Biological and Environmental Research

Overview

The mission of the Biological and Environmental Research (BER) program is to support fundamental research and scientific user facilities to achieve a predictive understanding of complex biological, climatic, and environmental systems for a secure and sustainable energy future.

The program seeks to understand the biological, biogeochemical, and physical principles needed to predict a continuum of processes occurring at the molecular and genomics-controlled smallest scales to environmental and Earth system change at the largest scales. Starting with the genetic potential encoded by organisms' genomes, BER research seeks to define the principles that guide the translation of the genetic code into functional proteins and the metabolic and regulatory networks underlying the systems biology of plants and microbes as they respond to and modify their environments. This predictive understanding can enable more confident redesign of microbes and plants for sustainable biofuels production, improved carbon storage, and controlled biological transformation of materials such as nutrients and contaminants in the environment. BER research also advances understanding of how the Earth's dynamic, physical, and biogeochemical systems (the atmosphere, land, oceans, sea ice, and subsurface) interact and cause future climate and environmental change to provide information that will inform plans for future energy and resource needs.

BER's scientific impact has been transformative. Mapping the human genome, including the U.S.-supported international Human Genome Project that DOE began in 1990, initiated the era of modern biotechnology and genomics-based systems biology. Today, with its Genomic Sciences activity and the DOE Joint Genome Institute (JGI), BER researchers are using the powerful tools of plant and microbial systems biology to pursue fundamental breakthroughs needed to develop sustainable, cost-effective cellulosic biofuels as outlined in the latest DOE Quadrennial Technology Review (DOE QTR 2015, Chapter 7.3)[a]. The three DOE Bioenergy Research Centers lead the world in fundamental biofuels-relevant research.

Since the 1950s, BER has been a critical contributor to climate science research, beginning with atmospheric circulation studies that were the forerunners of modern climate models. Today, BER research contributes to model development and analysis using community-based models, e.g., Community Earth System Model (CESM), the Accelerated Climate Model for Energy (ACME), and the Global Change Assessment Model (GCAM). These leading U.S. models are used to address two of the most critical areas of uncertainty in contemporary climate science—the impacts of clouds and aerosols—with data provided by the Atmospheric Radiation Measurement Climate Research Facility (ARM), a DOE user facility serving hundreds of scientists worldwide. Also, BER has been a pioneer of ecological and environmental studies in terrestrial ecosystems and seeks to describe the continuum of biological, biogeochemical, and physical processes across multiple scales that control the flux of climate and environmentally-relevant compounds between the terrestrial surface and the atmosphere. BER's Environmental Molecular Sciences Laboratory (EMSL) provides the scientific community with a powerful suite of instruments and a high performance computer to characterize biological organisms and molecules as well as atmospheric aerosol particulates.

Highlights of the FY 2017 Budget Request

Biological and Environmental Research will support core research and scientific user facilities in key areas of bioenergy, climate, and environmental sciences. In the FY 2017 Budget Request, most funding for the Working Capital Fund (WCF) is transferred to Program Direction to establish a consolidated source of funding for goods and services provided by the WCF. CyberOne is still funded through program dollars. In FY 2016 and prior years, WCF costs were shared by SC research programs and Program Direction.

<u>Biological Systems Science</u>

Investments in Biological Systems Science will provide the fundamental understanding to underpin advances in sustainable bioenergy production and to gain a predictive understanding of carbon, nutrient and contaminant transformation in support of DOE's environmental missions. These investments are strongly aligned with national priorities[b] in Clean Energy and Innovation in life sciences. Genomic Sciences research activities continue with core research to provide a scientific basis for

[a] http://energy.gov/epsa/downloads/quadrennial-energy-review-full-report
[b] https://www.whitehouse.gov/sites/default/files/omb/memoranda/2015/m-15-16.pdf

sustainable and cost effective bioenergy production; this includes the DOE Bioenergy Research Centers (BRCs) and Mission Innovation funding to speed translation of basic research results to industry for contributions to clean energy. Biosystems design research increases to develop the knowledge necessary to engineer specific beneficial traits into plants and microbes for making clean energy biofuels or products from renewable biomass. A new investment in microbiome research is also proposed that builds on BER's considerable experience in fundamental genomic science of plants and microbes and extends that expertise to understand the fundamental principles governing microbiome establishment, function, and interactions in diverse environments[a]. Gaining a predictive understanding of how microbiomes control the availability of materials such as carbon and nutrients, and respond to changes in the environment or interact with plants, is crucial to advancing DOE's sustainable bioenergy production and environmental research. These fundamental genomic science activities are supported by ongoing efforts to combine molecular and genomic scale information and to develop integrated networks and computational models of system dynamics and behavior. The DOE Joint Genome Institute (JGI) remains an essential component for DOE systems biology efforts providing high quality genome sequence data and analysis techniques for a wide variety of plants and microbial communities. The JGI continues to implement its strategic plan to incorporate new capabilities to sequence DNA and also to interpret, manipulate, and synthesize DNA in support of sustainable renewable energy and products, and environmental research. With this range of capabilities, JGI is also uniquely positioned to support and advance DOE bioenergy and environmental microbiome research, as well as provide broader user access to DNA synthesis capabilities in support of the BRAIN initiative.

Climate and Environmental Sciences

Climate and Environmental Research activities will focus on scientific analysis of the sensitivity and uncertainty of climate predictions to physical and biogeochemical processes, with emphasis on both Arctic and Tropical environments, as part of the Next Generation Ecosystem Experiments (NGEEs) in Alaska and at tropical sites. These investments reflect national priorities[1] in Global Climate Change, Information Technology and High Performance Computing, Ocean and Arctic Issues, and R&D for informed policy-making and management. Each major field study, including the two NGEEs, contains a modeling component; investments in Climate Model Development and Validation focus on model architecture restructuring, exploiting new software engineering and computational upgrades, incorporating scale-aware physics in all model components and enhanced efforts to assess and validate model results. Increased investment will produce an earth system model capability that includes a human component involving vulnerability analysis and integrated assessment, tailored to DOE requirements, e.g., new research to understand the interdependencies of water, energy and climate change, for a variety of scenarios applied to spatial scales as small as 10km. The model system will have improved resolution that will include new codes for running on numerous processors, flexibility toward future computer architectures, and enhanced usability, testing, adaptability, multi-scale treatments, and provenance. The modeling efforts will be validated against new atmospheric and terrestrial observations.

ARM continues long-term measurements at fixed sites in Alaska, Oklahoma, and the Azores, selected for scientific impact on improving climate models. The ARM mobile facilities will deploy to three climate-sensitive regions demanding focused and targeted measurements in the Arctic, Antarctic, and the Atlantic Ocean.

EMSL will focus on an aggressive research agenda aligned with BER program research areas and highlighting opportunities with the new High Resolution and Mass Accuracy Capability (HRMAC) instrument; with greatly improved dynamic range and sensitivity, HRMAC will enable a characterization and quantitation of the chemical constituents and dynamics of complex natural systems in the environment including microbial communities, atmospheric aerosols, and the soil and rhizosphere ecosystem. EMSL funding levels are enhanced to support characterization of novel biosensors and biomaterials relevant to the goals of the BRAIN initiative.

The Data Management effort will focus on advancing the Climate and Environmental Data Analysis and Visualization activity that will incorporate high resolution Earth system models with interdependent components involving energy and infrastructure sector models, field observations, raw data from environmental field experiments, and analytical tools for system diagnostics, validation, and uncertainty quantification.

Within the FY 2017 Budget Request, Climate and Environmental Sciences, specifically, Climate and Earth System Modeling Integrated Assessment activities, supports the DOE Energy-Water Nexus (EWN) crosscut. EWN is a set of cross-program collaborations designed to accelerate the Nation's transition to more resilient energy and coupled energy-water systems.

[a] https://www.whitehouse.gov/sites/default/files/microsites/ostp/NSTC/ftac-mm_report_final_112015_0.pdf

There is increasing urgency to address EWN challenges in an integrated way due to changing precipitation and temperature patterns, changes in extreme weather, accelerated drawdown of critical water supplies, population growth and regional migration trends, and the introduction of new technologies that could shift water and energy demands. The BER contribution to the EWN crosscut is in its first key focus area: advanced, integrated data, modeling, and analysis platform to improve understanding and inform decision-making for a broad range of users and at multiple scales.

Increased BER funding for energy-water efforts in FY 2017 will support a set of regional-scale data, modeling and analysis (DMA) test beds focusing on the integration of diverse observational data and modeling outputs, data assimilation, and both analytic and visualization tools to exercise and extend capabilities, and test limits for predictive insights. The regional-scale DMA test beds will serve as the basis for a new high resolution modeling capability for impact, adaptation, and vulnerability (IAV) analysis of energy-water systems.

Exascale computing systems, capable of at least one billion billion (1×10^{18}) calculations per second are needed to support diverse areas of research that are critical to national security objectives and applied research advances in areas such as climate and energy modeling. Exascale systems' computational power is needed to develop the science base and allow for increasingly complex modeling and data-analytic and data-intense applications across the entire Federal complex. The Exascale Computing Initiative (ECI) is a product of long-term collaboration between the SC's Advanced Scientific Computing Research (ASCR) program and the National Nuclear Security Administration's (NNSA) Advanced Simulation and Computing Campaign (ASC) program.

As part of the ECI, BER will be responsible for determining the scope and management of the Climate Modeling programs that in turn demand access to extreme scale computational capabilities. Climate modeling science requires very high resolution representations of atmospheric, oceanic, and terrestrial processes across multiple scales, to project how systems such as aerosols, clouds, precipitation, surface hydrology, ecosystems, and Arctic tundra, sea ice, and ice sheets will shift in highly variable and complex ways in response to and as part of climate change. Energy and infrastructure planning will require precise projections of temperature exceedances, water availability, sea-level rise, storm likelihood, and crop potentials. The Extreme Challenges workshop series and the Advanced Scientific Computing Advisory Committee Subcommittee report on Exascale climate science described the need to understand the dynamic physical, hydrological, biogeochemical, and ecological evolution of the climate system, with quantification of the uncertainties in regional projections as well as the impacts on regional and sub-decadal to multi-decadal scales.

FY 2017 Crosscuts ($K)

	EWN	ECI	Total
Biological and Environmental Research	24,300	10,000	34,300

Biological and Environmental Research
Funding ($K)

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs FY 2016
Biological Systems Science					
Genomic Science					
Foundational Genomics Research	73,228	73,228	76,125	104,171	+28,046
Genomics Analysis and Validation	10,000	10,000	9,248	9,248	0
Metabolic Synthesis and Conversion	16,262	16,262	16,262	16,262	0
Computational Biosciences	16,395	16,395	16,395	16,395	0
Bioenergy Research Centers	75,000	75,000	75,000	89,550	+14,550
Total, Genomic Science	**190,885**	**190,885**	**193,030**	**235,626**	**+42,596**
Mesoscale to Molecules	**9,680**	**9,680**	**9,623**	**10,623**	**+1,000**
Radiological Sciences					
Radiochemistry and Imaging Instrumentation	2,665	2,665	1,000	0	-1,000
Radiobiology	2,409	2,409	1,000	0	-1,000
Total, Radiological Sciences	**5,074**	**5,074**	**2,000**	**0**	**-2,000**
Biological Systems Facilities and Infrastructure					
Structural Biology Infrastructure	14,895	14,895	10,000	10,000	0
Joint Genome Institute	69,500	69,500	69,500	70,463	+963
Total, Biological Systems Facilities and Infrastructure	**84,395**	**84,395**	**79,500**	**80,463**	**+963**
SBIR/STTR	9,858	0	10,118	12,339	+2,221
Total, Biological Systems Science	**299,892**	**290,034**	**294,271**	**339,051**	**+44,780**
Climate and Environmental Sciences					
Atmospheric System Research	**25,892**	**25,966**	**26,392**	**26,392**	**0**
Environmental System Science					
Terrestrial Ecosystem Science	44,034	44,034	40,035	40,035	0
Subsurface Biogeochemical Research	23,533	23,533	23,207	23,207	+0
Total, Environmental System Science	**67,567**	**67,567**	**63,242**	**63,242**	**+0**
Climate and Earth System Modeling					
Climate Model Development and Validation	0	0	15,448	10,000	**-5,448**
Regional and Global Climate Modeling	26,159	26,029	30,088	30,088	**0**
Earth System Modeling	35,303	35,303	35,569	35,569	**0**
Integrated Assessment	9,733	9,789	17,567	27,874	**+10,307**
Total, Climate and Earth System Modeling	**71,195**	**71,121**	**98,672**	**103,531**	**+4,859**

[a] Reflects the transfer of Small Business Innovation/Technology Transfer Research (SBIR/STTR) funds within the Office of Science.
[b] A transfer of $1,269,000 to Science Program Direction is to consolidate all Working Capital Funds in one program.

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs FY 2016
Climate and Environmental Facilities and Infrastructure					
Atmospheric Radiation Measurement Climate Research Facility	67,429	67,429	65,429	65,429	**+0**
Environmental Molecular Sciences Laboratory	45,501	45,501	43,191	45,552	**+2,361**
Data Management	5,000	5,000	7,066	7,066	**+0**
Total, Climate and Environmental Facilities and Infrastructure	**117,930**	**117,930**	**115,686**	**118,047**	**+2,361**
SBIR/STTR	9,524	0	10,737	11,657	**+920**
Total, Climate and Environmental Sciences	**292,108**	**282,584**	**314,729**	**322,869**	**+8,140**
Total, Biological and Environmental Research	**592,000**	**572,618**	**609,000**	**661,920**	**+52,920**

SBIR/STTR Funding:

- FY 2015 transferred: SBIR $17,033,000 and STTR $2,349,000.
- FY 2016 projected: SBIR $18,135,000; STTR $2,720,000.
- FY 2017 Request: SBIR $21,038,000; STTR $2,958,000.

[a] Reflects the transfer of Small Business Innovation/Technology Transfer Research (SBIR/STTR) funds within the Office of Science.
[b] A transfer of $1,269,000 to Science Program Direction is to consolidate all Working Capital Funds in one program.

Biological and Environmental Research
Explanation of Major Changes ($K)

	FY 2017 vs FY 2016
Biological Systems Science: Investments in Genomic Science increase integrative and knowledge transfer efforts at the DOE Bioenergy Research Centers with continued complementary research on potential bioenergy feedstock plants, sustainability research for bioenergy, biosystems design, microbial community impacts on carbon and nutrient cycling, and integrative computational approaches for systems biology research. Increased investment in Genomic Science will build on BER's fundamental genomic science research and extend these activities to understanding how microbes and plants interact in a range of microbiomes of relevance to DOE's bioenergy and environmental missions. Additionally, the development of new bioimaging technology through the Mesoscale to Molecules activity will expand efforts to create new integrative imaging platforms to understand the expression and function of genome information encoded within cells. JGI continues to provide DNA sequencing, analysis and synthesis support to researchers, as well as for targeted efforts relevant to the BRAIN initiative. Final funding for Radiological Sciences is provided in FY 2016.	**+44,780**
Climate and Environmental Sciences: Climate and Earth System modeling continues investments in new research to evaluate an additional set of geographic regions that complement existing efforts in the Arctic and the Tropics, which are poorly represented in climate models yet are cause for significant sources of prediction uncertainty. New data, modeling and analysis efforts in support of the energy-water nexus crosscut will be structured around regional-scale test beds. Climate Model Development and Validation is decreased in response to model architecture restructuring that initially uses only the ARM Oklahoma site as a research testbed plus limited data collection for the ARM Alaska sites, uses new software engineering and computational upgrades, and incorporates scale-aware physics in all model components. Environmental System Science continues and will seek greater efficiencies by aggregating a higher fraction of its research into decadal-scale climate-ecosystem science campaigns e.g., NGEE Arctic, NGEE Tropics, a northern peatland experiment, and AmeriFlux. The Environmental Molecular Sciences Laboratory (EMSL) increase will address a more focused set of scientific topics that exploit recently installed capabilities involving HRMAC, live cell imaging, and radiological science capabilities, as well as more extensive use of integrating data from other EMSL instrumentation into process and systems models and simulations to address challenging problems in the biological, environmental, and climate sciences, and to benefit the BRAIN initiative. The Climate and Environmental Data Analysis and Visualization activity continues to provide an integrated capability that allows compatibility and interoperability involving both observed and model generated climate information. Information as part of this activity involves multiple model products in the Earth System Grid Federation (ESGF), and data from environmental field experiments, ARM facility observations, and components of the EMSL data base. ARM continues its investments in planned field deployments of the ARM Mobile Facilities (AMFs) to under-observed regions and develops new Unmanned Aerial Vehicle (UAV) capabilities.	**+8,140**
Total, Biological and Environmental Research	**+52,920**

Basic and Applied R&D Coordination
BER research underpins the needs of DOE's energy and environmental missions. Basic research on microbes and plants provides fundamental understanding that can be used to develop new bioenergy crops and improved biofuel production processes that enable a more sustainable bioeconomy, as outlined in the latest DOE Quadrennial Technology Report (QTR[a]) and highlighted in a recent National Academy of Sciences study on the Industrialization of Biology (NAS 2015[b]). BER fundamental bioenergy science underpins and is relevant to other DOE offices and agencies, including DOE's Office of Energy Efficiency and Renewable Energy (EERE) and the Advanced Research Projects Agency-Energy (ARPA-E), and the U.S. Department of Agriculture. Coordination with other federal agencies on priority science needs occurs through the Biomass Research and Development Board, a Congressionally mandated interagency group created by the Biomass Research and Development Act of 2000, as amended by the Energy Policy Act of 2005 and the Agricultural Act of 2014, and under the White House Office of Science and Technology Policy (OSTP). Additionally, memoranda of agreement (MOAs) have been signed with the National Science Foundation (NSF) and the National Institute of Allergy and Infectious Diseases (NIAID) to cooperate on computational biology and bioinformatic developments within the DOE Systems Biology Knowledgebase (KBase). Microbiome research is coordinated by OSTP through the Life Science Subcommittee of the National Science and Technology Council (NSTC) and priorities articulated in a recent NSTC report[c]. BER, along with other SC program offices, is in close coordination with the National Institutes of Health (NIH) and the Presidential BRAIN Initiative to develop next generation tools and technologies to optimally align exascale developments with research into the brain. The major goals for the DOE contribution to the BRAIN Initiative focus on the development of these enabling technologies, with respect to three major themes: developing the specialized, high-resolution tools for measuring key neurological processes, developing the capabilities for obtaining a dynamic, real-time read-out of these measurements, and developing the integrated computational framework for analyzing and interpreting this dynamic multi-modal data. Developing the tools to integrate and synthesize multimodal data on the brain and nervous system would be unprecedented and would inform other analyses of complex systems. A workshop will be held in FY 2016 to inform the priority requirements for developing novel biosensors and probes that can measure key molecular components or processes relevant to neuroscience.

BER research to understand and predict future changes in the earth's climate system provides important tools that link climate predictions to evaluations of new energy policies and help to guide the design criteria for next generation energy infrastructures. An example is water and the role that water plays in energy extraction, supply and transmission over a range of potential climate states including, for example, multi-year drought, and its role as a balancing factor for energy production when wind and solar energy renewables are included. Water and energy bring together SC, energy technology offices, and energy policy offices of the Department. Coordination among these offices is important for understanding not only water required for all facets of energy production, from biofuels to thermoelectric cooling, but also the energy required to provide water for various uses. BER research on the transport and transformation of energy-related substances in subsurface environments provides understanding that can enable DOE's Office of Environmental Management (EM) to develop new strategies for the remediation of weapons-related and other contaminants at DOE sites, as informed by a recent workshop on Basic Research Needs for EM. In general, BER coordinates with DOE's applied technology programs through regular joint program manager meetings, by participating in their internal program reviews and in joint principal investigator meetings, as well as conducting joint technical workshops. Coordination with other federal agencies on priority climate science needs occurs through the interagency U.S. Global Climate Change Research Program (USGCRP) under OSTP.

Program Accomplishments
Fundamental Bioenergy Research. Research results from the DOE Bioenergy Research Centers (BRCs) continue to demonstrate significant progress towards developing new dedicated bioenergy feedstocks and new products from renewable biomass. Switchgrass, specifically modified to be less recalcitrant to cellulosic sugar extraction, thrived in field trials demonstrating the environmental robustness of this potential bioenergy crop. Upon harvest, the modified switchgrass displayed superior bioenergy conversion characteristics relative to native switchgrass demonstrating the development of a new potential bioenergy feedstock. New insights into the composition and structure of lignin have identified ways to recover value-added products from this otherwise by-product of cellulose extraction. Research on the bond structure of lignin has led to new ways to recover aromatic chemicals from this polymer. Likewise, components of ionic liquids, used for the deconstruction of biomass to cellulosic sugars, can be synthesized from compounds derived from lignin. Combined, these results advance the ability to recover and/or make useful products from biomass-derived lignin, a notoriously recalcitrant

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[a] http://energy.gov/epsa/downloads/quadrennial-energy-review-full-report
[b] http://www.nap.edu/catalog/19001/industrialization-of-biology-a-roadmap-to-accelerate-the-advanced-manufacturing
[c] https://www.whitehouse.gov/sites/default/files/microsites/ostp/NSTC/ftac-mm_report_final_112015_0.pdf

structural component of plant cell walls. Because lignin makes up a significant percentage of biomass by weight, these findings represent new potential methods to increase the overall efficiency and range of products that can be produced from renewable biomass.

Biosystems Design Research. Recent advances in the Genomic Science activity are making progress on developing the required techniques to underpin a burgeoning biotechnology industry focused on the production of biofuels and bioproducts from renewable biomass. Researchers within the Genomic Science activity recently developed a new genetic system for photosynthetic diatoms that will enable investigations of the biofuel and bioproduct production potential of these microbes. Lack of a robust genetic system often limits the use of most microorganisms as platforms for genetic engineering. This new technique, while applicable to diatoms, may also hold promise for a range of other currently genetically intractable microorganisms needed for biotechnological purposes. Similarly, new high throughput methods to track genetic manipulations within genetically tractable microorganisms are needed to accelerate biotechnological research. A new technique (TRACE) has recently been demonstrated that can more efficiently track genetic modifications in tens of thousands of individual test microbes at a time. The new method efficiently maps combinations of engineered genomic mutations to track and identify those microbes with an enhanced tolerance to biofuel compounds. The technique is broadly applicable to a range of microbial species and will enable rapid screening of modified microbes for bioenergy and bioproducts production. Rapid advances in genetic modification of microorganisms have raised concerns over the potential for proliferation of modified organisms in the environment. New insights into genomic recoding techniques show how microorganisms could be engineered for not only beneficial bioenergy or bioproduct production purposes but also to strictly limit their survival to laboratory settings. New results show how microbial genomes can be recoded to rely on nonstandard amino acids (not available in Nature) thereby restricting their survival to laboratory settings. This research is important to demonstrate new biocontainment strategies that could be employed as developments in biotechnology continue to advance at a very rapid pace in concert with concerns over its use.

Plant Genomes for Bioenergy Research. Researchers at the DOE Joint Genome Institute (JGI) recently completed the genome of the eucalyptus tree. JGI is a primary source of complex plant and microbial community genomes for bioenergy and environmental research and completion of the eucalyptus genome is a milestone for BER's bioenergy research efforts. Eucalyptus is one of the most widely planted hardwood trees in the world and represents a globally significant resource for pulp, paper, biomaterials and bioenergy. The complex genome extending across 11 chromosomes is significant because eucalyptus produces a rather diverse set of metabolites that can be readily developed into a range of biofuels or other bioproducts. With the completed genome researchers can also use the information for comparative genomic studies of hardwood trees to identify other beneficial bioenergy traits.

Improving Climate Models to Better Predict Precipitation. While climate models are adept at predicting future temperature changes on regional and global scales, the quality of precipitation predictions has not kept pace. To address this need, scientists used observations from the DOE Atmospheric Radiation Measurement Climate Research Facility (ARM) to discover that precipitation forecasts are limited largely by overly simplistic formulas for Secondary Organic Aerosols (SOAs) that influence droplet initiation and cloud formation. Using laboratory and field experimental data, the research has improved the understanding of SOA chemistry, including better understanding of how SOAs serve as cloud condensation nuclei. The improved formulas were incorporated into a climate model with significantly improved predictability of clouds and precipitation.

Simulating Agricultural Irrigation in Earth System Models. World agriculture consumes about 87 percent of global fresh water withdrawal, acting as a dominant component of the global water cycle with impacts on local and regional climates. Previous studies of irrigation impacts on climate have focused on a subset of local surface processes, but no study has applied uncertainty quantification methodologies to the combination of atmospheric, terrestrial, and water cycle interdependencies. Scientists upgraded the land component (CLM4) of the Community Earth System Model (CESM), to simulate irrigation water use and climatic feedbacks. Drawing upon two widely-used data sets from the agriculture census, they found that CLM4 could be improved by applying updated calibrations and incorporating information on the spatial distribution and intensity of irrigated areas. More importantly, the team identified a way to realistically assess the impacts of irrigation on climate and strategies to improve water management practices. Their results integrate a new set of CLM4 modules into CESM that describe groundwater pumping and irrigation efficiency, stream flow routing, and water management.

Biological and Environmental Research
Biological Systems Science

Description

Biological Systems Science integrates discovery- and hypothesis-driven science with technology development on plant and microbial systems relevant to national priorities in clean energy and innovation in life sciences and biology. Systems biology is the multidisciplinary study of complex interactions specifying the function of entire biological systems—from single cells to multicellular organisms—rather than the study of individual isolated components. The Biological Systems Science subprogram employs systems biology approaches to define the functional principles that drive living systems, from microbes and microbial communities to plants and other whole organisms.

Key questions that drive these studies include:

- What information is encoded in the genome sequence?
- How is information exchanged between different subcellular constituents?
- What molecular interactions regulate the response of living systems and how can those interactions be understood dynamically and predictively?

The subprogram builds upon a successful track record in defining and tackling bold, complex scientific problems in genomics—problems that require the development of large tools and infrastructure; strong collaboration with the computational sciences community and the mobilization of multidisciplinary teams focused on plant and microbial bioenergy research. The approaches employed include genome sequencing, proteomics, metabolomics, structural biology, high-resolution imaging and characterization, and integration of information into computational models that can be iteratively tested and validated to advance a predictive understanding of biological systems from molecules to mesoscale.

The subprogram supports operation of a scientific user facility, the DOE Joint Genome Institute (JGI), and use of structural biology facilities through the development of instrumentation at DOE's national scientific user facilities. Support is also provided for research at the interface of the biological and physical sciences and instrumentation to develop new methods for real-time, high-resolution imaging of dynamic biological processes.

Genomic Science

The Genomic Science activity supports research seeking to reveal the fundamental principles that drive biological systems relevant to DOE missions in energy, climate, and the environment. These principles guide the interpretation of the genetic code into functional proteins, biomolecular complexes, metabolic pathways, and the metabolic/regulatory networks underlying the systems biology of plants, microbes, and communities. Advancing fundamental knowledge of these systems will enable new solutions to national challenges in sustainable bioenergy production, understanding how microbial activity impacts the fate and transport of materials such as nutrients and contaminants in the environment, and developing new approaches to examine the role of biological systems in carbon cycling, biosequestration, and global climate.

The major objectives of the Genomic Science activity are to determine the molecular mechanisms, regulatory elements, and integrated networks needed to understand genome-scale functional properties of microbes, plants, and communities; develop "-omics" experimental capabilities and enabling technologies needed to achieve a dynamic, system-level understanding of organism and community functions; and develop the knowledgebase, computational infrastructure, and modeling capabilities to advance predictive understanding, manipulation and design of biological systems.

A major effort within the portfolio seeks to provide a fundamental understanding of the biology of plants and microbes as a basis for developing cost effective processes for biofuel production from cellulosic biomass. The DOE BRCs are central to this effort and have provided a substantial body of scientific literature and intellectual property towards this goal; increased funding will speed translation of basic research results to industry for contributions to clean energy. Genomic Science also supports fundamental research on identification and introduction of desired traits for new bioenergy crops and microbes, as well as understanding soil microbial communities and how they impact the cycling and fate of carbon, nutrients and contaminants in the environment. A new effort in microbiome research will build on and complement existing genomic-based research, through the study of natural microbiomes and model microbiomes in targeted field environments relevant to BER's bioenergy and climate science research efforts. With a long history in microbial genomics-based research coupled with substantial biotechnological and computational capabilities available within the DOE user facilities, BER is well positioned to make significant contributions to understanding microbiome function.

Finally, these systems biology efforts are supported by the ongoing development of bioinformatics and computational biology capabilities within the DOE Systems Biology Knowledgebase (KBase). The integrative KBase project seeks to develop the necessary hypothesis-generating analysis techniques and simulation capabilities on high performance computing platforms to accelerate collaborative and reproducible systems biology research within the Genomic Sciences.

Mesoscale to Molecules

BER approaches to systems biology focus on translating information encoded in an organism's genome to those traits expressed by the organism. These genotype to phenotype translations are key to gaining a predictive understanding of cellular function under a variety of environmental and bioenergy-relevant conditions. The Mesoscale to Molecules activity will continue to encourage the development of new measurement and imaging technologies to visualize the spatial and temporal relationships of key metabolic processes governing phenotypic expression in plants and microbes. This information is crucial towards developing an understanding of the impact of various environmental and/or biosystems designs on whole cell or community function. The activity also has relevance to visualizing cell-cell or cell-plant interactions within a microbiome association.

Biological Systems Science Facilities and Infrastructure

Biological Systems Science supports unique scientific facilities and infrastructure related to genomics and structural biology that are widely used by researchers in academia, the national laboratories, and industry. The DOE JGI is the only federally funded major genome sequencing center focused on genome discovery and analysis in plants and microbes for energy and environmental applications. High-throughput DNA sequencing underpins modern systems biology research, providing fundamental biological data on organisms and groups of organisms. By understanding shared features of multiple genomes, scientists can identify key genes that may link to biological function. These functions include microbial metabolic pathways and enzymes that are used to generate fuel molecules, affect plant biomass formation, degrade contaminants, or capture CO_2, leading to the optimization of these organisms for biofuels production and other DOE missions.

The JGI is developing aggressive new strategies for interpreting complex genomes through new high-throughput functional assays, DNA synthesis and manipulation techniques and, genome analysis tools in association with the DOE Systems Biology KBase. These new capabilities are part of the JGI's latest strategic plan to provide users with additional capabilities supporting biosystems design efforts for biofuels and environmental process research, and can also provide synergistic capabilities in partnership with other SC user facilities for the BRAIN initiative. The JGI also performs metagenome (genomes from multiple organisms) sequencing and analysis from environmental samples and single cell sequencing techniques for hard-to-culture microorganisms from understudied environments relevant to the DOE missions. These new metagenomics capabilities will be crucial to supporting a new effort in microbiome research.

BER also supports development and use of specialized instrumentation for biology at major DOE user facilities, such as synchrotron light sources and neutron facilities, in collaboration with the other SC program offices. These research facilities enable science aimed at understanding the structure and properties of biological molecules at resolutions and scales not accessible with instrumentation available in university, research institute, or industrial laboratories. This information is critical in contributing to our understanding of the relationship between genome, biological structure, and function. BER is also taking steps to ensure that the data will be integrated into the DOE Systems Biology KBase to help accelerate practical applications of this knowledge for energy and the environment.

Biological and Environmental Research
Biological Systems Science

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs FY 2016 Enacted
Biological Systems Science $294,271,000	**$339,051,000**	**+$44,780,000**
Genomic Science $193,030,000	**$235,626,000**	**+$42,596,000**
Genomic Science continues to remain a top priority. Foundational Genomics increases to develop biosystems design techniques for plants and microbial systems relevant to bioenergy production and research on key parameters influencing the sustainability of bioenergy crops. Genome Analysis and Validation continues research on improving the functional characterization of microorganisms and microbial communities relevant to biofuel production. Metabolic Synthesis and Conversion continues research to broaden the range of model plant and microbial systems available for bioenergy research and, to understand the impact of microbial communities on the fate of carbon, nutrients and contaminants in the environment. At least 5% of the funding for biodesign efforts is provided for studies on the environmental, ethical, legal, and societal impacts. Computational Biosciences continues to advance the bioinformatics and computational biology techniques needed within the DOE Systems Biology KBase to accelerate systems biology research. Bioenergy research at the DOE Bioenergy Research Centers continues to provide a fundamental scientific basis for cellulosic biofuels production.	Microbes rarely exist in isolation in nature and in fact interact in myriad dynamic ways with each other and with changing signals from the environment. These collective interactions constitute a microbiome and most of BER's basic bioenergy and environmental process research depends on gaining a more predictive understanding of microbiome function. Foundational Genomics will increase to support a new effort in microbiome research to evaluate interactions between microorganisms and plants in microbiomes of relevance to BER's bioenergy and environmental science missions. Biosystems design efforts will increase to pursue innovative techniques to manipulate microbe and plant genomes for beneficial purposes and sustainability research will provide new insights into bioenergy crop production for clean energy. Genome Analysis and Validation will continue research on improving the functional characterization of microorganisms and microbial communities relevant to biofuel production. Metabolic Synthesis and Conversion will continue research to expand the range of model plant and microbial systems for bioenergy research and, to understand the impact of microbial communities on the fate of carbon, nutrients and contaminants in the environment. Computational Biosciences will continue to develop the computational platforms, analysis techniques and bioinformatics tools needed within the DOE KBase to accelerate systems biology research. Bioenergy research at the DOE BRCs will begin its tenth year of operations providing DOE with a fundamental scientific basis for cellulosic biofuels production.	The increase will support a new effort in microbiome research, which will provide insight into multiple microbiomes of relevance to DOE's sustainable bioenergy and environmental missions. It will also provide funding to initiate new work in biosystems design research to allow the selective transfer of genomic traits among plants and microbes. This facilitates developing the metabolic potential of plants and microbes for clean energy and a bio-based economy. The BRCs will receive increased funding for the final year of their funding period, which will support efforts to speed translation of basic research results to industry for contributions to clean energy.

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs FY 2016 Enacted
	Additional funding will accelerate knowledge transfer. A competitive FOA issued in FY 2016 will determine the selection of the next phase of the BRCs in FY 2017.	
Mesoscale to Molecules $9,623,000	**$10,623,000**	**+$1,000,000**
The program continues to develop new enabling technologies to visualize key metabolic processes in plants and microbes. These new techniques provide integrative information on the spatial and temporal relationships of metabolic processes occurring within and among cells. This information is crucial to integrating molecular scale understanding of metabolic processes into the context of the dynamic whole cell environment and to the development of predictive models of cell function.	The program will continue efforts to develop new integrative bioimaging technologies. These efforts dovetail with the ongoing research in the genomic science activity and seek to provide ways to visualize the dynamic processes of gene expression and function in vivo. Increased funding will broaden the activity to a more diverse set of potential bioimaging applications under development.	Increased funding will expand the current set of bioimaging projects under development within the portfolio.
Radiological Sciences $2,000,000	**$0**	**-$2,000,000**
Funding supports the orderly closeout of Radiological Science activities in FY 2016.	Activities are completed.	
Biological Systems Science Facilities and Infrastructure $79,500,000	**$80,463,000**	**+$963,000**
The JGI remains an essential component for genomic research within BER. The facility continues to implement its latest strategic plan and provide scientific users with plant and microbial genome sequences of the highest quality and advanced capabilities to analyze, interpret and manipulate genes in support of bioenergy, biosystems design and environmental research. The JGI continues to collaborate closely with the DOE Systems Biology KBase to provide not only community access to sequenced genomes but access to computational systems to experimentally interrogate those genomes.	The JGI will continue to provide essential genome sequencing and new genome analysis capabilities for BER programs. The facility will continue to evolve with the scientific user community as it revises and implements its strategic plan. The facility will continue to focus on complex plant and microbial communities' genome sequencing efforts that are the hallmark of the facility and of fundamental importance to BER's genomic science-based efforts in bioenergy and environment. The JGI will continue to collaborate closely with the DOE Systems Biology Knowledgebase to provide community access to sequenced genomes and access to high performance computational systems to experimentally interrogate those genomes. The JGI will partner with other SC user facilities to provide targeted user access to recently developed	This increase supports JGI partnerships with other SC user facilities to provide targeted user facility access for the BRAIN initiative.

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs FY 2016 Enacted
	new capabilities for high throughput functional assays and DNA writing and manipulation techniques, aligned with priorities identified in a scientific workshop held in FY 2016. These new capabilities would be uniquely synergistic with the BRAIN initiative efforts to develop bioprobes and bio-compatible electronics for neurological networks.	
Access to the Structural Biology Infrastructure at the DOE synchrotron light and neutron sources continues to provide information on the structural features of biomolecules and continue to make this information available to the larger research community through the Protein Data Base and the DOE Systems Biology Knowledgebase (KBase).	Access to the Structural Biology Infrastructure at the DOE synchrotron light and neutron sources will continue. These capabilities will continue to provide access to instrumentation to evaluate structural features of biomolecules and make this information available to the larger research community through the Protein Data Base and the DOE Systems Biology Knowledgebase.	

Biological and Environmental Research
Climate and Environmental Sciences

Description

The Climate and Environmental Sciences subprogram supports fundamental science and research capabilities that enable major scientific developments in climate-relevant atmospheric and ecosystem process and modeling research, in support of DOE's mission goals for basic science, energy, and national security. This includes research on clouds, aerosols, and the terrestrial carbon cycle; large-scale climate change and Earth system modeling; the interdependence of climate change and ecosystems; and integrated analysis of climate change impacts on energy and related infrastructures, with a view toward increasing fractions of renewable energy of total U.S. energy production. It also supports subsurface biogeochemical research that advances fundamental understanding of coupled physical, chemical, and biological processes controlling both the terrestrial component of the carbon cycle and the environmental fate and transport of energy byproducts, including greenhouse gases. This integrated portfolio of research from molecular-level to field-scales emphasizes the coupling of multidisciplinary experimentation and advanced computer models and is aimed at developing predictive, systems-level understanding of the fundamental science associated with climate change and other energy-related environmental challenges. The Department will continue to advance the science necessary to further develop predictive climate and Earth system models targeting resolution at the regional spatial scale and interannual to centennial time scales and to focus on areas of critical uncertainty including Arctic ecology and permafrost thaw, tropical ecological change, and carbon release, in close coordination with the U.S. Global Change Research Program (USGCRP) and the international science community. In addition, environmental research activities will support fundamental research to explore advances in environmental cleanup and reductions in life cycle costs.

The subprogram supports three primary research activities, two national scientific user facilities, and a major data activity. The two national scientific user facilities are the Atmospheric Radiation Measurements Climate Research Facility (ARM) and the Environmental Molecular Sciences Laboratory (EMSL). ARM provides unique, multi-instrumented capabilities for continuous, long-term observations and model–simulated high resolution information that are needed to develop and test understanding of the central role of clouds and aerosols on climate scales and on spatial scales extending from local to global. EMSL provides integrated experimental and computational resources needed to understand the physical, biogeochemical, chemical, and biological processes that underlie DOE's energy and environmental mission. The data activity encompasses observations collected by dedicated field experiments, routine and long term observations accumulated by user facilities, and model generated information derived from climate modeling platforms.

<u>Atmospheric System Research</u>

Atmospheric System Research (ASR) is the primary U.S. activity addressing two major areas of uncertainty in climate change model projections: the role of clouds and the effects of aerosols on precipitation, and the atmospheric radiation balance. ASR coordinates with ARM, using the facility's continuous long-term datasets that provide three-dimensional measurements of radiation, aerosols, clouds, precipitation, dynamics, and thermodynamics over a range of environmental conditions at diverse climate-sensitive locations. The long-term observational datasets are supplemented with laboratory studies and shorter-duration, ground-based and airborne field campaigns to target specific atmospheric processes under a diversity of locations and atmospheric conditions. ASR research results are incorporated into Earth system models developed by Climate and Earth System Modeling to both understand the processes that govern atmospheric components and to advance Earth system model capabilities with greater certainty of predictions. ASR seeks to develop integrated, scalable test-beds that incorporate process-level understanding of the life cycles of aerosols, clouds, and precipitation into dynamic models.

<u>Environmental System Science</u>

Environmental System Science supports research to provide a robust, predictive understanding of terrestrial surface and subsurface ecosystems, including the effects of climate change, from the subsurface to the top of the vegetated canopy and from molecular to global scales. This includes understanding the role of ecosystems in climate with an emphasis on carbon cycling and the role of subsurface biogeochemical processes in the fate and transport of carbon, nutrients, radionuclides, and heavy metals.

A significant fraction of the CO_2 released to the atmosphere during fossil fuel combustion is taken up by terrestrial ecosystems, but the impacts of climatic change, particularly warming, on the uptake of CO_2 by the terrestrial biosphere remain poorly understood. The significant sensitivity of climate models to terrestrial carbon cycle feedback and the uncertain signs of that feedback make resolving the role of the terrestrial biosphere on the carbon balance a high priority.

Using decadal-scale investments such as the Next Generation Ecosystem Experiments (NGEEs) to study the variety of time scales and processes associated with ecological change, the research focuses on understanding, observing, and modeling the processes controlling exchange rates of greenhouse gases, in particular CO_2 and methane (CH_4), between atmosphere and terrestrial biosphere, evaluating terrestrial source-sink mechanisms for CO_2 and CH_4, and improving and validating the representation of terrestrial ecosystems in coupled Earth system models. This research supports the USGCRP interagency priority to understand the impacts of global change on the Arctic Region and resulting effects on global climate. Subsurface biogeochemical research supports integrated experimental and modeling research, ranging from molecular to field scales, to understand and predict the role that biogeochemical processes play in controlling the cycling and mobility of energy-relevant materials in the subsurface and across key surface-subsurface interfaces in the environment, including environmental contamination from past nuclear weapons production.

Climate and Earth System Modeling

Climate and Earth System Modeling develops physical, chemical, and biological model components, as well as fully coupled Earth system models that combine with sophisticated representations of human activities. This research includes the interactions of human and natural Earth systems needed to simulate climate variability and change from years to decades to centuries at regional and global scales. The research specifically focuses on quantifying and reducing the uncertainties in Earth system models based on more advanced model development, diagnostics, and climate system analysis. Priority model components include the ocean, sea-ice, land-ice, aerosols, atmospheric chemistry, terrestrial carbon cycling, multi-scale dynamical and physical interdependencies, and dynamical cores. This research supports the USGCRP interagency priority in intraseasonal to centennial predictability, predictions and projections, including focus on extreme events.

Climate Model Development and Validation continues at reduced levels. The focus of the investment involves model architecture restructuring, exploiting new software engineering and computational upgrades, and incorporating scale-aware physics in all model components, as part of the DOE-wide Exascale Computing Initiative (ECI) crosscut. DOE modeling activities will continue development of modularized components that can act either alone or as a system able to run on current and next generation supercomputers, thus allowing greater certainty of predictions in a flexible structure. Because model development requires systematic validation at each step, investment in model assessment and validation will continue. Examples include the use of ARM data combined with scale-aware Large Eddy Simulation products. High resolution ARM and model ensemble data bases will be integrated into the advanced data management infrastructure effort, the Climate and Environmental Data Analysis and Visualization activity, for use by the scientific research community. Other validation platforms include the sensitivity and uncertainty of climate predictions to explore climate sensitive geographies or processes as well as the representation of extreme events in these next generation models.

The Regional and Global Climate modeling activity will increase investments in scientific analyses using DOE's capabilities in climate and Earth system modeling. Models will be utilized in order to develop and analyze a new set of high resolution simulations of extreme events, that directly support the DOE-wide Energy-Water Nexus crosscut objectives, with particular focus on evaluating the influence of extremes on the interdependence of energy and water, in the context of Sankey diagrams. The Regional and Global Climate modeling activity will additionally conduct scientific analyses to study the predictability of statistical distributions of future weather extremes that exhibit short repeat times, i.e., that in turn have the potential to cause cascading impacts on energy-water infrastructures. The Regional and Global Climate Modeling activity will continue to analyze the causes and distributions of droughts; biogeochemical controls on abrupt climate change; the role of the highly resolved patterns of carbon budgets on regional and global climate change; and the roles of cryospheric phenomena (sea ice, glaciers, ice sheets, and permafrost thaw) on Arctic climate, sea level rise, and large scale modes of variability. Also, research will explore model–derived analogs that combine historical and projected climate changes, with an objective to validate and improve the uncertainty characterization of future climate projections based on the prediction successes using existing data testbeds. To rapidly and efficiently advance model capabilities, BER supports a unique and powerful intercomparison resource, the Program for Climate Model Diagnosis and Intercomparison (PCMDI), for global climate model development, validation, diagnostics, and outputs, using over 40 world-leading climate models. This set of diagnostic and intercomparison activities combined with scientific analysis, ensures that BER funded researchers can exploit the best available science and practice within each of the world's leading climate research programs.

The Earth System Modeling activity in BER will continue to coordinate with the National Science Foundation (NSF) to provide support for greater sophistication of Earth system models, in particular the Community Earth System Model system (CESM) that is co-funded by DOE and NSF. CESM is designed by the research community with open access and broad use by climate researchers worldwide. In addition, DOE will continue to advance a new version of CESM, i.e., the Accelerated Climate

Model for Energy (ACME), as a computationally efficient model adaptable to emerging computer architectures and with greater sophistication and fidelity for high resolution simulation. This system of models provides a critical capacity for regional climate projections, including information on how the frequency of occurrence and intensity of storms, droughts, heat waves, and regional sea-level will change as climate evolves. The scientific priorities for improvement of the community models are based on efforts to quantify uncertainties relative to specific scientific questions; and the outputs of the intercomparison and validation resource allow one to determine best features of all global models that can be considered for incorporation into DOE's ACME modeling platform. DOE also has provided computational capability and expertise to the climate research community through a partnership between BER and the Office of Science's Advanced Scientific Computing Research (ASCR) program, which is investing in innovative code and algorithm designs for optimal model computation on its petascale computers. Climate modeling, simulation, and analysis tools are essential for informing investment decision-making processes for infrastructure associated with future large-scale deployment of energy supply and transmission.

The Integrated Assessment activities in BER develop integrated assessment (IA) models and impacts analyses, and will continue efforts to integrate adaptation and vulnerability (IAV) capabilities into the modeling and predictive capabilities. Expanded efforts will specifically support the Energy-Water Nexus objectives, with focus on development and demonstration of a novel high–resolution community IA-IAV hybrid model system, improving not only the resolution but also the detailed process representations for autonomous elements as well as for coupled energy-water-land system interdependencies. Also, efforts will be dedicated to establish a set of three to four regional-scale data, modeling and analysis test beds, outputs from which provide a foundation for future development of an Integrated Field Laboratory (IFL), an instrumented field research and observation site to conduct sophisticated research that utilizes the enhanced data, modeling, and analytical capabilities of the regional test beds to understand process and infrastructure interdependencies under water-stressed conditions. The Integrated Assessment activity will address uncertainty characterization of both the individual physical, biogeophysical, and sectoral (including energy infrastructure as well as emerging clean energy technology deployment) drivers, extending from macroscale (greater than 50 km resolution) to the much finer scales of Earth system prediction (order of 10 km).

Climate and Environmental Facilities and Infrastructure

Climate and Environmental Facilities and Infrastructure include two scientific user facilities, and climate data management for the climate science community. The scientific user facilities—the Atmospheric Radiation Measurement Climate Research Facility (ARM), and the Environmental Molecular Sciences Laboratory (EMSL)—provide the broad scientific community with technical capabilities, scientific expertise, and unique information to facilitate science in areas integral to BER's mission.

ARM is a multi-platform, multi-site, national scientific user facility, providing the world's most comprehensive continuous field measurements of climate data to advance atmospheric process understanding and climate models through precise observations of atmospheric phenomena. ARM currently consists of three fixed, long-term measurement facility sites (in Oklahoma, Alaska, and the Azores), three mobile facilities, and an airborne research capability that operates at sites selected by the scientific community. The ARM fixed sites and mobile measurement campaigns are distributed around the world in locations where the scientific community most critically needs enhanced understanding and data to incorporate into climate models, thereby improving model performance and predictive capabilities. Each of the ARM sites includes scanning radars, lidar systems, and *in situ* meteorological observing capabilities; the sites are also used to demonstrate technologies as they are developed by the community. ARM experiments to study the impact of evolving clouds, aerosols, and precipitation on the Earth's radiative balance and rate of climate change address the two most significant scientific uncertainties in climate research. ARM will incorporate very high resolution Large Eddy Simulations (LES) at the permanent Oklahoma site, during specific campaigns requested by the scientific community. BER is also maintaining the exponentially increasing data archive to support enhanced analyses and model development. The data extracted from the archive are used to improve climate projections at higher resolution, greater sophistication, and lower uncertainty.

EMSL provides integrated experimental and computational resources for discovery and technological innovation in the environmental molecular sciences. EMSL enables users to undertake molecular-scale experimental and theoretical research on biological systems, biogeochemistry, aerosol chemistry, and interfacial and surface science relevant to climate, energy, and environmental challenges facing DOE and the Nation. This includes science supporting alternative energy sources, improved catalysts and materials for industrial applications, insights into factors influencing climate change and carbon sequestration processes, and subsurface biogeochemical drivers. EMSL will address a more focused set of scientific topics that capitalize on recently installed capabilities involving HRMAC, live cell imaging, and radiological science capabilities, and more extensive utilization of other EMSL instrumentation into process and systems models and simulations to address challenging problems in the biological, environmental, and climate sciences.

Data sets generated by ARM, other DOE and Federal Earth observing activities, and Earth system modeling activities, are enormous. The information in Earth observations data can be used to achieve broad benefits ranging from planning and development of energy infrastructure to natural disaster impact mitigation to commercial supply chain management to natural resource management. Access to and uses of these data are fundamental to supporting decision-making, scientific discovery, and technological innovation. DOE's data management activities will be coordinated with the Big Data Research and Development Initiative,[a] and internally collaborative with ASCR programs.

In FY 2017, the BER Data Management activity will continue efforts to harmonize and integrate metadata from the Earth System Grid Federation, ARM and NGEE field experiments, and relevant components of data. Analytical tools will be integrated into the program, including capabilities for diagnostics, validation, and uncertainty quantification.

[a] http://www.whitehouse.gov/sites/default/files/microsites/ostp/big_data_press_release_final_2.pdf

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016 Enacted
Climate and Environmental Sciences $314,729,000	**$322,869,000**	**+$8,140,000**
Atmospheric System Research (ASR) $26,392,000	**$26,392,000**	**$0**
ASR continues to focus on atmospheric cloud and aerosol issues that limit climate modeling capabilities, with a particular emphasis on Arctic mixed phase clouds and tropical systems with large variations of aerosol characterization. ASR exploits Large Eddy Simulation (LES) as a tool to understand scale-aware physics governing aerosol transformations, cloud nuclei formation and growth, and cloud evolution. ASR utilizes a combination of observations and LES modeling to explore strongly heterogeneous environments, as observed in the Arctic and the Tropics, to advance the range of conditions applicable to nonhydrostatic parameterizations (models with less than 10 km resolution).	ASR will coordinate with Climate and Earth System Modeling to focus activities on atmospheric cloud and aerosol issues that limit climate modeling capabilities, with increasing emphasis on very high resolution process representations and new efforts on land-atmosphere interactions that impact aerosol and cloud processes. Research on Arctic mixed phase clouds and marine stratocumulus clouds will exploit new observational capabilities. Increased use of Large Eddy Simulation (LES) as a tool to understand scale-aware physics governing aerosol transformations, cloud nuclei formation and growth, and cloud evolution will benefit from enhanced ARM measurements at the Oklahoma site and case study data sets for northern Alaska.	Funding continues at the FY 2016 Enacted level. Research will exploit new data generated by Large Eddy Simulations available from ARM sites, newly developed airborne data sets collected with Unmanned Aerial Systems, and new marine, Arctic, and Antarctic observations. A new class of ASR research efforts will couple observations and the ARM Facility Large Eddy simulation database to extend process level understanding.
Environmental System Science (ESS) $63,242,000	**$63,242,000**	**+$0**
Research continues with NGEE Arctic Phase II, with multiple sites in northern Alaska involved in observation and modeling. NGEE Tropics begins early observations to test new modeling architectures, appropriate for tropical terrestrial systems. The subsurface biogeochemistry investments involve a combination of advanced modeling architectures and field research, with existing data used to test predictive modeling concepts. AmeriFlux supports efforts to improve terrestrial land modeling component, to test new concepts and build testbeds for high resolution land model validation.	Research will continue in Alaska, using a larger set of field stations expanded from Barrow. NGEE tropics will continue model analysis with field measurements collected in a variety of tropical regimes, e.g., in Puerto Rico and Brazil, where diverse ecological conditions are exposed to significant climate forcing.	Funding continues at the FY 2016 Enacted level. Research will begin to incorporate field experimental data into new climate model architectures.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016 Enacted
Climate and Earth System Modeling $98,672,000	**$103,531,000**	**+$4,859,000**
Research continues to extend capabilities for the Accelerated Climate Model for Energy (ACME) to include nonhydrostatic atmospheric modeling (less than 10 km resolution), more sophisticated ice sheet physics, and a new approach for terrestrial modeling that uses plant functional traits instead of plant "types" for more physical representation of biology. The program initiates investments to advance software and physics describing the interface between ice-sheets and other components (ocean, land and atmosphere), and new methods for capturing the statistics of climate change. Regional modeling analysis addresses interdependencies involving the water and energy sectors, using details on existing and projected infrastructures. In addition, funding for this program supports the development of new multi-ensemble statistical methods for vulnerability analysis applied to the energy-water-land nexus, with special focus on regional coastal inundation and storm-surge, changes in water availability for a coupled climate-human system, and energy implications of extreme events. Interdependencies of the energy-water nexus are explored within a full climate system analysis, as well as developing vulnerability analysis techniques to treat the energy-water nexus with existing and projected infrastructure.	Research to extend ACME capabilities will continue to focus on enhancing the land component (including ecological processes) to address the more rapidly changing conditions expected for a variety of geographic domains. Statistical and dynamical uncertainty methods will be incorporated for all components of the ACME system, including land, ocean, atmosphere, cryosphere, and the human component. This will considerably enhance the human component, with the development of a hybrid model that combines Integrated Assessment and Impact, Adaptation, and Vulnerability; and this hybrid modeling approach will be exercised to describe the energy-water nexus of challenges facing U.S. energy and water infrastructures. The program will apply advanced software upgrades to all modeling components. A set of science topics involving future extremes in climate states, including drought, will be studied with both the ACME model and other models (such as the Community Earth System Model) that have a sufficient level of process level sophistication that is needed to address mission challenges of relevance to the Department.	Increases will be dedicated to new efforts in integrated assessment modeling to understand process interactions involving the energy-water nexus, and will fund a set of three to four regional-scale data, modeling, and analysis test beds to accelerate synthesis of integrated toolsets in diverse environments and explore predictive challenges associated with the energy-water nexus.
Climate Model Development and Validation focus on model architecture restructuring, exploiting new software engineering and computational upgrades, incorporating scale-aware physics in all model components and enhanced efforts to assess and validate model results.	Climate Model Development and Validation will continue to develop model architecture restructuring, exploiting new software engineering and computational upgrades, incorporating scale-aware physics in all model components and efforts to assess and validate model results.	
Core research in Regional and Global Climate Modeling, Earth System Modeling and Integrated Assessment continues to underpin high-resolution	Efforts will continue to focus on the dynamical and statistical analysis of climate extremes, with supporting efforts specifically focused on arctic-	

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016 Enacted
predictability using adaptive grids and uncertainty characterization, and more sophisticated data management.	midlatitude interactions, drought evolution, atmospheric rivers, carbon-nutrient cycle feedbacks, and impacts of interannual variations of ocean circulations (such as El Nino and the Arctic Oscillation).	
Climate and Environmental Facilities and Infrastructure $115,686,000	**$118,047,000**	**+$2,361,000**
ARM continues to support its long-term measurements at fixed sites, and the mobile facilities are deployed to three climate-sensitive regions demanding targeted measurements. The first mobile facility remains in the Amazon Basin for the first quarter, thereafter undergo maintenance; the second is deployed to Antarctica; and the third continues the experiment in Oliktok, Alaska. These observations, combined with dedicated modeling and simulation, are key to reducing the earth system model uncertainties attributed to clouds and aerosols. The ARM second mobile facility deployment to Antarctica represents the first major ARM campaign in the southern hemisphere. Incorporation of modeling and simulation as part of ARM data acquisition is initiated	ARM will continue to support and enhance its long-term measurements at fixed sites. To support the goal of better linking ARM observations to global climate models to reduce key climate uncertainties, ARM will increase the measurement density around its Oklahoma and Alaska sites, enhance observations for land-atmosphere coupling, develop higher order data products that are more suitable for model evaluation, and develop instrument simulators for direct evaluation of models with observational data. Dedicated high resolution Large Eddy Simulations will be integrated routinely into ARM data acquisition. New Unmanned Aerial Vehicle capabilities will provide unprecedented observations in extreme Arctic conditions. ARM mobile facilities will be deployed to under-observed climate-sensitive regions where targeted measurements will provide critical data to the science community.	The ARM mobile facility will provide the first scanning cloud radar data in Antarctica to the scientific community. Data generated by Large Eddy Simulations and newly deployed Unmanned Aerial Vehicles at the Oklahoma and Alaska sites trigger a new level of sophisticated science on aerosol and cloud processes.
EMSL continues to support users and their research in biological systems, biogeochemistry, aerosol chemistry, and interfacial and surface science relevant to climate, energy, and environmental challenges facing DOE and the Nation. Emphasis is placed on utilization of new capabilities in the Radiological Annex and Quiet wing. In FY 2016 the integrated HRMAC system is available for new research. The installation and availability of the HRMAC, with its 21Tesla magnet, provides unique enhancements to EMSL's capabilities available to the research community.	EMSL facility operations support experimental and computational user research in biological systems science, hydrobiogeochemistry, ecosystems science, vegetative emissions and aerosol chemistry, and interfacial chemistry and surface science relevant to climate, energy, and environmental challenges facing DOE and the Nation. Support will emphasize the use of advanced imaging capabilities in the Quiet wing to investigate processes in living plant and microbial cells and their interactions with the surrounding environment. The HRMAC 21 Tesla mass spec system will be used to identify the molecular composition of	EMSL expands user research on the new and unique HRMAC system to address previously unattainable research challenges and provide new scientific understanding of the molecular composition of aerosol particles and emissions from plants, interactions within microbial biofilms, intra- and intercellular processes, and imaging of intact proteins. EMSL will partner with other SC user facilities to provide targeted user facility access for the BRAIN initiative.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016 Enacted
	aerosol samples, microbial communities and cellular products. Molecular-level reaction chemistry of radioactive elements and materials from waste tanks and the subsurface will be explored using unique instruments in RadEMSL. EMSL (in partnership with other SC user facilities) will provide targeted user facility access to the JGI and EMSL, to address BRAIN and systems biology science priorities in cellular biochemical and metabolic flux, membrane protein dynamics, and develop modeling approaches that can be used to integrate multimodal data. These priorities will be informed by a scientific workshop held in FY 2016.	
The Climate and Environmental Data Analysis and Visualization activity continues to advance high resolution earth system models and data management capabilities, with a greater focus on nonhydrostatic dynamical cores, extreme events, and the assimilation of Large Eddy Simulation ensembles to provide statistics of sub-grid parameterizations for a wider range of conditions involving extreme events. Model-data fusion is explored with new visualization technologies.	The data activity will continue to develop an integrative framework of metadata, data standards, and interoperability, such that data holdings of the Carbon Dioxide Information Analysis Center, Earth System Grid Federation, and the Atmospheric Radiation Measurement Climate Research Facility will be linked by a common framework. In addition, data from other agencies of interest to DOE funded scientists, such as the NASA DAACs, will be established within the common framework. In order to support the requirements of the next Coupled Model Intercomparison Project of the IPCC, the framework will also be improved with capabilities to conduct server side analyses that utilize all data archives accessible by the framework.	The Climate and Environmental Data Analysis and Visualization activity will provide an integrated capability that allows compatibility and interoperability involving both observed and model generated climate information. Information as part of this activity involves multiple model products in the Earth System Grid Federation (ESGF), and data from environmental field experiments, ARM facility observations, and components of the EMSL data base.
Participation in the Big Earth Data Initiative continues.		

Biological and Environmental Research
Performance Measures

In accordance with the GPRA Modernization Act of 2010, the Department sets targets for, and tracks progress toward, achieving performance goals for each program. The following table shows the targets for FY 2015 through 2017. Details on the Annual Performance Report can be found at http://energy.gov/cfo/reports/annual-performance-reports.

	FY 2015	FY 2016	FY 2017
Performance Goal (Measure)	**BER Climate Model—Develop a coupled climate model with fully interactive carbon and sulfur cycles, as well as dynamic vegetation to enable simulations of aerosol effects, carbon chemistry, and carbon sequestration by the land surface and oceans and the interactions between the carbon cycle and climate**		
Target	Develop capabilities to extend temporal resolution to sub-decadal for earth system models.	Develop and apply a fully coupled ice-sheet model to estimate near-term changes to the West Antarctic ice sheet.	Extend the capabilities of the DOE's Accelerated Climate Model for Energy (ACME), to simulate and evaluate human-natural interdependencies for the carbon and water cycles.
Result	Met	TBD	TBD
Endpoint Target	BER supports the Community Earth System Model, a leading U.S. climate model, and addresses two of the most critical areas of uncertainty in contemporary climate science—the impacts of clouds and aerosols. Delivery of improved scientific data and models (with quantified uncertainties) about the potential response of the earth atmosphere system to more accurately predict the earth's future climate is essential to plan for future energy needs, water resources, and land use. DOE will continue to advance the science necessary to further develop predictive climate and earth system models at the regional spatial scale and decadal to centennial time scales, involving close coordination with the U.S. Global Change Research Program and through the international science community.		
Performance Goal (Measure)	**BER Predictive Understanding of Biological Systems—Advance an iterative systems biology approach to the understanding and manipulation of plant and microbial genomes as a basis for biofuels development and predictive knowledge of carbon and nutrient cycling in the environment.**		
Target	Develop 1 new computationally enabled approach to analyze complex genomic datasets.	Develop an improved metabolic engineering method for modifying microorganisms for biofuel production from cellulosic sugars.	Develop improved open access platforms for computational analysis of large genomic datasets.
Result	Met	TBD	TBD
Endpoint Target	BER will advance understanding of the operating principles and functional properties of plants, microbes, and complex biological communities relevant to DOE missions in energy and the environment. Deciphering the genomic blueprint of organisms and determining how this information is translated to integrated biological systems permits predictive modeling of bioprocesses and enables targeted redesign of plants and microbes. BER research will address fundamental knowledge gaps and provide foundational systems biology information necessary to advance development of sustainable bioenergy systems and predict impacts of changing environmental conditions on carbon cycling and other biogeochemical processes.		

Biological and Environmental Research
Capital Summary ($K)

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Capital Operating Expenses Summary							
Total Non-MIE Capital equipment (projects under $5 million TEC)	n/a	n/a	4,667	5,139	4,500	4,500	0

Funding Summary ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Research	375,293	375,293	400,025	446,480	+46,455
Scientific user facilities operations and research	197,325	197,325	188,120	191,444	+3,324
Other[a]	19,382	0	20,855	23,996	+3,141
Total, Biological and Environmental Research	**592,000**	**572,618**	**609,000**	**661,920**	**+52,920**

Facility Operations ($K)

The treatment of user facilities is distinguished between two types: TYPE A facilities that offer users resources dependent on a single, large-scale machine; TYPE B facilities that offer users a suite of resources that is not dependent on a single, large-scale machine.

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
TYPE B FACILITIES					
Atmospheric Radiation Measurement Climate Research Facility (ARM)	**$67,429**	**$67,429**	**$65,429**	**$65,429**	**+0**
Number of users	900	900	950	1,000	+50
Joint Genome Institute	**$69,500**	**$69,500**	**$69,500**	**$70,463**	**+963**
Number of users	1,000	1,000	1,300	1,300	0
Environmental Molecular Sciences Laboratory	**$45,501**	**$45,501**	**$43,191**	**$45,552**	**+2,361**
Number of users	715	715	715	750	+35
Structural Biology Infrastructure[b]	**$14,895**	**$14,895**	**$10,000**	**$10,000**	**0**
Total Facilities	**$197,325**	**$197,325**	**$188,120**	**$191,444**	**+3,324**
Number of users	2,615	2,615	2,965	3,050	+85

[a] Includes SBIR and STTR.
[b] Structural Biology Infrastructure activities are at Basic Energy Sciences user facilities and the user statistics are included in the BES user statistics.

Scientific Employment

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Estimate	FY 2017 vs FY 2016
Number of permanent Ph.D.'s	1,295	1,295	1,350	1,410	+60
Number of postdoctoral associates	320	320	330	342	+12
Number of graduate students	440	440	450	470	+20
Other[a]	320	320	330	342	+12

[a] Includes technicians, engineers, computer professionals and other support staff.