EFRC: PHOTOSYNTHETIC ANTENNA RESEARCH CENTER (PARC)

UPDATED: AUGUST 2016

AWARDS: \$20.0M (August 2009 – July 2014); \$14.4M (August 2014 – July 2018)
WEBSITES: http://science.energy.gov/bes/efrc/centers/parc/; http://parc.wustl.edu/
TEAM: **Washington University in St. Louis (Lead):** Robert Blankenship (Director), Dewey Holten (Associate Director), Himadri Pakrasi, Christine Kirmaier, Michael Gross; **Los Alamos National Laboratory:** Gabriel Montaño; **North Carolina State University:** Jonathan Lindsey; **Northwestern University:** Paul Loach, Pamela Parkes-Loach; **Oak Ridge National Laboratory:** Dean Myles, Volker Urban; **Princeton University:** Gregory Scholes; **Sandia National Laboratories:** Jerilyn Timlin; **The Pennsylvania State University:** Donald Bryant; **University of California-Riverside:** David Bocian; **University of Glasgow (UK):** Richard Cogdell; **University of Illinois at Urbana-Champaign:** Klaus Schulten; **University of New Mexico:** Andrew Shreve; **University of Pennsylvania:** P. Leslie Dutton, Christopher Moser; **University of Sheffield (UK):** C. Neil Hunter

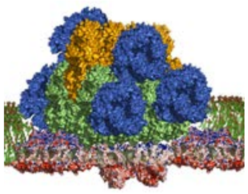
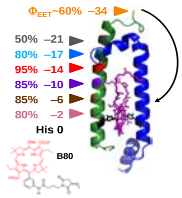
SCIENTIFIC MISSION AND APPROACH

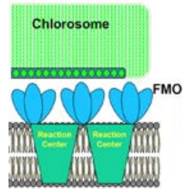
PARC is dedicated to understanding the basic scientific principles that underpin the efficient functioning of natural photosynthetic antenna systems as a basis for design of biohybrid and bioinspired architectures for next-generation systems for solar-energy conversion. Through basic scientific research, PARC seeks to understand the principles of light harvesting and energy funneling. The center has three scientific themes:

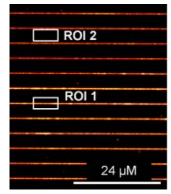
1) **Natural Antennas: Structure and Efficiency –** To determine and manipulate the antenna architecture and composition to maximize photosynthetic efficiency and functionality in any such organism.
2) **Biohybrid and Bioinspired Antennas: Design and Characterization –** To design biohybrid and bioinspired architectures for energy collection and storage.
3) **Antenna-Reaction Center Interface: Organization and Delivery –** To understand and control the coupling of antenna and reaction center functions in solar energy conversion systems.

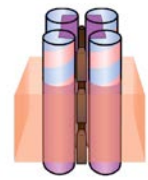
SELECTED SCIENTIFIC ACCOMPLISHMENTS

- Discovered and characterized a megacomplex in oxygenic photosynthetic cynobacteria consisting of Photosystems I and II and the large phycobilisome antenna complex using chemical cross-linking and mass spectrometry.
- Melded tunable synthetic chromophores, native bacteriochlorophyll and scaffolding provided by native or native-like α and β peptides from photosynthetic bacteria to develop versatile biohybrid antennas that expand the light-harvesting capacity over native systems.
- The role of red-shifted pigments in increasing photosynthetic efficiency has been investigated and the biosynthetic pathway of the most red-shifted chlorophyll, chlorophyll *f*, has been elucidated.
- Synthetic biology has been utilized to engineer a yellow fluorescence protein into a bacterial photosystem. Studies spanning isolated complexes to whole cells reveals that the introduced protein affords 50% energy transfer efficiency to the native phototrap and augments photosynthetic growth.
- Novel surface nanostructures have been nanopatterned from native, biohybrid and artificial components and characterized by cutting-edge microscopy. The results open the door to achieving efficient, directional energy and charge flow over meso-scale distances.







PARC research, from left: Fig. 1. Structural model of the cyanobacterial megacomplex. Fig 2. Biohybrid antennas with native bacterial peptides and synthetic chromophores. Fig. 3. Mass-spectrometry based footprinting tests two models for Fenna-Matthews-Olson protein. Fig. 4. Nanopatterned LHCII complexes. Fig. 5. Synthetic maquette 4-helix pigment-protein complexes.

IMPACT

- Provided fundamental insights into native, biohybrid and synthetic antennas driving future research.
- Promoted the use of synthetic biology to confer new capabilities on photosynthetic organisms, such as engineering a bacterial species to utilize multiple biosynthesis pathways to synthesize alternative carotenoids to probe light-harvesting and photoprotection functions.
- Developed/implemented antenna fabrication and characterization tools that foster detailed insight into structure and function of light-harvesting architectures. These include chemical cross-linking, mass spectrometry, hyperspectral imaging, neutron scattering, nanopatterning and advanced microscopy. These methods have been highly cited and adopted by numerous other research groups.
- Significant outreach efforts through PARC lead Saturday Hot Topics Workshops, Summer Workshop Series, tours, and the availability of PARC-developed energy kits and materials have reached >5500 K-12 students and 230 teachers. PARC's Science in St. Louis Seminar Series at local libraries, designed to connect people with scientists in the community, have been attended by 900 public community members (513 adults, 387 students) with 1400 hits on PARC and Science in St. Louis Youtube sites.

PUBLICATIONS AND INTELLECTUAL PROPERTY

As of May 2016, PARC had published 174 peer-reviewed publications cited over 2,100 times. The following is a selection of impactful papers:

- Liu, H., Zhang, H., Niedzwiedzki, D. M., Prado, M., He, G., Gross, M. L. and Blankenship, R. E. Phycobilisomes supply excitations to both photosystems in a megacomplex in cyanobacteria. *Science* **342**, 1104-1107, doi: 10.1126/science.1242321, (2013). [**84 citations**]
- Harris, M. A., Jiang, J., Niedzwiedzki, D.M., Jiao, J., Taniguchi, M., Kirmaier, C., Loach, P.A., Bocian, D.F., Lindsey, J.S., Holten, D., and Parkes-Loach, P.S. Versatile Design of Biohybrid Light-Harvesting Architectures to Tune Location, Density and Spectral Coverage of Attached Synthetic Chromophores for Enhanced Energy Capture, *Photosynthesis Research* **121**, 35–48, doi: 10.1007/s11120-014-9993-8, (2014). [**6 citations**]
- Vasilev, C., Johnson, M. P., Gonzales, E., Wang, L., Ruban, A. V., Montaño, G., Cadby, A. J., and Hunter, C. N. Reversible Switching between Nonquenched and Quenched States in Nanoscale Linear Arrays of Plant Light-Harvesting Antenna Complexes. *Langmuir* **30**, 8491-8490, doi: 10.1021/la501483s, (2014). [**3 citations**]
- Goparaju, G., Fry, B. A., Chobot, S. E., Wiedman, G., Moser, C. C., Dutton, P. L., Discher, B. First principles design of a core bioenergetic transmembrane electron transfer protein. *Biochimica et Biophysica Acta* **1857**, 503-512, doi: 10.1016/j.bbabio.2015.12.002, (2016). [**2 citations**]
- Collins, A.M., Liberton,M., Garcia, O.F., Jones, H.D.T., Pakrasi, H.B. and Timlin, J.A. Photosynthetic pigment localization and thylakoid membrane morphology are altered in *Synechocystis* 6803 phycobilisome mutants. *Plant Physiology* **158**:1600-1609, doi: 10.1104/pp.111.192849, (2012). [**25 citations**]
- Orf, G. S., Saer, R., McIntosh, C.L., Zhang, H., Niedzwiedzki, D.M. and Blankenship, R.E. Reactive cysteine residues gate energy transfer in the FMO complex from *Chlorobaculum tepidum*. *Proc. Nat'l. Acad. Sci. USA*, doi: 10.1073/pnas.1603330113, (2016). [**1 citation**]
- Ho, M.-Y., Shen, G., Canniffe, D. P., Zhao, C. and Bryant, D. A. Light-dependent chlorophyll *f* synthase is a highly divergent paralog of PsbA of photosystem II. *Science* **353**, 886. doi: 10.1126/science.aaf9178 (2016) [**2 citations**]