# Physical Biosciences

## Portfolio Description

This activity combines experimental and computational tools from the physical sciences with biochemistry and molecular biology. A fundamental understanding of the complex processes that convert and store energy in plants, algae, and non-medical microbes is sought. Research supported includes studies that investigate the principles and mechanisms by which energy transduction systems are assembled and maintained, the processes that regulate energy-relevant chemical reactions within the cell, the underlying biochemical and biophysical principles determining the architecture of biopolymers and the plant cell wall, and the structure/function of the active sites of energy-relevant proteins that provide a basis for highly selective and efficient bioinspired catalysts. Capital equipment is provided for items including advanced atomic force and optical microscopes, lasers and detectors, equipment for x-ray or neutron structure determinations, and Fourier transform infrared and nuclear magnetic resonance spectrometers.

## Unique Aspects

Physical Biosciences is a unique federal program devoted to fundamental science that applies the tools of physical science to address biological phenomena underlying the production and conservation of energy in plants, algae and non-medical microbial systems, including the archaeal kingdom. It occupies an essential niche within DOE's Office of Science, lying at the interface between the life sciences and the chemical and physical sciences. Accordingly, this activity promotes multi- and cross-disciplinary research activities required for the development of bio-inspired energy-relevant technologies and processes.

In addition to its broad portfolio of funded projects in universities and at the DOE National Laboratories, this activity sponsors the Complex Carbohydrate Research Center (CCRC) at the University of Georgia. The CCRC is internationally acclaimed, not only for research excellence, but also for its leadership in providing analytical support and training for the carbohydrate chemistry community. In conjunction with the Photosynthetic Systems program, the Physical Biosciences program also supports the DOE Plant Research Laboratory (PRL) at Michigan State University.  The PRL has been devoted to fundamental plant biology research and the training of graduate students and postdoctoral researchers, the next generation of plant scientists who will provide the knowledge base for meeting future energy needs.  The multidisciplinary research program at the PRL is focusing on complex questions in photobiology, carbon fixation, and high energy redox reactions. As part of this research, the PRL is developing and using novel high-throughput, non-invasive phenotyping technologies.

## Relationship to Other Programs

This research activity interfaces with several complementary activities within BES as well as within DOE and other federal agencies.

- Within BES, research efforts are coordinated with the Photosynthetic Systems program in the areas of natural photosynthesis, carbon fixation, and the organizational and structural principles of the cellular machinery; with the Catalysis Science program in the area of enzyme and biomimetic catalysis; with the Separations and Analysis program in the area of analytical tool and technology development; and with the Biomolecular Materials program in the area of synthesis of novel bio-inspired materials.

- This research activity sponsors – jointly with other core research activities and the Energy Frontier Research Centers program as appropriate – program reviews, principal investigators' meetings, and programmatic workshops.
- This activity also supports and complements basic research relevant to the DOE Office of Biological and Environmental Research, in particular for its activities in imaging and biomass conversion technologies; the DOE Office of Energy Efficiency and Renewable Energy, in particular with Biomass Program efforts to enhance microbially-mediated conversions of lignocellulosic and other plant feed stocks; and the Advanced Research Projects Agency-Energy, in particular related to its efforts to develop new technologies for methane utilization and to enhance the capabilities of plants to store solar energy as plant lipids.
- The program collaborates and coordinates its activities with the National Science Foundation, U. S. Department of Agriculture, and National Institutes of Health in areas of mutual interest where there are multiple benefits.

**Significant Accomplishments**

Through its origin in the Energy Biosciences program, the Physical Biosciences program has a strong record of scientific impact as exemplified by its support of research that was instrumental in defining *Archaea* as the third kingdom of life. The recognition of scientists supported by the program is illustrated by numerous awards and prizes, including the 2008 Wolf Foundation Prize in Chemistry for the unique coupling of single molecule spectroscopy with electrochemistry. Significant accomplishments of the program include:

- The determination of the biosynthetic pathway for methane production from $CO_2$ and molecular hydrogen, which led to the discovery and structural determination of many unique cofactors involved in archaeal electron transfer pathways. Mechanistic studies are now providing insights that will aid the design of novel catalysts.
- The elucidation of the biochemistry and genetic regulation of plant lipid synthesis, as well as enzyme structure/function studies that have identified the catalytic basis for the introduction of various modifications at precise points on a fatty acid chain. Current studies in this area are providing important information needed to increase the production of energy-rich lipids in oil seeds as well as aerial tissues.
- The determination of the structure of many of the complex polysaccharide components of the plant cell wall, as well as many important aspects of its supramolecular structure, have guided strategies aimed at improving the conversion efficiencies of plant biomass to fuel molecules.
- The elucidation of the specificities and insights into the mechanisms of numerous plant membrane transporters has opened up new opportunities to improve the properties and sustainability of plants being considered as future energy crops.
- Studies of hydrogenase structure, function, and biosynthesis have provided information on the assembly and mode of action of complex metal-organic cofactors and gated electron flow that are critical for the production of hydrogen in biological systems.

**Mission Relevance**

The research provides basic structure/function and mechanistic information necessary to accomplish bio-inspired solid-phase nanoscale synthesis in a targeted manner, i.e., design and control of the basic architecture of energy-transduction and storage systems. This impacts numerous DOE interests, including improved biochemical pathways for biofuel production, next generation energy conversion/storage devices, and efficient, environmentally benign catalysts.

**Scientific Challenges**

The application of physical science and computational tools to increase our understanding of biological systems will enable important new insights into structure/function and chemical mechanisms required to develop new energy capture, conversion, and storage systems and technologies. Analysis of both spatial and temporal dynamics and their subsequent integration into coherent and testable models represent a significant scientific challenge, but also present new opportunities. For instance, understanding aspects of lipid biosynthesis and deposition in membranes as well as storage vesicles would benefit substantially from such integrated approaches, and will lead to new strategies for increasing the energy-rich lipid content of target organisms. Probing the organizational principles of biological energy transduction and chemical storage systems exemplifies another substantial programmatic challenge. In this regard, the use of advanced molecular imaging and x-ray or neutron scattering methods will provide new and essential insights into cell wall and other supramolecular architectures, as well as into the sophisticated structures of enzyme complexes, leading to novel bio-inspired materials and renewable sources of energy.

**Projected Evolution**

Future impact is, in general, envisioned through increased use of physical science and computational tools (ultrafast laser spectroscopy, current and future x-ray light sources, and quantum chemistry) to probe spatial and temporal properties of biological systems. Combined with efforts in molecular biology and biochemistry, this will give us an unprecedented architectural and mechanistic understanding of such systems and allow the incorporation of identified principles into the design of bio-inspired synthetic or semi-synthetic energy systems. The application of such tools to the detailed study of individual enzymes (and multi-enzyme complexes) will enable the design of improved industrial catalysts and processes (e.g. more cost-effective, highly-efficient, etc.) through a more complete understanding of structure and mechanistic principles. One such priority area for the program is achieving a greater understanding of the active site chemistries of multi-electron redox reactions (e.g. $CO_2$ reduction). Another unique aspect of biological systems is their ability to self-assemble and self-repair. These capabilities occur via complex processes that are not well understood, and enhanced efforts will be devoted to the identification of the underlying chemical/physical principles that govern such behaviors. Still another area of emphasis for the program lies in the application of these same tools to achieve a more detailed understanding of the structure and dynamics of complex biological nanomaterials such as plant cell walls, biological motors, and cytoskeletal and other assemblies involved in energy capture, transduction, and storage.