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 clean energy and climate innovation. 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 evidence-based climate solutions with a focus on environmental justice. 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 (including Artificial Intelligence [AI] and Machine Learning [ML]), and experimental approaches. Foundational knowledge of the structure and function of these systems underpins the ability to leverage natural processes for clean 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 seek 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 User 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 2023 Request

The FY 2023 Request for BER is $903.7 million. BER will enhance its research on climate science by:

- Expansion of 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;
- Utilizing the enhanced National Virtual Climate Laboratory (NVCL), to serve as a one stop portal to advance access to climate science and as a workforce training and outreach arm from the DOE national laboratories; and
- Continued planning for a network of climate centers, affiliated with Historically Black Colleges or Universities (HBCUs) or Minority Serving Institutions (MSIs).
- New investments in AI approaches for improving earth system predictability.

The four Bioenergy Research Centers (BRCs) will be reviewed for potential renewal and enhanced to initiate new cross-BRC collaborative research addressing clean energy challenges. BER will initiate the Energy Earthshot Research Centers (EERCs) to bring together multi-investigator, multi-disciplinary teams to remove barriers to implementation of the innovations emerging from basic science into potential solutions for technological challenges and are vital to realizing the stretch goals of the DOE Energy Earthshots. Complementing and expanding the scope of the Energy Frontier Research Centers (EFRCs) and SciDAC, aligned with both SC and the technology offices, EERCs will address key research challenges at the interface between currently supported basic research and applied research and development activities, to bridge the R&D gap. BER will also support early discovery stage research underpinning future and emerging Earthshots. BER research will also support six new activities to: 1) examine the global carbon carrying capacity of terrestrial ecosystems; 2) enhance investment in AI approaches for improving earth system predictability; 3) support the Accelerate Innovation in emerging technologies (Accelerate) initiative to develop sensors that scale from laboratory fabricated ecosystems to field ecosystems; 4) continue support for novel quantum science for biological systems and continued support of crosscutting SC QIS Research Centers; 5) expand the Biopreparedness Research Virtual Environment (BRaVE); 6) and commence activities in low carbon biodesign approaches as well as new bio-based and bioinspired materials and foundational bioenergy research underpinning new biotechnology and the bioeconomy. BER will continue a pilot project to study complex coastal estuaries, including the Chesapeake Bay, Puget Sound, and the Great Lakes.

Key elements in the FY 2023 Request include:

Research

- Within Genomic Sciences, in FY 2022 the BRCs will undergo a merit review for a possible 5-year renewal. Pending the successful outcome of that review, in FY 2023, the BRCs will provide new, fundamental research underpinning the production of clean energy and chemicals from sustainable biomass resources for translation of basic research results to industry. The BRCs will continue clean energy innovative research while initiating new inter-BRC collaborations to tackle complex clean energy challenges. BRaVE will provide the cyber infrastructure, computational platforms, and next generation experimental research capabilities and workflows within a single portal allowing distributed networks of scientists to work together on multidisciplinary research priorities and/or national emergency challenges. BER will invest in efforts to identify core biodesign rules translatable to energy efficient, low carbon manufacturing of functional properties of novel biological polymers. New efforts on developing lab to field sensors will complement 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 support Advanced Computing 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 complementing tools and approaches at Office of Science user facilities for predictive understanding of biological processes.
- BER will participate in the new Funding for Accelerated, Inclusive Research (FAIR) initiative to provide focused investment on enhancing biological research on clean energy, climate, and related topics at minority serving institutions, including attention to underserved and environmental justice regions. The activities will improve the capability of MSIs to perform and propose competitive research and will build beneficial relationships between MSIs and DOE national laboratories and facilities.

- 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 expand and enhance activities to utilize advanced software and AI/ML for running on future DOE computer architectures. The Data Management effort will 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 Great Lakes. Research involving field-based observing and modeling will be expanded through Urban IFLs to incorporate environmental justice as a key tenet of research involving climate-sensitive regions. Additionally, the National Virtual Climate Lab (NVCL) will be fully implemented and continue unified access to climate science to MSIs and HBCUs, connecting frontline communities with the key climate science capabilities and workforce training opportunities at the DOE national laboratories. Planning activities continue for a network of climate centers affiliated with an HBCU or MSIs; the centers will serve as the translational agents connecting BER climate science with broader socioeconomic and environmental justice issues for equitable solutions. All activities will enhance research capacity at the affiliated universities and bring interdisciplinary strength and diversity to DOE's climate research.
- BER will expand support for 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.

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 complete deployment near Houston, TX to conduct the aerosol-convection interactions experiment and then be prepared and deployed to San Diego. A second mobile unit will continue the study on water and energy cycles in mountainous watersheds. A third will begin operations in the southeastern U.S. in FY 2023. Acceptance testing and evaluation will be completed on the crewed aircraft. Research flight operations will begin in late FY 2023.
- 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 continue a multiyear instrumentation refresh to ensure these facilities are delivering the capabilities required by the scientific community.

Biological and Environmental Research
FY 2023 Research Initiatives

Biological and Environmental Research supports the following FY 2023 Research Initiatives.

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Accelerate Innovations in Emerging Technologies	–	–	5,000	+5,000
Advanced Computing	–	–	5,183	+5,183
Artificial Intelligence and Machine Learning	3,000	3,000	8,000	+5,000
Biopreparedness Research Virtual Environment (BRaVE)	–	–	14,000	+14,000
Climate Resilience Centers	–	–	5,000	+5,000
Exascale Computing	15,000	15,000	15,000	–
Fundamental Science to Transform Advanced Manufacturing	–	–	3,000	+3,000
Funding for Accelerated, Inclusive Research (FAIR)	–	–	1,935	+1,935
National Virtual Climate Laboratory (NVCL)	–	–	3,000	+3,000
Quantum Information Science	12,000	14,500	14,500	+2,500
Reaching a New Energy Sciences Workforce (RENEW)	–	–	6,000	+6,000
Revolutionizing Polymers Upcycling	6,250	6,250	6,250	–
SC Energy Earthshots	–	–	50,000	+50,000
Urban Integrated Field Laboratory	–	–	22,000	+22,000
Total, Research Initiatives	**36,250**	**38,750**	**158,868**	**+122,618**

Biological and Environmental Research
Funding

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Biological and Environmental Research				
Genomic Science	277,574	257,817	338,185	+60,611
Biomolecular Characterization and Imaging Science	45,000	45,000	45,000	–
Biological Systems Facilities & Infrastructure	80,000	84,500	85,000	+5,000
Total, Biological Systems Science	**402,574**	**387,317**	**468,185**	**+65,611**
Atmospheric System Research	36,000	35,924	39,000	+3,000
Environmental System Sciences	87,777	91,500	127,500	+39,723
Earth and Environmental Systems Modeling	100,674	100,461	118,000	+17,326
Earth and Environmental Systems Sciences Facilities and Infrastructure	125,975	137,798	151,000	+25,025
Total, Earth and Environmental Systems Sciences	**350,426**	**365,683**	**435,500**	**+85,074**
Subtotal, Biological and Environmental Research	**753,000**	**753,000**	**903,685**	**+150,685**
Total, Biological and Environmental Research	**753,000**	**753,000**	**903,685**	**+150,685**

SBIR/STTR funding:

- FY 2021 Enacted: SBIR $23,850,000 and STTR $3,352,000
- FY 2022 Annualized CR: SBIR $23,738,000 and STTR $3,339,000
- FY 2023 Request: SBIR $28,054,000 and STTR $3,945,000

(dollars in thousands)

	FY 2023 Request vs FY 2021 Enacted
Biological Systems Science	**+$65,611**

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. Pending the outcome of a merit review, FY 2023 begins a five-year renewal term for the BRCs, which will provide new, fundamental research underpinning the production of clean energy and chemicals from sustainable biomass resources for translation of basic research results to industry and expand ambitious collaborative approaches to address the clean energy challenges. 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. Increased 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. The Funding for Accelerated, Inclusive Research (FAIR) initiative will provide focused investment on enhancing clean energy genomic research at minority serving institutions. New emerging technologies will develop capabilities that scale from laboratory fabricated ecosystems to field ecosystems, through the use of integrated automated sensor networks, complementing new efforts 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. Research will be enhanced for BRaVE, providing the integrated computational and experimental platforms and workflows for multidisciplinary research, and new focus on low carbon approaches for creating new bio-based and bioinspired materials. Computational Biosciences will focus on an integrated computational platform, building out the National Microbiome Data Collaborative and continuing to add functionality to the Systems Biology Knowledgebase. Development of new bioimaging, measurement and characterization approaches through the Biomolecular Characterization and Imaging Science activity will include expanded integrative imaging and analysis platforms, including using QIS materials, to understand the expression, structure, and function of genome information encoded within cells. BER will initiate the EERCs to bring together multi-investigator, multi-disciplinary teams to remove barriers to implementation of the innovations emerging from basic science into potential solutions for technological challenges and are vital to realizing the stretch goals of the DOE Energy Earthshots. Complementing and expanding the scope of the EFRCs and SciDAC, aligned with both SC and the technology offices, EERCs will address key research challenges at the interface between currently supported basic research and applied research and development activities, to bridge the R&D gap.

	(dollars in thousands) FY 2023 Request vs FY 2021 Enacted
Earth and Environmental Systems Sciences The Request continues to support the development of high-resolution Earth system modeling, analysis, and intercomparison capabilities focused on DOE mission needs for evidence-based energy and infrastructure resilience and security. The new Integrative Artificial Intelligence Framework for Earth System Predictability (AI4ESP) effort will motivate the radical acceleration of predictive capabilities across the DOE climate model-data-experiment enterprise, taking advantage of emerging AI techniques, such as deep learning supporting climate science. Environmental System Science will increase support of the Urban Integrated Field Sites (IFLs) providing new place-based data for informing Earth system models. Research on coastal estuaries will be continued, with a focus on the Chesapeake Bay, Puget Sound, and Great Lakes, as well as increased focus on the role of watersheds and clean water. The National Virtual Climate Laboratory (NVCL) will continue its role as a unified access point for workforce training and engagement with key climate science capabilities at the DOE labs; an enhanced RENEW will leverage the NVCL to address workforce and capacity building at under-represented institutions. Planning will continue for a new network of climate centers. 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 complete deployment to the Houston, TX area and then be redeployed to San Diego; the second unit will continue observations in the upper Colorado River watershed; and the third unit will initiate full operations in the southeastern U.S. acceptance testing and evaluation will be completed on the crewed aircraft. Research flight operations will begin in late FY 2023. EMSL will focus on biological and environmental molecular science and new technologies for molecular microbial phenotyping. Data management activities will enhance applying advanced analytics to observations and environmental field data.	**+$85,074**
Total, Biological and Environmental Research	**+$150,685**

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 energy 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
Biological Systems Science conducts fundamental genomic science on plants and microorganisms across a broad range of biological applications including biosystems design and environmental research. The portfolio also includes the development of enabling computational, analytical, and bioimaging capabilities for hypothesis-based experimental research.
New biosystems design research led to the development of the iPROBE system, a cell-free machine learning-informed framework for testing multiple biosynthetic pathways in rapid fashion. The system was used to accelerate the design of an optimized metabolic pathway for 3-hydroxybutryate production in *Clostridium* species. This new approach reduced the time needed to develop engineered strains from months to weeks and could be used to optimize pathways for a range of other compounds including biofuels and bioproducts. New microbiome research conducted as part of a 6-year prairie soil warming experiment in central Oklahoma led to the observation that soil microbial community networks grew larger, more complex, and more stable over time, providing insight into the effect of soil warming on soil microbial communities as a proxy for understanding effects under warmer climate scenarios. New multi-modal bioimaging capabilities integrating four different types of spatial and chemical measurement techniques were developed to image cells on pollen grains. The results show the importance of a multimodal approach to microscopy to image processes within complex biosystems.

Bioenergy Research Centers are focused on research to fill basic science knowledge gaps for the commercial production of biofuels and bioproducts, including sustainable production of biomass, plant feedstock development, and biomass deconstruction and conversion.

Notable accomplishments include:

- The Center for Advanced Bioenergy and Bioproduct Innovation (CABBI) engineered grasses to hyper-accumulate tri-acylglyerides (TAGs), oils that can be easily transformed to biodiesel and other specialty lubricants and compounds.
- At the Joint BioEnergy Institute (JBEI), over expression of a metabolic gene (QsuB) resulted in the over production of protocatechuate (PCA) in sorghum, an aromatic precursor to biofuel compounds and a range of other chemicals. The result is another step towards crops engineered to produce specific fuels and chemicals.
- The Center for Bioenergy Innovation (CBI) demonstrated the production of C-lignin in plants, an alternate lignin form found in seed coats. The finding is important as a potential tool to alter lignin composition in bioenergy crops to improve biofuel production.
- The Great Lakes Bioenergy Research Center (GLBRC) developed modified plants to over produce terpenoid compounds. These versatile molecules can be further converted to flavors, scents, and other commodity chemicals normally produced from petroleum.

Earth and Environmental Systems Sciences conducts research to improve the predictability of the Earth system at different scales, with particular focus on the interdependencies of the physical, biogeochemical, and human processes that govern variability, change, and the evolution of extreme climate events.

An analysis and comparison of tropical cyclone observations and computer simulations in the DOE Energy Exascale Earth System Model (E3SM) showed that improvements in high resolution model biases can alleviate errors in tropical cyclone simulations and improve predictability in Earth system models. In linking regional modeling to Earth system modeling efforts, perennial bioenergy crops were incorporated into the global Community Terrestrial System Model for the first time, enabling simulation and understanding of feedbacks among bioenergy crops and Earth system processes at local, regional, and global scales. Atmospheric researchers studied aerosols in a cloud chamber under varied water vapor concentrations and found that turbulent fluctuations led to cloud formation at much lower relative humidity levels than which occur under average steady state conditions, potentially leading to new parameterizations for Earth system models. Ecologists conducting a field warming and elevated CO_2 experiment in a high-latitude forest found increased fine-root growth, particularly in shrub vegetation, highlighting a mechanism that enables shrubs to rapidly adapt to warmer and drier conditions.

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 reference genome for the switchgrass bioenergy crop, based on the collection of 700+ switchgrass plants from 25 states, and established ten experimental switchgrass plots across 1,100 miles to enable testing of climate adaptations with switchgrass biology;
- The Environmental Molecular Sciences Laboratory (EMSL) analyzed differences in predicted and observed light absorption from atmospheric soot, and found that particle shape and composition could explain the variation in light absorption, thereby improving estimates of black carbon effects on the global radiation balance; and
- The Atmospheric Radiation Measurement (ARM) user facility used a machine learning approach to represent cloud processes at scales too small to be resolved by global climate models and succeeded with a new machine learning technique that outperformed current model formulations.

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 from a genome-based perspective to define the functional principles that drive living systems, from microbes and microbial communities to plants and other whole organisms and microbiomes. The research will pursue the fundamental science needed to understand, predict, manipulate, and design biological systems that underpin innovations for clean energy production and biotechnology and enhance our understanding of natural, DOE-relevant environmental processes needed to promote social equity and enhance response to the climate crisis.

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. These problems 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 on open access computational platforms into models that can be iteratively tested and validated to advance a predictive understanding of biological systems.

The subprogram supports the operation of the DOE Bioenergy Research Centers (BRCs) and the DOE Joint Genome Institute (JGI) scientific user facility.

Genomic Science
The Genomic Science activity supports research seeking to reveal the fundamental principles that drive biological systems relevant to DOE missions in clean energy and climate 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 decarbonized bioeconomy, understanding the role of biological systems in the environment, including carbon capture and sequestration, 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. Systems biology research on microorganisms with potential bioenergy/bioproduct-relevant traits will yield new pathways to convert plant biomass to a range of fuels, chemicals, and bioinspired products and biomaterials. Efforts in biosystems design research builds on existing genomics-based research and develops broad-based, secure gene-editing techniques in plants and microbes for a wide variety of advanced biotechnologies. Together these efforts will yield a broader range of platform organisms to be employed in a range of clean energy and biotechnology applications underpinning a more decarbonized bioeconomy. The climate related science supports new approaches and systems to support low carbon biomanufacturing, especially with respect to genome-enabled engineering and design of biomaterials, along with developing new emerging technologies and integrated automated sensors that scale from laboratory-fabricated ecosystems to field ecosystems in support of the Accelerate initiative. BER's contribution towards understanding and anticipating the convergence of advanced genome 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 Funding for Accelerated, Inclusive Research (FAIR) initiative will provide opportunities to enhance clean energy genome research at minority serving institutions, including attention to underserved and environmental justice communities.

The Energy Earthshot Research Centers (EERCs) program is a new modality of research to be launched in FY 2023, building on the success of the Energy Frontier Research Centers (EFRCs). Like the EFRCs and the Scientific Discovery through Advanced Computing (SciDAC) program, EERCs will bring together multi-investigator, multi-disciplinary teams to perform energy-relevant research with a scope and complexity beyond what is possible in standard or small-group awards. Complementing and expanding the scope of the EFRCs and SciDAC, aligned with both SC and the energy technology offices, EERCs will address key research challenges at the interface between currently supported basic research and applied research and development activities, to bridge the R&D gap. These challenges are barriers to implementation of the innovations emerging from basic science into potential solutions for technological challenges and are vital to realizing the stretch goals of the DOE Energy Earthshots. EERCs' team awards will entail collaboration involving academic, national laboratories, and industrial researchers with SC and the DOE technology offices, establishing a new era of cross-office research cooperation. BER funding will focus efforts directly at the interface, ensuring that directed biological fundamental research and capabilities at SC user facilities tackle the most challenging barriers identified in the applied research and development activities.

Existing DOE Energy Earthshots include the Hydrogen Shot, the Long Duration Storage Shot, and the Carbon Negative Shot. Additional topics are under consideration for future announcements. From a science perspective, many research gaps for the Energy Earthshots crosscut all topics and will provide a foundation for other energy technology challenges, including biotechnology, critical minerals/materials, energy-water, subsurface science (including geothermal research), and materials and chemical processes under extreme conditions for nuclear applications. These gaps require multiscale computational and modeling tools, new artificial intelligence and machine learning technologies, real-time characterization, including in extreme environments, and development of the scientific base to co-design processes and systems rather than individual materials, chemistries, and components. EERCs will leverage individual Center research to cross-fertilize the ideas that emerge in one topical area to benefit others with similar challenges—accelerating the science, as well as the technologies.

Biopreparedness Research Virtual Environment (BRaVE) will continue to 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 challenges and provide a ready resource to quickly address urgent national emergencies as 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/or sequestration 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 Advanced Computing initiative.

The 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 sustainable innovative processes for clean bioenergy and a range of bioproducts from inedible cellulosic biomass supporting a more decarbonized bioeconomy. Research will accelerate genome engineering, using AI/ML techniques, in plants and microbes to expand the range of products that can be produced from sustainable plant biomass, expand understanding of plant-microbe interactions to inform better agronomic practices for clean bioenergy production, develop new plant varieties with expanded capabilities for sustainable product production and increased collaboration among the broader research community including Historically Black Colleges and Universities (HBCUs) and within rural communities where new crop-based clean energy and bioproduct production could spark new industries and bioeconomic development.

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 activity will enable development of new multimodal 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 includes efforts in QIS-enabled concepts for imaging and to advance design of sensors and detectors based on correlated materials, 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 sequester 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 and the NMDC. Related efforts use genomic information to infer natural product production from microorganisms and plants. These advanced capabilities are part of the DOE JGI 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 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Biological Systems Science	**$402,574**	**$468,185**	**+$65,611**
Genomic Science	$277,574	$338,185	+$60,611
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 research on microorganisms with advantageous bioenergy and bioproduct traits. Biosystems design research will accelerate the ability to design plants and microorganisms with specific beneficial low carbon clean energy, bioproduct and biomaterials production traits. New efforts will support emerging technologies to develop integrated automated sensors that scale from laboratory fabricated ecosystems to field ecosystems as part of the new Accelerate initiative.	Funding increase will support new research on microorganisms with clean energy and bio-inspired bioproduct-relevant traits to broaden the range of platform organisms available for biotechnology use, for cross-cutting goals supporting a more decarbonized bioeconomy and the Carbon Negative Earthshot. To support Accelerate, new emerging technologies will integrate *in situ* sensors, imaging, Omics analysis, and autonomous controls and continuous data acquisition and analysis. New funds support genome science opportunities at MSIs.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
	BER will launch Energy Earthshot Research Centers to address key biological research challenges at the interface between currently supported basic research and applied research and development activities. Environmental Genomics will continue plant functional genomics research to understand genotype to phenotype translations leading to beneficial bioenergy or bioproduct traits in potential bioenergy crops. Environmental microbiome science continues efforts to understand the functions of environmentally relevant microbial communities in a variety of ecosystems. The Biopreparedness Research Virtual Environment (BRaVE) will expand to build out a computational platform and experimental workflow through which a distributed network of data and experimental capabilities can be accessed by multidisciplinary teams of scientists working together on urgent multiprogram priorities. The Funding for Accelerated, Inclusive Research (FAIR) initiative strengthens clean energy genomic research at minority serving institutions, building partnerships with the DOE national labs.	

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 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 research efforts within Genomic Science by providing bioinformatics, simulation and modeling capabilities through the KBase platform and within the NMDC. Both platforms will continue integrative activities among each other within the Advanced Computing Initiative and with the JGI.	Funding will support continued development of new analysis capabilities within KBase and NMDC for genomic science supporting clean energy research towards a more decarbonized bioeconomy. The activity will also support the Advanced Computing initiative.
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 undergo a FY 2022 merit review for a possible 5-year renewal to support multidisciplinary clean energy research underpinning a broader bio-based economy. The renewal will allow the BRCs to broaden their collaborative activities to accelerate plant and microbial genome engineering with AI/ML techniques to diversify the range of products that can be sustainably produced from plant biomass, expand understanding of plant-microbe interactions to create better agronomic practices for clean bioenergy production, develop new plant varieties with expanded capabilities for biofuels and bioproduct production and increase collaboration among the broader research community (including HBCUs) and within rural communities where new crop-based clean energy and bioproduct production could spark new industries and bioeconomy development.	If renewed, the four BRCs will expand their collaborative activities to accelerate genome engineering for plants and microbes, expand sustainability research through research on plant-microbe interactions, develop new plant varieties with an expanded range of biofuels and bioproducts, and engage a broader spectrum of the research community (including HBCUs) and rural communities where this research could lead to new bioeconomy opportunities.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 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 multimodal bioimaging research will provide new capabilities to characterize, measure, visualize and test hypotheses on plant and microbial cell function and metabolism. Quantum-enabled science concepts for imaging techniques will continue.	No change.
Biological Systems Facilities & Infrastructure $80,000	$85,000	+$5,000
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 sequences and new analysis techniques for complex plant and microbiome samples. Integrative activities with KBase and the NMDC will provide new cross-platform capabilities for users. Genome-based discovery efforts for natural product production in microbial isolates continues in concert with expanded metagenomics analysis techniques. The multi-year instrument and equipment refresh will continue at a reduced pace to support the integrative activities with KBase and the NMDC.	Funding will support expanded integrative efforts with KBase and the NMDC to provide new analysis capabilities for microbiome science. The continuing instrument and equipment refresh will be slowed to support the expanded integrative activities with KBase and the NMDC.

Note:

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

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 oceanic and Great Lakes systems; 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 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 increasing opportunities provided by machine learning (ML) and emerging technologies. The research will pursue the fundamental scientific understanding necessary to inform the design, development, financing, and deployment pathways of climate friendly technical solutions that promote social equity and enhance urban resilience in response to the climate crisis.

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) 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 to improve scientific understanding of atmospheric and climate processes involving clouds, aerosols, precipitation, 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 provide three-dimensional measurements of a variety of aerosol types that includes natural, brown, and black carbon; cloud, aerosols, and precipitation microphysics under a variety of dynamical conditions; and turbulence and convection over a range of spatially varying environmental and thermodynamical 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 that limit the predictability of atmospheric processes, properties, and dynamical evolution. Using integrated, scalable testbeds 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 Sciences

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, clean water, environmental stewardship and identifying equitable solutions to the Nation's most vulnerable communities. 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.

Research activities will expand place-based Urban Integrated Field Laboratories (IFLs) in support of climate science. The Urban IFLs are 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 that can be deployed to urban and suburban regions; and addressing environmental justice by enabling neighborhood scale evaluation of climate impacts and energy needs. The Urban IFL scope targets a greater set of urban regions, integrates field data within a next generation Earth System Modeling framework, and creates a science capability to advance climate and energy research as a unified co-dependent system. The enhanced 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.

BER will continue support for 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. The National Virtual Climate Laboratory (NVCL) will continue to provide greater access to climate science to Historically Black Colleges and Universities (HBCUs), Tribal Colleges and Universities (TCUs), Hispanic Serving Institutions (HSIs), and other Minority Serving Institutions (MSIs), connecting frontline communities with the key climate science capabilities at the DOE national laboratories. A network of climate centers that are affiliated with MSIs will complete planning, with a focus on developing climate resilience solutions that can be deployed to America's communities.

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 new Integrative Artificial Intelligence Framework for Earth System Predictability (AI4ESP) effort will motivate the radical acceleration of predictive capabilities across the DOE climate model-data-experiment enterprise, taking advantage of emerging AI and unsupervised learning techniques, 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 computationally efficient model adaptable to DOE's Leadership Computing Facility supercomputer architectures (including Exascale computational systems), with greater sophistication and fidelity for high resolution simulation of extreme phenomena and complex processes in heterogeneous landscapes. 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 and environmental justice. New modeling efforts will support emerging Earthshot topics.

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, 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 2023, ARM will continue operations at the three fixed sites. One mobile facility will complete deployment to the Houston, TX area for Tracking Aerosol Convection Interactions Experiment (TRACER), where scientists are using a sophisticated precipitation radar together with radiosonde and aerosol measurements to learn more about cloud and aerosol interactions in deep convection, and then be prepared and deployed to San Diego. 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 in the activity called Surface Atmosphere Integrated Field Laboratory (SAIL). The third mobile unit will complete its installation at a site in the southeastern U.S. with long term 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 uncrewed aerial system (UAS) and crewed aircraft. Acceptance testing and evaluation on the crewed 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 late 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. Enhanced research across the Earth and Environmental Systems Sciences portfolio that involves hybrid capabilities based on the combination of physics-based and machine learning and artificial intelligence research will further these objectives.

The BER Data Management activity will focus efforts on archiving scientifically useful data from the Earth System Grid Federation, 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 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Earth and Environmental Systems Sciences $350,426	**$435,500**	**+$85,074**
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 continue 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 data from the TRACER and SAIL campaigns. ASR will continue to make use of data generated by Large Eddy Simulations at the ARM Oklahoma site.	The continuing research will focus on using the new observations from ARM field studies including the FY 2020 Arctic campaign and initial TRACER and SAIL data to inform Earth system model development.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Environmental System Sciences $87,777	$127,500	+$39,723
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 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) expand to support climate science. The National Virtual Climate Lab (NVCL) will be fully implemented and continue to provide access to the single portal to DOE lab climate capabilities. Planning will continue for a network of climate centers focused on resilience. The Request also expands support for RENEW to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem.	Funding will continue investments in field experiments and process modeling activities associated with the terrestrial-aquatic project located in the mid-Atlantic, Great Lakes, and Puget Sound, and will support new observations, enhanced modeling, and data-model synthesis, along with focused efforts to understand the role that watersheds play in providing clean water. The Urban IFLs will target an increased 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. Also, funding will support climate science and the continuation of the NVCL that will provide access through a single portal to partner the capabilities at the DOE national laboratories with key stakeholders from underrepresented and impacted communities through training and outreach for equitable climate resilience solutions. Funding also supports the RENEW initiative through engagement with the NVCL.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Earth and Environmental Systems Modeling $100,674	$118,000	+$17,326
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 more advanced exascale computing architectures. The E3SM version 2 will begin to incorporate AI and unsupervised learning capabilities and enable more sophisticated research based on higher model resolution, through the Integrative Artificial Intelligence Framework for Earth System Predictability (AI4ESP). 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 also supports foundational modeling in support of Energy Earthshot topics.	Funding will continue 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. The Integrative Artificial Intelligence Framework for Earth System Predictability (AI4ESP) activity will feature development of novel approaches for automated feature detection and unsupervised learning techniques in heterogeneous multi-scale laboratory and field data; data quality validation; edge computing; nonlinear and multiscale data assimilation methodologies; model parameter estimation; and hybrid prediction model architectures that combine physics with AI/ML across multiple aspects of climate models. New investments also support earth system modeling underpinning emerging Earthshot topics including energy-water.
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), mid-latitude-Arctic interactions, and high-resolution studies of urban and urban-rural transition regions.	Funding will continue to support research with a shift in emphasis from the science of Arctic-midlatitude interactions to examine heterogeneous and boundary regions that also include urban regions as well as coastal zones that encompass the mid-Atlantic, the Great Lakes, and Puget Sound.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Earth and Environmental Systems Sciences Facilities and Infrastructure $125,975	$151,000	+$25,025
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 complete installation and begin operations at a location in the southeastern U.S. The Request prioritizes all ARM activities for critical observations needed to improve the E3SM model. ARM will continue deployment of its second mobile facility to Colorado; and it will prepare and deploy its first mobile facility to San Diego. Scientists will use the precipitation radars together with sophisticated meteorological instrumentation to learn more about cloud and aerosol interactions in a variety of geographic domains, including 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. The ARM support for the Urban IFL for climate science will continue as well as continue a multi-year instrumentation refresh.	Funding will support ARM site operations, and a mobile facility will continue its deployment to the Colorado Rockies. A second mobile facility will be prepared for and deployed to a new field campaign in San Diego. The aerial facility will be available for research in FY 2023.
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 emphasize new science that requires combinations of advanced technologies, such as mass spectrometry, live cell imaging, Quiet Wing, Dynamic Transmission Electron Microscopy, and high-performance computing. Planning for a multi-year instrumentation refresh continues, including a microbial molecular phenotyping capability.	Funding will promote multi-disciplinary science using various combinations of EMSL's most sophisticated instrumentation.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 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 enhance support to maintain existing and new 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 using machine learning to advance scientific insight based on the fusion of model generated and observed data.

Note:

- *Funding for the subprogram above, includes 3.65 percent 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 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	7,700	11,200	21,000	+13,300
Total, Capital Operating Expenses	**N/A**	**N/A**	**7,700**	**11,200**	**21,000**	**+13,300**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Capital Equipment						
Total, Non-MIE Capital Equipment	N/A	N/A	7,700	11,200	21,000	+13,300
Total, Capital Equipment	**N/A**	**N/A**	**7,700**	**11,200**	**21,000**	**+13,300**

Biological and Environmental Research
Funding Summary

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Research	571,089	555,432	708,185	+137,096
Facility Operations	181,911	197,568	195,500	+13,589
Total, Biological and Environmental Research	**753,000**	**753,000**	**903,685**	**+150,685**

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 2021 Enacted	FY 2021 Current	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Scientific User Facilities - Type B					
Environmental Molecular Sciences Laboratory	**45,000**	**43,054**	**53,000**	**53,000**	**+8,000**
Number of Users	525	801	850	850	+325
Joint Genome Institute	**80,000**	**77,117**	**84,500**	**85,000**	**+5,000**
Number of Users	1,550	2,180	2,200	2,200	+650
Atmospheric Radiation Measurement Research Facility	**72,672**	**70,110**	**75,798**	**87,000**	**+14,328**
Number of Users	900	960	975	1,010	+110
Total, Facilities	**197,672**	**190,281**	**213,298**	**225,000**	**+27,328**
Number of Users	2,975	3,941	4,025	4,060	+1,085

Biological and Environmental Research
Scientific Employment

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	1,510	1,510	1,740	+230
Number of Postdoctoral Associates (FTEs)	375	375	450	+75
Number of Graduate Students (FTEs)	530	530	640	+110
Number of Other Scientific Employment (FTEs)	375	375	430	+55
Total Scientific Employment (FTEs)	**2,790**	**2,790**	**3,260**	**+470**

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