Photosynthetic Systems

Portfolio Description
This activity supports fundamental research on the biological conversion of solar energy to chemically stored forms of energy. Topics of study include light harvesting, exciton transfer, charge separation, transfer of reductant to carbon dioxide, as well as the biochemistry of carbon fixation and carbon storage. Emphasized areas are those involving strong intersection between biological sciences and energy-relevant chemical sciences and physics, such as in self-assembly of nanoscale components, efficient photon capture and charge separation, predictive design of catalysts, and self-regulating/repairing systems. Capital equipment funding is provided for items such as ultrafast lasers, high-speed detectors, spectrometers, environmentally controlled chambers, high-throughput robotic systems, and computational resources.

Unique Aspects
The Photosynthetic Systems program is the most prominent supporter of basic research in natural photosynthesis in the United States. This distinctive federal program brings together biology, biochemistry, chemistry, and biophysics to uncover the fundamental science of biological capture of sunlight and its conversion to and storage as chemical energy. Through its broad portfolio of projects at universities and DOE National Laboratories, the program will provide a critical scientific knowledge base that can inspire the roadmap for artificial photosynthesis and enable new strategies and technologies for more efficient generation of biomass as a renewal energy source.

Initiated with funding from its predecessor program (Energy Biosciences), the DOE Plant Research Laboratory (PRL) at Michigan State University is a unique facility jointly supported by the Photosynthetic Systems and Physical Biosciences programs. The PRL is 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.

Relationship to Other Programs
The Photosynthetic Systems research effort interfaces with several activities within BES, including the Physical Biosciences program in the organizational and structural principles of cellular machinery as well as the Solar Photochemistry, Catalysis Science, and Biomolecular Materials programs in biomimetic and bioinspired photosynthetic systems. The basic research supported by the program also is relevant to biotechnology- and genomics-related programs in the DOE Office of Biological and Environmental Research, to the DOE Office of Fossil Energy, and to the DOE Office of Energy Efficiency and Renewable Energy, in particular, its activities in the Solar Energy Technologies Program on photovoltaics, the Biomass Program on algal feedstocks, and the Fuel Cell Technologies Program. 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 Photosynthetic Systems program has a rich history of scientific impact. Among those accomplishments are the elucidation of the structure of the highly efficient light-harvesting chlorosome antenna complex, determination of the biosynthetic pathway for hydrogen production in photosynthetic bacteria, and characterization of critical components of the algal light-harvesting complex. Scientists supported by the program have

received numerous awards and prizes including the 2006 Balzan Prize (Plant Molecular Genetics Award) for efforts in developing *Arabidopsis thaliana* as a model plant experiment system.

Mission Relevance

The impact of research in this activity is to uncover the underlying structure-function relationships and to probe dynamical processes in natural photosynthetic systems to guide the development of robust artificial and bio-hybrid systems for conversion of solar energy into electricity or chemical fuels. The ultimate goal is the development of bio-hybrid systems in which the best features from nature are selectively used while the shortcomings of biology are bypassed. Achieving this goal would impact DOE's efforts to develop solar energy as an efficient, renewable energy source. Knowledge generated by this research may also guide the enhancement of photosynthetic efficiency which would significantly impact DOE's efforts to produce advanced biofuels.

Scientific Challenges

Plants, cyanobacteria, and algae use solar energy to convert water and carbon dioxide into chemical energy, i.e. energy-rich organic molecules such as carbohydrates, fat, and protein, which can be collectively termed biomass. Nature has had approximately 3 billion years to modify and refine photosynthesis, a time period 10- to 100-fold longer than humans have had to evolve their complicated biochemical machinery. Understanding nature's complex design for converting sunlight into chemical energy remains a grand challenge for increasing solar energy utilization and enhancing carbon fixation. Despite research efforts, a detailed understanding is still lacking of the structure of the oxygen-evolving complex, the mechanism of action of Rubisco, and the energy dissipation of reactive oxygen species. Molecular, biochemical, and biophysical studies of the mechanisms of the photosynthetic apparatus are much needed, particularly pertaining to light harvesting and energy transduction as well as to the maintenance of the biological integrity of these systems including defect tolerance and self-repair. Another critical research need is increased understanding of the temporal and spatial dynamics and regulation of photosynthesis. Photon absorption and harvesting occur on a femtosecond time scale; charge separation and electron transport on a nano- to picosecond time scale; and photocatalysis and carbon-carbon bond formation on a micro- to millisecond time scale – while presenting experimental and technical challenges, appreciation of the kinetics of each of these processes can provide important insight into natural photosynthetic mechanisms and how they might be altered for use in biomimetic systems for instance. Such fundamental knowledge of natural photosynthesis can play a critical role in the development of renewable, cost-effective, and environmentally-sustainable energy systems and supplies.

Projected Evolution

In FY 2009, the prior Energy Biosciences program evolved into two complementary and synergistic programs: 1) Photosynthetic Systems and 2) Physical Biosciences. Both programs support unique areas of fundamental research on plant and microbial systems. While it is envisioned that the Photosynthetic Systems program will remain tightly integrated with the Physical Biosciences program, the program also anticipates that solar energy utilization research will be enhanced through complementary efforts and greater coordination of its activities with the Solar Photochemistry, Catalysis Science, and Biomolecular Materials programs within BES, as well as with other Offices in DOE in selected areas where programmatic synergies are achievable.

Advances in genomics technologies such as metabolomics along with increased availability of plant genomic sequences provide new opportunities to leverage the strengths of the Photosynthetic Systems program in molecular biology and biochemistry with powerful capabilities in imaging and computation. This will allow an unprecedented biophysical understanding at the nanoscale of photosynthesis and related processes such as carbon fixation. Research will continue to emphasize understanding and control of the weak intermolecular forces governing molecular assembly in photosynthetic systems; understanding the biological machinery for cofactor insertion into proteins and protein subunit assemblies; adapting combinatorial, directed evolution, and high-throughput screening methods to enhance fuel production in photosynthetic systems; characterizing the structural and mechanistic features of new photosynthetic complexes; and determining the physical and chemical rules that underlie biological mechanisms of repair and photo-protection.