DOE Office of Science
Biological and Environmental Research (BER)

U.S. National Academies National Academy of Sciences
Board on Physics and Astronomy, May 7-8

Dorothy Koch
Associate Director, BER

U.S. DEPARTMENT OF ENERGY | Office of Science

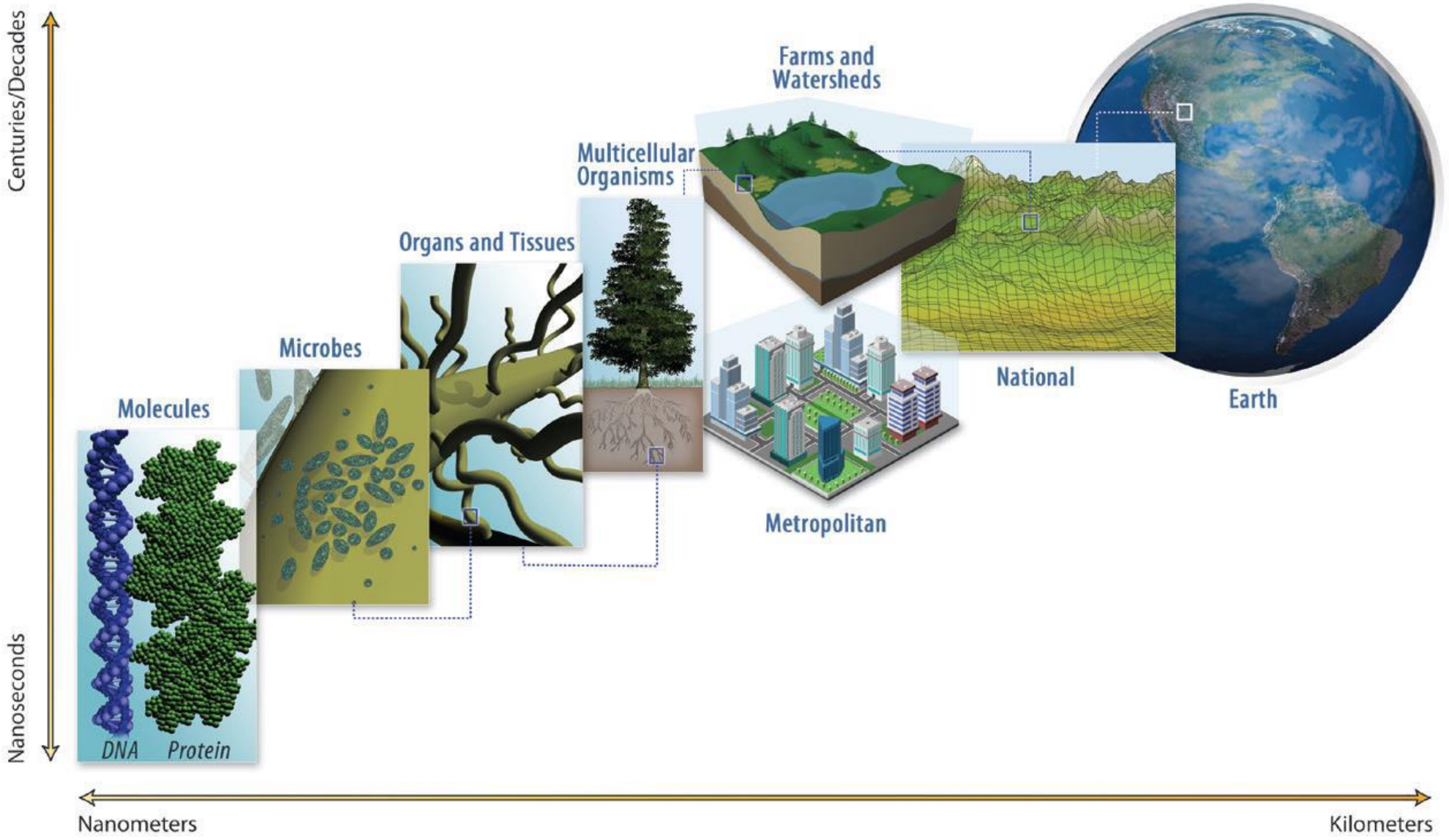
Energy.gov/science

Office of Science Research Portfolio

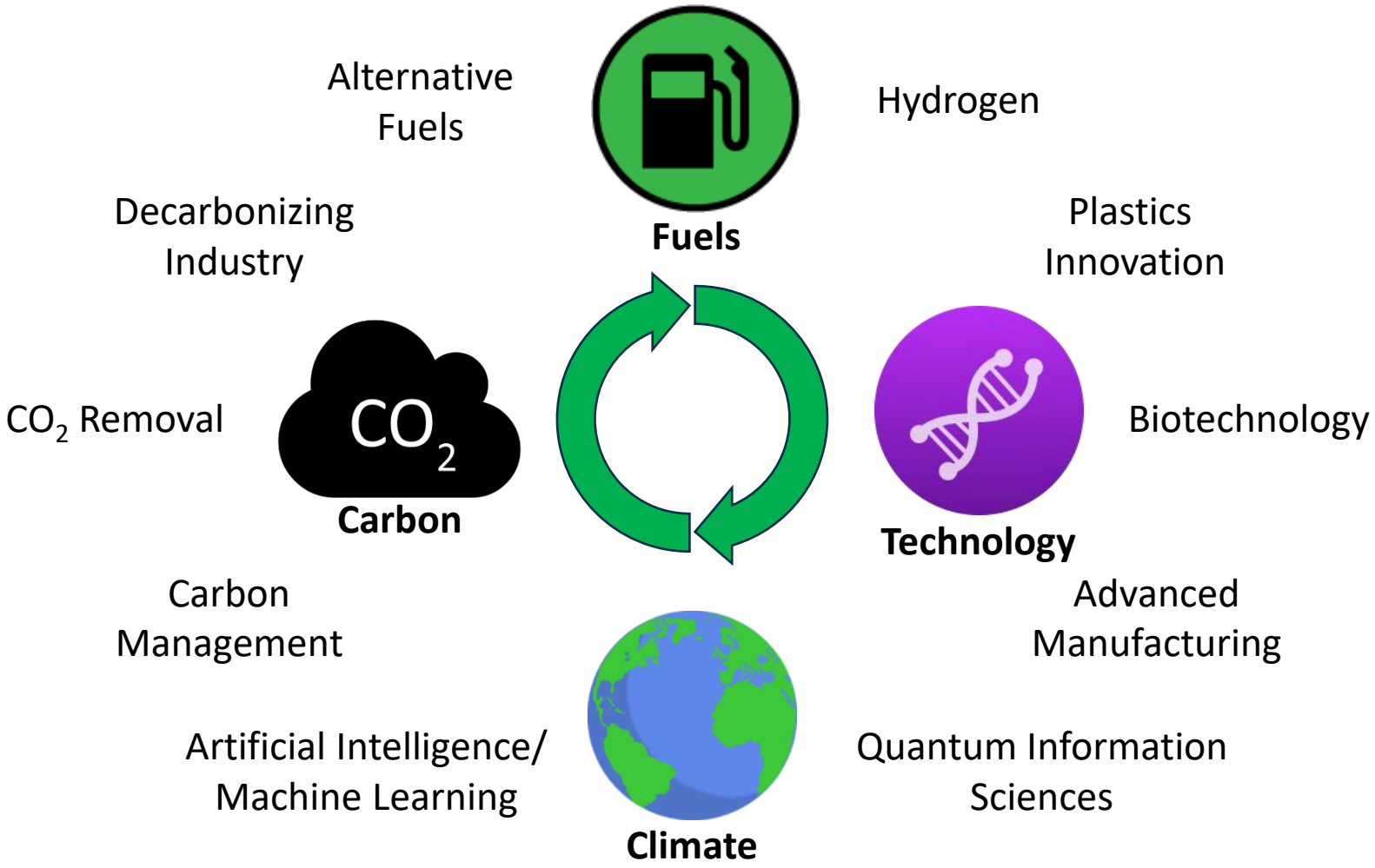
Advanced Scientific Computing Research	• Delivering world leading computational and networking capabilities to extend the frontiers of science and technology
Basic Energy Sciences	• Understanding, predicting, and ultimately controlling matter and energy flow at the electronic, atomic, and molecular levels
Biological and Environmental Research	• Understanding complex biological, earth, and environmental systems
Fusion Energy Sciences	• Supporting the development of a fusion energy source and supporting research in plasma science
High Energy Physics	• Understanding how the universe works at its most fundamental level
Nuclear Physics	• Discovering, exploring, and understanding all forms of nuclear matter
Isotope R&D and Production	• Supporting isotope research, development, production, processing and distribution to meet the needs of the Nation
Accelerator R&D and Production	• Supporting new technologies for use in SC's scientific facilities and in commercial products

Physics Today

Scope of the BER Portfolio



BER Priorities and Crosscuts



BER User Facilities: EESSD and BSSD

Atmospheric Radiation Measurement (ARM) user facility

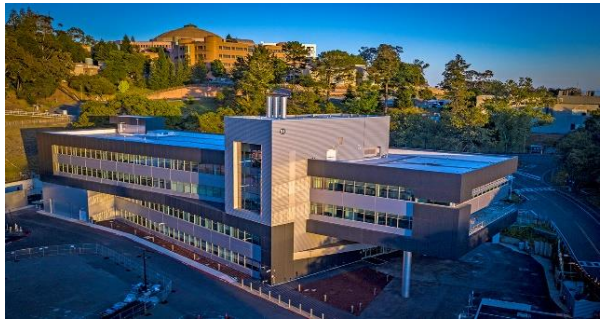
ARM deploys instruments at fixed and varying locations around the globe for obtaining continuous field measurements of clouds, aerosols, precipitation, radiation, surface properties & the atmospheric state since 1992

Environmental Molecular Sciences Laboratory

EMSL provides capabilities to understand physical, chemical, and intra- and inter-cellular processes and interactions.

Joint Genome Institute

JGI provides advanced genome sequencing, data and analysis for bioenergy, carbon cycling and biosequestration, and biogeochemical processes. It is the leading provider of plant, fungal, algal, & microbial community genomes and genomic analyses.



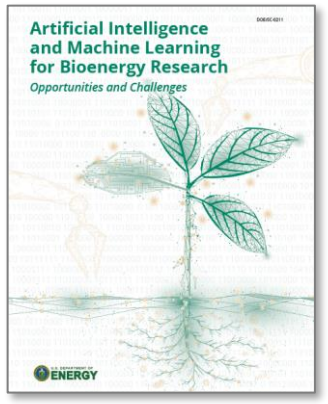
Artificial Intelligence (AI) and Quantum

Examples of BER AI activities:

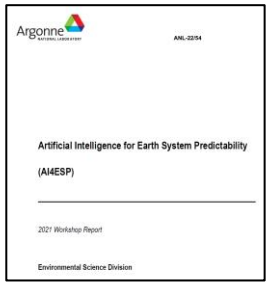
- Genomic and metagenomic annotation analysis
- Predict cellular metabolic network dynamics influenced by changing environment
- Design of new of biological systems
- Energy Exascale Earth System Model (E3SM) component surrogates; E3SM initialization
- Better predict future climate and extreme weather likelihood
- Optimize multi-model solutions for physical and human/energy components
- Data for training, quality-control, gap-filling and analysis of facility data
- Digital twins

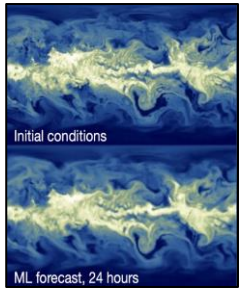
BER quantum activities:

- Novel approaches for biological imaging, e.g. quantum entanglement for non-destructive imaging of biological samples



Biological applications span genomic to plant systems





AI provides better model initialization and predictability

Digital twins and system analysis for soils

DOE Office of Science

Biological and Environmental Research

Dorothy Koch, Associate Director

Biological Systems Science

Todd Anderson, Director

- Genomic Science
  - Bioenergy Research Centers
- Biomolecular Characterization and Imaging Science
- Facilities & Infrastructure
  - Joint Genome Institute

Earth & Environmental Systems Science

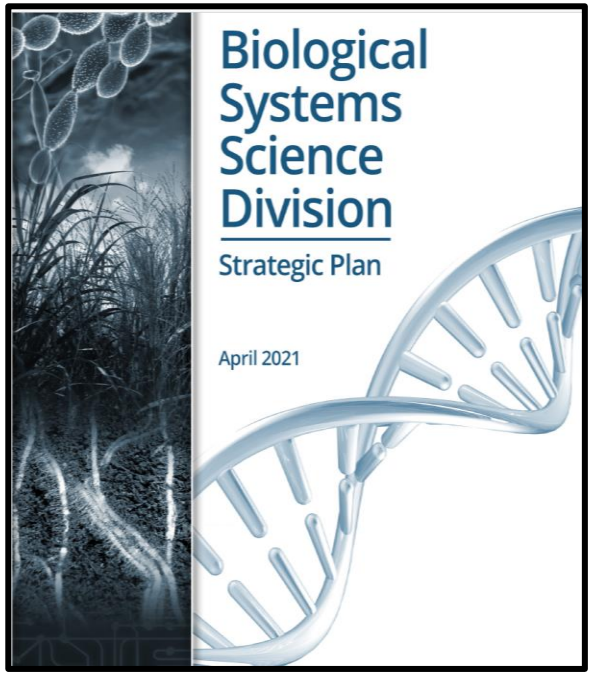
Gary Geernaert, Director

- Atmospheric System Research
- Environmental System Science
- Climate & Earth System Modeling
- Facilities & Infrastructure
  - Environmental Molecular Sciences Lab
  - ARM Climate Research Facility

Biological Systems Science Strategic Directions

Provide the necessary fundamental science to understand, predict, manipulate, and design biological processes that underpin innovations for bioenergy and bioproduct production and to enhance the understanding of natural environmental processes relevant to DOE.

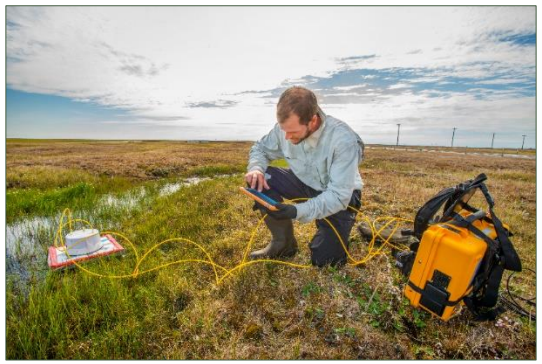
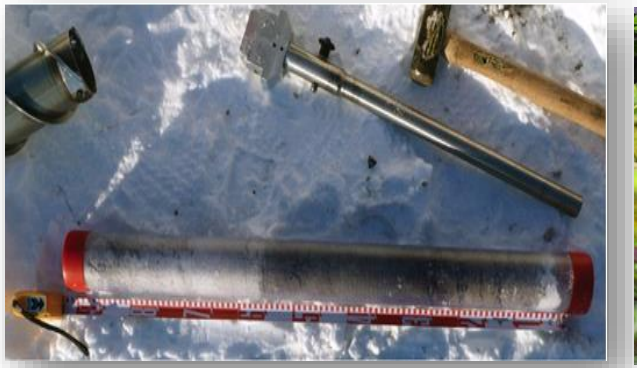
- What information is encoded in the genome sequence and how does this explain the functional characteristics of cells, organisms, and biological systems?
- How do cellular interactions regulate the functional behavior of living systems?
- How do plants, microbes, and communities of organisms adapt and respond to changing environmental conditions and how can their behavior be manipulated toward desired outcomes?
- Science underpinning the design and engineering of new biological systems for beneficial purposes.



BSSD Strategic Plan - April 2021

Earth and Environmental Systems Sciences Strategic Directions

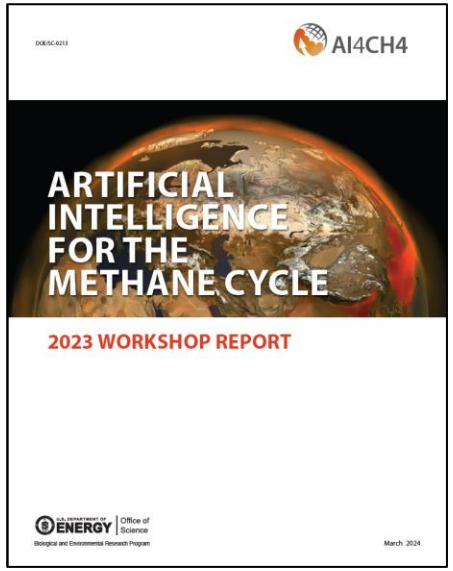
- Design Earth system models that accurately reflect advanced scale-aware process representations of Earth system observations, incorporating physical, chemical, and biological modeling components?
- Understand cloud-aerosol-precipitation interactions, and their influence on the Earth's energy balance.
- Study terrestrial ecosystems, watersheds, urban and coastal systems and their resilience to climate-relevant changes and disturbance, with particular attention to disadvantaged communities?

Recent Environmental and Earth System Workshops

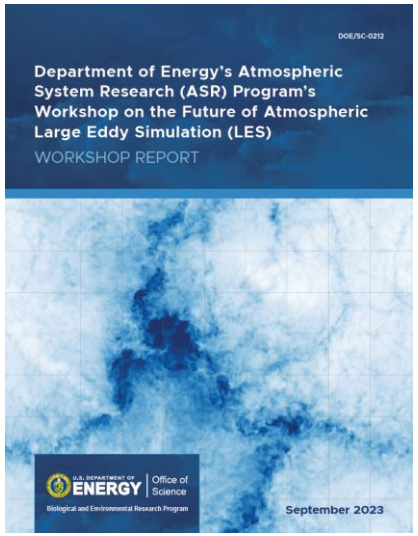
Artificial Intelligence for the Methane Cycle

March 2023



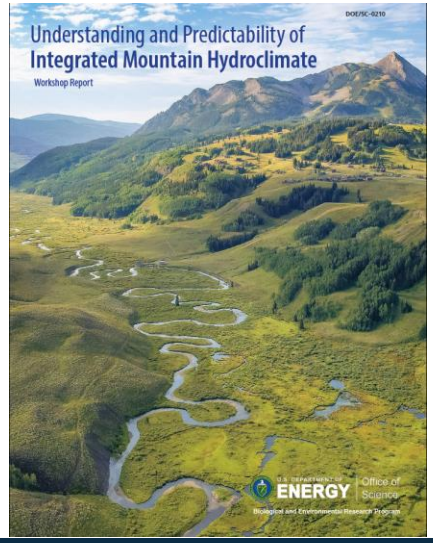
DOE's Atmospheric System Research Program's Workshop on the Future of Atmospheric Large Eddy Simulation (LES)

April 25-26, 2022



Understanding and Predictability of Integrated Mountain Hydroclimate

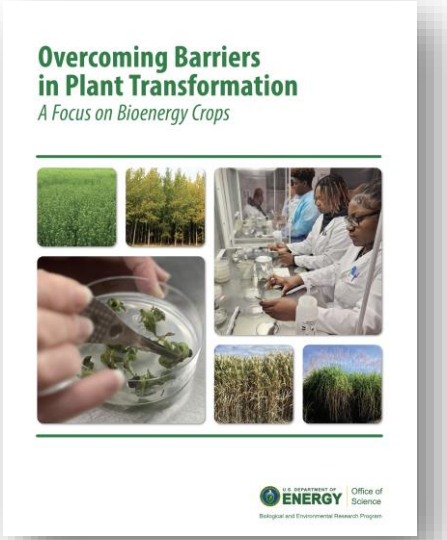
November 15-16, 2021



Recent Biological System Sciences Workshops

Overcoming Barriers in Plant Transformation: A Focus on Bioenergy Crops

September 18-20, 2023



Artificial Intelligence & Machine Learning (AI/ML) for BioEnergy Research Opportunities and Challenges (AMBER)

August 23-25, 2022 (Joint with EERE-BETO)

Genomes to Structure and Function Workshop

October 27-28, 2021, December 15-16, 2021, January 26-27, 2022

Frontier Science for the Bioeconomy Workshop Series

Microbial Design for a Developing Bioeconomy

How do we accelerate our ability to harness and leverage the diverse genetic and metabolic potential of microbes as a platform to efficiently produce the biofuels, bioproducts, and biomaterials?

Microbiome Research: Engineering Microbial Communities

How do we harness the behavior of microbiomes and to manipulate them to facilitate microbial solutions to challenging bioeconomy and environmental problems?

Resilient Bioenergy Crop Production

How do we predict and improve both plant and plant microbiome responses to a changing environment to optimize biomass feedstock production?

Plant Design for a Developing Bioeconomy

How do we understand and transform bioenergy plants into advanced factories that generate clean, renewable, and sustainable biofuels, bioproducts, and biomaterials?

Low Dose Radiation Research

Developing an integrated portfolio combining computational and experimental research to understand the effects of low dose radiation on cells, tissues and organs/organoids and bridge gaps with human epidemiological observations.

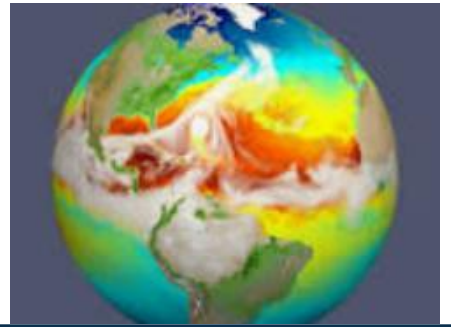
- BER Advisory Committee report just finalized, also drawing from NASEM and other reports.
- Utilize unique DOE capabilities (user facilities, AI/ML computation, analysis capabilities).
- Supporting National Laboratory and academic-led projects in low dose radiation research.
- BRaVE funding will include and expand low dose radiation research to understand the genomics-level changes induced by radiation to gain insights into cellular effects.
- CHIPS and Science Act assigns DOE the role to convene multiple agencies to address low dose research challenges.

Earth and Environmental Systems Modeling

Goal: Enhance the predictability of the climate system in support of DOE's science, energy and security mission.

Capabilities: Ultra-high resolution E3SM, hierarchical and multi-model analyses for deep scientific insights, and discovery at the interface of natural and human systems.

E3SM Energy Exascale Earth System Model



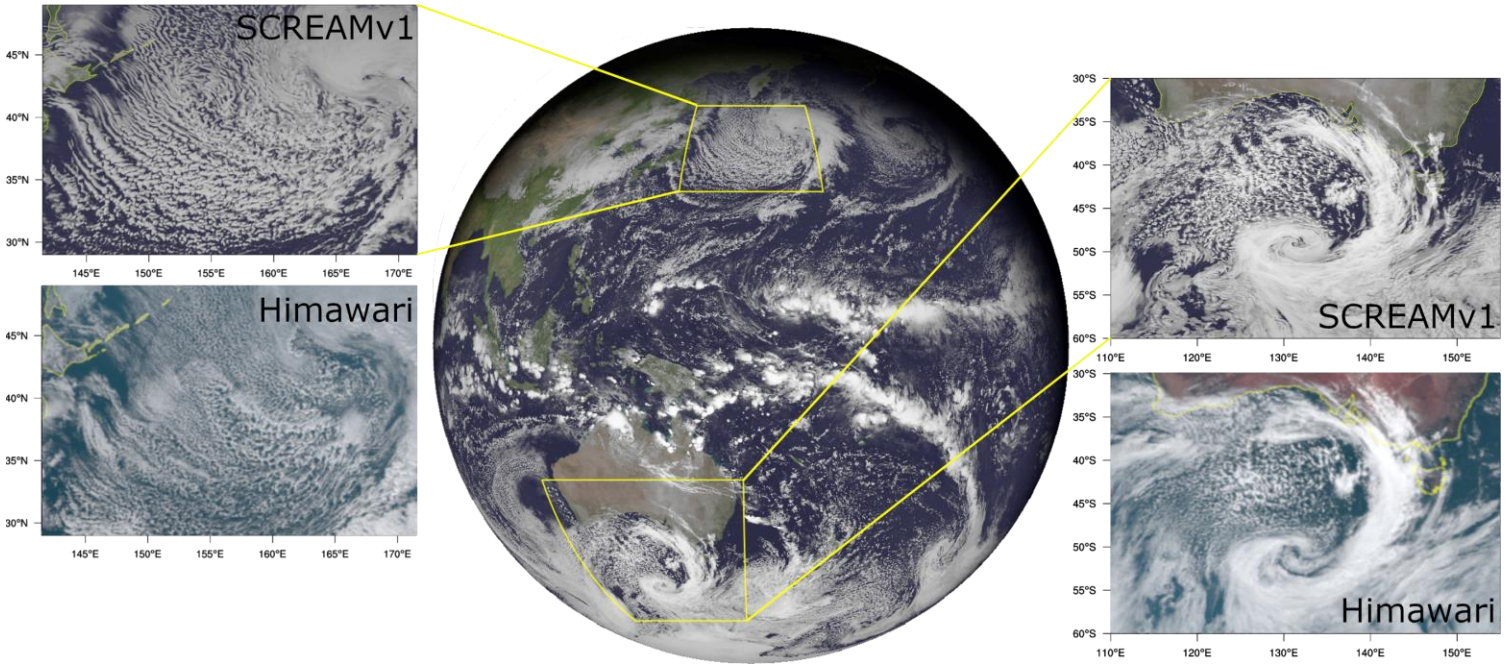
DOE's flagship climate model is the highest resolution prediction capability in the world and is the only model that includes details of infrastructures, urban systems, and economics

AI4ESP

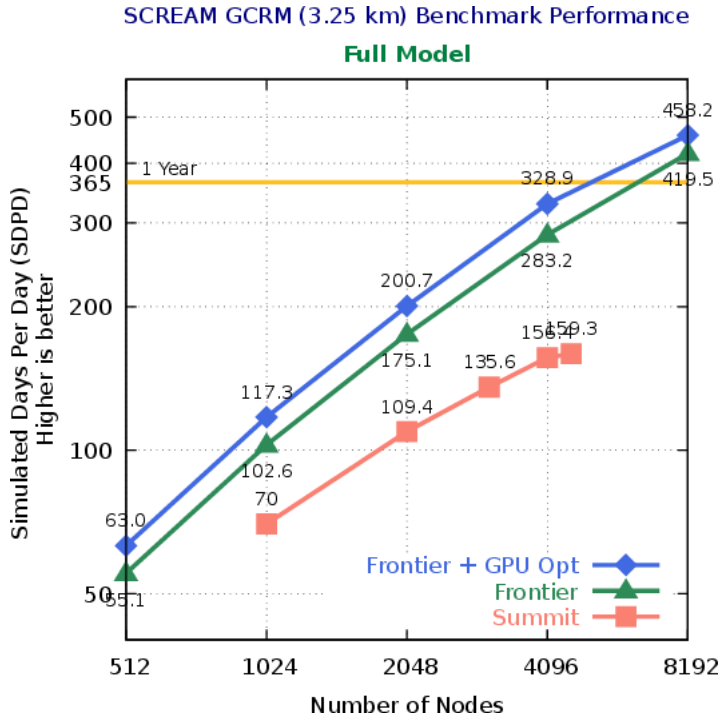
New in FY2023! Development of exascale-class models with machine learning to reduce uncertainties

Applications: The capabilities help address high priority climate challenges and contribute to the IPCC and the NCA

SCREAM: E3SM's Global Cloud Resolving Model



SCREAM DYAMOND simulation compared to shortwave cloud radiative flux compared to satellite image.



SCREAM 3.25 km Performance on DOE's Fronter and Summit

First GCRM to run on an Exascale computer, break the 1 SYPD barrier at cloud resolving resolutions, and run on both AMD and NVIDIA GPUs

Winner for the 2023 ACM Gordon Bell Prize in Climate Modeling

Taylor et al, The Simple Cloud-Resolving E3SM Atmosphere Model Running on the Frontier Exascale System, to appear, SC '23: Proceedings of the International Conference for High Performance Computing, Networking, Storage and Analysis, November 2023, 7, Pages 1–11, https://doi.org/10.1145/3581784.3627044.

Process Research in Earth and Environmental Sciences

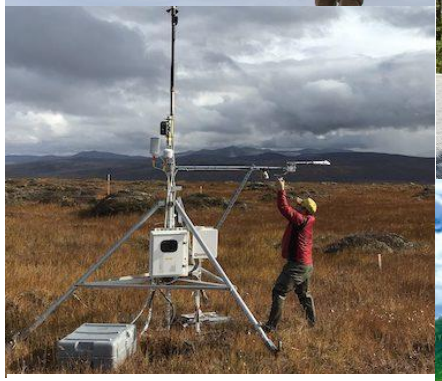
Advance basic understanding of ecosystems, watersheds, and the atmospheric system

Addressing:

- Biogeochemical and hydrological drivers of terrestrial environmental systems in sensitive geographies
- Integrated carbon, nitrogen, and water cycles in the terrestrial-atmosphere system
- Model-experiment integration as a research framework

Using research approaches:

- Large-scale, long-term field studies and manipulations (SPRUCE, NGEE-Arctic, NGEE-Tropics)
- Intensive campaigns, deployments, and synthesis activities (ARM GOAmazon, ARM MOSAiC, AmeriFlux Year of Methane)
- Observations (ARM, AmeriFlux network)
- Research in the context of addressing uncertainties, gaps, and needs, of process and Earth system models



SC Initiatives and Programs to Broaden Participation

RENEW
Reaching a New Energy Sciences Workforce

FAIR
Funding for Accelerated, Inclusive Research

EPSCoR
DOE Established Program to Stimulate Competitive Research that promotes geographically inclusive and equitable research

Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe and Secure American Bioeconomy

September 12, 2022


BRIEFING ROOM

Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy

SEPTEMBER 12, 2022 • PRESIDENTIAL ACTIONS

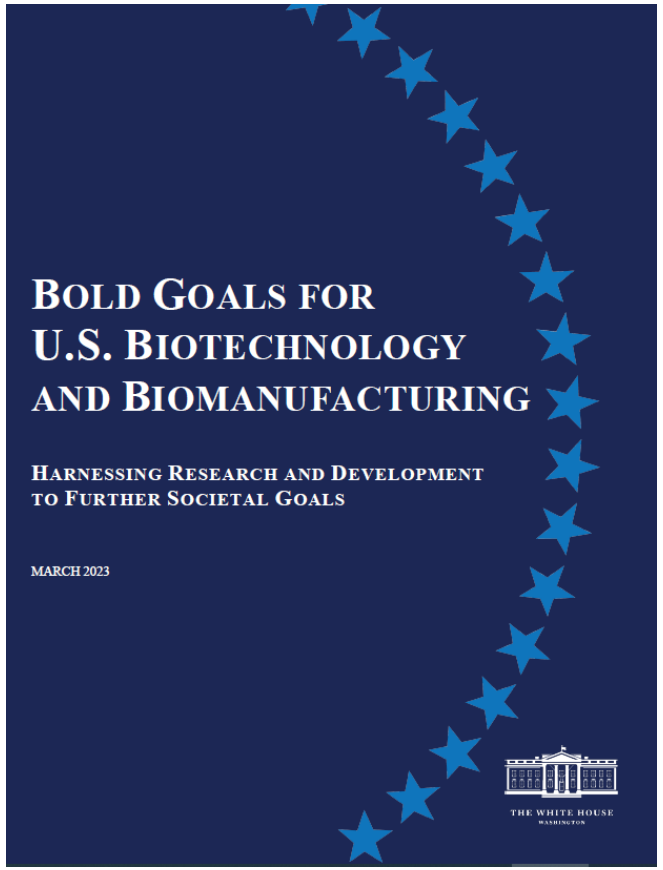
[Executive Order 9-12-2022]


MARCH 22, 2023

FACT SHEET: Biden-Harris Administration Announces New Bold Goals and Priorities to Advance American Biotechnology and Biomanufacturing

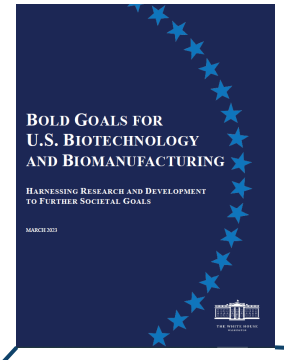
OSTP › NEWS & UPDATES › PRESS RELEASES

[March 22-2023 fact-sheet-biden-harris-administration-announces-new-bold-goals-and-priorities-to-advance-american-biotechnology-and-biomanufacturing/]



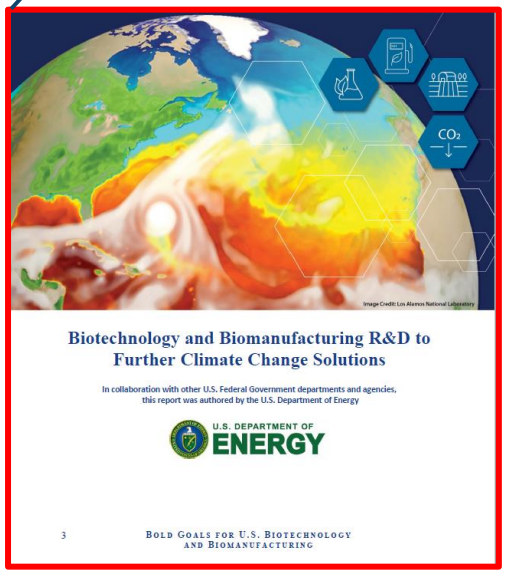
[Bold-Goals-for-U.S.-Biotechnology-and-Biomanufacturing-Harnessing-Research-and-Development-To-Further-Societal-Goals-FINAL.pdf]

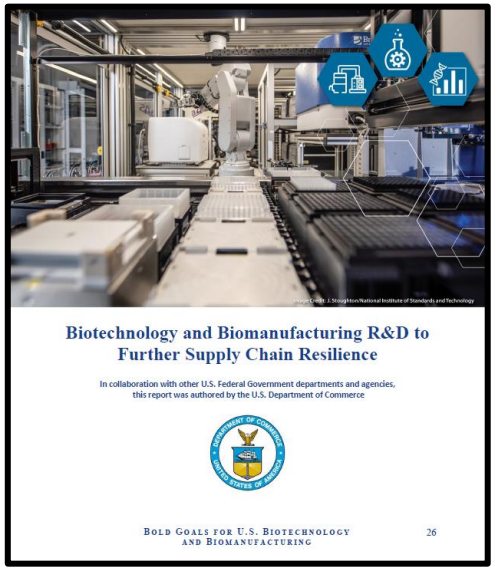
Executive Order acknowledges advances in biotechnology and seeks to establish US leadership in a very competitive global bioeconomy

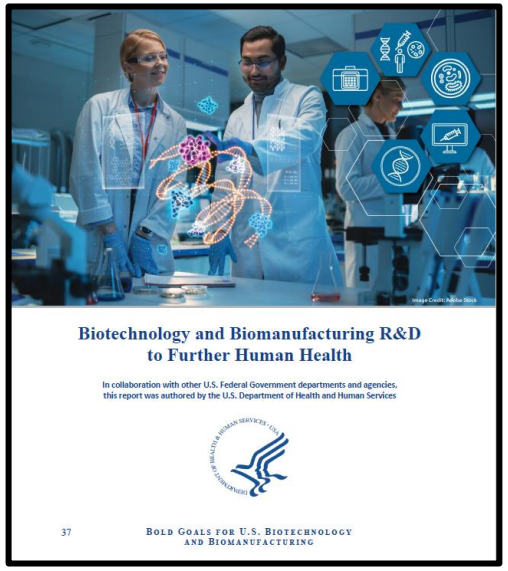


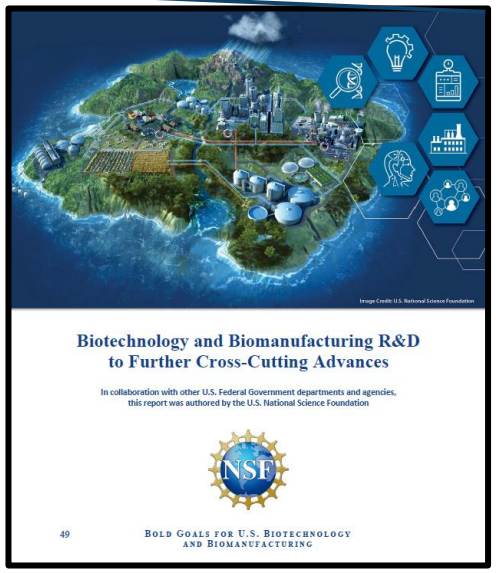
E.O. Reports: A Compilation of Five Reports Addressing:

Climate Change Solutions
Food and Agricultural Innovation
Supply Chain Resilience
Human Health
Cross-Cutting Advances









DOE led the Climate Change Solutions Report with SC-BER EERE-BETO, USDA


THANK YOU!

U.S. DEPARTMENT OF ENERGY | Office of Science

The nation's largest supporter of basic research in the physical sciences

Principal roles:

- Direct support of scientific research
- Direct support of the development, construction, and operation of unique, open-access scientific user facilities available for use by external researchers

U.S. DEPARTMENT OF ENERGY | Office of Science

Our Mission:

Deliver scientific discoveries and major scientific tools to transform our understanding of nature and advance the energy, economic, and national security of the United States.

More than **34,000 r**esearchers supported at more than **300** institutions and **17** DOE national laboratories

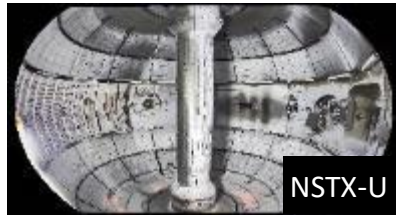
Steward **10** of the 17 DOE national laboratories

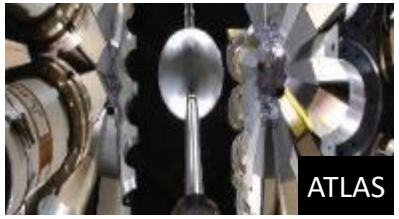
More than **37,000** users of **28** Office of Science scientific user facilities

$8.1B (FY 23 enacted)

Office of Science User Facilities

FY 2023
28 scientific
user facilities
>37,000 users





U.S. DEPARTMENT OF ENERGY
Office of Science

Office of Science and BER initiatives

Office of Science wide

- Advanced and Exascale computing
- Artificial Intelligence and Machine Learning
- Quantum Information Science
- SC Energy Earthshots
- Reaching a New Energy Sciences Workforce (RENEW)
- Funding to Accelerated, Inclusive Research (FAIR)
- Biopreparedness Research Virtual Environment (BRaVE)
- Advanced microelectronics
- Critical materials
- Accelerator Science and Technology
- Accelerate Innovations in Emerging Technologies (Accelerate)
- Fundamental Science to Transform Advanced Manufacturing

BER

- Urban Integrated Field Laboratory
- National Virtual Climate Laboratory (NVCL)
- Climate Resilience Centers

Examples of BER Collaborations with DOE Energy Technology Offices

Atmospheric Radiation Measurement (ARM) User Facility

- BER's ARM User Facility and modeling programs provide high resolution wind and turbulence data that informs the design and siting of wind energy systems. BER is assisting the EERE Wind Energy Technology Office (WETO) in strategic planning.

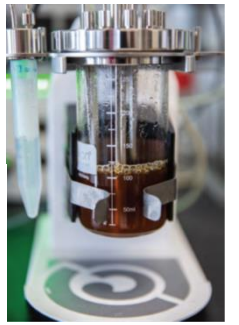
E3SM – Energy Exascale Earth System Model

- BER's Energy Exascale Earth System Model (E3SM) provides long term predictions of weather extremes to inform risk and resilience of the Nation's energy systems. BER is working with the Office of Electricity to provide an integrated capability that combines the North American Energy Resilience Model (NAERM) and E3SM for improved risk assessments.

- BER's JGI User Facility is working with the EERE Bioenergy Technology Office (BETO) to develop improved algal strains and for mid-scale fermentation capacity to support metabolomics and product characterization.

ABPDU
ADVANCED BIOFUELS AND BIOPRODUCTS PROCESS DEVELOPMENT UNIT

Agile BioFoundry



BER/EESSD Climate Initiative Components

- **Urban Integrated Field Laboratories**: Advance underpinning science of integrated natural-human urban systems to assure resilience to climate extremes using equitable solutions

- **National Virtual Climate Laboratory (NVCL):** A single portal to DOE national lab climate science capabilities, to advance access to climate science through public engagement on local to regional scale climate science. In future years this will serve as the lab partner portal for RENEW.

- **Network of Climate Resilience Centers:** Initiate first centers in a network of climate resiliency research that accelerates basic climate system science towards equitable solutions at the local scale

Enabling Capabilities and User Facilities

Joint Genome Institute (JGI)
Provides the global research community with access to the most advanced integrative genome science capabilities for advancing solutions to bioenergy & environmental grand challenges

National Microbiome Data Collaborative (NMDC)
Supports microbiome data exploration through a sustainable data discovery platform that promotes open science and shared-ownership across a broad and diverse community of researchers.

DOE Systems Biology Knowledgebase (KBase)
Empowers scientists via an open, FAIR biological data science platform to collaboratively drive discovery, for prediction, control and design of function in plants, microbes and their communities.

BER Structural Biology and Imaging Resources
Enables scientists to understand the relationships between plant and microbial genomes, protein structure and function, and environmental interactions using techniques available only at DOE User facilities.

Environmental Molecular Sciences Lab (EMSL)
Provides access to premier multimodal molecular science instruments, data analytics, production computing, and multiscale modeling to study biotic and abiotic process to under their function in a systems context.

*relevant to BSSD science

Data Archives, management, and analytics for EESSD

ESS-DIVE
Deep Insight for Earth Science Data

Repository for environmental system data involving watershed, ecosystem, and manipulation studies, hosted at LBNL

Earth System Grid Federation
ESGF

Repository of model-generated data from all climate and Earth system models worldwide, hosted by ORNL-ANL

ARM
CLIMATE RESEARCH FACILITY

ARM data archive contains 2 PB of in-situ and remote sensing observations, model simulations, and tools for rapid access, host ORNL-ANL

MSD-LIVE: a cloud-based Multi-sector dynamics data and code management system and computing platform, for climate-human interactions, hosted by PNNL