EFRC: CENTER FOR BIO-INSPIRED ENERGY SCIENCE (CBES)

UPDATED: AUGUST 2016

AWARDS: $19.0M (August 2009 – July 2014); $12.0M (August 2014 – July 2018)

WEBSITES: http://science.energy.gov/bes/efrc/centers/cbes/; http://cbes.northwestern.edu/

TEAM: Northwestern University (Lead): Samuel Stupp (Director), Chad Mirkin, Monica Olvera de la Cruz, Mark Ratner, George Schatz, Igal Szleifer, Emily Weiss; **Columbia University**: Kyle Bishop; **Harvard University**: George Whitesides; **New York University**: Paul Chaikin; **University of Michigan**: Sharon Glotzer; **University of Pittsburgh**: Anna Balazs

SCIENTIFIC MISSION AND APPROACH

The goal of the Center for Bio-inspired Energy Science (CBES) is to develop artificial materials and systems that take inspiration from biology to optimize the way we use energy and interconvert between different energy forms, for example converting chemical energy into mechanical energy the way muscles do in living organisms. The center consists of three thrusts:

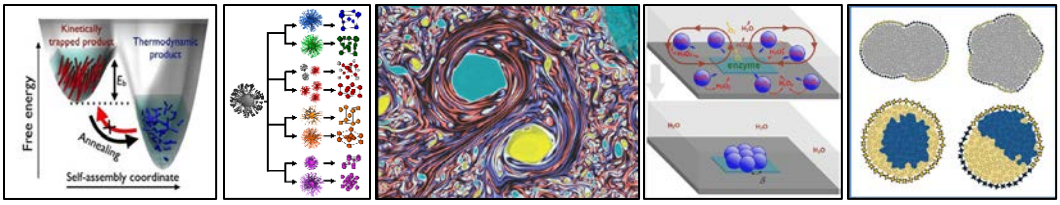
1) **Materials with Bio-Inspired Functions** focuses on materials with biomimetic functions related to inter-conversion between chemical and mechanical energy forms (as muscles do), particles inspired by biological organelles that utilize feedback mechanisms to mediate chemical reactions, and the development of adaptive materials.

2) **Colloidal Machines** investigates active matter in the form of colloidal machines, which are systems of nanometer to micrometer scale colloids that behave collectively far from equilibrium.

3) **Bio-Inspired Transport of Energy and Charge** explores artificial matter that could exhibit bio-inspired mechanisms of electron and ion transport, such as those of transmembrane ion pumps, electronic ratchets, and photosynthetic systems.

SELECTED SCIENTIFIC ACCOMPLISHMENTS

- Inorganic nanoparticles covered with complementary DNA strands can assemble into 20 different lattice symmetries and a wide variety of lattice constants that had not previously been possible with other nanoscale assembly schemes. Unlike other methods, the crystalline structures are fully "programmable" depending on the sequences of the DNA strands mediating nanoparticle assembly.
- Energy landscapes of peptide amphiphile and chromophore amphiphile assemblies can be controlled to determine their function. Molecular dynamics simulations capture differences in assembly between pathways, such as density of β-sheet hydrogen bonds.
- Mechanically bistable molecules were developed that display dissipative transitions between metastable states. Transitions between these states provide switching functions that can be combined with external forces or light to make molecular machines.
- Muscle tissue is a remarkable hierarchically organized material, the foundation of which rests on the ability of motor proteins to convert chemical energy into mechanical motion. A novel family of molecular machine prototypes known as daisy chains were developed that express large-amplitude length changes in response to thermal or electrochemical stimuli. These mechanical motions resemble the extension and contraction of a sarcomere, the basic functional unit of muscle tissue.
- Nanostructures were developed to demonstrate the energy conversion of plasmonic excitations (short-lived and highly-dissipative but collective and strong) into a photocurrent or to drive chemical reactions in solution. Theoretical work suggests that such a conversion is not possible without concentrating the energy within a small region of space.



CBES research, from left: preparative pathway of self-assembled supramolecular systems can determine their final position in their energy landscape; transmutable nanoparticles are building blocks with different possible binding characteristics that can be selectively activated and deactivated; self-propelled vortex doublets within mixtures of actively rotating fluids; reactions catalyzed by surface-bound enzymes generate fluid flow, causing reagent-laden microcapsules to aggregate; and model of "colloidal cells" from active particles.

IMPACT

- Public CBES Research Symposium held at Northwestern University, July 31, 2015, featured guest speakers Joanna Aizenberg from Harvard University and Juan de Pablo from the University of Chicago and selected CBES investigators. 66 students and post-docs attended.
- Gordon Research Conference on "Complex Active & Adaptive Material Systems: Designing Biomimetic, Dissipative Material Systems" will be held Jan. 29-Feb. 3, 2017 in Ventura, California (Anna C. Balazs, Chair; will include research presentations by five different CBES faculty).
- Endowment funds totaling $5 million were provided to Northwestern to build a dedicated facility for CBES because of the donors' interest in the concept of bio-inspired energy science. CBES administration and part of its research activities will be localized in this new space at Northwestern.
- Out of 86 alumni in permanent jobs, 53 now have academic positions, 31 work in industry, and 2 have government positions.

PUBLICATIONS AND INTELLECTUAL PROPERTY

As of May 2016, CBES had published 350 peer-reviewed publications cited over 13,300 times and filed 22 disclosures, 13 US patent applications, and 8 foreign patent applications. One patent has been issued and five disclosures or patent applications have been licensed. The following is a selection of impactful papers:

- Tagliazucchi, M., Azzaroni, O., Szleifer, I. Responsive Polymers End-Tethered in Solid-State Nanochannels: When Nanoconfinement Really Matters. *Journal of the American Chemical Society* **132**, 12404-12411 doi:10.1021/ja104152g (2010). [**62 citations**]
- Morris-Cohen, A. J., Frederick, M. T., Lilly, G. D., McArthur, E. A., Weiss, E. A. Organic Surfactant-Controlled Composition of the Surfaces of CDSE Quantum Dots. *Journal of Physical Chemistry Letters* **1**, 1078-1081 doi:10.1021/jz100224q (2010). [**67 citations**]
- Baytekin, H. T.; Patashinski, A.; Branicki, M.; Baytekin, B., Soh, S., Grzybowski, B. A. Mosaic Of Surface Charge In Contact Electrification. *Science* **333**, 308, doi:10.1126/science.1201512 (2011). [**167 citations**]
- Coskun, A., Banaszak, M., Astumian, R. D., Stoddart, J. F., Grzybowski, B. A. Great Expectations: Can Artificial Molecular Machines Deliver on Their Promise? *Chemical Society Reviews* **41**, 19-30, doi:10.1039/c1cs15262a (2012). [**327 citations**]
- Demirors, A. F., Pillai, P. P., Kowalczyk, B., Grzybowski, B. A. Colloidal Assembly Directed by Virtual Magnetic Moulds. *Nature* **503**, 99-103, doi: 10.1038/nature12591 (2013). [**56 citations**]
- Tantakitti, F., Boekhoven, J., Wang, X., Kazantsev, R., Yu, T., Li, J., Zhuang, E., Zandi, R., Ortony, J. H., Newcomb, C. J., Yu, T., Palmer, L. C., Shekhawat, G. S., Olvera de la Cruz, M., Schatz, G. C., Stupp, S. I. Energy landscapes of peptide amphiphiles determine their function. *Nature Materials* **15**, 469–476, doi:10.1038/nmat4538 (2016). [**11 citations**]