Biomolecular Materials

Portfolio Description

This activity supports fundamental research on the discovery, design and synthesis of functional materials, structures and materials aspects of energy conversion processes, based on principles and concepts of biology. Since biology provides a blueprint for translating atomic and nanoscale phenomena into mesoscale materials that display complex yet well-coordinated collective behavior, the major programmatic focus is on the hypothesis-driven creation of energy-relevant materials optimized for harsher, non-biological environments. Major thrust areas include: harnessing or mimicking the energy-efficient synthesis approaches of biology to generate new, optimized, energy-relevant materials; bioinspired self-, directed-, and active assembly approaches with control of assembly pathway mechanisms and kinetics to form materials that are far from equilibrium and display novel and unexpected properties; adaptive, resilient materials with self-repairing capabilities; and development of science-driven tools and techniques to achieve fundamental understanding of how these new materials and systems are formed and how they function in real time.

Unique Aspects

Basic research supported in this activity underpins DOE's mission to develop future, transformative energy technologies in areas such as energy conversion, transduction, and storage; light-weight/high-strength materials; efficient membranes for highly selective separations; and energy-efficient low temperature synthesis of materials. Current scientific thrusts balance grand challenge and use-inspired basic research, and require strong interactions among biology, chemistry, physics, and computational disciplines. This activity's quest for new energy-related materials by exploiting biological principles and concepts is complementary to the focus on chemistry-based formation and control of new materials and morphologies of the Materials Chemistry research activity, and the emphasis on physical, rather than chemical, control of structure and properties, and on bulk synthesis, crystal growth, and thin films of the Synthesis and Processing Science research activity. The Biomolecular Materials activity's focus on the intersection of biology and materials sciences complements the BES Physical Biosciences activity, which focuses on biological aspects of capture, conversion, and storage of solar energy in plants and/or non-medical microbes. The researchers supported by the program benefit from significant use of BES-supported scientific user facilities with their advanced synchrotron x-ray, neutron scattering, electron microscopy and nanoscience tools.

Relationship to Other Programs

The Biomolecular Materials program is a vital interdisciplinary component of the materials sciences that interfaces materials sciences with biology. This interfacing results in active relationships within BES, within DOE, and within the larger federal research enterprise:

- Within BES, this research activity sponsors – jointly with other core research activities and the Energy Frontier Research Centers program, as appropriate – program reviews, contractor meetings, and programmatic workshops.
- There are active interactions with the DOE Office of Energy Efficiency and Renewable Energy (EERE) through workshops, program reviews, principal investigator meetings, and communication of research activities and highlights.

- Nanoscience-related projects in this activity are coordinated with the Nanoscience Research Center activities and reviews in the Scientific User Facilities Division within BES. BES further coordinates nanoscience activities with other federal agencies through the National Science and Technology Council (NSTC) Nanoscale Science, Engineering, and Technology subcommittee, which leads the National Nanotechnology Initiative.
- Predictive materials sciences activities and the associated theory, modeling, characterization and synthesis research are coordinated with other federal agencies through the NSTC Subcommittee on the Materials Genome Initiative.
- Active interactions with the National Science Foundation through workshops, joint support of National Academy studies in relevant areas, and communication about research activities.

Significant Accomplishments

The Biomolecular Materials research activity has produced several notable accomplishments that show promise of significant impact:

- Stiff polymeric materials able to spontaneously repair, a key feature of natural materials, without any external help from light, heat, or healing agents;
- The first "directed evolution" of an enzyme, capable of synthesizing semiconductors never before produced by living organisms, using a new cell-free approach;
- The fabrication of cell/silica composites and silica replicas using mammalian cells to direct complex structure formation, and the use of this process to reinforce cellular structures;
- A hybrid biological-organic solar converter that produces hydrogen from sunlight at a rate two to three times faster than that of natural photosynthesis;
- The first functional bio-nanoelectronic device that seamlessly integrates biological functions of membrane proteins with nanowire electronics;
- The first artificial solar cell that mimics the self-repair process used by plants as they convert light into energy; and
- An innovative biomimetic approach for directed formation and manipulation of colloidal assemblies that perform elaborate functions such as grasping, transporting and releasing cargo.

Mission Relevance

Research supported by the Biomolecular Materials activity underpins a broad range of energy technologies such as lighter and stronger materials to improve fuel economy, membranes for making separations and purification processes more efficient, energy-efficient synthesis and assembly of functional materials, and processes that can convert light, carbon dioxide, and water to fuels.

Scientific Challenges

Since biology has already figured out ways in which matter, energy, entropy, and information are organized and/or manipulated across multiple length scales, the challenge for us is to understand, adapt, and improve upon them so that it will become valuable and practical under a broader range of harsher, non-biological conditions. The major scientific challenges that drive the Biomolecular Materials activity directly correspond to four of the five scientific grand challenges in basic energy sciences, as described in the report, *Directing Matter and Energy: Five Challenges for Science and Imagination* (report link):

- How do we design and perfect atom- and energy-efficient synthesis of revolutionary new forms of matter with tailored properties?
- How do remarkable properties of matter emerge from complex correlations of the atomic and electronic constituents and how can we control these properties?
- How can we master energy and information on the nanoscale to create new technologies with capabilities rivaling those of living systems?
- How do we characterize and control matter–especially very far away–from equilibrium?

Additional challenges directly correspond to the objectives laid out in the two recent BES reports, *From Quanta to the Continuum: Opportunities for Mesoscale Science* (report link) and *Computational Materials Science and Chemistry: Accelerating Discovery and Innovation through Simulation-Based Engineering and Science* (report link):

- Discovering, controlling, and manipulating complex mesoscale architectures and phenomena to realize new functionality
- The development and use of powerful new theory/modeling and physical/chemical characterization tools that can accelerate materials discovery.

Projected Evolution

Recent BES Basic Research Needs (and other) workshops and reports have clearly identified mastering the capabilities of living systems as a Grand Challenge that could provide the knowledge base to discover, design, and synthesize new materials with the precise control of complexity needed to yield totally new properties for next-generation energy technologies. Biomolecular Materials research activity will seek to advance the ability for materials to self-repair, self-regulate, sequester impurities, tolerate abuse, and produce, convert and store energy, with an emphasis on achieving mechanistic understanding of these new materials and systems. New approaches that will lead to predictable and scalable synthesis of novel, hierarchically structured polymeric, inorganic, and hybrid functional materials in vitro with controllable morphology, content, behavior and performance are sought. The activity will expand research on creating materials optimized for non-biological conditions (i) in which the components work in concert to initiate, maintain, cease functions, and communicate to coordinate collective behavior in response to multiple external signals; (ii) that are capable of spontaneous error-correcting formation and deformation; (iii) that undergo self-repair without external input; and (iv) that are capable of self-replication. This activity also will expand research to design and create next generation membrane materials with programmable selectivity and transport based on biological gating and pumping functions. Integration of theory and experiment to understand how materials complexity leads to new functionalities and the development of new design ideas and opportunities for accelerated discovery will also be emphasized.