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 fundamental biological, biogeochemical, and physical principles needed to seamlessly predict the processes ranging from the molecular and genome-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 the 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. BER research pioneers 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 2021 Request

The FY 2021 Request for BER is $516,934,000, which directly aligns with the FY 2021 Administration research and development (R&D) Budget Priorities memo[a] issued by OMB and OSTP that identifies five high priority crosscutting actions that span the five R&D budget priorities to ensure that America remains at the forefront of science. BER research on secure biodesign and high-resolution Earth System models aligns with the R&D priority American Security to underpin improving

[a] https://www.whitehouse.gov/wp-content/uploads/2019/08/FY-21-RD-Budget-Priorities.pdf

the security and resilience of the Nation from emerging threats from biological agents and extreme terrestrial events; investments in novel quantum sensors for biological and ecological systems align with the R&D priority American Leadership in Industries of the Future to develop advanced imaging capabilities that leverage and complement the SC QIS Center(s) established in FY 2020 as an interdisciplinary partnership among SC Program Offices' research in support of the National Quantum Initiative; investments in early-stage research and innovative technologies at the four BRC's align with the R&D priority American Health and Bioeconomic Innovation to lead to domestic sources of clean, affordable, and reliable energy; and the BER foundational research on Earth Systems models and environmental systems directly aligns with the R&D priority American Energy and Environmental Leadership with new observations and exascale-capable, high resolution Earth system prediction models to obtain substantial improvements in computational model performance and spatial resolution across all scales. All BER activities work to Build and Leverage a Diverse, Highly Skilled American Workforce; Support Transformative Research of High Risk and Potential High Reward and Build, Strengthen, and Expand Strategic Multisector Partnerships thought the merit review process and interagency coordination. 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.

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 2021 Request include:

Research

- Investments in the Biological Systems Science subprogram to 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. Significant new experimental paradigms reflecting the Next-Generation Biology initiative will leverage new tools and approaches across the Office of Science, to move from genomics and biochemistry of biological systems to implementation of this new understanding in bio-inspired, biohybrid and biomimetic systems. The Genomic Sciences activity will prioritize support for the fourth 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. New efforts in translating biodesign rules to functional properties of novel biological polymers will be initiated. 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 integrate prior efforts on microbiome within the DOE Systems Biology Knowledgebase to develop integrated networks and computational models of system dynamics and behavior.

- Biomolecular Characterization and Imaging Science research, which will continue to support structural, spatial, and temporal understanding of functional biomolecules and processes occurring within living cells. 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, which will focus on scientific analysis of how physical and biogeochemical processes impact the sensitivity and uncertainty of Earth system predictions. Environmental

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

System Science will integrate terrestrial ecosystem and subsurface sciences to provide a robust and scale-aware predictive understanding of ecosystems. Investments will continue to support, at a slower pace, the Energy Exascale Earth System Model (E3SM) capability tailored to DOE requirements for a variety of scenarios applied to spatial scales resolved to 10 km. The model system 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 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

Facility Operations

- 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[a] 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. In FY 2021, the JGI will prioritize improved integration with the Systems Biology Knowledgebase.

- ARM investments will continue to provide new observations selected to represent the diversity of environmental conditions necessary to advance Earth System models. ARM prioritizes long-term measurements at fixed sites in Alaska and Oklahoma, while limiting activities at the East North Atlantic (Azores) site. In addition, the Arctic mobile facility deployed at Oliktok Point will be closed and prepared for a future deployment. One mobile facility will be deployed to the Houston, TX area for Tracking Aerosol Convection Interactions Experiment (TRACER). Scientists will use the second generation C-band ARM Scanning Precipitation Radar (CSAPR2), and a small satellite site with radiosonde and aerosol measurements to learn more about cloud and aerosol interactions in deep convection over the Houston area. The ARM user facility will continue to develop and deploy aerial capabilities, including unmanned aerial system (UAS) and manned aircraft. The newly acquired manned aircraft will continue to undergo testing and evaluation.

- 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.

[a] https://jgi.doe.gov/wp-content/uploads/2019/01/2019_JGI-Strategic-Plan.pdf

FY 2021 Research Initiatives

Biological and Environmental Research supports the following FY 2021 Research Initiatives.

(dollars in thousands)

	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
New Research Initiatives				
Next Generation Biology Initiative	—	—	6,250	+6,250
Revolutionizing Polymer Upcycling	—	—	6,250	+6,250
Total, New Research Initiatives	**—**	**—**	**12,500**	**+12,500**
Ongoing Research Initiatives				
Artificial Intelligence and Machine Learning	—	3,000	3,000	—
Biosecurity	4,000	20,000	25,000	+5,000
Exascale Computing Initiative	15,000	15,000	10,000	-5,000
Quantum Information Science	4,500	12,000	12,000	—
Total, Ongoing Research Initiatives	**23,500**	**50,000**	**50,000**	**—**

Biological and Environmental Research
Funding

(dollars in thousands)

	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
Biological Systems Science				
Genomic Science	249,695	268,235	242,135	-26,100
Bioenergy Research Centers (non-add)	*[100,000]*	*[100,000]*	*[100,000]*	*[–]*
Biomolecular Characterization and Imaging Science	34,908	45,000	24,908	-20,092
Biological Systems Facilities and Infrastructure	70,000	77,000	60,000	-17,000
SBIR/STTR	13,194	14,544	12,257	-2,287
Total, Biological Systems Science	**367,797**	**404,779**	**339,300**	**-65,479**
Earth and Environmental Systems Sciences				
Atmospheric System Research	28,000	35,000	12,000	-23,000
Environmental System Science[a]	62,143	77,638	19,000	-58,638
Earth and Environmental Systems Modeling	97,000	97,000	37,643	-59,357
Earth and Environmental Systems Sciences Facilities and Infrastructure	138,500	123,110	102,635	-20,475
SBIR/STTR	11,560	12,473	6,356	-6,117
Total, Earth and Environmental Systems Sciences	**337,203**	**345,221**	**177,634**	**-167,587**
Total, Biological and Environmental Research	**705,000**	**750,000**	**516,934**	**-233,066**

SBIR/STTR funding:

- FY 2019 Enacted: SBIR $21,702,000 and STTR $3,052,000
- FY 2020 Enacted: SBIR $23,687,000 and STTR $3,330,000
- FY 2021 Request: SBIR $16,318,000 and STTR $2,295,000

[a] New structure change in FY 2021 for Environmental System Science to reflect all previous Terrestrial Ecosystem Science and Subsurface Biogeochemical Research combined.

Biological and Environmental Research
Explanation of Major Changes

(dollars in thousands)

	FY 2021 Request vs FY 2020 Enacted
Biological Systems Science	**-65,479**
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, forming the basis for the next generation of biological discovery. 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. Novel extensions of biodesign and synthetic biology approaches to the design of new plant and microbially-derived polymers have the potential for sparking new biotechnology applications in resource recovery and recycling ventures. 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. The Request fully supports the four DOE BRCs in their fourth 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. The JGI will operate with reduced user support.	
Earth and Environmental Systems Sciences	**-167,587**
The Request continues to support, at a reduced pace, 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 the Houston, TX area; operations of the Arctic mobile facility at Oliktok, AK are completed and operations at the East North Atlantic fixed site will be limited. The newly acquired manned aircraft will continue to undergo testing and evaluation. 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	**-233,066**

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.

All Earth systems research activities are specifically coordinated through the interagency U.S. Global Change Research Program. For example, the DOE E3SM has evolved to become the world's highest resolution capability; and the E3SM version 1 released in April 2018 will be updated to a version 2 model that is anticipated to be released in FY 2022. Version 2 will provide numerous universities the ability to conduct much more sophisticated research based on higher resolution. The new version will add advanced capabilities for exploring cryosphere-ocean dynamics' impacts of climate variability on Antarctic ice shelf melting, continental ice sheet evolution and sea level rise, and the effects of changing water cycles on watershed and coastal hydrological systems. 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 fundamental research on a broad range of biological processes with a recent focus on plant-microbe interactions in soil.
Results from a Lawrence Berkeley National Laboratory (LBNL)-led team examining changes in soil microbial community structure found that plant root exudates exert a strong influence on soil community composition. This mechanistic understanding offers the attractive possibility of altering soil microbiomes for beneficial purposes. Similarly, a research team from the University of Washington, Harvard Medical School, and Oak Ridge National Laboratory (ORNL) investigating plant-microbe processes found a specific plant compound that induces a regulator of gene expression in an associated bacteria. These types of inter-kingdom communication have important implications for mutualistic and antagonistic interactions between plants and microbes and are key to understanding key control points for plant-microbe interactions. These research findings on plant-microbe interactions are complemented by new technologies developed to image metabolic processes in plants and microorganisms.

A team led by Pacific Northwest National Laboratory (PNNL) developed a mass spectrometry-based imaging capability at the DOE EMSL and demonstrated 3-D imaging of cellular metabolites associated with nitrogen fixation in soybean root nodules, a well-known example of a mutualistic plant-microbe interaction. The new technique can be extended to image

similar processes in other systems to visualize and test hypotheses of plant-microbe interactions. More broadly, the activity also supports research on CRISPR[a]-based systems.

Recent research from the University of Illinois, Urbana-Champaign, developed a new CRISPR method that can create tens of thousands of yeast mutants with specific genome edits. This new technique enables the rapid editing of targeted genes across an entire genome and adds to a vast array of new and powerful metabolic engineering techniques underpinning a rapidly expanding global biotechnology industry.

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, continued research on switchgrass has led to the identification of a number of genes impacting cell wall recalcitrance to deconstruction and conversion to biofuels. Recent results showed that down-regulation of a pectin biosynthesis gene resulted in a plant with enhanced growth characteristics and increased yield of cellulosic sugars, a major step towards developing dedicated bioenergy crops.

Researchers at the Center for Advanced Bioenergy and Bioproducts Innovation working with the newly sequenced sugarcane genome identified 178 genes associated with nitrogen transport. This is important because sugarcane is notorious for a low nutrient uptake and these identified genes are now genomic targets for improving nutrient use efficiency in sugarcane. At the Joint BioEnergy Institute researchers have developed a new CRISPR-based interference (CRISPRi) technique that silences gene expression in competing pathways within an engineered cell. The technique was used to divert metabolic flux in an engineered E. coli cell towards increased production of isopentenol, an advanced biofuel. Researchers at the Great Lakes BRC engineered a strain of bacteria capable of utilizing aromatic compounds derived from lignin to produce an important chemical precursor for bioplastics. The work sets the stage for developing valuable chemical products from lignin, a major goal of the BRCs and a major bottleneck towards cost effective production of bioenergy and bioproducts from renewable plant biomass.

Earth and Environmental Systems Sciences conducts research to improve the scale-aware predictability of the Earth system, with particular focus on the interdependencies of the physical, biogeochemical, and human processes that govern variability, change, and the evolution of extreme events.
Using improved process level understanding based on field observations that combines with advanced modeling concepts and access to DOE's high performance computing, DOE's investments allow Earth System models to more confidently capture changes to the hydrologic cycle, the cryosphere, and extreme weather events. As part of the Next-Generation Ecosystem Experiments Arctic program, Los Alamos National Laboratory and University of Texas at Austin developed a novel machine-learning methodology that quickly delineates tundra (i.e., frozen soil) polygons from digital elevation models, thereby providing an automated method to quantify rates and amounts of change in arctic permafrost.

Researchers at LBNL and Sandia National Laboratory developed a new sub-model to represent saturated and unsaturated hydrologic processes in E3SM. The new sub-model unifies the physics of unsaturated and saturated zones, improving model predictions based on comparison with observations. A large field experiment, known as the Spruce and Peatland Responses Under Changing Environments (SPRUCE) and led by ORNL, demonstrated that increased ambient temperatures prolonged the growing season, but also made ecosystems more vulnerable to late season frost damage and plant growth. Lastly, an international team of scientists, including researchers at PNNL and LBNL, discovered that fungal spores make up as much as 69 percent of airborne salt particles in the Amazon basin; never before have fungal spores been considered a significant source of salt particle formation.

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.
- JGI provides the necessary genome sequencing of plants and microorganisms as a basis for identifying beneficial bioenergy properties and traits. The Eucalyptus family of plants is well known to produce a broad range of terpene compounds which are important biofuel and bioproduct components. The sequencing and analysis of a member of the

[a] CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) – advanced genome editing tools with broad potential for biotechnology applications.

Eucalyptus family (*C. Citriodora*) led to the identification of 102 new functional terpene synthase (TPS) genes. The work broadens the known TPS gene family lineage in Eucalyptus species and provides new genomic targets for biofuel and bioproduct development.

- Bioimaging capabilities developed by University of Idaho researchers and the EMSL are providing enhanced capabilities to monitor metabolic processes within single cells. This was recently demonstrated by tracking net lipid (biofuel precursors) production in yeast cells and quantifying the rates of metabolic processes. The work provides a new way to utilize imaging information to calculate rates of metabolism in single cells.
- The ARM user facility used ground-based ARM observations to study how optical depth (i.e., low-cloud reflectivity) changes with warming at three ARM sites. Findings were consistent with satellite measurements, increasing confidence in the data trends and enabling these ARM observations to be used to assess, calibrate, and improve the accuracy of Earth system models.

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 BRCs and the DOE 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 in concert with integrative, collaborative, and open access computational platforms will accelerate next generation of biological research for 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. Building on knowledge gained from breaking down plant cell wall polymers for bioenergy, engineered microbial and fungal systems will be explored for polymer recycling. Fungal systems and some bacteria utilize powerful enzymatic machinery to breakdown polymers to monomers for use as substrates. 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.[a]

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) and the National Microbiome Data Collaborative (NMDC). 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 carbon dioxide, 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.

[a] https://www.whitehouse.gov/wp-content/uploads/2018/09/National-Biodefense-Strategy.pdf

Activities and Explanation of Changes

(dollars in thousands)

FY 2020 Enacted		FY 2021 Request	Explanation of Changes FY 2021 Request vs FY 2020 Enacted
Biological Systems Science	**$404,779**	**$339,300**	**-$65,479**
Genomic Science	$268,235	$242,135	-$26,100
Foundational Genomics supports biosystems design techniques to modify microbes and plants for beneficial bioenergy, bioproduct and biotechnology purposes. Complementary efforts increase on genome-modification techniques to identify and predict biosecurity implications for energy and the environment. Environmental Genomics focuses 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. Computational analysis related to low dose radiation exposure is supported.		Foundational Genomics research will support expanded secure biosystems design research to gain the ability to stably and securely modify microorganisms and plants with specific beneficial traits for renewable bioenergy, bioproduct and biomaterials production with particular emphasis on programmable materials production and provide foundational research for the Next Generation of Biology. New efforts will be initiated in biological-based polymer recycling and upcycling research. Environmental Genomics will focus research to understanding environmentally relevant microbiomes and the interdependencies between plants and microbes in a sustainable and resilient ecosystem.	Funding will support new concepts in biosystems design for programmable production (and/or deconstruction) of organic/inorganic/hybrid materials in modified plants and microorganisms. Building on knowledge gained from breaking down plant cell wall polymers for bioenergy, engineered microbial and fungal systems will be explored for polymer recycling.
Computational Bioscience enhances research to 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. The efforts for the National Microbial Data Collaborative (NMDC) continue.		Computational Bioscience will support open computational platform development for microbiome science integrative with the JGI and the DOE Systems Biology Knowledgebase for bioenergy, bioproduct and programmable biomaterials design.	Funding will support new computational techniques and design tools to enable programmable organic/inorganic/hybrid materials production in modified plants and microorganisms.
The four BRCs continue 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,		The four BRCs will begin their fourth year of operations to develop modified bioenergy crops with expanded traits for bioenergy and bioproduct production and tolerance to a range of environmental stresses, development of biomass deconstruction process	The four BRCs will expand the knowledge needed to develop a range of plants modified with beneficial traits and conversion pathways in microorganisms to sustainably produce a broad

(dollars in thousands)

FY 2020 Enacted	FY 2021 Request	Explanation of Changes FY 2021 Request vs FY 2020 Enacted
and research to understand sustainable regional-scale bioenergy crop production.	streams, design of new engineered pathways in microbes to convert biomass components to a range of fuels, chemicals and bioproducts, and new analysis concepts for sustainable production of bioenergy crops on marginal lands.	spectrum of fuel components, bioproducts and biomaterials from renewable biomass.
Biomolecular Characterization and Imaging Science $45,000	$24,908	-$20,092
Biomolecular Characterization and Imaging Science supports new multi-modal imaging, visualization and structural characterization of biomolecular processes occurring in plants and microbes in support of systems biology research, including the use of neutrons. Investments in electron cryomicroscopy instrumentation at SC light sources are underway and will be completed. Research funding continues support for 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.	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 quantum science-enabled techniques, to understand and validate hypotheses of cellular metabolism and/or pathway design relevant to bioenergy, bioproduct and biomaterials production in plants and microorganisms.	Funding will support the exploration of new quantum science-based concepts for bioimaging and/or measurement and characterization capabilities for analyses of biological processes relevant to bioenergy/bioproduct/biomaterials research.

(dollars in thousands)

FY 2020 Enacted	FY 2021 Request	Explanation of Changes FY 2021 Request vs FY 2020 Enacted
Biological Systems Science Facilities and Infrastructure $77,000	$60,000	-$17,000
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 is enhancing efforts 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 are closely coupled with KBase for open access on an integrated bioinformatics platform. JGI and KBase move to Integrative Genomics Building on the LBNL campus.	JGI will provide users with expanded analysis capabilities in a more integrative computational platform for microbiome science through the NMDC and within the DOE Systems Biology Knowledgebase. New capabilities for natural product identification will be explored in concert with expanded metagenomic datasets and analysis techniques.	Integrative computational platforms among JGI, the NMDC, and KBase will allow the research community to conduct large scale metagenomics and microbiome analyses in a collaborative and reproducible manner facilitating BER's larger efforts in bioenergy, bioproduct and biomaterials research.
SBIR/STTR $14,544	$12,257	-$2,287
In FY 2020, SBIR/STTR funding is set at 3.65 percent of non-capital funding	In FY 2021, SBIR/STTR funding is set at 3.65 percent of non-capital funding.	The SBIR/STTR funding will be consistent with the BER total budget.

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 systems; modeling of component interdependencies under a variety of forcing conditions; interdependence of atmospheric, oceanic, hydrological, biogeochemical, ecological, and cryospheric variabilities; vulnerability and resilience of the full suite of energy and related infrastructures to extreme events; and uncertainty quantification. 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 support basic science to advance Earth system models as well as to optimize and accelerate environmental cleanup and reductions in life cycle costs.

The subprogram supports three primary research activities: atmospheric sciences; environmental system science; and modeling. In addition, the subprogram supports a data management activity, and two SC scientific user facilities: the ARM and the 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 management activity encompasses both observed and model-generated data that are collected by the ARM facility and 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 the main source 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 an integrated, robust and scale-aware predictive understanding of environmental systems, 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, and short-term extreme events that act on spatial scales that span from molecular to global. Multi-scale new data and understanding are essential to advance Earth system modeling that can and is being 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 and environmental stewardship. The vision for this activity is to develop a unified predictive capability that integrates scale-aware process understanding with unique characteristics of watersheds, coastal zones, and terrestrial-aquatic interfaces that are present in, e.g., the Arctic, boreal zone, and the Tropics, including the Great Lakes.

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 environmental systems in coupled Earth system models. Research supports the integration of observations with process modeling from molecular to field scales, to improve understanding of hydrological, and biogeochemical processes that affect terrestrial environments.

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 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 continues to support the Energy Exascale Earth System Model (E3SM), which is a part of the DOE Exascale Computing Initiative, and is a computationally efficient model adaptable to DOE's Leadership Computing Facility supercomputer architectures 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 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. These observations provide new data to address the main source of uncertainty in Earth system models: the interdependence of clouds, atmospheric aerosols, and precipitation that in turn influences the radiation balance. In addition to supporting interdisciplinary science challenges, extreme events represented in DOE's Earth system model are used to inform plans for designs and deployment of future energy infrastructures. 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 2021, ARM will continue operations at the three fixed sites. One mobile facility will be deployed to the Houston, TX area for Tracking Aerosol Convection Interactions Experiment (TRACER). Scientists will use the second-generation C-band ARM Scanning Precipitation Radar (CSAPR2), and a small satellite site with radiosonde and aerosol measurements to learn more about cloud and aerosol interactions in deep convection over the Houston area. 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 fixed 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 atmospheric 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 capabilities, including unmanned aerial system (UAS) and manned aircraft. In FY 2021, the newly acquired manned aircraft will continue to 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.

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, catalysts and materials, and interfacial and surface (including aerosol) science relevant to energy and environmental challenges facing DOE and the Nation. This research informs the development of advanced biofuels and bioproducts, the design of novel methods to accelerate environmental cleanup, and an improved understanding of Arctic infrastructure vulnerability due to biogenic processes that govern permafrost thaw. 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 new science derived from Earth observations and model-generated data can be used to achieve broad benefits ranging from informing the design of robust resilient infrastructures to risk analysis involving natural disaster impact mitigation to commercial supply chain management to natural resource management and environmental stewardship. 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 on archiving scientifically useful data from the Earth System Grid Federation, ARM, Ameriflux, NGEE field experiments, SPRUCE site observations, and long- term DOE investments to understand watershed systems.

Activities and Explanation of Changes

(dollars in thousands)

FY 2020 Enacted	FY 2021 Request	Explanation of Changes FY 2021 Request vs FY 2020 Enacted
Earth and Environmental Systems Sciences $345,221	**$177,634**	**-$167,587**
Atmospheric System Research (ASR) $35,000	$12,000	-$23,000
ASR accelerates 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. Initial data from the Arctic campaign is included in the analyses. ASR continues to make use of data generated by Large Eddy Simulations at the ARM Oklahoma site.	The Request for ASR will continue limited research on clouds, aerosols, and thermodynamic processes, with a focus on data from the ARM fixed sites as well as recent field campaigns conducted in the Arctic during FY 2020. ASR will continue to make use of data generated by Large Eddy Simulations at the ARM Oklahoma site.	Reduced research will focus on using the new observations from ARM field studies to inform Earth system model development.
Environmental System Science (ESS) $77,638	$19,000	-$58,638
The ESS activity focuses research on permafrost and continues investments in studies of boreal ecology and modeling hydrobiogeochemistry of watersheds and terrestrial-aquatic interfaces, including the Great Lakes. Research on tropical ecology and subsurface biogeochemistry research on radionuclides and mercury continues.	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, with a focus on the coastal zones encompassed by the Delaware and Susquehanna watersheds and the Great Lakes.	Funding for ESS will support investment in modeling activities associated with the terrestrial-aquatic project located in the mid-Atlantic and Great Lakes region.

(dollars in thousands)

FY 2020 Enacted	FY 2021 Request	Explanation of Changes FY 2021 Request vs FY 2020 Enacted
Earth and Environmental Systems Modeling $97,000	$37,643	-$59,357
Earth and Environmental Systems Modeling investments focus 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 research continues to support activities on the modeling of extreme phenomena (e.g., hurricanes), improved representation of biogeochemistry, and a better understanding of the water cycle.	The Request for Earth and Environmental Systems Modeling will focus investments on further refinement of the science underpinning non-hydrostatic adaptive mesh modeling and incorporating the necessary software for deployment of the model onto exascale computing architectures. The E3SM version 1 release in April 2018 will be updated to a version 2 model that is anticipated to be released in FY 2022. Version 2 will enable more sophisticated research based on higher model resolution, and the new version will add advanced capabilities for exploring cryosphere-ocean dynamics' impacts of climate variability on Antarctic ice shelf melting, continental ice sheet evolution and sea level rise, and the effects of changing water cycles on watershed and coastal hydrological systems.	Funding will support development of Version 2 of E3SM, with a planned release in FY 2022 to the scientific community in support of broad-based basic research as well as to energy sector stakeholders who require projections.
Core research continues to support model intercomparisons and diagnostics. In addition, research focuses on understanding the fine scale physics and dynamics that govern interactions between the Arctic and midlatitudes.	The Request will focus on core research in model intercomparisons and diagnostics. In addition, research will incorporate limited fine scale physics and dynamics that can be applied to metrics that can be applied to coastal zones and mid-latitude-Arctic interactions.	Funding will support research with a shift in emphasis from the science of just Arctic-midlatitude interactions to examine boundary regions that also include coastal zones.

(dollars in thousands)

FY 2020 Enacted	FY 2021 Request	Explanation of Changes FY 2021 Request vs FY 2020 Enacted
Earth and Environmental Systems Sciences Facilities and Infrastructure $123,110	$102,635	-$20,475
ARM activities continue to provide new observations, through long term measurements at fixed sites in Alaska and Oklahoma and the Eastern North Atlantic. The ARM continues the seasonal mobile facility deployment at the Oliktok site. The research prioritizes all ARM activities for critical observations needed to improve the E3SM model. ARM is deploying the third mobile facility to northern Norway. Furthermore, ARM is completing a major multi-agency and multi-national campaign in the Arctic. Testing continues on the new aircraft acquired in FY 2019 to evaluate performance.	The Request for ARM will continue to provide new observations through long term measurements at fixed sites in Alaska and Oklahoma, while limiting active operations at the Eastern North Atlantic site. ARM will complete a long-term deployment of its Oliktok, AK, mobile facility in preparation for a new location in the southeastern U.S. in FY 2022. The Request prioritizes all ARM activities for critical observations needed to improve the E3SM model. ARM will initiate deployment of its second mobile facility to Houston, TX. The newly acquired aircraft will continue to 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.	Funding will support limited ARM Eastern North Atlantic site operations, and the mobile facility at Oliktok, Alaska will complete its deployment.
EMSL continues 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 continues to build the Dynamic Transmission Electron Microscope, in support of 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 complete construction of the Dynamic Transmission Electron Microscope (DTEM) and provide some new capabilities in support of BER science.	Funding will support the multiple experimental capabilities of the new DTEM and a reduced number of users.

(dollars in thousands)

FY 2020 Enacted	FY 2021 Request	Explanation of Changes FY 2021 Request vs FY 2020 Enacted
The Earth and Environmental Sciences Data Management activity continues to maintain existing critical software and data archives in support of ongoing experimental and modeling research. Essential data archiving and storing protocols, capacity is maintained. New analytical methodologies are being explored to advance scientific insight based on the fusion of model generated and observed data.	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. Advanced analytical methodologies such as Machine Learning (ML) will be used to improve the predictability of extreme events more rapidly using Earth system models.	Funding will support new analytical methodologies to advance scientific insight based on the fusion of model generated and observed data.
SBIR/STTR $12,473	$6,356	-$6,117
In FY 2020, SBIR/STTR funding is set at 3.65 percent of non-capital funding.	In FY 2021, SBIR/STTR funding is set at 3.65 percent 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 2019 Enacted	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	26,800	9,800	7,000	-2,800
Total, Capital Operating Expenses	**N/A**	**N/A**	**26,800**	**9,800**	**7,000**	**-2,800**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
Capital Equipment						
Major Items of Equipment[a]						
Earth and Environmental Systems Sciences						
Atmospheric Radiation Measurement Research Facility (ARM) – ARM Aircraft project	17,700	200[b]	17,500	—	—	—
Total, MIEs	N/A	N/A	17,500	—	—	—
Total, Non-MIE Capital Equipment	N/A	N/A	9,300	9,800	7,000	-2,800
Total, Capital Equipment	**N/A**	**N/A**	**26,800**	**9,800**	**7,000**	**-2,800**

[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-159 (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-1s that remained in service worldwide and was at the end of its service life. BER initiated retirement and replacement of the aircraft in FY 2019. The FY 2019 Enacted budget included funding to replace the Battelle-owned G-1 aircraft that supported airborne data collection as part of ARM field campaigns. The FY 2020 Enacted budget and the FY 2021 Request will support continued testing and evaluation of the newly acquired DOE-owned Bombardier Challenger 850 Regional Jet aircraft. This includes supporting modifications to the air frame as needed to install numerous existing and new atmospheric aerosol, cloud, turbulence, and other sensors. This aircraft will allow for observations that will provide new data to address the main source of uncertainty in Earth system models: the interdependence of clouds, atmospheric aerosols, and precipitation that in turn influences the radiation balance. Earth system modeling, simulation, and analysis tools that will be enabled through this capability are essential for informing energy infrastructure investment decisions that have the future potential for large-scale deployment that in turn benefit national security.

Biological and Environmental Research
Funding Summary

(dollars in thousands)

	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
Research	516,858	570,500	367,684	-202,816
Facility Operations	170,642[a]	179,500	149,250	-30,250
Projects				
Major Items of Equipment	17,500	—	—	—
Construction	—	—	—	—
Total, Projects	17,500	—	—	—
Total, Biological and Environmental Research	**705,000**	**750,000**	**516,934**	**-233,066**

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

Biological and Environmental Research
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 2019 Enacted	FY 2019 Current	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
TYPE B FACILITIES					
Atmospheric Radiation Measurement Research Facility (ARM)	**$85,500[a]**	**$85,500[a]**	**$70,110**	**$54,500**	**-$15,610**
Number of users	980	980	1,100	900	-200
Joint Genome Institute	**$70,000**	**$70,000**	**$77,000**	**$60,000**	**-$17,000**
Number of users	1,933	1,933	1,925	1,550	-375
Environmental Molecular Sciences Laboratory	**$45,000**	**$45,000**	**$45,000**	**$43,500**	**-$1,500**
Number of users	577	577	577	525	-52
Total Facilities	**$200,500**	**$200,500**	**$192,110**	**$158,000**	**-34,110**
Number of users	3,490	3,490	3,602	2,975	-627

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

Biological and Environmental Research
Scientific Employment

	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Request	FY 2021 Request vs FY 2020 Enacted
Number of permanent Ph.D.'s (FTEs)	1,425	1,500	1,250	-250
Number of postdoctoral associates (FTEs)	350	370	280	-90
Number of graduate students (FTEs)	490	520	400	-120
Other scientific employment (FTEs)[a]	350	370	280	-90

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