Biological and Environmental Research

Overview

The mission of the Biological and Environmental Research (BER) program is to support transformative science and scientific user facilities to achieve a predictive understanding of complex biological, earth, and environmental systems for energy and infrastructure security, independence, and prosperity.

The program seeks to understand the biological, biogeochemical, and physical principles needed to understand fundamentally and be able to predict the processes occurring at scales ranging from the molecular and genomics-controlled smallest scales to environmental and ecological processes at the scale of planet Earth. Starting with the genetic information encoded in organisms' genomes, BER research seeks to discover the principles that guide the translation of the genetic code into the 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 will enable design and reengineering of microbes and plants underpinning energy independence and a broad clean energy portfolio, including improved biofuels and bioproducts, improved carbon storage capabilities, and controlled biological transformation of materials such as nutrients and contaminants in the environment. An equally important focus is ensuring that emerging technologies in gene editing and genomics are developed using approaches that enhance the stability, resilience, and controlled performance of biological systems in the environment. BER research also advances the fundamental understanding of dynamic, physical, and biogeochemical processes required to systematically develop Earth System models that integrate across the atmosphere, land masses, oceans, sea ice, and subsurface. These predictive tools and approaches are needed to inform policies and plans for ensuring the security and resilience of the Nation's critical infrastructure.

Over the last two decades, BER's scientific impact has been transformative. Mapping the human genome through the U.S.-supported international Human Genome Project that DOE initiated in 1990 ushered in a new era of modern biotechnology and genomics-based systems biology. Today, researchers in the BER Genomic Sciences activity and the Joint Genome Institute (JGI), as well as in the four DOE Bioenergy Research Centers (BRCs), are using the powerful tools of plant and microbial systems biology to pursue the innovative early-stage research that will lead to the development of future transformative bio-based products, clean energy, and next generation technologies.

Since the 1950s, BER and its predecessor organizations have been critical contributors to fundamental scientific understanding of the atmospheric, land, ocean, and environmental systems in which life exists. The earliest work included atmospheric and ocean circulation studies initiated to understand the effects of fallout from nuclear explosions in the early period of the Cold War. These efforts were the forerunners of the modern Earth System models that are in use today. Presently, BER research contributes to model development and analysis and intercomparison; in the last decade, DOE research has made considerable advances in increasing the reliability and predictive capabilities of these models using applied mathematics and systematic comparisons with observational data to reduce uncertainties. BER-supported research also has produced the software and algorithms that enable the productive application of these models on DOE supercomputers, which are among the most capable in the world. These leading U.S. models are used to further fundamental understanding of two of the most critical areas of uncertainty in contemporary Earth system sciences—the impacts of clouds and aerosols—with data provided by the Atmospheric Radiation Measurement Research Facility (ARM), a DOE user facility serving hundreds of scientists worldwide. Also, BER research has pioneered ecological and environmental studies in terrestrial ecosystems, seeking to describe the continuum of biological, biogeochemical, and physical processes across the multiple scales that control the flux of 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 tools to characterize biological organisms and molecules as well as atmospheric aerosol particulates.

Highlights of the FY 2019 Budget Request

The FY 2019 BER Request continues the Administration decisions in FY 2018 to prioritize early-stage, innovative research and technologies that show promise in harnessing American energy resources safely and efficiently. This program supports research that advances the core missions of the DOE while maintaining American leadership in the area of scientific inquiry and discovery. BER's support of basic research today will contribute to a future of stable, reliable, and secure sources of American energy based on transformative science for economic prosperity. BER activities continue to support core research in genomics and high-resolution Earth System models, leveraging investments and scientific user facilities in key areas of bioenergy and secure biosystems design, Earth systems modeling and observations, and environmental sciences.

The federally chartered BER Advisory Committee (BERAC) advises BER on its future development of effective research strategies for sustained leadership in biological and environmental research. BERAC holds targeted workshops, periodic reviews, and forward looking overviews of BER relevant science, and the outcomes of these activities inform BER's ongoing and future research in reports such as the "Grand Challenges for Biological and Environmental Research: Progress and Future Vision"[a].

Biological Systems Science

Investments in the Biological Systems Science subprogram provide the fundamental understanding to underpin transformative science in sustainable bioenergy production and to gain a predictive understanding of plant and microbial physiology, microbiomes, and biological systems in support of DOE's energy and environmental missions. The Genomic Sciences activity will prioritize support for the second year of four next phase DOE Bioenergy Research Centers (BRCs), performing new fundamental research underpinning the production of fuels and chemicals from sustainable biomass resources and the building blocks of new technological advances for translation of basic research results to industry. Within the Genomics Sciences activity, Genomics Analysis and Validation and Metabolic Synthesis and Conversion will be combined and retitled Environmental Genomics. New secure biosystems design activities will be initiated to identify the fundamental engineering principles that control biological systems, with a specific goal of enhancing the stability, resilience, and controlled performance of engineered biological systems. These fundamental genomic science activities will consolidate and coordinate ongoing environmental genomics efforts on sustainability and microbiomes research in mission-relevant ecosystems. Computational Biosciences efforts will continue to combine molecular and genomic scale information within the DOE Systems Biology Knowledgebase and to develop integrated networks and computational models of system dynamics and behavior.

Mesoscale to Molecules and Structural Biology Infrastructure will be combined and retitled Biomolecular Characterization and Imaging Science. Research will continue to support structural, spatial, and temporal understanding of functional biomolecules and processes occurring within living cells. New efforts in advanced bioimaging and characterization of quantum information science (QIS) and advanced sensors will contribute to a systems-level predictive understanding of biological processes.

The DOE Joint Genome Institute (JGI) will continue to be 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 will continue 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 bioenergy and bioproducts research, and environmental research. The JGI will initiate a slow ramp down of activities in preparation for a FY 2020 move into the Integrative Genomics Building on the Lawrence Berkeley National Laboratory campus.

Earth and Environmental Systems Sciences

Earth and Environmental Systems Sciences research activities will focus on scientific analysis of how physical and biogeochemical processes impact the sensitivity and uncertainty of Earth system predictions. The Subsurface Biogeochemistry Research activity will focus on modeling of the flows of subsurface nutrients and materials. Investments will continue to support the E3SM (Energy Exascale Earth System Model) capability, tailored to DOE requirements for a variety of scenarios applied to spatial scales as small as 10 km. The model system will have improved resolution that will include advanced software for running on numerous processors, flexibility toward future DOE 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 will continue to provide new observations selected to represent the diversity of environmental conditions necessary to advance Earth System models. ARM continues long-term measurements at fixed sites in Alaska and Oklahoma. ARM will limit operations of the Arctic mobile facility at Oliktok and maintain operations at the Azores fixed site. The mobile facility will be deployed to the Cloud, Aerosol, and Complex Terrain Interactions (CACTI) field campaign in the Andes to improve understanding of cloud life cycle and organization in relation to environmental conditions so that cumulus, microphysics,

[a] https://science.energy.gov/~/media/ber/berac/pdf/Reports/BERAC-2017-Grand-Challenges-Report.pdf

and aerosol parameterizations in multiscale models can be improved. The ARM facility will acquire and replace the aerial capability.

EMSL will focus on a research agenda aligned with priority BER biology and environmental program research areas enabling characterization and quantification of the biological and chemical constituents as well as dynamics of complex natural systems in the environment, with a focus on microbial communities, and soil and rhizosphere ecosystems.

The Data Management effort will focus on field observations and data from environmental field experiments.

Biological and Environmental Research
Funding ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Biological Systems Science				
Genomic Science				
Foundational Genomics Research	89,571	–	80,000	-9,571
Environmental Genomics[b]	25,510	–	16,000	-9,510
Computational Biosciences	16,395	–	16,000	-395
Bioenergy Research Centers	75,000	–	100,000	+25,000
Total, Genomic Science	**206,476**	–	**212,000**	**+5,524**
Biomolecular Characterization and Imaging Science[c]	**19,623**	–	**24,908**	**+5,285**
Biological Systems Facilities and Infrastructure				
Joint Genome Institute	69,463	–	70,000	+537
Total, Biological Systems Facilities and Infrastructure	**69,463**	–	**70,000**	**+537**
SBIR/STTR	11,159	–	11,589	+430
Total, Biological Systems Science	**306,721**	–	**318,497**	**+11,776**
Earth and Environmental Systems Sciences				
Atmospheric System Research	**25,836**	–	**12,000**	**-13,836**
Environmental System Science				
Terrestrial Ecosystem Science	40,035	–	14,000	-26,035
Subsurface Biogeochemical Research	22,143	–	5,000	-17,143
Total, Environmental System Science	**62,178**	–	**19,000**	**-43,178**
Earth and Environmental Systems Modeling[d]	**90,564**	–	**33,626**	**-56,938**
Earth and Environmental Systems Sciences Facilities and Infrastructure				
Atmospheric Radiation Measurement Research Facility	65,429	–	66,000	+571
Environmental Molecular Sciences Laboratory	43,191	–	42,000	-1,191
Data Management	7,066	–	3,000	-4,066
Total, Earth and Environmental Systems Sciences Facilities and Infrastructure	**115,686**	–	**111,000**	**-4,686**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] Environmental Genomics contains previous subprograms of Genomics Analysis and Validation, and Metabolic Synthesis and Conversion.

[c] Biomolecular Characterization and Imaging Science contains previous Mesoscale to Molecules, and Structural Biology Infrastructure.

[d] Earth and Environmental Systems Modeling reflects all previous Modeling activities (Regional and Global Model Analysis, Earth System Modeling, and Integrated Assessment).

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
SBIR/STTR	11,015	–	5,877	-5,138
Total, Earth and Environmental Systems Sciences	**305,279**	–	**181,503**	**-123,776**
Total, Biological and Environmental Research	**612,000**	**607,844**	**500,000**	**-112,000**

SBIR/STTR Funding:

- FY 2017 Enacted: SBIR $19,440,000; and STTR $2,734,000
- FY 2019 Request: SBIR $15,313,000; and STTR $2,153,000

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

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

	FY 2019 Request vs FY 2017 Enacted
Biological Systems Science: Within Genomic Sciences, the Request prioritizes research activities to continue early-stage core research to understand the complex mechanisms controlling the interplay of microbes and plants within broader organized biological systems. Foundational Genomics research supports secure biosystems design research to understand the fundamental genome structure and functional relationships that result in specific new and beneficial plant and microbial traits. Environmental Genomics (formerly Genomics Analysis and Validation, and Metabolic Synthesis and Conversion) supports research on understanding environmentally relevant microbiomes and the interdependencies between plants and microbes in a sustainable and resilient ecosystem. The four DOE Bioenergy Research Centers will be fully supported in their second year of bioenergy research to underpin efforts to produce innovative biofuels and bioproducts from renewable biomass resources. Development of new bioimaging, measurement and characterization approaches through the Biomolecular Characterization and Imaging Science activity (formerly Mesoscale to Molecules and Structural Biology Infrastructure) will include new integrative imaging and analysis platforms, including using QIS materials, to understand the expression, structure, and function of genome information encoded within cells.	**+11,776**
Earth and Environmental Systems Sciences: The Request continues to support the development of high-resolution Earth system modeling, analysis, and intercomparison capabilities focused on DOE mission needs for energy and infrastructure resilience and security. Environmental System Science will continue a focus on Arctic field studies and the fate and transport of nutrients. ARM will acquire and replace its aerial capability. Using observations from the ARM facility, Atmospheric System Research will continue to advance knowledge and improve model representations of atmospheric gases, aerosols, and clouds on the Earth's energy balance. The ARM mobile facility will be deployed to the Andes; operations of the Arctic mobile facility at Oliktok will be seasonally limited. EMSL will focus on biological and environmental molecular science.	**-123,776**
Total, Biological and Environmental Research	**-112,000**

Basic and Applied R&D Coordination
BER research underpins the needs of DOE's energy and environmental missions, and is coordinated through the National Science and Technology Council (NSTC). This includes all biological, Earth and environmental systems modeling, renewable energy, and field experiments involving atmospheric, ecological, and hydro-biogeochemical sciences research. Basic research on microbes and plants provides fundamental knowledge that can be used to develop new bioenergy crops and improved biofuel and bioproduct production processes that enable a more sustainable bioeconomy, coordinated with other federal agencies on priority bioeconomy 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.

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.

Program Accomplishments
Fundamental Bioenergy Research. Efforts at the DOE BRCs continue to lead the world in basic research to underpin the development of biofuels and bioproducts from sustainable biomass resources.

Bioenergy Research Centers: Ten years of research from the original three BRCs has led to significant advances in bioenergy research. The prospect of developing dedicated bioenergy crops with specific engineered traits capable of thriving in the environment was recently demonstrated by researchers at the BioEnergy Science Center (BESC). Switchgrass engineered to express an altered lignin structure thrived in field trials over a 3-year period relative to controls. The crops retained the reduced recalcitrance phenotype and yielded 25-32% more sugar release upon deconstruction demonstrating the viability of a specifically designed bioenergy crop. Progress in biomass deconstruction has led Great Lakes Bioenergy Research Center (GLBRC) researchers towards development of new solvents that can break down biomass into defined component streams. Research with gamma-valerolactone dissolves and separates up to 80% of biomass into cellulose, hemicellulose and lignin. These components can be further converted to useful biofuels, specialty chemicals and lignin-based carbon foam, all commercially valuable products, as a basis for an integrated biorefinery process producing fuels and chemicals from renewable biomass. Research at the Joint BioEnergy Institute (JBEI) built on previous metabolic engineering advances to produce advanced jet fuel compounds from cellulosic sugars. A constructed mevalonate pathway was designed to produce linalool and eucalyptol, jet fuel components from cellulosic glucose. The research is a culmination of a series of metabolic engineering advances at JBEI laying a foundation for a broader biotechnology industry producing fuels and chemicals from renewable biomass.

Genomic Science: Basic research efforts continue to gain insights into the functioning of biological systems relevant to DOE missions.

- Researchers at Massachusetts Institute of Technology have designed a yeast strain that accumulates 25% more lipids than control strains, useful for renewable biodiesel fuel production. The research uses an innovative combination of computational hypothesis generation and experimental testing to guide metabolic engineering techniques, an important approach for systematizing biosystems design techniques.
- Oak Ridge National Laboratory researchers using multi-omics approaches identified 417 specific genes in *Populus* that may serve as signaling molecules between plants and microbial communities. These molecules secreted by the plant were shown to be present in fungal nuclei and may serve as regulatory proteins for symbiotic interactions, a key finding for understanding controls on plant-microbe interactions.
- Lawrence Berkeley National Laboratory (LBNL)-led researchers are developing new tools to experimentally identify genes of unknown function in bacterial genomes, a major limitation in systems biology research. The new high through-put technique tracks the impact of random mutations in bacteria during growth under a broad range of conditions to identify genes of unknown function. Using this system, the team identified ~8,500 genes whose functions were not previously known from a set of 25 tested bacteria.
- Researchers from the University of Washington examining methane oxidation in lake sediments have developed a new approach to understand microbial community dynamics. Using a combination of constructed microbial communities and multi-omics techniques, the researchers could track gene expression within the community and observed nutritional dependencies within the population to explain changes in observed methane oxidation

patterns from the environment. The work demonstrates an approach to use advanced "-omics" techniques of microbial communities to explain larger biogeochemical processes in the environment.

Joint Genome Institute: The JGI continues to be the primary source for genomic information on plants, microorganisms and microbial communities for BER programs and a leader in developing new genomics techniques for BER research. Deep sequencing of environmental samples continues to reveal the breadth of microbial species and the diversity of genes detected in the environment. JGI, in a collaboration led by the University of Washington are using metagenomics to identify protein encoding genes from environmental samples. Using the Rosetta software, researchers were able to generate 614 model structures of protein families with no known structure. Many of these structures contained unique protein folds not currently represented in the Protein Data Bank. The work highlights a unique attempt to marry structural biology with environmental metagenomics to uncover the diversity of protein structures detectable in nature, with broad implications for bioenergy, environmental and health research.

Modeling the Earth System. Advanced modeling concepts, high performance computing, and new observations allow emerging Earth System models to more confidently capture extreme weather events and to better understand how these events interact with the atmospheric, oceanic, and terrestrial components of the Earth system. A new DOE high-resolution Earth System model will be released in April 2018 as the world's highest resolution capability to study interdependencies involving the atmosphere, oceans, and terrestrial processes. With the power of DOE's fastest supercomputers, this Energy Exascale Earth System Model (E3SM) will be able to conduct complex uncertainty analyses on spatial resolutions that span from 10 km down to 500 m. These analyses resulted in identification and reduction of significant errors and biases in Earth System models that have previously been limiting confidence in model analyses and predictions. In addition, super parameterization of clouds in the high resolution atmospheric component of E3SM can more accurately capture extreme precipitation patterns and rainfall events. Results also indicate that the amount of precipitation can vary over the course of successive El Niño Southern Oscillation (ENSO) events of different strengths, thereby producing even more confident projections of extreme precipitation in the future.

Observations from the Atmospheric Radiation Measurement Research Facility (ARM), a SC scientific user facility, were used to develop and evaluate new formulations of low cloud processes for global models. Low clouds, which are highly reflective of incoming sunlight, are a source of significant uncertainty in Earth System models. An analysis of cloud condensation nuclei from ARM observations collected at five different sites around the world led to improved model representation of the variability of cloud water content in different geographic regions.

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 energy security and resilience 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 subprogram employs approaches such as 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 the operation of the DOE Bioenergy Research Centers (BRCs) and the DOE Joint Genome Institute (JGI) scientific user facility.

<u>Genomic Science</u>
The Genomic Science activity supports research seeking to reveal the fundamental principles that drive biological systems relevant to DOE missions in energy security and resilience. 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 clean energy production, breakthroughs in genome-based biotechnology, understanding the role of biological systems in the environment, and adapting biological design paradigms to physical and material systems.

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; to develop "-omics" experimental capabilities and enabling technologies needed to achieve a dynamic, system-level understanding of organism and community functions; and to develop the knowledgebase, computational infrastructure, and modeling capabilities to advance predictive understanding, manipulation and design of biological systems.

Foundational Genomics supports fundamental research on discovery and manipulation of genome structural and regulatory elements and epigenetic controls to scale from genotype to phenotype in microbes and plants. Efforts in biosystems design research build on and complement existing genomics-based research, through development of new secure gene-editing and multi-gene stacking techniques for microbes and plants. The results will yield an increased range of microorganisms and plants as model research organisms to expand and complement available biological systems for bioenergy and biotechnology research.

Environmental Genomics combines previous Genomics Analysis and Validation, and Metabolic Synthesis and Conversion activities, and supports research focused on understanding plants and soil microbial communities and how they impact the cycling and fate of carbon, nutrients, and contaminants in the environment. The activity includes the study of a range of natural and model microbiomes in targeted field environments relevant to BER's research efforts. With a long history in plant and microbial genomics research coupled with substantial biotechnological and computational capabilities available within the DOE user facilities, BER is well positioned to make transformative contributions in biotechnology and understanding microbiome and phytobiome function.

Computational Biosciences supports all Genomic Science systems biology activities through 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.

The major DOE BRCs effort within the Genomic Science portfolio seeks to provide a fundamental understanding of the biology of plants and microbes as a basis for developing innovative processes for bioenergy and bioproducts production from inedible cellulosic biomass. The four BRCs develop a range of advanced biofuels and bioproducts from sustainable biomass resources and provide high-payoff technology and early-stage research results that can be adapted for industry adoption and development of transformative commercial products and services.

Biomolecular Characterization and Imaging Science (formerly known as Mesoscale to Molecules, and Structural Biology Infrastructure) supports approaches to systems biology that 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 Biomolecular Characterization and Imaging Science activity will enable development of new bioimaging, measurement, and characterization technologies to visualize the structural, spatial, and temporal relationships of key metabolic processes and critical biomaterials governing phenotypic expression in plants and microbes. The activity will include new efforts to characterize quantum information science materials in new environmental sensors. This information is crucial for developing an understanding of the impact of various environmental and/or biosystems designs on whole cell or community function.

Biological Systems Science Facilities and Infrastructure

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, and is widely used by researchers in academia, the national laboratories, and industry. 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 cost effective biofuels and bioproducts production and other DOE missions.

The DOE 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 KBase. These advanced capabilities are part of the DOE JGI's latest strategic plan to provide users with additional, highly efficient, capabilities supporting biosystems design efforts for biofuels and environmental process research. The DOE 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.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Biological Systems Science $306,721,000	**$318,497,000**	**+$11,776,000**
Genomic Science $206,476,000	**$212,000,000**	**+$5,524,000**
The funding for Foundational Genomics enabled BER to lead the anticipated growth in synthetic biology and biosystems design efforts for biofuels and bioproducts. This included establishing selected sets of well-defined model microbes, plants and fungi as platforms for synthetic biology, with a robust set of tools tailored to industrially-relevant conditions and a range of environmental variables. Microbiome research focused on improved bioinformatic tools for microbiome gene annotation, high-throughput approaches to cultivate organisms of interest, characterized their physiological properties, and developed genetic tool kits for their experimental manipulation across a range of different plant hosts and soil types. Computational Biosciences continued and integrated new datasets for protein structure, genome-based biomaterials and biosystems design toolkits and software. BER selected four new BRCs from a recompetition in FY 2017, and provided first year funding in FY 2018 at reduced funding levels.	Foundational Genomics research will support biosystems design research to develop the understanding needed to engineer beneficial traits into microbes, plants, and fungi for a variety of bioenergy, bioproduct and biotechnological purposes. Environmental Genomics will focus on environmental microbiome research and develop new multi-omics techniques with computational modeling and experimentation to infer interactions among and between microbial species and/or plants and fungi and the impacts on the cycling of materials in the environment. Computational Bioscience will focus on integration of high priority multi-omic datasets for microbiome and bioenergy-related research within the DOE Systems Biology Knowledgebase in collaboration with bioinformatics capabilities within the JGI. The four BRCs will begin their second year of support. Research will focus on development of dedicated bioenergy crops informed by economic/agronomic modeling, feedstock agnostic deconstruction processes, development of a broader range of microbial conversion pathways to produce fuels and chemicals from cellulose and lignin, and new ways to sustainably cultivate bioenergy crops on marginal lands.	Foundational Genomics will focus on development of a number of high priority platform organisms for secure biosystems design research. Environmental Genomics will emphasize microbiome research efforts to understand interactions among plants and microbes in soils. Computational Bioscience will emphasize multiomics capabilities supporting microbiome and bioenergy research needs within the DOE Systems Biology Knowledgebase, in collaboration with the JGI. The BRCs are fully supported in FY 2019. The BRCs will prioritize research on bioenergy crops with the greatest projected economic/agronomic benefit, cost efficient deconstruction processes, microbial conversion pathways to valorize lignin and new methods to sustainably cultivate bioenergy crops.

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Biomolecular Characterization and Imaging Science[1] $19,623,000	**$24,908,000**	**+$5,285,000**
Biomolecular Characterization and Imaging Science funding continued to augment advanced imaging capabilities for biological systems through strategic investments in end stations and beamlines for the BES-supported light sources and neutron sources. BER continues to need new capabilities beyond x-ray crystallography, such as electron cryomicroscopy and other bioimaging techniques, including the use of quantum materials, to support BER's systems-level approach to understanding biological processes. Advanced multi-functional imaging techniques provided spatial and temporal understanding of functional genomics within living cells; this information can be integrated to gain a systems-level predictive understanding of biological processes.	Funding will support molecular science capabilities to characterize, measure and image basic metabolic processes and critical biomaterials occurring in plant and microbial cells relevant to BER's bioenergy and environmental research efforts. Development of multi-functional techniques will continue and include quantum techniques providing atomic-level imaging and characterization capabilities. These characterization and imaging capabilities offer the ability to validate current understanding and models of biological processes through direct visualization and/or measurement.	Multifunctional imaging development will prioritize on those methods most relevant to bioenergy and environmental research including quantum imaging, molecular characterization techniques and characterization of critical biomaterials to provide unprecedented observations of biological processes with which to validate current understanding and models.
Biological Systems Science Facilities and Infrastructure $69,463,000	**$70,000,000**	**+$537,000**
JGI continued to focus on sequencing very large and complex plant genomes and metagenomics samples, especially from complex field environments. It continued to advance its capabilities to interpret genomes and provide the research community with a broad variety of new and cutting functional genomics techniques that increase efficiency. Funding also allowed for incorporation of JGI bioinformatics techniques.	JGI will continue to serve as a primary source of genomic sequences of plants, microorganisms and microbial communities for BER programs and the broader research community. It will continue to develop its capabilities to support large complex plant, metagenomics and environmental microbiome sequencing efforts, including support for the four new Bioenergy Research Centers. It will continue to collaborate with the DOE Systems Biology Knowledgebase and prepare for a move to the LBNL campus.	JGI will prioritize on supporting bioenergy research and integrating its bioinformatics capabilities with the DOE Systems Biology Knowledgebase. Support will continue for the Community Science Program to support plant, microbial, fungal and metagenomic sequencing needs of the larger scientific community and preparing for the move to the LBNL campus.
Access to the Structural Biology Infrastructure at the DOE Synchrotron light and Neutron sources continued for high-resolution structural characterization of biomolecules. Efforts began to link data resources (i.e., PDB) with the DOE KBase.	Structural Biology Infrastructure is moved and combined within the Biomolecular Characterization and Imaging Science activity, as noted above.	

[1] Formerly known as Mesoscale to Molecules and Structural Biology Infrastructure

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
SBIR/STTR $11,159,000	**$11,589,000**	**+$430,000**
In FY 2017, SBIR/STTR funding was set at 3.65% of non-capital funding.	In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.	

Description

The Earth and Environmental Systems Sciences subprogram supports fundamental science and research capabilities that enable major scientific developments in Earth system-relevant atmospheric and ecosystem process and modeling research in support of DOE's mission goals for transformative science for energy and national security. This includes research on components such as clouds, aerosols, and terrestrial ecology; modeling of component interdependencies under a variety of forcing conditions; interdependence of atmospheric, hydrological, ecosystem, and cryospheric variabilities; vulnerability and resilience of the full suite of energy and related infrastructures to extreme events; and uncertainty quantification. It also supports subsurface biogeochemical research that advances fundamental understanding of coupled physical, chemical, hydrological, and biological processes controlling energy byproducts in the environment. This integrated portfolio of research from molecular-level to field-scales emphasizes the coupling of multidisciplinary experimentation and advanced computer models, with a goal to develop and enhance a predictive, systems-level understanding of the fundamental science that addresses environmental and energy-related challenges associated with e.g. extreme phenomena. The Department will continue to advance the science necessary to further develop an understanding of Earth System models of variable sophistication, targeting resolution at the regional spatial scale and from seasonal to multi-decadal time scales, and to focus on areas of critical uncertainty. In addition, environmental research activities will continue to advance basic science to optimize and accelerate environmental cleanup and reductions in life cycle costs.

The subprogram supports three primary research activities, two SC scientific user facilities, and a data activity. The two SC scientific user facilities are the Atmospheric Radiation Measurement 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 researchers need to improve understanding and develop and test hypotheses involving the role of clouds and aerosols on the atmosphere's spectrally-resolved radiative balance over a variety of spatial scales, extending from local to global. EMSL provides integrated experimental and computational resources that researchers utilize in order to extend understanding of the physical, biogeochemical, chemical, and biological processes that underlie DOE's energy and environmental mission. The data activity encompasses both observed and model-generated data that are collected by the ARM facility and during dedicated field experiments; this activity also archives information generated by Earth System models of variable complexity and sophistication.

Atmospheric System Research

Atmospheric System Research (ASR) is the primary U.S. research activity addressing two major areas of uncertainty in earth system models: the interdependence of clouds, atmospheric aerosols, and precipitation that in turn influences the radiation balance. ASR coordinates with ARM, using the facility's continuous long-term datasets that in turn provide three-dimensional measurements of radiation, aerosols, clouds, precipitation, dynamics, and thermodynamics over a range of environmental conditions at diverse geographic 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 diverse locations and atmospheric conditions. Earth System models incorporate ASR research results to both understand the processes that govern atmospheric components and to advance Earth System model capabilities with greater certainty. ASR seeks to develop integrated, scalable test-beds that incorporate process-level understanding of the life cycles of aerosols, clouds, and precipitation, that can be incorporated into dynamic models.

Environmental System Science

Environmental System Science supports research to provide a robust and scale-aware predictive understanding of terrestrial surface and subsurface ecosystems, including the role of hydro-biogeochemistry from the subsurface to the top of the vegetative canopy that considers effects of seasonal to interannual variability and change on spatial scales that span from molecular to global.

Using decadal-scale investments such as the Next Generation Ecosystem Experiment (NGEE) to study the variety of time scales and processes associated with ecological change, Environmental System Science research focuses on understanding, observing, and modeling the processes controlling exchange flows between the atmosphere and the terrestrial biosphere, and improving and validating the representation of terrestrial ecosystems in coupled Earth System models. Subsurface biogeochemical research supports integrated modeling research, ranging from molecular to field scales, to understand and predict the role that hydrological and 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.

Earth and Environmental Systems Modeling

Earth and Environmental Systems Modeling develops physical, chemical, and biological model components, as well as fully coupled Earth System models, in coordination with other Federal efforts. The research specifically focuses on quantifying and reducing the uncertainties in Earth System models based on more advanced process representations, sophisticated software, robust couplers, diagnostics, and performance metrics. Priority model components include the ocean, sea-ice, land-ice, atmosphere, and terrestrial ecosystems, where each are treated as interdependent and is able to exploit dynamic grid technologies. Support of diagnostic and intercomparison activities, combined with scientific analysis, allows BER funded researchers to exploit the best available science and practice within each of the world's leading Earth system research programs. In addition, DOE will continue to support the Energy Exascale Earth System Model (E3SM) as a computationally efficient model adaptable to DOE's emerging Leadership Computing Facility supercomputer architectures and with greater sophistication and fidelity for high resolution simulation of extreme phenomena and complex processes. Earth system modeling, simulation, and analysis tools are essential for informing energy infrastructure investment decisions that have the future potential for large-scale deployment that in turn benefit our national security.

Earth and Environmental Systems Sciences Facilities and Infrastructure

The Earth and Environmental Systems Sciences Facilities and Infrastructure activity supports data management and two scientific user facilities for the earth and environmental systems sciences communities. The scientific user facilities, ARM and 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-laboratory, multi-platform, multi-site, national scientific user facility, providing the world's most comprehensive continuous and precise observations of clouds, aerosols, and related meteorological information. ARM currently consists of three fixed, long-term measurement facility sites (in Oklahoma, Alaska, and the Azores), three mobile observatories, and an airborne research capability that operates at sites selected by the scientific community. In FY 2019, ARM will continue operations at the fixed sites, prioritizing measurements in Alaska and Oklahoma. In FY 2019, one mobile facility will be deployed for targeted observations and measurements in the southern Andes. Each of the ARM fixed and mobile observatories 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 investigators study the impact of evolving clouds, aerosols, and precipitation on the Earth's radiative balance and rate of Earth system change, addressing the most significant scientific uncertainties in predictability research. ARM will continue to incorporate very high resolution Large Eddy Simulations 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 atmospheric process representations at higher resolution, greater sophistication and robustness of ultra-high resolution models. Besides supporting BER atmospheric sciences and Earth system modeling research, the ARM facility freely provides key information to other agencies that are engaged in, e.g., calibration and validation of space-borne sensors.

The G-1 aircraft used by ARM was built in 1961, is one of only 10 G-1's that remain in service worldwide and is nearing the end of its service life. BER plans to retire and replace the aircraft in 2019. BER-supported scientists require high-quality and well-characterized in situ aircraft observations of aerosol and cloud microphysical properties and coincident dynamical and thermodynamic properties in order to continue to improve fundamental understanding of the physical and chemical processes that control the formation, life cycle, and radiative impacts of cloud and aerosol particles. To meet these needs, the ARM user facility requires a replacement aircraft with the capacity to carry multi-sensor instrument packages; a flight duration of at least 5 hours with full payload; the ability to fly safely at low altitudes at speeds suitable for gathering in situ observations of aerosol and cloud microphysical properties; and multiple engines for safe operations within clouds, and over the ocean or sea-ice.

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, and interfacial and surface (including aerosol) science relevant to energy and environmental challenges facing DOE and the nation. This includes science supporting improved catalysts and materials for industrial applications and developing improved representations of biological and subsurface biogeochemical processes. EMSL will address a more focused set of scientific topics that continue to exploit High Resolution and Mass Accuracy Capability, live cell imaging, and more extensive utilization of other EMSL instrumentation into process and systems models and simulations to address challenging problems in the biological and environmental system 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 and model-generated 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. Accessibility and usage of these data sets are fundamental to supporting decision-making, scientific discovery, technological innovation, and National security.

The BER Data Management activity will focus efforts to store data from the Earth System Grid Federation, ARM, and NGEE field experiments.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Earth and Environmental Systems Sciences $305,279,000	**$181,503,000**	**-$123,776,000**
Atmospheric System Research (ASR) $25,836,000	**$12,000,000**	**-$13,836,000**
ASR conducted research on cloud, aerosol, and thermodynamic processes using data collected during observational campaigns involving in-situ sensors and Unmanned Aerial Systems, and the full suite of data from campaigns conducted in Alaska, Oklahoma, Antarctica, the Southern Ocean, and Azores, has been utilized in the research.	ASR will continue research on cloud, aerosol, and thermodynamic processes, with a focus on data from the fixed sites, and using data from prior and ongoing field campaigns in the Southern Andes, Antarctica, the Eastern Atlantic, and the Southern Ocean. ASR research will increasingly make use of data generated by Large Eddy Simulation at the ARM fixed site in Oklahoma.	ASR will focus its investment on cloud and aerosol science in regions that exhibit the greatest uncertainties in earth system prediction, i.e., the Arctic and convection in midlatitudes.
Environmental System Science (ESS) $62,178,000	**$19,000,000**	**-$43,178,000**
Within Environmental System Science, NGEE projects continued to provide new observations for model development and validation. The Subsurface Biogeochemistry Research subprogram focused on fate and transport of subsurface elements and hydrological cycling, uptake, and acquisition by plants and microbes, which allows for improved integration with the Terrestrial Ecosystem Science subprogram and facilitate multi-scale, very high resolution process modeling from the bedrock to the canopy.	ESS will continue to support research on permafrost ecology, and will maintain its investments in modeling studies involving boreal ecology and hydro-biogeochemistry of river catchments. Support to the management of the Ameriflux network will continue at a reduced level. ESS will initiate a pilot project on ecology of Terrestrial-Aquatic Interfaces (TAIs).	ESS will prioritize scientific challenges that demand integrative observations of sensitive ecological system in mountainous watersheds of the western U.S. and permafrost regions of the Alaska Arctic. A small pilot project on TAI will be initiated.

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Earth and Environmental Systems Modeling **$90,564,000**	**$33,626,000**	**-$56,938,000**
Earth and Environmental Systems Modeling — Earth System Modeling continued investment in the high-resolution E3SM project, with research to introduce a non-hydrostatic dynamical core, dynamic coupling of ocean and ice, and basin and sub-basin treatments for the land models. Activities aligned with anticipated exascale developments in high-performance computing platforms and algorithms. The E3SM version 1 will be released during FY 2018, with both existing and new users conducting basic research using results derived from the newest DOE computer architectures.	Earth and Environmental Systems Modeling will focus its investment in further development of a non-hydrostatic dynamical cores for the atmospheric component of the E3SM model that targets higher resolution over scales that span from seasonal to multi-decadal. Activities will continue to assimilate the best available software for E3SM to exploit DOE's high-performance computing architectures in order to analyze and characterize extreme events within the earth system.	The E3SM model development timetable will be less ambitious, with efforts prioritized on modeling the atmospheric and cryospheric components.
Core research in model intercomparison and diagnostics were continued. Research continued to explore how modes of variability affect spatial and temporal patterns of weather and extreme events, including the roles of atmospheric rivers and droughts. The incorporation of uncertainty and performance benchmarks will increasingly become part of research efforts.	Core research in model intercomparison and diagnostics will continue. Research will focus on the water cycle, in order to understand how uncertainties involving the spatial and temporal patterns of drought can be characterized.	Research will prioritize the science of water cycle in system models; and investments in tropical-extratropical-midlatitude interactions will be eliminated.
Earth and Environmental Systems Sciences Facilities and Infrastructure $115,686,000	**$111,000,000**	**-$4,686,000**
ARM continued to provide new observations, through long-term measurements at fixed sites in Alaska, Oklahoma, and the Eastern North Atlantic; ; observations continued to be collected from the three mobile facilities, based on limit term deployments to Alaska, Southern Oceans, and south Atlantic. ARM will also maintain an aerial capability and explore the science driven need for equipment refresh for archive upgrades, aerial capabilities, and the mobile and fixed observatories. All ARM activities have been prioritized for critical observations necessary to advance earth system models.	ARM will continue to provide new observations, through long-term measurements at fixed sites in Alaska, Oklahoma, and the Eastern North Atlantic. ARM will utilize one of its mobile units for field campaigns, and it will hold one mobile unit in reserve. The mobile unit at Oliktok will operate seasonally. All ARM activities will be prioritized for critical observations necessary to advance the E3SM model. ARM will deploy a mobile facility to the Southern Andes. ARM will acquire a manned aircraft, to replace the existing G1 aircraft that will be retired in FY 2019. The completed analysis of alternatives indicates that purchase of a used aircraft and subsequent	ARM will prioritize investments in its two fixed sites in Alaska and Oklahoma, and the mobile unit will be deployed to the Southern Andes for seven months of field data collection. ARM will acquire a manned aircraft to replace the current ARM G-1 aircraft that will be retired at the end of FY 2019.

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
	retrofitting to achieve functionality for scientific instrumentation is the most cost-effective option.	
EMSL focused on scientific topics that exploit recently installed capabilities involving HRMAC, live cell imaging, and more extensive use of integrating data from other EMSL instrumentation into process and systems models and simulations that addressed challenging problems in the biological and environmental sciences.	EMSL will continue to focus on science that exploits its unique capabilities, including the HRMAC, live cell imaging, Quiet Wing, and high performance computing, in order to advance biological and environmental sciences. EMSL will initiate building a next generation Dynamic Transmission Electron Microscope, to support future BER science.	EMSL will prioritize its investments on the science of biological and biogeochemical systems, and surface chemistry, using best-in-class sensors that combine with high performance computing.
The Earth and Environmental Systems Sciences Data Management activity emphasized the first phase of metadata compatibility and consolidation via common protocols and standards, involving environmental observations and the Earth System Grid Federation. Essential data archiving and storing protocols, capacity, and provenance were achieved, as part of an effort to simplify scientific community access to observed and model generated data produced by DOE.	The Earth and Environmental Systems Sciences Data Management activity will provide support to maintain existing software and data archives in support of ongoing experimental and modeling research. Essential data archiving and storing protocols, capacity, and provenance will be maintained.	Data Management research efforts will prioritize maintenance of existing software and capabilities in support of ongoing DOE research. Research on improved metadata compatibility and enhanced consolidation via common protocols and standards will be completed.
SBIR/STTR $11,015,000	**$5,877,000**	**-$5,138,000**
In FY 2017, SBIR/STTR funding was set at 3.65% of non-capital funding.	In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.	

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.

	FY 2017	FY 2018	FY 2019
Performance Goal (Measure)	**BER Earth System Model - Develop a coupled earth system model with fully interactive water, carbon and sulfur cycles, as well as dynamic vegetation to enable simulations of earth system responses to change.**		
Target	Extend the capabilities of the DOE's high-resolution Earth System Model to simulate and evaluate human-natural interdependencies for the carbon and water cycles.	Demonstrate improved ocean model simulations with the new high-resolution Model for Prediction Across Scales - Ocean (MPAS-Ocean).	Demonstrate in the coupled DOE-E3SM model, the importance of environmental factors in affecting ecosystem productivity and surface energy exchanges.
Result	Met	TBD	TBD
Endpoint Target	BER supports the leading U.S. high-resolution earth system model, and addresses two of the most critical areas of uncertainty in contemporary earth system science—the impacts of clouds and aerosols that combine with biogeochemical and cryospheric processes. Delivery of improved scientific data and models (with quantified uncertainties) about the earth's atmospheric, oceanic, cryospheric, and terrestrial system to more accurately predict the earth system responses to change. The information is essential to plan for future national security, energy and infrastructure needs, water resources, and land use. DOE will continue to advance the science necessary to further develop predictive earth system models at the regional spatial scale and multiple time scales, involving close coordination with the U.S. and international science community.		
Performance Goal (Measure)	**BER Predictive Understanding - 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 improved open access platforms for computational analysis of large genomic datasets.	Using genomics-based techniques, develop an approach to explore the functioning of plant-microbe interactions.	Develop metagenomics approaches to assess the functioning of microbial communities in the environment.
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 biotechnology and predict impacts of changing environmental conditions on carbon cycling and other biogeochemical processes.		

Capital Summary ($K)

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Capital Operating Expenses Summary						
Total Non-MIE Capital equipment (projects under $5 million TEC)	n/a	n/a	4,500	–	4,000	-500
Major Items of Equipment (TEC over $5 million)						
Atmospheric Radiation Measurement Research Facility (ARM) – ARM Aircraft project (TPC $17,700)	17,700	200[b]	–	–	17,500	+17,500
Total, Capital Summary	n/a	n/a	4,500	–	21,500	+17,000

Atmospheric Radiation Measurement Research Facility - BER-supported scientists require high-quality and well-characterized *in situ* aircraft observations of aerosol and cloud microphysical properties and coincident dynamical and thermodynamic properties to continue to improve fundamental understanding of the physical and chemical processes that control the formation, life cycle, and radiative impacts of cloud and aerosol particles. To meet these needs, the Atmospheric Radiation Measurement (ARM) user facility has been using a dedicated large twin-turboprop Gulfstream-1 (G-1) aircraft to conduct weeks- to months-long intensive observational campaigns over a range of meteorological conditions and locations around the world. The G-1 aircraft used by ARM was built in 1961, is one of only 10 G-1's that remain in service worldwide, and is rapidly nearing the end of its service life. BER will retire and replace the aircraft in 2019.

To replace the capability of the G-1 aircraft, ARM requires: an airborne platform with the payload capacity (floor space, weight, electricity) to carry multi-sensor packages; the appropriate physical structure to install instruments including atmospheric inlets, free airstream sensors, and radiometers; a flight duration capability of at least 5 hours with full payload; the ability to fly safely at low altitudes (200 ft) at speeds (100 m/s) suitable for gathering *in situ* observations of aerosol and cloud microphysical properties; multiple engines for safe operations within clouds, and over the ocean or sea-ice; and the ability to operate in conditions ranging from the Arctic to the Tropics with a full payload.

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] Reporting $200K in prior year ($100K in FY 2017 and $100K in FY 2018). $100K in FY 2017 not previously reported since below the DOE capitalization threshold of $500,000.

Funding Summary ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Research	426,951	–	319,000	-107,951
Scientific user facilities operations and research	185,049	–	163,500	-21,549
Projects (Major Item of Equipment)	–	–	**17,500**	**+17,500**
Total, Biological and Environmental Research	**612,000**	**607,844**	**500,000**	**-112,000**

Scientific User 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 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
TYPE B FACILITIES				
Atmospheric Radiation Measurement Research Facility (ARM)	**$65,429**	–	**$66,000**	**+571**
Number of users	1,109	–	1,100	-9
Joint Genome Institute	**$69,463**	–	**$70,000**	**+537**
Number of users	1,598	–	1,600	+2
Environmental Molecular Sciences Laboratory	**$43,191**	–	**$42,000**	**-1,191**
Number of users	616	–	600	-16
Total Facilities	**$178,083**	–	**$178,000**	**-83**
Number of users	3,323	–	3,300	-23

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

Scientific Employment

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Estimate	FY 2019 Request vs FY 2017 Enacted
Number of permanent Ph.D.'s	1,350	–	1,195	-155
Number of postdoctoral associates	330	–	280	-50
Number of graduate students	450	–	405	-45
Other[b]	330	–	280	-50

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

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