Biomolecular Materials

Portfolio Description

This activity supports basic research in the discovery, design and synthesis of biomimetic and bioinspired functional materials and complex structures, and materials aspects of energy conversion processes based on principles and concepts of biology. The major program emphasis is the creation of robust, scalable, energy-relevant materials and systems with emergent behavior that work with the extraordinary effectiveness of molecules and processes of the biological world. Major thrust areas include: understanding, controlling, and building complex hierarchical structures by mimicking nature's self- and directed-assembly approaches; design and synthesis of environmentally adaptive, self-healing multi-component, e.g., inorganic, polymeric, and biological, materials and systems that demonstrate energy conversion and storage capabilities found in nature; functional systems with collective properties not achievable by simply summing the individual components; biomimetic and/or bioinspired routes for the synthesis of energy relevant materials, e.g., semiconductor and magnetic materials under mild conditions; and development of science-driven tools and techniques for the characterization of biomolecular and soft materials.

Unique Aspects

Basic research supported in this activity underpins many energy-related technological areas such as energy conversion and storage, light-weight/high-strength materials, efficient membranes for highly selective separations, and advanced catalytic systems/architectures with enzyme-like specificities and high turnover ratios. Current scientific thrusts balance discovery-class 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 biology is complementary to the emphasis on exploratory chemical synthesis and chemical control of materials properties (BES Materials Chemistry) and the emphasis on innovative synthesis concepts and underlying physical phenomena (BES Synthesis and Processing Science). The Biomolecular Materials activity's focus on the intersection of biology and materials sciences complements the Physical Biosciences activity in the BES Chemical Sciences, Geosciences and Biosciences Division, focused on the intersection of physical sciences with biochemistry and molecular biology.

Relationship to Other Programs

The Biomolecular Materials program is a vital component of the materials sciences that interfaces materials sciences with biology. This interfacing results in very active relationships.

- Within DOE, there is coordination through the Energy Materials Coordinating Committee involving representatives of the Offices of Science, National Nuclear Security Administration, Fossil Energy, Environmental Management, Nuclear Energy Science and Technology, Energy Efficiency and Renewable Energy (EERE), and Electricity Delivery and Energy Reliability.
- Within BES, there are jointly funded programs between the DOE national laboratories and universities (about six currently), joint program reviews, joint contractor meetings (with EERE), and workshops. There is also coordination between this activity and Energy Frontier Research Centers in topically related areas.
- Nanoscience-related projects in this activity are coordinated with the Nanoscale Science

Research Center (NSRC) activities and reviews in the BES Scientific User Facilities Division. BES further coordinates nanoscience activities with other federal agencies through the National Science and Technology Council's Nanoscale Science, Engineering, and Technology subcommittee, which leads the National Nanotechnology Initiative.
- Active interactions with the National Science Foundation and National Institutes of Health through joint workshops and joint support of National Academy studies in relevant areas (two were completed recently).

Significant Accomplishments
A recent achievement is the development of a method to genetically encode unnatural amino acids with diverse physical, chemical, or biological properties in bacteria *E.Coli* and mammalian cells. This makes it possible to synthesize proteins incorporating unnatural amino acids, thereby producing "synthetic" analogs of proteins and, potentially, long-sought-after mono-disperse versions of industrial polymers such as polyesters and polyimides. Biosynthetic routes found in nature have been harnessed or mimicked to produce a wide variety of semiconductor, ferroelectric, and magnetic nanocrystals under mild, environmentally benign conditions. A novel strategy to stabilize liposomes as well as to immobilize them on surfaces has been demonstrated by use of nanoparticles, thus opening their possible use as smart materials and nanoscale chemical reactors for massively parallel synthesis. The first functional bio-nanoelectronic device that integrates membrane proteins with nanowire electronics has been created. A recent discovery is that synchrotron x-rays can act as a reversible switch for the self-assembly of disordered bundles of nanoscale filaments into a crystalline, ordered state opens up novel approaches and mechanisms to organize nanoscale filaments and wires over long distances. A broad-spectrum light-harvesting system that self-assembles into precisely shaped rods like tobacco mosaic virus and mimics the light-harvesting antenna in photosynthetic bacteria has been developed. Recently, the DNA-guided assembly of nanoparticles into three-dimensional crystalline assemblies has been demonstrated for the first time. A new benchmark for efficient hydrogen production by a hybrid photo-catalyst system comprising molecular wire-linked Photosystem I and platinum nanoparticles has been demonstrated.

Mission Relevance
Research supported in this activity underpins many energy-related technological areas such as batteries and fuel cells, catalysis, energy conversion and storage, friction and lubrication, high efficiency electronic devices, hydrogen generation and storage, light-emitting materials, light-weight high-strength materials, and membranes for advanced separations.

Scientific Challenges
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*: (1) How do we design and perfect atom- and energy-efficient synthesis of revolutionary new forms of matter with tailored properties? (2) How do remarkable properties of matter emerge from complex correlations of the atomic and electronic constituents and how can we control these properties? (3) How can we master energy and information on the nanoscale to create new technologies with capabilities rivaling those of living systems? (4) How do we characterize and control matter--especially very far away--from equilibrium? Since biology has already figured

out ways in which matter, energy, entropy, and information are organized and/or manipulated, the challenge 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.

Projected Evolution

This activity will continue to support curiosity-driven and multi-disciplinary approaches to model, design, and synthesize novel materials with unique functionalities. The program will continue to seek a fundamental understanding of thermodynamic, kinetic, and dynamical aspects of self-assembly processes to produce both equilibrium and far-from-equilibrium materials and systems like those found in nature. Enhanced integration of theory, computation, and experiment is sought to develop a more comprehensive understanding of the nanoscale structure and non-equilibrium behavior of bioinspired/bioderivative materials and systems leading to new design ideas and opportunities for discovery. In addition, the program will expand in the following areas: dynamically adaptive and self-repairing materials; low temperature synthesis of energy relevant materials; effective and unique strategies for interfacing biological and non-biological materials systems in search of emergent behavior; synthetic enzymes; material architectures for efficiently integrating light-harvesting, photo-redox, and catalytic functions; and biomolecular functional structures that take inspiration from biological gates, pores, channels, and motors.