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 three 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 2020 Request

The FY 2020 Request for $494,434,000 directly aligns with the FY 2020 Administration research and development (R&D) Budget Priorities memo[a] issued by OMB and OSTP that identifies eight priority R&D subjects and five practices for leveraging R&D resources more effectively. BER research on secure biodesign aligns with the R&D priority Security of the American People, to underpin improving the security and resilience of the Nation from emerging threats from biological agents; investments in novel quantum sensors for biological and ecological systems aligns with the R&D priority American

[a] https://www.whitehouse.gov/wp-content/uploads/2018/07/M-18-22.pdf

Leadership in Quantum Information Science (QIS); and investments in early-stage research and innovative technologies at the four Bioenergy Research Centers align with the R&D priority American Energy Dominance, and can lead to domestic sources of clean, affordable, and reliable energy. These priority R&D subjects and the FY 2020 Request will reflect priority practices in Educating and Training a Workforce for the 21st Century Economy, Managing and Modernizing R&D Infrastructure, and Maximizing Interagency Coordination and Cross-Disciplinary Collaboration. BER research continues to build on 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 DOE's core missions 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 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].

Key elements in the FY 2020 Request include:

Research

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 third year of the four DOE 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. Secure biosystems design activities will be extended to test the fundamental engineering principles that control plant and microbial 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 and testbeds. Computational Biosciences efforts will combine structural, molecular, and genomic scale information within the DOE Systems Biology Knowledgebase and to develop integrated networks and computational models of system dynamics and behavior.

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 QIS and advanced sensors will contribute to a systems-level predictive understanding of biological processes.

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 watershed scale hydro-biogeochemical modeling. 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, including exascale, and enhanced usability, testing, adaptability, multi-scale treatments, and provenance. In addition to leveraging of existing data from other agencies, modeling efforts will be validated against new atmospheric and terrestrial observations.

The Data Management effort will continue to enhance data archiving and management capabilities but will also focus on using and demonstrating artificial intelligence (AI) and machine learning (ML) tools to observations and data from environmental field experiments.

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

Scientific User Facilities

The DOE 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. JGI operations are reduced to accommodate the FY 2020 move into the Integrative Genomics Building on the Lawrence Berkeley National Laboratory campus.

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, but operations at the East North Atlantic (Azores) will be limited to basic data collection. In addition, the Arctic mobile facility deployed at Oliktok Point will limit research activities to the summer season. One mobile facility will be deployed to Norway to study "Cold-Air Outbreaks in the Marine Boundary Layer" to improve parameterizations in multiscale models. The ARM user facility will continue to develop the aerial capability that will be acquired in FY 2019.

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.

Biological and Environmental Research supports the following FY 2020 Administration Priorities:

FY 2020 Administration Priorities

(dollars in thousands)

	Biosecurity	Exascale Computing Initiative (ECI)	Artificial Intelligence (AI)	Quantum Information Science (QIS)
Biological and Environmental Research	20,000	10,000	3,000	12,000

Biological and Environmental Research
Funding

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Biological Systems Science				
Genomic Science				
Foundational Genomics Research	104,199	90,194	100,000	+9,806
Biosecurity (non-add)	*(—)*	*(4,000)*	*(20,000)*	*(+16,000)*
Environmental Genomics[a]	28,000	29,000	15,000	-14,000
Computational Biosciences	17,000	30,501	15,000	-15,501
Bioenergy Research Centers	90,000	100,000	100,000	—
Total, Genomic Science	**239,199**	**249,695**	**230,000**	**-19,695**
Biomolecular Characterization and Imaging Science[b]	**30,000**	**34,908**	**24,908**	**-10,000**
Biological Systems Facilities and Infrastructure				
Joint Genome Institute	69,401	70,000	60,000	-10,000
Total, Biological Systems Facilities and Infrastructure	**69,401**	**70,000**	**60,000**	**-10,000**
SBIR/STTR	12,789	13,194	11,892	-1,302
Total, Biological Systems Science	**351,389**	**367,797**	**326,800**	**-40,997**
Earth and Environmental Systems Sciences				
Atmospheric System Research	**28,000**	**28,000**	**12,000**	**-16,000**
Environmental System Science				
Terrestrial Ecosystem Science	41,000	40,000	14,000	-26,000
Subsurface Biogeochemical Research	26,000	22,143	5,000	-17,143
Total, Environmental System Science	**67,000**	**62,143**	**19,000**	**-43,143**
Earth and Environmental Systems Modeling[c]	**92,000**	**97,000**	**37,643**	**-59,357**

[a] Environmental Genomics contains previous subprograms of Genomics Analysis and Validation, and Metabolic Synthesis and Conversion.
[b] Biomolecular Characterization and Imaging Science contains previous Mesoscale to Molecules, and Structural Biology Infrastructure.
[c] Earth and Environmental Systems Modeling reflects all previous Modeling activities (Regional and Global Model Analysis, Earth System Modeling, and Integrated Assessment).

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Earth and Environmental Systems Sciences Facilities and Infrastructure				
Atmospheric Radiation Measurement Research Facility	70,000	85,500	43,000	-42,500
Environmental Molecular Sciences Laboratory	45,000	45,000	40,000	-5,000
Data Management	8,000	8,000	10,000	+2,000
Total, Earth and Environmental Systems Sciences Facilities and Infrastructure	**123,000**	**138,500**	**93,000**	**-45,500**
SBIR/STTR	11,611	11,560	5,991	-5,569
Total, Earth and Environmental Systems Sciences	**321,611**	**337,203**	**167,634**	**-169,569**
Total, Biological and Environmental Research	**673,000**	**705,000**	**494,434**	**-210,566**

SBIR/STTR Funding:

- FY 2018 Enacted: SBIR $21,393,000 and STTR $3,007,000
- FY 2019 Enacted: SBIR $21,702,000 and STTR $3,052,000
- FY 2020 Request: SBIR $15,679,000 and STTR $2,204,000

Biological and Environmental Research
Explanation of Major Changes

(dollars in thousands)

	FY 2020 Request vs FY 2019 Enacted
Biological Systems Science	**-40,997**
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 expanded secure biosystems design research to understand the fundamental genome structure and functional relationships that result in specific, stable and predictable, new, and beneficial traits in model plant and microbial systems. Environmental Genomics will limit research to understanding environmentally relevant microbiomes and the interdependencies between plants and microbes in a sustainable and resilient ecosystem. Computational Bioscience will focus on an integrated computational platform for microbiome and bioenergy-related research with the completion of initial funding for a national microbiome database. The Request fully supports the four DOE Bioenergy Research Centers in their third 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 will include expanded integrative imaging and analysis platforms and biosensors, including using QIS materials, to understand the expression, structure, and function of genome information encoded within cells and for real-time measurements in ecosystems and field sites of mission relevance. User access to static protein crystallographic structural analysis is reduced. The Request reduces support for operations at JGI to accommodate the move to the Integrated Genomics Building on the LBNL campus.	
Earth and Environmental Systems Sciences	**-169,569**
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 modeling the fate and transport of nutrients. Using observations from the ARM facility, Atmospheric System Research will focus activities to advance knowledge and improve model representations of atmospheric gases, aerosols, and clouds on the Earth's energy balance. One ARM mobile facility will be deployed to Norway; operations of the Arctic mobile facility at Oliktok and the East North Atlantic fixed site will be limited. EMSL will focus on biological and environmental molecular science with reduced user support. Data management activities will include applying advanced AI methods to observations and environmental field data.	
Total, Biological and Environmental Research	**-210,566**

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.

Specifically, BER coordinates its fundamental research on bioenergy crops with other federal agencies through the Biomass Research and Development Initiative (BRDi) Board. DOE-EERE and USDA jointly issue a solicitation for applied funding topics informed by a BRDi federal technical advisory committee. BER supports some interagency projects to manage databases (such as the Protein Database) through interagency awards and funding for complementary community resources (such as beamlines and electron cryomicroscopy), mostly with NIH and NSF. BER participates in some co-funded interagency calls with USDA.

All Earth systems research activities are specifically coordinated through the interagency U.S. Global Change Research Program. For example, the Energy Exascale Earth System Model (E3SM) modeling system has evolved to become the world's highest resolution capability, and the v1 release in April 2018 provided numerous universities the ability to conduct research with this model. Other agencies, e.g., NOAA, NASA, the Navy, and NSF, are following developments in E3SM via the Earth System Prediction Capability forum (led by DOD and NOAA weather services, but with DOE as a member), so that their modeling platforms can adopt the best practices in physics and computing developed by DOE. The National Geospatial-Intelligence Agency has indicated significant interest in E3SM, as a platform to incorporate their data to address national security problems. The E3SM research also provides BER with strong linkages to DOE applied programs and DOE Office of Policy.

Program Accomplishments
Genomic Science conducts research on complex biological systems by analyzing genetic material and associated relationships with the surrounding environment. Recent advances using genome-enabled techniques are unlocking key insights into how plants and associated microbial communities function in the environment and within microbiomes. Researchers at the USDA Agricultural Research Station in Lincoln, NE have deciphered the active metabolic and gene expression signals found in dormant switchgrass that could lead to improving the cold tolerance of this potential bioenergy crop. The fundamental research points towards ways to engineer new strains of switchgrass with an extended northern growing range. Researchers at the University of Minnesota are developing innovative methods for genome engineering in plants. Using a combination of techniques including CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats)-based systems, the group has developed a comprehensive toolset for gene editing in plants that can accommodate single or multiple gene deletions and gene editing. The work highlights improvements in gene editing-based techniques for plants for a variety of agricultural and biotechnological purposes. University of California-Berkeley and Lawrence Berkeley National Laboratory researchers, using a range of metagenomics and metabolomics analyses to explore plant-microbe interactions in the field, have uncovered predictable patterns in shifts in microbial community composition and function with plant growth. The work documents how plant exudates change during growth and how these compounds impact the growth and composition of the soil microbiology. Thus, the data captures the activity of an environmental microbiome across multiple growth seasons and provides a mechanistic, genomic basis to predict change in microbiome structure and function. All these latest results are examples of how genome-enabled science is continuing to yield valuable insights into the functioning of plant and microbial systems and how this information could be used to engineer solutions to a range of bioenergy and environmental challenges.

Bioenergy Research Centers' research continues to highlight significant basic science advances underpinning biofuels and bioproduct production from sustainable plant biomass. At the Center for Bioenergy Innovation, new understanding of the composition of plant cell walls in switchgrass and poplar has revealed a series of genes controlling pectin biosynthesis that, when downregulated, produce a plant much more amendable to conversion to biofuel. Using RNA silencing, the resulting plants exhibit up to seven fold increased ethanol production relative to controls. The engineered traits were also maintained in the plants during a 3-year field trials demonstrating the robustness of strains under environmental conditions. At the Center for Advanced Bioenergy and Bioproducts Innovation, new genome editing techniques are being developed for industrial yeast strains for a range of biotechnology purposes. These new techniques take advantage of CRISPR/Cas9 methods to perform multiplex genome engineering on complex polyploid yeast strains. This work extends gene editing techniques to commonly used, but genetically complex, industrial yeast strains thereby broadening the range of genome engineering tools with these strains. Joint BioEnergy Institute researchers are exploring innovative approaches to metabolic engineering by coupling genes from disparate organisms together in pathways to boost fatty alcohol production in model yeast strains. Fatty acid reductase from the common mouse is used to boost fatty alcohol production in an engineered yeast to the highest titers yet observed for this strain. The work highlights an efficient and renewable source of fatty alcohols from lignocellulosic sugars for fuels and products. Great Lakes Bioenergy Research Center researchers evaluating land use changes into and out of agricultural and bioenergy production show important changes in ecosystem carbon balance. Results from an 8-year field experiment suggest cropland fields converted to grasslands will accumulate carbon whereas converting grasslands to croplands results in net carbon loss to the atmosphere. The work has important implications for bioenergy (and agricultural) crop production and assessments of carbon capture and storage within landscapes.

Earth and Environmental Systems Sciences conducts research on Earth systems at the local to global scales to further understanding of all system components, including atmospheric circulation, terrestrial biogeochemistry, and the coupling of all components using numeric modeling. Incorporation of advanced modeling concepts, high performance computing, and new observations allows emerging Earth System models to more confidently capture changes to the hydrologic cycle, the cryosphere, and extreme weather events. A new DOE high-resolution Earth System model, the E3SM v1 was released in April 2018 as the world's highest resolution capability to study multi-annual to decadal-scale interdependencies involving the atmosphere, oceans, cryosphere, and terrestrial processes. The E3SM model is currently running at all of DOE's best-in-class high performance computing platforms and the project is now open-source, to foster increased collaboration on next-generation model developments. The next version (v2) will focus higher-resolution over North America in order to enhance research on extremes in precipitation, storms, floods and droughts, vegetation changes and coastal impacts. Simulations also capture detailed interactions between ice sheets and ocean waters to improve our understanding of ice sheet stability vulnerabilities.

User Facilities house state-of-the-art tools and expertise to enable the scientific community to address and solve research questions for biological and environmental systems. High resolution patterns of environmental processes influence microbial degradation of soil carbon in Arctic permafrost.

- A research effort using capabilities at the *Joint Genome Institute (JGI)* was carried out to ascertain how spatial patterns of hydrology and biogeochemistry influence the ability of microbial communities to mediate air-surface gas exchange in the polygonal Arctic permafrost soil landscapes. Using comparative metagenomics, genome binning of novel microbes, and gas flux measurements, it was found that microbial activity and gas production strongly correlate with fine-scale topography. Microbial functions such as fermentation and methanogenesis were dominant in wetter portions of polygons, and drier portions of polygons supported carbon mineralization and methane oxidation.
- At the *Environmental Molecular Sciences Laboratory (EMSL),* a team of scientists from several universities produced a three-dimensional map of the metabolic products of bacteria found in the root nodules. Using EMSL's high-field Fourier transform ion cyclotron resonance mass spectrometers, the team was able to visualize metabolites co-located into different compartments within the nodules. This spatial perspective will help to unravel the complexity of these highly interdependent organisms and optimize crop production and enable more sustainable agricultural practices for food crops used all over the world.
- Data from the *Atmospheric Radiation Measurement (ARM)* scientific user facility were analyzed and assimilated into predictive models to demonstrate improved predictability, with a particular focus on processes and mechanisms

responsible for observed storm intensification of atmospheric convection. Findings indicated that ultrafine aerosol particles can invigorate thunderstorms in a much more powerful manner than their larger counterparts through an enhanced condensation mechanism. This is contrary to previous assumptions about the impacts of ultrafine aerosol particles, thus opening up the opportunity to make major scientific advances towards improved predictions of severe storms.

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 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.

Genomic Science
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. BER's contribution towards understanding and anticipating the *convergence* of advanced genomics science with other fields is critical for foresight into secure technology development, leveraging scientific communities across biological, physical, and computational science fields with the unique ability to evaluate systems across disciplinary boundaries. All secure biosystems design efforts on plant and microbial systems will be consistent with the National Biodefense Strategy framework.

Environmental Genomics 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 advance the development of 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 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 develop QIS materials for imaging and characterization and to advance design of sensors and detectors based on correlated materials for real-time biological and environmental sensing technology. 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. Related efforts to use genomic information to infer natural product production from microorganisms and plants are also underway. 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 bioproducts research, 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 2019 Enacted		FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Biological Systems Science	**$367,797,000**	**$326,800,000**	**-$40,997,000**
Genomic Science	$249,695,000	$230,000,000	-$19,695,000
The FY 2019 Enacted budget for Foundational Genomics research supports 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 focuses on environmental microbiome research and develops 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.		The Request for Foundational Genomics will support biosystems design techniques to modify microbes and plants for beneficial bioenergy, bioproduct and biotechnology purposes. Funding will also support complementary efforts on genome-modification techniques to identify and predict biosecurity implications for energy and the environment. Environmental Genomics will focus on sustainable plant and microbial community interactions in model and natural microbiomes, and complementary research on plant and microbial physiology for bioenergy and ecosystem purposes.	Foundational Genomics increases to support Biosystems Design research, including broader investigations of genome modification techniques to inform biosecurity research purposes. Environmental Genomics will decrease, limiting research to understanding environmentally relevant microbiomes and the interdependencies between plants and microbes in a sustainable and resilient ecosystem.
The FY 2019 Enacted budget for Computational Bioscience focuses 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 activity establishes and fully funds a platform for a national microbiome data collaborative.		The Request for Computational Bioscience will merge bioinformatics capabilities within the JGI and the DOE Systems Biology Knowledgebase to produce an open source, integrated computational platform for microbiome and bioenergy-related research.	Computational Biosciences will focus on advanced computational techniques to facilitate the analysis of environmental microbiomes. The activity to establish a platform for a national microbiome data collaborative was completed in FY 2019.
The FY 2019 Enacted budget supports the four BRCs as they begin their second year of support. Research focuses 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		The Request for the four BRCs will begin their third year of operations to develop bioenergy crops with enhanced tolerance to environmental stress, biomass deconstruction techniques to breakdown biomass, biotechnology approaches to produce fuels, chemicals and products from lignocellulosic materials, and	The BRCs will focus on development of dedicated bioenergy crops and conversion technologies that produce fuels, chemicals, and products sustainably from renewable plant biomass.

FY 2019 Enacted	FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
from cellulose and lignin, and new ways to sustainably cultivate bioenergy crops on marginal lands.	research to understand sustainable regional-scale bioenergy crop production.	
Biomolecular Characterization and Imaging Science[a] $34,908,000	$24,908,000	-$10,000,000
The FY 2019 Enacted budget for Biomolecular Characterization and Imaging Science supports 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. Funding supports investments in electron cryomicroscopy that leverage other capabilities at the Office of Science user facilities. Development of multi-functional techniques continues and includes 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.	The Request for Biomolecular Characterization and Imaging Science will support new multi-modal imaging, visualization and structural characterization of biomolecular processes occurring in plants and microbes in support of systems biology research. Investments in electron cryomicroscopy instrumentation at SC light sources are completed, and support is reduced for user access for static protein crystallography structural analysis. Research funding will support exploring new imaging, characterization and/or sensor techniques that take advantage of quantum-enabled science concepts, with an emphasis on improvements in quantifying nutrient and metabolite flows in situ in field environments.	The research will focus on opportunities for broader development of visualization and characterization technologies. FY 2020 budget priorities will emphasize efforts in quantum-enabled research for imaging/characterization and advances in designing sensors and detectors based on correlated materials for real-time sensing technology.
Biological Systems Science Facilities and Infrastructure $70,000,000	$60,000,000	-$10,000,000
The FY 2019 Enacted budget for JGI continues to serve as a primary source of genomic sequences of plants, microorganisms and microbial communities for BER programs and the broader research community. It continues 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 continues to collaborate with the DOE Systems Biology	The Request for the JGI serves as a central source for genome sequence production capabilities for plants, microbes and microbial communities. These services are crucial to BER programs, such as the BRCs, and are also available to the larger research community. JGI will focus on metagenomics efforts to support microbiome research, and production of complex plant, fungal and microbial genomes supporting systems biology research within the BRCs and the BER portfolio. The resulting data and analyses will be	The Request includes a reduction associated with moving the facility to the LBNL campus, during which time JGI will reduce sequencing and analysis capabilities intermittently. These reductions will lower the number of users for a period of 30-90 days.

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

FY 2019 Enacted	FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Knowledgebase and prepare for a move to the LBNL campus. Structural Biology Infrastructure is moved and combined within the Biomolecular Characterization and Imaging Science activity, as noted above.	closely coupled with KBase for open access on an integrated bioinformatics platform. JGI (and KBase) will move to Integrated Genomics Building on the LBNL campus.	
SBIR/STTR $13,194,000	$11,892,000	-$1,302,000
In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.	In FY 2020, SBIR/STTR funding is set at 3.65% of non-capital funding.	The SBIR/STTR funding will be consistent with the BER total budget.

Biological and Environmental Research
Earth and Environmental Systems Sciences

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. SC 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 watersheds, including environmental contamination from past nuclear weapons production.

The activity also supports Ameriflux, a network of 373 field sites funded by a variety of federal agencies and other research institutions to measure the exchange of heat, moisture and other gases between the atmosphere and the surface to maintain data quality and organizational support to the network and funding for 13 of the network sites.

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 (ESMs), in coordination with other Federal efforts. The research specifically focuses on quantifying and reducing the uncertainties in ESMs 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 2020, ARM will continue operations at the three fixed sites, maintaining mobile facility seasonal observations at Oliktok. One mobile facility will be deployed to Norway to study Cold-Air Outbreaks in the Marine Boundary Layer to improve parameterizations in multiscale models. 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.

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 will continue to develop the aerial capability that will be acquired in FY 2019. The replacement aircraft will undergo field testing in FY 2020 in order to evaluate its capabilities under a variety of conditions.

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 (HRMAC), 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, Ameriflux and NGEE field experiments.

Activities and Explanation of Changes

FY 2019 Enacted	FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Earth and Environmental Systems Sciences $337,203,000	**$167,634,000**	**-$169,569,000**
Atmospheric System Research (ASR) $28,000,000	$12,000,000	-$16,000,000
The FY 2019 Enacted budget for ASR continues research on cloud, aerosol, and thermodynamic processes, with a focus on data from the three 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.	The Request for ASR will continue research on clouds, aerosols, and thermodynamic processes, with a focus on data from the Oklahoma and Alaska fixed sites, and using data from prior and ongoing field campaigns in Argentina, Norway, and the Southern Ocean. ASR will continue to make use of data generated by Large Eddy Simulations at the ARM Oklahoma site.	ASR will focus its investments on the Arctic and deep convection in mid-latitudes. Analysis of emerging data from the Norway field campaign will be conducted over multiple years rather than immediately following the field campaign, delaying the scientific impact of the new observations.
Environmental System Science (ESS) $62,143,000	$19,000,000	-$43,143,000
The FY 2019 Enacted budget for ESS supports research on permafrost and tropical ecology, and maintains its investments in observational and modeling studies involving boreal ecology and hydro-biogeochemistry of river catchments. Support to the management of the Ameriflux network continues. ESS initiates a pilot project on ecology of Terrestrial-Aquatic Interfaces (TAIs) and maintains investments in subsurface biogeochemistry.	The Request for ESS will focus research on permafrost and will maintain limited investments in studies of boreal ecology and modeling hydrobiogeochemistry of watersheds and terrestrial-aquatic interfaces. Research on tropical ecology and subsurface biogeochemistry research on radionuclides and mercury will be terminated.	ESS will prioritize challenges involving research on the ecology, biogeochemistry, and the water cycle, emphasizing Arctic regimes. Analysis of the data from the pilot TAIs continues, however no further TAI field studies will be initiated. Modeling and experimental research involving subsurface fate and transport of radionuclides will be terminated.

FY 2019 Enacted	FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Earth and Environmental Systems Modeling $97,000,000	$37,643,000	-$59,357,000
The FY 2019 Enacted budget for Earth and Environmental Systems Modeling focuses its investment in further development of non-hydrostatic dynamical cores for the atmospheric component of the E3SM model that targets higher resolution over scales from seasonal to multi-decadal. Research activities continue to assimilate the best available software for E3SM to exploit DOE's high-performance computing architectures in order to analyze, model, and characterize extreme events within the earth system. The FY 2019 Enacted budget continues to support research in model intercomparison and diagnostics. Research focuses on the water cycle in order to understand how uncertainties involving the spatial and temporal patterns of drought can be characterized.	The Request for Earth and Environmental Systems Modeling will focus investments on further refinement of the science underpinning non-hydrostatic modeling, and incorporating the necessary software for deployment of the model onto exascale computing architectures. The Request will continue to support research at a reduced level, on the modeling of extreme phenomena (e.g., hurricanes), improved representation of biogeochemistry, and a better understanding of the water cycle. The Request will continue support core research in model intercomparisons and diagnostics. In addition, research will focus on understanding the fine scale physics and dynamics that govern interactions between the Arctic and midlatitudes.	The E3SM model will emphasize improvements based on the incorporation of advanced software and further development of the science governing extreme phenomena. Investments in tropical-extratropical-midlatitude interactions will be eliminated. E3SM model development timetable will be less ambitious. Further development of the cryospheric and Arctic component of the model will be delayed several years, reducing E3SMs full use of future exascale computing capabilities. Research will prioritize further studies of the water cycle, with efforts to incorporate representations of groundwater into regional and global models.
Earth and Environmental Systems Sciences Facilities and Infrastructure $138,500,000	$93,000,000	-$45,500,000
The FY 2019 Enacted budget for ARM continues to provide new observations, through long-term measurements at fixed sites in Alaska, Oklahoma, and the Eastern North Atlantic. The mobile unit at Oliktok operates seasonally. All ARM activities are prioritized for critical observations necessary to advance the E3SM model. ARM deploys a mobile facility to the Southern Andes and one as an icebreaker-based Arctic observatory. ARM acquires a manned aircraft, to replace the existing Battelle-owned G1 aircraft that is retired in FY 2019. The completed analysis of alternatives indicates that purchase of a used aircraft	The Request for ARM will continue to provide new observations, through long term measurements at fixed sites in Alaska and Oklahoma; activities at the Eastern North Atlantic will be limited. ARM will continue seasonal mobile facility deployment at the Oliktok site. The Request prioritizes all ARM activities for critical observations needed to improve the E3SM model. ARM will deploy the third mobile facility to northern Norway. Subsequent to the FY 2019 procurement of a refreshed aerial capability, the new aircraft will be tested and evaluated during FY 2020 in	ARM will prioritize investments at its permanent sites in central Oklahoma and northern Alaska. A mobile unit will be deployed to northern Norway to study Arctic air mass transformations. The new ARM aircraft will be tested and evaluated in order to become available for future campaigns.

FY 2019 Enacted	FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
and subsequent retrofitting to achieve functionality for scientific instrumentation is the most cost-effective option.	limited field campaigns in order to evaluate performance.	
The FY 2019 Enacted budget for EMSL continues 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 initiates building a next generation Dynamic Transmission Electron Microscope, to support future BER science.	The Request for EMSL will continue to focus on science that exploits unique capabilities of mass spectrometry (e.g., the HRMAC and nuclear magnetic resonance), live cell imaging, Quiet Wing, and high performance computing. EMSL will continue building the Dynamic Transmission Electron Microscope, in support of BER science.	EMSL will prioritize research that focuses on environmental biogeochemistry, microbial metabolomics, aerosol chemistry, and early scientific applications of Dynamic Transmission Electron Microscope, in support of BER science. User support is reduced.
The FY 2019 Enacted budget for the Earth and Environmental Systems Sciences Data Management activity provides support to maintain existing software and data archives in support of ongoing experimental and modeling research, and for an open source distributed data and computation platform. Essential data archiving and storing protocols, capacity, and provenance are maintained.	The Request for the Earth and Environmental Sciences Data Management activity will provide support to maintain existing critical software and data archives in support of ongoing experimental and modeling research. Essential data archiving and storing protocols, capacity, and provenance will be maintained.	The Data Management effort will initiate new research on applying and demonstrating artificial intelligence and machine learning tools to observations and data from environmental field experiments.
SBIR/STTR $11,560,000	$5,991,000	-$5,569,000
In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.	In FY 2020, SBIR/STTR funding is set at 3.65% of non-capital funding.	The SBIR/STTR funding will be consistent with the BER total budget.

Biological and Environmental Research
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Capital Operating Expenses Summary						
Total Non-MIE Capital equipment (Capital Equipment > $500K)	N/A	N/A	4,500	9,300	4,500	-4,800
Major Items of Equipment [a]						
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**	**26,800**	**4,500**	**-22,300**

[a] Each MIE located at a DOE facility Total Estimated Cost (TEC) > $5M and each MIE not located at a DOE facility TEC > $2M.

[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.

Biological and Environmental Research
Major Items of Equipment Description(s)

Earth and Environmental Systems Sciences Facilities and Infrastructure MIE(s):

Atmospheric Radiation Measurement Research Facility (ARM) – ARM Aircraft project: 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 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, was one of only 10 G-1's that remain in service worldwide, and is at the end of its service life. BER has initiated retirement and replacement of the aircraft in FY 2019. The FY 2019 Enacted Budget includes funding to replace the Battelle-owned G-1 aircraft that supported airborne data collection as part of ARM field campaigns. In FY 2020, the newly acquired aircraft will undergo testing and evaluation, including modifications to the air frame as needed to install numerous existing and new atmospheric aerosol, cloud, turbulence, and other sensors. Also, the aircraft will undergo ground-based and airborne testing, in order to prepare it for scientific studies.

Biological and Environmental Research
Funding Summary

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Research	500,957	516,858	360,184	-156,674
Facility Operations	172,043	170,642[a]	134,250	-36,392
Projects				
Major Items of Equipment	—	17,500	—	-17,500
Total, Projects	—	17,500	—	-17,500
Total, Biological and Environmental Research	**673,000**	**705,000**	**494,434**	**-210,566**

Scientific User Facility Operations

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.

(dollars in thousands)

	FY 2018 Enacted	FY 2018 Current	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
TYPE B FACILITIES					
Atmospheric Radiation Measurement Research Facility (ARM)	**$70,000**	**$70,000**	**$85,500[b]**	**$43,000**	**-$42,500**
Number of users	1,086	1,086	1,100	900	-200
Joint Genome Institute	**$69,401**	**$69,401**	**$70,000**	**$60,000**	**-$10,000**
Number of users	1,882	1,882	1,800	1,550	-250
Environmental Molecular Sciences Laboratory	**$45,000**	**$45,000**	**$45,000**	**$40,000**	**-$5,000**
Number of users	561	561	600	550	-50
Total Facilities	**$184,401**	**$184,401**	**$200,500**	**$143,000**	**-$57,500**
Number of users	3,529	3,529	3,500	3,000	-500

[a] Facility Operations amount less Air-ARM MIE – replacement aircraft.

[b] Includes Air-ARM MIE - replacement aircraft.

Biological and Environmental Research
Scientific Employment

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Number of permanent Ph.D.'s	1,415	1,425	1,195	-230
Number of postdoctoral associates	330	350	280	-70
Number of graduate students	475	490	405	-85
Other[a]	330	350	280	-70

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