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. This fundamental research, conducted at universities, DOE national laboratories, and research institutions across the country, explores organisms and ecosystems that can influence the U.S. energy system and advances understanding of the relationships between energy and environment from local to global scales, including a focus on climate change modeling. BER's support of basic research will contribute to a future of stable, reliable, and resilient energy sources and infrastructures that will contribute to climate solutions with a focus on environmental justice while strengthening economic prosperity. Research within BER can be categorized into biological systems and Earth and environmental systems. Biological systems research seeks to characterize and predictively understand microbial and plant systems using genomic science, computational analyses, and experimental approaches. Foundational knowledge of the structure and function of these systems underpins the ability to leverage natural processes for energy production, including the sustainable development of biofuels and other bioproducts, as well as natural carbon sequestration capabilities. Characterization of microbial communities will lead to understanding the impacts of how vulnerable environments will respond to climate change. Earth and environmental systems research seeks to characterize and understand the feedback between Earth and energy systems, which includes studies on atmospheric physics and chemistry, ecosystem ecology and biogeochemistry, and development and validation of Earth system models extending from regional to global scales. These models integrate information on the biosphere, atmosphere, terrestrial land masses, oceans, sea ice, subsurface, and human components. To promote world-class research in these areas, BER supports user facilities that enable observation and measurement of atmospheric, biological, and biogeochemical processes using the latest technologies. All BER activities are informed by community and the federally chartered BER Advisory Committee engagement.

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 and clean energy technologies to underpin a burgeoning bioeconomy.

Since the 1950s, BER and its predecessor organizations have been critical contributors to the fundamental scientific understanding of climate change and 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 climate and Earth System models that are in use today. Presently, BER research contributes to reducing the greatest uncertainties in model predictions, e.g., involving clouds and aerosols. In the last decade, DOE research has made considerable advances in increasing the reliability and predictive capabilities of these models using applied mathematics, access to DOE's fastest computers, and systematic comparisons with observational data to improve confidence in model predictions.

BER-supported research has also produced the software and algorithms that enable the productive application of models that span genomics, systems biology, environmental, and Earth system science. These mission-driven models that are run on DOE's fastest supercomputers, are game-changing and among the most capable in the world. For example, BER's models of biological and environmental processes are exploring the systems level complexity of genomics, protein structures, and microbial dynamics that will serve the basis of future bioenergy sources. BER's Joint Genome Institute (JGI) and Environmental Molecular Sciences Laboratory (EMSL) provide the necessary information to achieve these goals. Model developments in climate and Earth system science are shifting to ultra-high resolution to better represent the processes that limit prediction uncertainty, e.g., in the most climate-sensitive regions. Cloud-aerosol data provided by the Atmospheric Radiation Measurement Research Facility (ARM) as well as environmental data provided by BER's long term observatories are necessary in developing, testing, and validating climate and Earth systems.

Highlights of the FY 2022 Request

The FY 2022 Request for BER is $828.0 million. BER will enhance its research on climate modeling by: 1) initiating new Urban Integrated Field Laboratories (Urban IFLs) that will build integrated models and tools that improve our understanding of the interdependence of the natural and human components of the climate system; 2) establishing the National Virtual Climate Laboratory (NVCL), which will serve as a one stop portal to advance access to climate science from the DOE National Laboratories; and 3) initiating planning for a Climate Laboratory, which is included in the American Jobs Plan, or a center award, affiliated with a Historically Black College or University (HBCU) or other Minority Serving Institution (MSI). BER research will also support new activities to examine the global carbon carrying capacity of terrestrial ecosystems; continue investment in artificial intelligence (AI); enhance support for novel quantum sensors for biological systems and continued support of crosscutting SC QIS Research Centers; launch a new Biopreparedness Research Virtual Environment (BRaVE); and support new activities in advanced manufacturing for novel polymer upcycling approaches as well as new bio-based materials and foundational bioenergy research underpinning new biotechnology and the bioeconomy. BER will continue a pilot project to study complex coastal estuaries, including Puget Sound.

Key elements in the FY 2022 Request include:

Research

- Within Genomic Sciences, the Biopreparedness Research Virtual Environment (BRaVE) will provide the cyber infrastructure, computational platforms, and next generation experimental research capabilities within a single portal allowing distributed networks of scientists to work together on multidisciplinary research priorities and/or national emergency challenges. The overall goals of BRaVE are to understand the function of whole biological systems, effectively integrating knowledge from distributed datasets, individual process components, and individual component models in an AI/ML-enabled, open access computational environment. BER also prioritizes the four BRCs, which perform new fundamental research underpinning the production of clean energy and chemicals from sustainable biomass resources for translation of basic research results to industry. BER will initiate efforts to translate biodesign rules to functional properties of novel biological polymers and efforts to understand the key factors controlling soil carbon residence time through detailed characterization of soil-plant-microbe-environment processes governing carbon turnover. Computational Biosciences efforts will include a new initiative on Integrated Computational and Data Infrastructure for Scientific Discovery to deploy a flexible multi-tier data and computational management architecture for microbiome system dynamics and behavior. Research in Biomolecular Characterization and Imaging Science will develop QIS enabled techniques and sensors for predictive understanding of biological processes.
- Earth and Environmental Systems Sciences research will focus on improving the representation of physical and biogeochemical processes to enhance the predictability of Earth system models. Environmental System Science integrates physical and hydrobiogeochemical sciences to provide scale-aware predictive understanding of above- and below-surface terrestrial ecosystems. Atmospheric System Research will investigate cloud-aerosol-precipitation interactions to improve fine resolution cloud resolving models and to enhance the Energy Exascale Earth System Model (E3SM) down to spatial scales of 3 km. The E3SM system will include advanced software and AI/ML for running on future DOE computer architectures. The Data Management effort will continue to enhance data archiving and management capabilities, including using AI. Research on coastal estuaries will be continued, with a focus on the Chesapeake Bay, Puget Sound, and the Great Lakes. Research involving field-based observing and modeling will be initiated under new Urban Integrated Field Laboratories to incorporate environmental justice as a key tenet of research involving climate-sensitive regions. Additionally, the new NVCL will provide unified access to climate science to MSIs and HBCUs, connecting frontline communities with the key climate science capabilities at the DOE national laboratories. Planning efforts are initiated for a competition pending the AJP funding for a Climate Laboratory/Center affiliated with an HBCU or MSIs; the lab or center will serve as the translational agent connecting BER climate science with broader socioeconomic and environmental justice issues for equitable solutions. This will enhance research capacity at the affiliated universities and bring interdisciplinary strength and diversity to DOE's climate research.
- The Office of Science is fully committed to advancing a diverse, equitable, and inclusive research community. This commitment is key to providing the scientific and technical expertise for U.S. leadership in biological and environmental sciences. Toward that goal, BER will participate in the SC-wide Reaching a New Energy Sciences Workforce (RENEW) initiative that leverages SC's unique national laboratories, user facilities, and other research infrastructures to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. This includes MSIs and individuals from groups historically

underrepresented in STEM, but also includes students from communities with environmental justice impacts and the EPSCoR jurisdictions. The hands-on experiences gained through the RENEW initiative will open new career avenues for the participants, forming a nucleus for a future pool of talented young scientists, engineers, and technicians with the critical skills and expertise needed for the full breadth of SC research activities, including DOE national laboratory staffing.

Facility Operations

- The DOE JGI will continue providing high quality genome sequence data and analysis techniques for a wide variety of plants and microbial communities.
- ARM will continue to provide new observations to advance Earth System models. A mobile facility will continue to be deployed near Houston, TX to conduct the aerosol-convection interactions experiment. Another mobile unit will continue the study on water and energy cycles in mountainous watersheds. A third will relocate to the south eastern U.S. for operation starting in FY 2023. Acceptance testing and evaluation will be completed on the manned aircraft.
- 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.
- All BER facilities will begin a multiyear instrumentation refresh to ensure these facilities are delivering the capabilities required by the scientific community.

Biological and Environmental Research
FY 2022 Research Initiatives

Biological and Environmental Research supports the following FY 2022 Research Initiatives.

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Artificial Intelligence and Machine Learning	3,000	3,000	3,000	–
Biopreparedness Research Virtual Environment (BRaVE)	–	–	5,000	+5,000
Exascale Computing Crosscut	15,000	15,000	15,000	–
Fundamental Science to Transform Advanced Manufacturing	–	–	5,000	+5,000
Integrated Computational & Data Infrastructure	–	–	5,183	+5,183
Quantum Information Science	12,000	12,000	14,500	+2,500
Reaching a New Energy Sciences Workforce (RENEW)	–	–	3,000	+3,000
Revolutionizing Polymers Upcycling	–	6,250	6,250	–
Total, Research Initiatives	**30,000**	**36,250**	**56,933**	**+20,683**

Biological and Environmental Research
Funding

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Biological and Environmental Research				
Genomic Science	268,235	277,574	277,000	-574
Biomolecular Characterization and Imaging Science	45,000	45,000	45,000	–
Biological Systems Facilities & Infrastructure	77,000	80,000	84,500	+4,500
Biological Systems Science, SBIR/STTR	14,544	–	–	–
Total, Biological Systems Science	**404,779**	**402,574**	**406,500**	**+3,926**
Atmospheric System Research	35,000	36,000	39,000	+3,000
Environmental System Sciences	77,638	87,777	119,500	+31,723
Earth and Environmental Systems Modeling	97,000	100,674	108,000	+7,326
Earth and Environmental Systems Sciences Facilities and Infrastructure	123,110	125,975	155,000	+29,025
Earth and Environmental Systems Sciences, SBIR/STTR	12,473	–	–	–
Total, Earth and Environmental Systems Sciences	**345,221**	**350,426**	**421,500**	**+71,074**
Subtotal, Biological and Environmental Research	**750,000**	**753,000**	**828,000**	**+75,000**
Total, Biological and Environmental Research	**750,000**	**753,000**	**828,000**	**+75,000**

SBIR/STTR funding:

- FY 2020 Enacted: SBIR $23,687,000 and STTR $3,330,000
- FY 2021 Enacted: SBIR $23,851,000 and STTR $3,352,000
- FY 2022 Request: SBIR $25,504,000 and STTR $3,589,000

(dollars in thousands)

	FY 2022 Request vs FY 2021 Enacted
Biological Systems Science	**+$3,926**

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. Continued 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. New activities will be initiated to understand the key molecular processes governing soil-microbe-plant interactions with the environment that control carbon turnover. Environmental Genomics research is focused on understanding environmentally relevant microbiomes and the interdependencies between plants and microbes in a sustainable and resilient ecosystem. This research will be enhanced with the Biopreparedness Research Virtual Environment (BRaVE) providing the integrated computational and experimental platforms for multidisciplinary research and the Fundamental Science to Transform Advanced Manufacturing Initiative that will focus on novel polymer recycling approaches as well as new bio-based materials. Computational Bioscience will focus on an integrated computational platform, building out the National Microbiome Data Collaborative and continuing to add functionality to the Systems Biology Knowledgebase. The Request fully supports the four DOE BRCs in their fifth year of bioenergy research to underpin efforts to produce innovative clean energy and bioproducts from sustainable biomass resources, including augmented data dissemination to the broader community. 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.

	(dollars in thousands) FY 2022 Request vs FY 2021 Enacted
Earth and Environmental Systems Sciences The Request enhances support for 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 to understand and model the fate and transport of nutrients. Research on coastal estuaries will be continued, with a focus on the Chesapeake Bay, Puget Sound, and the Great Lakes. New integrated field laboratories focused on urban regions will be initiated, as will establishment of the National Virtual Climate Laboratory (NVCL) to serve as a unified access point for engagement with key climate science capabilities at the DOE labs. Planning begins for a new Climate Laboratory or Center. 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 continue deployment to the Houston, TX area; the second unit will continue observations in the upper Colorado River watershed; and the third unit will be deployed to the south eastern U.S. for operation in FY 2023. Acceptance testing and evaluation will be completed on the recently acquired manned aircraft. EMSL will focus on biological and environmental molecular science. Data management activities will include applying advanced analytics to observations and environmental field data.	**+$71,074**
Total, Biological and Environmental Research	**+$75,000**

Basic and Applied R&D Coordination

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

BER supports some interagency projects to manage databases (such as the Protein Data Bank) through interagency awards and funding for complementary community resources (such as beamlines and cryo-electron microscopy), mostly with NIH and NSF. BER also serves on a government advisory committee for DoD's latest Manufacturing Innovation Institute, the BioMADE project researching synthetic biology applications.

All Earth systems research activities are specifically coordinated through the interagency U.S. Global Change Research Program and other NSTC subcommittees. For example, the DOE E3SM has evolved to become the world's highest resolution Earth system model, that in turn serves as an integrating platform for the scientific community to develop and test system-level scientific concepts. The new version will add advanced capabilities for exploring cryosphere-ocean dynamics' impacts of climate variability, 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 Interagency Council for Advancing Meteorological Services (ICAMS). The ICAMS is co-led by OSTP and NOAA with DOE as a member. The Intelligence Community has indicated significant interest in E3SM, as a platform to incorporate their data to address national security problems. The E3SM research is tightly coordinated with BER's large scale experimental activities and has 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 focus on plant-microbe interactions in soil.

Researchers at Lawrence Livermore National Laboratory investigating RNA viruses in soil found that most RNA viruses infect soil fungi. Furthermore, the presence of root litter influenced viral community composition, and the RNA viral communities responded rapidly to resource availability. This work helped identify the potential role viruses play in soil microbial community dynamics with the potential to influence carbon cycling and/or sequestration in soil.

Bioenergy Research Centers' research continues to highlight significant basic science advances in clean energy technology underpinning biofuels and bioproduct production from sustainable plant biomass.

Notable accomplishments include:

- engineering of a soil bacterium with plant-derived amino acids boosted methyl ketone production, a biodiesel blendstock, nine-fold compared to the control experiment without plant-derived amino acids;
- use of genome-scale metabolic models to predict carbon use efficiency (CUE) in bacteria across soil types, provided a predictive link between genomics and carbon sequestration in soil;
- identification of new gene variations in the genomes of Poplar trees are now available as molecular targets for precision genome-editing to improve biomass feedstock characteristics for biofuel and bioproduct production;
- results from a long term field experiment indicate reduced nitrate pollution in agricultural landscapes over seven years from established perennial bioenergy crops.

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 climate variability, change, and the evolution of extreme events.
At Los Alamos National Laboratory, Arctic ice and permafrost dynamics were coded into a numerical model to understand how climate change will impact the growth of Arctic deltas, stream flow, and sediment delivery to the coastal ocean. Researchers concluded from new model results that reduced ice cover may make Arctic deltas more vulnerable due to sea level rise and increased coastal erosion, and increased sediment delivery to the ocean will likely lead to altered biogeochemistry and turbidity on coastal ocean shelves.

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.
Notable accomplishments from the User Facilities include:

- the Joint Genome Institute (JGI) developed a new technology, chassis-independent recombinase-assisted genome engineering (CRAGE), that enables up to 48,000 basepairs to be inserted into a bacterial host in a single step enabling more successful and efficient biomanufacturing;
- the Environmental Molecular Sciences Laboratory (EMSL) developed an approach to image and view interactions between bacteria and plants at the molecular level for the very first time, thereby offering insights for improving agricultural production; and
- the Atmospheric Radiation Measurement (ARM) user facility observed that evaporating precipitation from stratocumulus clouds cools and moistens the sub-cloud layer and decreases air turbulence below the clouds. This new measured observation will need to be accurately represented in Earth system models to improve climate simulations of radiation balance over the ocean.

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 and how does this information explain the functional characteristics of cells, organisms, and whole biological systems?
- How do interactions among cells regulate the functional behavior of living systems and how can those interactions be understood dynamically and predictively?
- How do plants, microbes, and communities of organisms adapt and respond to changing environmental conditions (e.g., temperature, water and nutrient availability, and ecological interactions), and how can their behavior be manipulated toward desired outcomes?
- What organizing biological principles need to be understood to facilitate the design and engineering of new biological systems for beneficial purposes?

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 and bioeconomy-related 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.

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 biological research for solutions to clean energy production, breakthroughs in genome-based biotechnology underpinning a broader bioeconomy, 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 understand genotype to phenotype translations 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 in support of the ongoing Revolutionizing Polymer Upcycling research initiative. The Fundamental Science to Transform Advanced Manufacturing Initiative will support new approaches and systems to support biomanufacturing, especially with respect to genome-enabled engineering and design of biomaterials. 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.

The new Biopreparedness Research Virtual Environment (BRaVE) will provide a single portal through which a distributed network of capabilities and scientists can work together on multidisciplinary and multiprogram priorities to tackle significant DOE mission-relevant science priorities and quickly address urgent national challenges when needed. The overall goals of the virtual environment are to understand the function of whole biological systems, effectively integrating knowledge from distributed datasets, individual process components, and individual component models in an AI/ML-enabled, open access computational environment.

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 bioenergy and environmental 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 analyses techniques and simulation capabilities on high performance computing platforms to accelerate collaborative and reproducible systems biology research within the Genomic Sciences. The activity supports the Integrated Computational and Data Infrastructure for Scientific Discovery initiative.

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 integrative approaches to detecting, visualizing, and measuring systems biology processes engaged in 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 holistic and 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 governing phenotypic expression in plants and microbes. The activity will include new efforts to incorporate QIS-enabled concepts into new approaches 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 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 a range of different chemicals, 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.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Biological Systems Science	**$402,574**	**$406,500**	**+$3,926**
Genomic Science	$277,574	$277,000	-$574
Foundational Genomics research supports 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 initiated in biological-based polymer recycling and upcycling research. Environmental Genomics focuses on research to understand environmentally relevant microbiomes and the interdependencies between plants and microbes in a sustainable and resilient ecosystem.		Foundational Genomics research will support new biosystems design research to accelerate the ability to design plants and microorganisms with specific beneficial functions for renewable bioenergy, bioproduct and biomaterials production, or carbon sequestration. Environmental Genomics will support new plant genomics research to elucidate genotype to phenotype translations leading to beneficial bioenergy or bioproduct traits in potential bioenergy crops and new environmental microbiome science to understanding the functions of environmentally relevant microbial communities in a variety of ecosystems. The Biopreparedness Research Virtual Environment (BRaVE) will provide a single platform through which a distributed network of data and experimental capabilities can be accessed by multidisciplinary teams of scientists working together on urgent multiprogram priorities requiring science-informed insights.	Funding will support new concepts in biosystems design for programmable production (and/or deconstruction) of organic/inorganic/hybrid materials in modified plants and microorganisms. These efforts will contribute towards knowledge of soil-microbe-plant interactions governing carbon sequestration in terrestrial systems. Also, new efforts in plant genomics and environmental microbiome science will extend advances in plant genome science and the ability to predictively understand the activity of microbial communities in relevant environmental microbiomes. These efforts, building on knowledge gained from breaking down plant cell wall polymers for bioenergy, will be explored in engineered microbial and fungal systems relevant to support the ongoing Revolutionizing Polymer Upcycling initiative. The Advanced Manufacturing Initiative will support new approaches and systems to support biomanufacturing to genome-enabled engineering and design of biomaterials. Funding will also initiate the BRaVE.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Computational Bioscience supports open computational platform development for microbiome science integrative with the JGI and the DOE Systems Biology Knowledgebase for bioenergy, bioproduct and programmable biomaterials design.	Computational Bioscience will support microbiome science through the National Microbiome Data Collaborative and provide capabilities within KBase to enable the design of microbes and plants for a variety of bioenergy, bioproduct and biomaterial production purposes. Platform integration among these two projects will continue in close coordination with the JGI.	Funding will support new computational techniques for new biosystems design, plant genomics and environmental microbiome tools supporting broader genomic science efforts within the portfolio. The activity will also support the Integrated Computational and Data Infrastructure for Scientific Discovery.
The four BRCs began 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 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.	The four BRCs will begin their fifth year of operations on multidisciplinary clean energy research underpinning a broader bio-based economy. The BRCs will identify the genomic underpinnings of complex plant traits in crops with promising bioenergy/bioproduct characteristics, streamline biomass deconstruction processes to funnel plant components into defined process streams, design new pathways in microorganisms to convert plant biomass components to a range of fuels, chemicals and products, and develop the needed agronomic understanding of how to manage bioenergy crops for sustainable production on marginal lands.	The four BRCs will expand the knowledge needed to further advance a broadening bioeconomy by developing a range of dedicated crops for bioenergy and bioproduct production; developing methods to breakdown and convert plant biomass to a range of fuels, chemicals and products, and how to sustain broader scale efforts in bioenergy/bioproduct production at larger agronomic scales. Funding supports acceleration of bioenergy data curation, deposition, and dissemination to the broader community.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Biomolecular Characterization and Imaging Science $45,000	$45,000	$ —
Development of new bioimaging, measurement and characterization approaches through the Biomolecular Characterization and Imaging Science activity includes expanded integrative imaging and analysis platforms and biosensors, including quantum science-enabled techniques, to understand and validate hypotheses of cellular metabolism and/or test pathway design relevant to bioenergy, bioproduct and biomaterials production in plants and microorganisms.	New quantum-enabled science concepts will be explored for application in bioimaging, measurement and characterization techniques through the Biomolecular Characterization and Imaging Science activity. Multimodal imaging concepts will also be pursued to create integrative systems to validate hypotheses of cellular function or design of new process.	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. New instrumentation based on these techniques will enhance capabilities to image biological processes dynamically and repeatedly without damage to the plant or microorganism under study.
Biological Systems Facilities & Infrastructure $80,000	$84,500	+$4,500
JGI provides 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.	JGI will provide users with high quality genome production and new analysis techniques for complex plant and microbiome samples. Integrative activities with the DOE Systems Biology Knowledgebase will provide new cross-platform capabilities for users and the NMDC. New methods for natural product identification and characterization of microbial isolates will be explored in concert with expanded metagenomics analysis techniques.	Funding will support integrative computational platforms among JGI, KBase, and NMDC which 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. A multi-year instrument and equipment refresh will be initiated to ensure that existing capabilities are state-of-the-art and to bring on new capabilities needed by the research community.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

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 climate, environmental, and Earth system research, in support of DOE's mission goals for transformative science for energy and national security. This includes research on atmospheric, terrestrial, and human components of the Earth system; modeling of component interdependencies under a variety of natural and anthropogenic forcings; studies involving the interdependence and perturbations involving cloud, aerosol, marine, ecological, hydrological, biogeochemical, and cryospheric processes; analysis of the vulnerabilities that affect the resilience of the full suite of energy and related infrastructures as well as the vulnerabilities of other human systems and to extreme events; and uncertainty quantification. This integrated portfolio of research extends from molecular-level to field-scales, spans time scales from seasonal to centennial, and emphasizes the coupling of multidisciplinary experimentation with increasingly sophisticated computer models. The ultimate goal of new science is to develop and enhance a predictive, systems-level understanding of the fundamental science that addresses environmental and energy-related challenges associated with extreme phenomena. Investments will emphasize the most difficult challenges limiting prediction uncertainty, including cloud-aerosol interactions; terrestrial systems experiencing rapid transitions; the role of human activities as they couple with the natural system; and opportunities provided by machine learning and emerging technologies.

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 Atmospheric Radiation Measurement (ARM) user facility and the Environmental Molecular Sciences Laboratory (EMSL). ARM provides unique, multi-instrumented, high resolution capabilities for continuous, three-dimensional, long-term observations that researchers need in order to improve scientific understanding of atmospheric and climate processes involving clouds, aerosols, and the Earth's energy balance. ARM also contains a sophisticated model-simulation component that scientists use to augment field observations. EMSL provides integrated experimental and computational resources that researchers utilize 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 dedicated environmental field experiments; on behalf of the DOE and the international community, this activity also archives information generated world-wide by climate and 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 climate and Earth system models: the interdependence of clouds, atmospheric aerosols, and precipitation that in turn influences the Earth's radiation balance. ASR coordinates with ARM, using the facility's continuous long-term datasets that in turn provide three-dimensional measurements of a variety of aerosol types that span natural to black carbon; cloud and precipitation microphysics under a variety of dynamical conditions; and turbulence and thermodynamics over a range of environmental conditions. Collected at diverse climate-sensitive geographic locations, the long-term observational datasets are supplemented with shorter-duration, ground-based and airborne field campaigns as well as laboratory studies to target specific atmospheric processes. Using integrated, scalable test-beds that incorporate process-level understanding, climate and Earth system models incorporate ASR research results to assure greater confidence in system level understanding and predictions that span local to global.

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. Short-term extreme events that act on spatial scales that span from molecular to global are of particular interest. New multi-scale data are essential to advance basic understanding and improve climate and Earth system models that can and are being used to achieve broad benefits ranging from planning and development of energy infrastructure 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, terrestrial-aquatic interfaces, and urban-rural transitions that are present in, e.g., the Arctic, midlatitude boreal zone, the Tropics, mountainous zones, and coastal regions that include the Delaware and Susquehanna watersheds, the Great Lakes, and Puget sound.

Using decadal-scale investments, such as the Next Generation Ecosystem Experiments (NGEEs), to study the variety of time scales and processes associated with ecological change, 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 climate and 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.

Urban Integrated Field Laboratories (IFLs) for climate science will be initiated. The Urban IFLs will be dedicated to developing the science framework for advancing observational and prediction capabilities to tackle the following interdependent challenges: constraining climate changes and its impacts on all scales across urban regions; evaluating the mitigation-potential for emerging energy technologies in urban regions and beyond; and addressing environmental justice by enabling neighborhood scale evaluation of climate impacts and energy needs. The Urban IFL scope will initially target a focused set of urban regions, integrate field data with a next generation Earth System Modeling framework, and create a science capability to advance climate and energy research as a unified co-dependent system. The scope will provide DOE, its stakeholders, and impacted communities with the best possible science-based tools that enable the evaluation of the societal and environmental benefits of current and future energy policies.

The National Virtual Climate Laboratory (NVCL) will provide access to climate science to MSIs and HBCUs, connecting frontline communities with the key climate science capabilities at the DOE national laboratories. Planning will also begin to establish a Climate Laboratory or center (pending AJP) affiliated with an HBCU or MSI.

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 air-surface exchanges 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 the physical, biogeochemical, and dynamical underpinning of fully coupled climate and Earth System Models (ESMs), in coordination with other Federal efforts. The research specifically focuses on quantifying and reducing the uncertainties in these system models, based on more advanced process representations, sophisticated software, robust couplers, diagnostics, performance metrics, and advanced data analytics. Priority model components include the ocean, sea-ice, land-ice, atmosphere, terrestrial ecosystems, and human activities, where these 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 within each of the world's leading climate and Earth system modeling 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. Both facilities will begin a multi-year instrumentation refresh.

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, radiative transfer, and related meteorological information. These observations provide new data to address the main source of uncertainty in climate and Earth system

models: the interdependence of clouds, atmospheric aerosols, and precipitation that in turn influences the Earth's 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 2022, 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), where scientists will use a sophisticated precipitation radar together with radiosonde and aerosol measurements to learn more about cloud and aerosol interactions in deep convection. A second mobile unit will continue deployment in central Colorado to study how water and energy budgets in a heterogeneous mountain environment affect precipitation patterns. The third mobile unit will be moved from its Oliktok site to the southeastern U.S. with operations beginning in FY 2023. 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 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. Acceptance testing and evaluation on the recently acquired manned aircraft will be completed, including modifications to the air frame as needed to install numerous existing and new atmospheric aerosol, cloud, turbulence, and other sensors. Research flight operations will begin in FY 2023.

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 models, combines with advanced data analytics such as machine learning 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 for scientific discovery, technological innovation, decision-making, 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 coastal and watershed systems.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Earth and Environmental Systems Sciences **$350,426**	**$421,500**	**+$71,074**
Atmospheric System Research $36,000	$39,000	+$3,000
ASR continues 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 continues to make use of data generated by Large Eddy Simulations at the ARM Oklahoma site.	The Request for ASR will enhance 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 and initial data from the TRACER campaign. ASR will continue to make use of data generated by Large Eddy Simulations at the ARM Oklahoma site.	The increase will support research focused on using the new observations from ARM field studies including the FY 2020 Arctic campaign and initial TRACER data to inform Earth system model development.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Environmental System Science $87,777	$119,500	+$31,723
ESS focuses research on permafrost and maintains 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, and Puget Sound.	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, and Puget Sound. Urban Integrated Field Laboratories (IFLs) for climate science as a single portal to DOE lab climate capabilities. Planning will begin for a Climate Laboratory or center. The Request also supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem.	The increase for ESS will enhance investments in field experiments and process modeling activities associated with the terrestrial-aquatic project located in the mid-Atlantic, Great Lakes, and Puget Sound. The Urban IFLs will initially target a diverse set of urban regions, integrate field data with a next generation Earth System Modeling framework, and create a science capability to advance climate and energy research as a unified co-dependent system. The research will provide DOE, its stakeholders, and impacted communities with the best possible tools that enable the evaluation of the societal and environmental impacts of current and future energy policies. The NVCL will provide a single portal to partner the capabilities at the DOE national labs with key stakeholders from underrepresented and impacted communities through training and outreach for equitable climate resilience solutions. Planning initiates for establishment of a Climate Laboratory or center affiliated with an HBCU or MSI. Funding also supports the RENEW initiative.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Earth and Environmental Systems Modeling $100,674	$108,000	+$7,326
Earth and Environmental Systems Modeling focuses investments on further refinement of the science underpinning nonhydrostatic 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.	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 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 enhance deployment of a higher resolution and more sophisticated version of E3SM and affiliate models to the scientific community in support of broad-based basic research as well as to energy sector stakeholders who require projections.
Focus is on core research in model intercomparisons and diagnostics. In addition, research incorporates limited fine scale physics and dynamics that can be applied to metrics for application to coastal zones and mid-latitude-Arctic interactions.	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 for application to coastal zones (including the Great Lakes and Puget Sound) and mid-latitude-Arctic interactions.	Funding will support research with a shift in emphasis from the science of Arctic-midlatitude interactions to examine boundary regions that also include coastal zones, the Great Lakes, and Puget Sound.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Earth and Environmental Systems Sciences Facilities and Infrastructure $125,975	$155,000	+$29,025
ARM continues to provide new observations through long term measurements at fixed sites in Alaska, Oklahoma, and 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. ARM activities are prioritized for critical observations needed to improve the E3SM model. ARM initiates deployment of its second mobile facility to Houston, TX. The newly acquired aircraft continues 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.	The Request for ARM will continue to provide new observations through long term measurements at fixed sites in Alaska, Oklahoma, and the Eastern North Atlantic site. An ARM mobile unit will begin deployment to a location in the southeastern U.S. with operations beginning in FY 2023. The Request prioritizes all ARM activities for critical observations needed to improve the E3SM model. ARM will continue deployment of its first and second mobile facilities, i.e., to Houston, TX, and Colorado. Scientists will use the precipitation radars together with sophisticated meteorological instrumentation to learn more about cloud and aerosol interactions in urbanized coastal regions and mountainous terrain. Acceptance testing and evaluation will be completed on the recently acquired aircraft, including modifications to the air frame as needed to install numerous existing and new atmospheric aerosol, cloud, turbulence, and other sensors.	Increased funding will support ARM site operations, and a mobile facility will be deployed to the southeastern U.S. and configured to begin operations in FY 2023. ARM will begin a multi-year instrumentation refresh. The ARM support for the Urban IFL for climate science will be developed.
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 will complete construction of the Dynamic Transmission Electron Microscope (DTEM) and provide some new capabilities 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. The Dynamic Transmission Electron Microscope (DTEM) will provide some new capabilities in support of BER science.	Funding will support the multiple experimental capabilities of the new DTEM and initiate planning for a high throughput multiomics pipeline. EMSL will begin a multi-year instrumentation refresh.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Earth and Environmental Sciences Data Management activity continues to provide support to maintain existing critical software and data archives for ongoing experimental and modeling research. Essential data archiving and storing protocols, capacity, and provenance continues. Advanced analytical methodologies such as Machine Learning (ML) is used to improve the predictability of extreme events more rapidly using Earth system models.	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 the combination of field observations with Earth system models.	Funding will support the incorporation of new analytical methodologies to advance scientific insight based on the fusion of model generated and observed data.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

Biological and Environmental Research
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	9,800	7,700	28,000	+20,300
Total, Capital Operating Expenses	**N/A**	**N/A**	**9,800**	**7,700**	**28,000**	**+20,300**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Capital Equipment						
Total, MIEs	N/A	N/A	–	–	–	–
Total, Non-MIE Capital Equipment	N/A	N/A	9,800	7,700	28,000	+20,300
Total, Capital Equipment	**N/A**	**N/A**	**9,800**	**7,700**	**28,000**	**+20,300**

Biological and Environmental Research
Funding Summary

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Research	570,500	571,089	627,000	+55,911
Facility Operations	179,500	181,911	201,000	+19,089
Total, Biological and Environmental Research	**750,000**	**753,000**	**828,000**	**+75,000**

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 2020 Enacted	FY 2020 Current	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Scientific User Facilities - Type B					
Environmental Molecular Sciences Laboratory	**45,000**	**45,000**	**45,000**	**56,000**	**+11,000**
Number of Users	577	766	525	715	+190
Joint Genome Institute	**77,000**	**77,000**	**80,000**	**84,500**	**+4,500**
Number of Users	1,925	2,038	1,550	2,115	+565
Atmospheric Radiation Measurement Research Facility	**70,110**	**70,110**	**72,672**	**90,000**	**+17,328**
Number of Users	1,100	1,001	900	1,250	+350
Total, Facilities	**192,110**	**192,110**	**197,672**	**230,500**	**+32,828**
Number of Users	3,602	3,805	2,975	4,080	+1,105

Biological and Environmental Research
Scientific Employment

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	1,500	1,510	1,600	+90
Number of Postdoctoral Associates (FTEs)	370	375	410	+35
Number of Graduate Students (FTEs)	520	530	580	+50
Number of Other Scientific Employment (FTEs)	370	375	395	+20

Note: Other Scientific Employment (FTEs) includes technicians, engineers, computer professionals and other support staff.