Biological Systems Science Division

A Division of the U.S. Department of Energy Office of Biological and Environmental Research

science.energy.gov/ber/research/bssd/

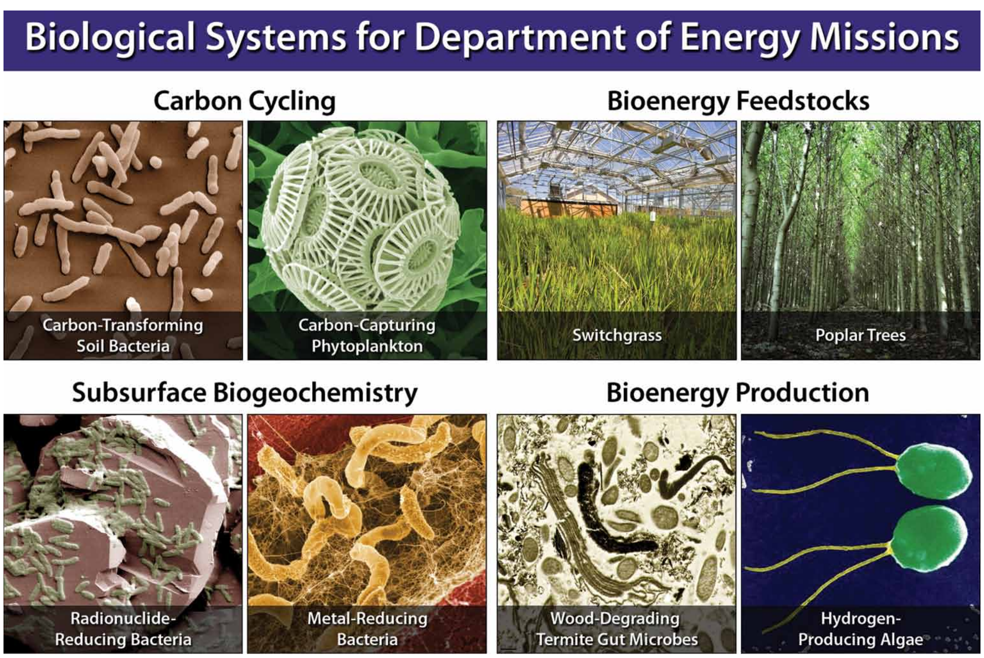
Building on decades of biological discovery that originally focused on the health effects of radiation exposure, the Department of Energy (DOE) Office of Science has long supported high-risk, high-return biological research that not only advances DOE missions but also brings together researchers from diverse fields to overcome complex problems. Today, some of the most daunting scientific challenges for DOE require understanding and ultimately predicting the behaviors of plant and microbial systems.

The range of biological systems important to DOE is remarkably diverse: microbes that chemically alter environmental contaminants; fungi and bacteria that degrade plant cell walls or produce next-generation biofuels; and trees, grasses, algae, and other microbes that cycle carbon or serve as sources for biofuel production (see figure below). Yet, even the simplest of these systems—a single bacterial cell—is so complex that we cannot predict how it regulates functions or how it responds to and modifies the environment.

The Biological Systems Science Division (BSSD) in DOE's Office of Biological and Environmental Research (BER) supports single-investigator and team research, technology development, research centers, and user facilities to advance a powerful new era of whole-systems understanding of biology.

BSSD Mission

The Biological Systems Science Division within the DOE Office of Biological and Environmental Research supports a diverse portfolio of fundamental research and technology development to achieve a predictive, systems-level understanding of complex biological systems to advance DOE missions in energy, climate, and environment.



BSSD Programs

A core driver of BSSD is its Genomic Science program, which includes research projects and centers that provide the scientific insights and analytical technologies needed to translate genome sequences into a profound and comprehensive understanding of the myriad processes carried out by biological systems. BSSD programs also address other biological questions relevant to DOE's missions. These include developing and using radiotracers to analyze the dynamic processes of life, investigating biological response to radiation exposure, and bringing together DOE's unique material science and engineering resources to serve diverse applications.

Genomic Science Program

From Genomes to Systems Understanding

The DNA code—the genome—is the foundation for building an integrated view of the complex and constantly changing molecular universe within cells. Building on microbial and plant genome sequences, the Genomic Science program is advancing research to understand biological systems well

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enough to develop predictive, computational models of these systems. The emergent behaviors of biological systems ranging from molecular and cellular networks to microbial communities and plants are condition dependent and cannot be deciphered by the reductionist study of individual components in isolation.

To achieve its goal of predictive understanding, the Genomic Science program funds a broad portfolio of single-investigator and team projects as well as three Bioenergy Research Centers for conducting system-wide investigations of changes in genome expression, regulation, metabolism, and molecular or cellular interactions (see sidebar, DOE Bioenergy Research Centers). To understand how shifts in environmental variables impact carbon cycling processes in terrestrial ecosystems, the Genomic Science program also funds genome-enabled systems-level studies on regulatory and metabolic networks of microbes and microbial consortia involved in biogeochemical cycling of carbon. The fundamental scientific advances emanating from this program are transferable to a wide range of application areas and will inspire new generations of industrial biotechnologies.

The Genomic Science program also supports research to develop methods that increase sample throughput and overcome the technological barriers limiting global analysis of biological systems and their components. Computing is another essential element for the success of this program. The deluge of heterogeneous data generated by genome-based investigations requires new computational tools and infrastructure to process, visualize, and integrate information needed to build, test, and improve models of biological systems. At the heart of this infrastructure will be the DOE Systems Biology Knowledgebase to provide the scientific community with open access to integrated collections of diverse datasets and suites of software and other tools for data analysis, modeling, and *in silico* hypothesis testing.

DOE Bioenergy Research Centers

genomicscience.energy.gov/centers/

To focus the talents of top multidisciplinary teams of scientists using the most advanced genomic and analytical technologies on the biological challenges of cellulosic biofuel production, DOE established three Bioenergy Research Centers in September 2007. Each center is a multi-institutional partnership collectively representing hundreds of researchers from national laboratories, universities, and several private companies and organizations. These centers are looking beyond corn ethanol to provide the scientific breakthroughs needed to produce next-generation biofuels—direct replacements for gasoline, diesel, and jet fuel—from the sugars locked within the cell walls of non-food, lignocellulosic materials such as trees, grasses, stems, and leaves.

Great Lakes Bioenergy Research Center

University of Wisconsin–Madison, Lead Institution
Madison, Wisconsin
glbrc.org

Joint BioEnergy Institute

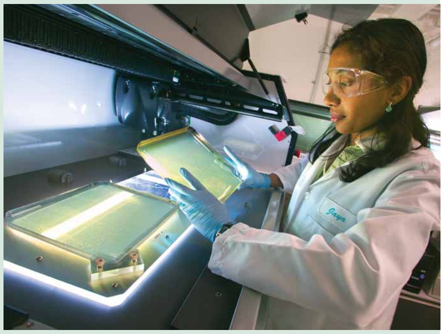
Lawrence Berkeley National Laboratory, Lead Institution
Emeryville, California
jbei.org

BioEnergy Science Center

Oak Ridge National Laboratory, Lead Institution
Oak Ridge, Tennessee
bioenergycenter.org

Bioenergy Crop Genomics. *Use genomic insights to develop grasses and trees as bioenergy crops with improved cell-wall degradability, crop sustainability, and biomass and biofuel yield. [Image credit: DOE Great Lakes Bioenergy Research Center]*

Biomass Deconstruction. *Screen DNA samples from diverse environments to discover and develop the most efficient biological processes for deconstructing plant cell walls into sugars for biofuel synthesis. [Image credit: DOE BioEnergy Science Center]*



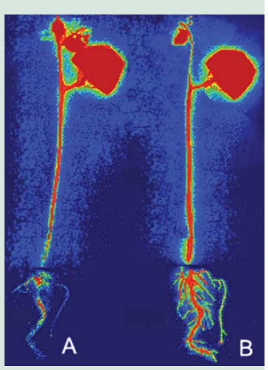
Microbial Biofuel Synthesis. *Use metabolic engineering and synthetic biology to design microbes that streamline the cellulosic biofuel production process and produce next-generation biofuels. [Image credit: Lawrence Berkeley National Laboratory]*

Taking advantage of novel computational modeling tools and systems-level experimental approaches, the design and construction of new biological systems with novel capabilities for defined purposes will be possible. These new biological systems and modules not only will generate new, useful functions but also provide powerful tools to further our understanding of the fundamental principles that rule biology. The Genomic Science program has recently released a funding opportunity announcement for research in the design of microbial and plant systems to advance the development of sustainable biofuels. Such research involves developing (1) new modeling algorithms and technologies to define, build, and apply functional biological modules for generating novel microbial systems and (2) new tools for redesigning bioenergy crops that can grow in marginal environments while producing high yields of biomass easily convertible to biofuels.

Radiochemistry and Imaging Instrumentation Program

Advancing Real-Time Visualization of Biological Processes

The electromagnetic waves and particles released from the unstable nuclei of radioactive elements—radionuclides—provide scientists with powerful capabilities for tracking organic compounds that contain these energy-emitting atoms. For over 60 years, DOE BER and its predecessor programs have supported radiochemical research that has delivered transformational advances in imaging. DOE's development and use of radionuclides as molecular tracers in living systems laid the foundation for modern nuclear medicine and revolutionized our understanding of metabolism and the kinetics of life processes. By leveraging DOE's landmark technological achievements for nuclear medicine, the Radiochemistry and Imaging Instrumentation program supports research to catalyze a new generation of radionuclide-based approaches for real-time, high-resolution analysis of dynamic plant and microbial processes addressing energy and environmental challenges (see figure below). Fundamental technologies generated by this program will be broadly transferable to the public and private sector for use in a variety of biological, environmental, and medical applications.



Imaging Carbon Allocation in Plants with Radionuclides. *Panel A shows radiolabeled sugar distribution throughout a poplar sapling. High sugar levels are red, and low levels are blue. Panel B shows greater sugar accumulation in the roots after the sapling's leaf is exposed to a hormone signaling "attack." [Image credit: R. Ferrieri and M. Thorpe, Brookhaven National Laboratory]*

Radiobiology Program

Analyzing Biological Response to Radiation Exposure

A major focus for this program is determining the biological risks from exposures to low levels of ionizing radiation typically encountered by the public, radiation workers, and other living systems in close proximity to radioactive materials. Building on recent advances in genomic technologies, the Radiobiology program supports research needed to measure and integrate the molecular, cellular, tissue-level, and organismal responses to low-dose radiation. New findings from this program provide compelling evidence that ionization events in cells and tissues are not completely independent and that tissues have surveillance mechanisms that dramatically affect cell development and behavior. Ongoing Radiobiology research will be critical to setting safe, evidence-based standards and guidelines for radiation protection.

BSSD User Facilities

DOE Joint Genome Institute

Bringing High-Throughput DNA Sequencing and Analysis to the Scientific Community

By providing the research community with access to the latest generation of genome sequencing and analysis capabilities, the DOE Joint Genome Institute (JGI) headquartered in Walnut Creek, California, is enabling teams of scientists worldwide to tackle DOE-relevant sequencing projects of unprecedented scale and complexity (see figure below). Supporting more than 1,800 global collaborators on active projects and sequencing trillions of DNA base pairs per year at a pace that is constantly increasing, the DOE JGI is one of the world's largest and most productive public genome-sequencing centers. This institute unites the expertise of five national laboratories—Lawrence Berkeley, Lawrence Livermore, Los Alamos, Oak Ridge, and Pacific Northwest—along with the HudsonAlpha Institute for Biotechnology.

Sequencing and Analysis at DOE JGI. *In addition to employing the latest advances in DNA sequencing technologies, JGI leverages the extensive computational resources of DOE national laboratories to provide users with a broad array of high-throughput analytical capabilities for transforming raw sequence data into useful biological knowledge. [Image credit: DOE JGI]*

The DOE JGI focuses the power of its sequencing capabilities on systematic large-scale surveys of genomes from plants, fungi, microbes, and microbial communities important to DOE missions in bioenergy, carbon cycling, subsurface biogeochemistry, and fundamental science. The DOE JGI Community Sequencing Program website (www.jgi.doe.gov/CSP/) provides information on how the scientific community can collaborate with JGI to sequence particular organisms or environmental samples.

Structural Biology Infrastructure

Accelerating Macromolecular Structure Determination with DOE Resources

Synchrotron light sources and neutron facilities at DOE national laboratories enable scientific applications for resolving the structure of matter down to the atomic or molecular level using approaches not possible with more conventional instrumentation. The intense beams of X rays and radiation of other wavelengths streaming off synchrotrons and the beams of neutrons from linear particle accelerators are directed toward experiment stations with instruments configured for specific scientific investigations. The Structural Biology Infrastructure program supports and provides user access to beamlines and experiment stations for revealing the relationships between structure and function for biological molecules within mission-relevant systems (see figures below).

For More Information

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Websites

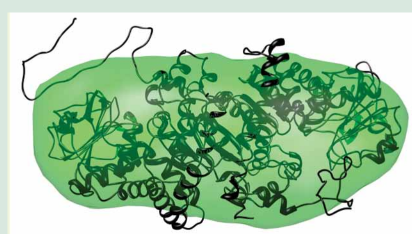
BSSD Programs
- science.energy.gov/ber/research/bssd/

Genomic Science Program
- science.energy.gov/ber/research/bssd/genomic-science/
- genomicscience.energy.gov

DOE Systems Biology Knowledgebase
- genomicscience.energy.gov/compbio/

DOE Bioenergy Research Centers
- genomicscience.energy.gov/centers/

DOE Joint Genome Institute
- jgi.doe.gov



Putting Protein Structure Determination on the Fast Track. *Using DOE's supercomputing resources and automated small-angle X-ray scattering instrumentation at an experiment station linked to Berkeley Lab's Advanced Light Source (right top), researchers in one month resolved the three-dimensional structures of 40 proteins from* Pyrococcus furiosis*—a hydrogen-producing microbe thriving in boiling temperatures. One of the protein structures is pictured at bottom right. This work would have taken several years with traditional X-ray crystallography techniques. By analyzing the molecular structures of this heat-tolerant microbe, scientists are working to understand which protein characteristics enable an organism to withstand the very hot and acidic conditions associated with biofuel production and other industrial processes. [Image credits: Lawrence Berkeley National Laboratory]*

Credits for "Biological Systems for Department of Energy Missions" image, p. 1. Soil bacteria image: M. Rohde, Helmholz Centre for Infection Research, Braunschweig. Phytoplankton image: J. Young, Natural History Museum, London. Switchgrass image: Lawrence Berkeley National Laboratory. Poplar image: DOE National Renewable Energy Laboratory. Radionuclide-reducing bacteria: A. Dohnalkova, DOE Environmental Molecular Sciences Laboratory. Metal-reducing bacteria: Pacific Northwest National Laboratory. Termite gut microbes image: R. Webb, University of Queensland. Hydrogen-producing algae image: E. Greenbaum, Oak Ridge National Laboratory.