

Photosynthetic Systems

Portfolio Description

This program supports basic research on natural photosynthesis—the capture of solar energy and its conversion to and storage as chemical energy in plants, algae, and photosynthetic prokaryotes. Natural photosynthesis encompasses a great diversity of energy-conversion biochemistry that is, as a rule, highly efficient. Understanding the mechanisms of this biochemistry is the overarching goal of the Photosynthetic Systems program. Research topics supported include, but are not limited to, light harvesting, photosynthetic electron and proton transport, photosynthetic uptake and reduction of carbon dioxide, and mechanisms of self-assembly, self-regulation, and self-repair exhibited by the proteins, membranes and cellular compartments that perform natural photosynthesis. A goal of the program is to foster greater fundamental knowledge of the structure and function of the diverse photosynthetic systems found in nature.

Scientific Challenges

Understanding the diverse and highly efficient chemical mechanisms by which natural photosynthesis converts sunlight into chemical energy remains a grand challenge for increasing solar energy utilization and enhancing biological and biomimetic reduction of carbon dioxide into carbon-based fuels. For example, despite the strong limitation on photosynthetic efficiency, the mechanisms by which the carboxylating enzymes of photosynthesis take carbon dioxide from air and incorporate it into carbohydrates are not completely defined. Similarly, cryptic pathways of electron transport within and between proteins of the photosynthetic electron transport system are poorly understood or, in some cases, unknown, despite their importance for regulating photosynthesis in response to variations in light and temperature. Molecular, biochemical, and biophysical studies of the mechanisms of the photosynthetic apparatus continue to be 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. Increased understanding of the temporal and spatial dynamics and regulation of photosynthesis continues to be a critical research need. The chemistry and chemical physics of highly efficient, long distance transfer of photon energy between pigments in photosynthetic antenna complexes is also an important topic of study.

Projected Evolution

Advances in laser spectroscopy and chemical imaging will allow an unprecedented fundamental understanding of photosynthesis at the nanometer scale. The Photosynthetic Systems program will continue to emphasize basic research to understand the structural and mechanistic features of photosynthetic complexes, determine the mechanisms behind photon capture and charge transfer, characterize and control the weak intermolecular forces governing molecular assembly in protein complexes of photosynthesis, understand the biological machinery for cofactor insertion into proteins and protein subunit assemblies, uncover the biochemical mechanisms that can enhance energy conversion in photosynthetic systems, and determine the physical and chemical rules that underlie biological mechanisms of photo-protection and self-repair.

The Photosynthetic Systems program does not fund: 1) development or optimization of devices or processes; 2) development or optimization of microbial strains or plant varieties for biofuel or biomass production; 3) phenotype analyses that do not test specific hypotheses relevant to the

program; 4) genomic or other “omic” data acquisition that does not test specific hypotheses relevant to the program; 5) theory or modeling projects that lack empirical testing.

Significant Accomplishments

Research supported by the Photosynthetic Systems program has made significant advances in fundamental understanding of natural photosynthesis.

- Analysis of the diverse paths of photosynthetic electron transport in plants led to a new paradigm for how cyclic electron transport regulates photosynthesis for optimal plant growth under changing conditions of light and temperature.
- Ultra-fast lasers and x-ray crystallography facilities at DOE national laboratories were used to generate better structural models for how oxygen is produced by photosynthesis. Understanding the chemistry of photosynthetic oxygen evolution can inform the design of efficient catalysts that can generate hydrogen or carbon-based fuels from water, air, and sunlight.
- Significant progress was made in understanding the biochemical mechanisms by which plants and algae protect themselves from bleaching by sunlight. These findings also involved the use of ultra-fast lasers and X-ray crystallography facilities at DOE national laboratories.
- An innovative plant phenotyping approach was used to generate hundreds of thousands of outdoor photosynthesis measurements from around the world. Machine learning applied to the resulting data revealed how to predict plant productivity under diverse conditions from these measurements of photosynthesis.
- Studies of hydrogen production by photosynthetic organisms have led to new understanding of the chemistry of hydrogenase enzymes and creation of a novel biohybrid system that generates hydrogen fuel from water and sunlight.

Unique Aspects

The Photosynthetic Systems program is distinctive for its focus on the biochemistry and chemistry of natural photosynthesis and for the diversity of methodological approaches taken to understanding it. Basic research funded by Photosynthetic Systems combines biochemistry, biophysics, molecular biology, and computational science to generate a mechanistic knowledge of the biological capture of sunlight and its conversion to and storage as chemical energy. This multidisciplinary approach is a key strength of Photosynthetic Systems that enables a multidimensional fundamental understanding of natural photosynthesis. The broad portfolio of research projects supported by Photosynthetic Systems at universities and DOE national laboratories also generates a scientific knowledge base and technical capabilities relevant to understanding light-driven chemical systems of many kinds. Such fundamental understanding provides insights for future development of bioinspired, bio-hybrid, and biomimetic energy systems and informs strategies for improvement of biological photosynthesis.

Mission Relevance

The basic research supported by this program uncovers the underlying structure-function relationships and dynamic processes of natural photosynthesis. This fundamental knowledge can inspire and inform the engineering of bio-hybrid and biomimetic energy systems for conversion of sunlight into chemical fuels or electricity and can guide the genetic improvement of natural photosynthesis in plants which can enhance production of biofuels and other useful products.

Relationship to Other Programs

The Photosynthetic Systems program coordinates with other programs in BES as well as across the DOE and in other Federal agencies.

- Within the BES Chemical Sciences, Geosciences, and Biosciences (CSGB) Division, Photosynthetic Systems coordinates with the Physical Biosciences program in the areas of biological electron transport mechanisms and carbon dioxide fixation and with the Solar Photochemistry program in the areas of natural and artificial photosynthesis. Photosynthetic Systems also interacts with the Catalysis Science program in CSGB and the Biomolecular Materials program in the BES Materials Science and Engineering Division in areas such as biocatalysis and bioinspired and biomimetic photochemical systems and their components.
- 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.
- The basic research supported by the program complements the genomics- and biotechnology-related programs in the DOE Office of Biological and Environmental Research, the DOE Office of Energy Efficiency and Renewable Energy, and the DOE Advanced Research Projects Agency-Energy.
- Outside the DOE, 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.