students at many MSU labs as a research training tool. Several other formal classes currently use the platform at MSU (in Biological Sciences Program, College of Natural Science, Horticulture, and at KBS) as well as in other countries (Ukraine, Zambia, Ghana, The Netherlands).

*2) “Establish a Photosynthetic Phenomics Center at MSU.* We established the MSU Center for Advanced Algal and Plant Phenotyping (CAAPP) to develop and apply transformative phenotyping technologies to enable us to directly address the next big challenges in plant biology, to establish MSU as an international innovation center and “international point of destination” for phenotyping analysis. In its first three years, the Center has established key instrumentation platforms and associated analytical software and approaches that start to bridge the gaps in our knowledge from genes to phenotype and from the lab to the fields.

As of Sept, 2015, more than 24 MSU faculty and researchers, from 9 departments and programs have used CAAPP technologies and facilities including 14 different MSU AgBioResearch groups focusing on agricultural-relevant projects. CAAPP facilities have been used in an estimated 50 or more publications (both within and external to PRL), and its capabilities, direct involvement and preliminary data have contributed to more than 20 external grant proposals from MSU (over 14 were funded, totaling more than $46M, roughly $24M of that went to MSU).

*3) Development and worldwide dissemination of new instrumentation and techniques.* One of the big, “stretch goals” of my proposed work was to bring the tools we develop “to the world” to 1) enable researchers around the work to perform sophisticated scientific experiments; 2) use this data to gain new insights into the basic mechanisms of photosynthesis and its responses to the environment; and 3) use this data to improve agriculture, especially in the developing world. We developed the PhotosynQ platform ([www.photosynq.org](http://www.photosynq.org)) to specifically address these issues, by bringing sophisticated phenotyping tools and analytics to farmers, researchers, extension agents and entrepreneurs, with the aim of enabling locally appropriate agricultural intelligence solutions. Using the PhotosynQ platform and tools, these communities will generate actionable data that can guide the management and breeding of plants to improve the productivity and sustainability of agriculture in their region. At the same time, the PhotosynQ platform enables the aggregation of regional data sets across the globe (on plant phenotypes, environmental parameters, outcomes), to produce global-level analytics capable of solving both global and local level problems. The PhotosynQ platform includes a sophisticated plant sensor, called the MultispeQ, that makes a series of useful plant and environmental measurements, yet is inexpensive, easy to use, wirelessly connected, expandable and reprogrammable and can be massively deployed anywhere in the world. In the first year of deployment, we have obtained approximately $1M in external funding, deployed 300 MultispeQ devices, engaged more than 980 members, supporting over 600 projects in 18 different countries, resulting in nearly 200,000 experimental points. From a pure scientific point of view, the results from our platforms have given us novel insights and basic understanding of photosynthetic responses to environmental changes, which we are pursuing in research proposed for the PRL renewal and other grants, as well as new crop status indicators, which form the bases of proposals to McKnight and Gates Foundations, ARPA-E etc.