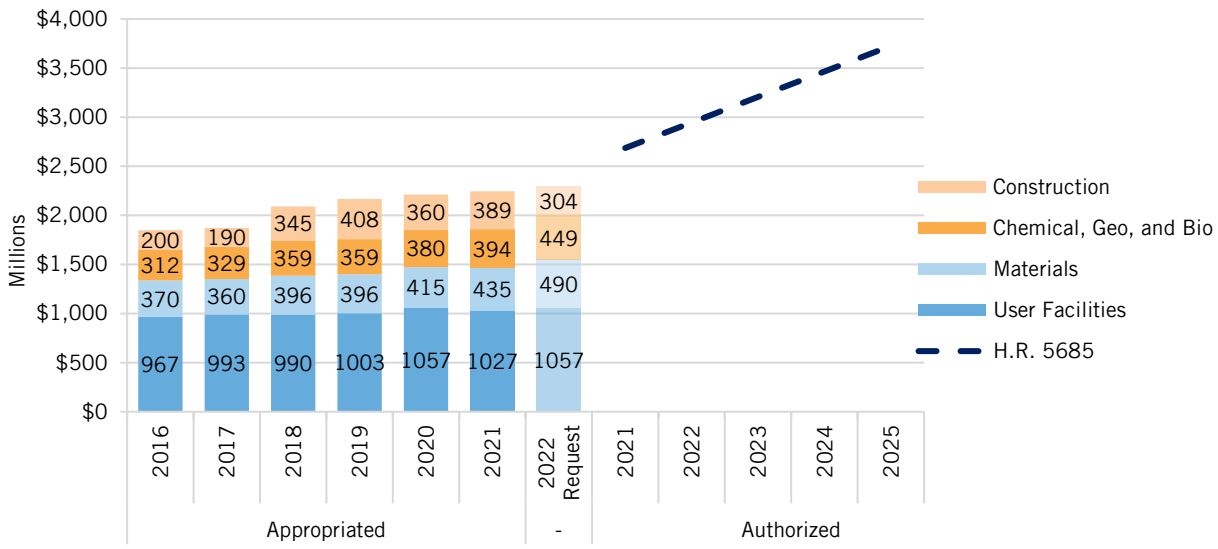
Federal Energy RD&D: Basic Energy Sciences

BY COLIN CUNLIFF AND LINH NGUYEN | JUNE 2021

The Department of Energy's (DOE) Office of Basic Energy Sciences (BES) supports fundamental research into understanding, predicting, and controlling matter and energy, thereby helping to build the foundation for new energy technologies. BES research—in condensed matter and materials physics, chemistry, geosciences, and aspects of biosciences—touches virtually every important facet of energy production, conversion, transmission, storage, and waste mitigation. BES also operates open-access scientific "user facilities" that enable researchers from private industry, national laboratories, and universities to use advanced instruments and tools that are too expensive for a single university lab or private company to own and operate.[1]

Figure 1: *Energizing America* recommends doubling funding for basic clean energy research in the Office of Science by FY 2026.[2]



What's at Stake

Fundamental scientific research across a range of fields—including advanced materials, electrochemistry, quantum computing, and advanced measurement and sensing—can enable breakthroughs in energy technologies. Better catalysts can lower the energy requirements for hydrogen and ammonia production. New solvents and membranes can make carbon capture—whether from power plants or directly from the atmosphere—cheaper and more efficient. New battery chemistries can improve the energy density and storage duration of batteries. On the international stage, Mission Innovation launched the Clean Energy Materials Innovation Challenge to integrate automated robotic laboratories with machine learning to identify new materials for batteries, solar cells, thermal storage, catalysts for conversion of captured carbon dioxide (CO_2), and other clean energy applications.[3] The innovation agenda for deep

decarbonization should embrace the entire innovation spectrum, including use-inspired basic energy research.

BES is fundamental to progress in clean energy technologies and comprises 25 percent of the energy research, development, and demonstration (RD&D) program budget. In 2018, the BES Advisory Committee produced a retrospective report, "A Remarkable Return on Investment in Fundamental Research," identifying some of the groundbreaking discoveries made as a result of BES funding, including the commercialization of new technologies that shape the way we produce and consume energy—years, and often decades, after the initial research was done.[4]

Basic research by DOE in subsurface fluid flow and high-strength materials in the early 1980s resulted in advancements in hydraulic fracturing and horizontal drilling that enabled the shale-gas boom of the mid-2000s that continues to reshape U.S. electricity markets.[5] The discovery of quantum dots—small semiconductor particles a few billionths of a meter wide that allow for conversion of blue light into other colors—were critical to the development of cheap, efficient light-emitting diodes (LEDs) that now account for 30 percent of all installed lighting.[6] The discovery in 1986 of high-temperature superconductors led to a burst of research at the Department of Defense (DOD), Department of Energy (DOE), National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), and National Institute of Standards and Technology (NIST), both in applications of superconductivity as well as basic science to explain the phenomena and develop new superconducting materials. Decades later, superconductors now have applications in offshore wind, electrical grid fail-safe devices, MRIs for medical imaging, and mobile communications towers.[7]

BES supports 46 Energy Frontier Research Centers (EFRCs), which are partnerships among universities, national laboratories, and industry that integrate the talents and insights of leading scientists and engineers to confront critical energy challenges across sectors. The EFRCs are organized around five "Transformational Opportunities" in basic energy sciences and span a diverse range of technologies—from molten salts for nuclear reactors to advanced catalysts for batteries.[8]

BES also houses two energy innovation hubs: the Joint Center for Artificial Photosynthesis (i.e., solar fuels hub) at the California Institute of Technology, which seeks to generate fuels directly from sunlight, CO_2, and water in a manner similar to natural photosynthesis; and the Joint Center for Energy Storage Research (i.e., batteries and energy storage hub) at Argonne National Laboratory, which researches nanoscale phenomena to develop next-generation, beyond-lithium-ion-energy storage systems.

Annually, BES's 12 user facilities provide nearly 16,000 industry, government, and academic researchers access to advanced research capabilities, including X-ray lasers, accelerators, neutron sources, and tools to probe matter on the nanoscale.[9] Many of these tools are too expensive for a single university lab or private company to own and operate. So instead, BES operates these large user facilities to enable academic and industry researchers to access those advanced tools. X-ray and neutron sources, in particular, are key tools for researching energy storage materials, advanced catalysts, and quantum processes and materials.

The National Academy of Sciences has called for a doubling of basic science research, including at BES, as a means of addressing challenges to U.S. competitiveness.[10] And House Republicans,

led by Rep. Frank Lucas (R-OK) put forward legislation in 2020 to double funding for BES to accelerate clean energy innovation over a ten-year period.[11]

Figure 1 shows historical DOE investment in BES RD&D by subprogram, for FY 2016 through FY 2021, and the FY 2022 budget request. The Energy Act of 2020 did not include reauthorizations of Office of Science programs. H.R. 5685, the Securing American Leadership in Science and Technology Act of 2020, put forth by House Republicans on the House Science, Space, and Technology Committee, included separate authorizations for Office of Science programs.[12] The bill included $2,686 million for FY 2021, $2,946 million for FY 2022, $3,206 million for FY 2023, $3,466 million for FY 2024, and $3,726 million for FY 2025 in funding authorizations for BES. However, the bill died in the 116th Congress and has not been reintroduced. Proposed funding for BES in H.R. 5685 is shown as a dashed blue line in figure 1.

Box 1: An Innovation Agenda for Basic Energy Sciences

The *Energizing America* report coauthored by the Information Technology and Innovation Foundation (ITIF) and Columbia University's Center on Global Energy Policy offers several recommendations to BES. Similarly, ITIF's report "An Innovation Agenda for Deep Decarbonization: Bridging Gaps in the Federal Energy RD&D Portfolio" provides recommendations to maximize the effectiveness of BES RD&D activities:

- Congress should provide full funding for the next generation of DOE user facilities, as well as planned upgrades at existing facilities. These facilities are critical to addressing basic research needs. DOE should evaluate whether the capacity of existing user facilities is sufficient to accommodate all research applications with scientific merit, and present a plan to Congress for building additional user facilities if warranted.[13]
- BES should identify and prioritize key crosscutting basic and use-inspired research programs that have multiple applications. For example, the International Energy Agency (IEA) has found that advances in electrochemistry could lead to dramatic cost declines and performance improvements in batteries, fuel cells, and electrolyzers due to synergies and spillovers between these technologies.[14]
- BES should double the number of EFRCs and organize them around key decarbonization challenges, particularly for hard-to-abate sectors such as heavy industry (steel, cement, and chemicals manufacturing), hard-to-electrify transportation sectors (aviation, shipping, and long-haul trucking), and negative emissions technologies.[15]
- DOE should take a leadership role in the Mission Innovation Clean Energy Materials Innovation Challenge, and establish a domestic automated materials discovery facility.

Basic Energy Sciences RD&D Activities

RD&D in basic energy is distributed across four subprograms:[16]

- **Materials Sciences and Engineering** supports research on materials synthesis, behavior, and performance for a wide range of energy-generation and end-use challenges, with a focus on the origin of macroscopic-material behaviors; their fundamental connections to atomic, molecular, and electronic structures; and their evolution as materials move from nanoscale building blocks to mesoscale systems.
- **Chemical Sciences, Geosciences, and Biosciences** supports research on chemical reactivity and energy conversion, which is the foundation for energy-relevant chemical processes—such as catalysis, synthesis, and light-induced chemical transformation—to achieve a fully predictive understanding of complex chemical, geochemical, and biochemical systems at the same level of detail as simple molecular systems.
- **Scientific User Facilities** supports the operation of 12 user facilities—5 light sources, 2 neutron-scattering facilities, and 5 nanoscale science research centers—that provide thousands of researchers from universities, industry, and government laboratories unique tools to advance a wide range of scientific research. These user facilities are operated on an open-access, competitive-merit review basis, enabling public and private researchers from every discipline to take advantage of the facilities' unique capabilities and instrumentation.
- **Construction** supports the development of new user facilities and upgrades to existing facilities, including the Linac Coherent Light Source-II, which will be the world's most powerful X-ray-free electron laser.

Key Elements of the FY 2022 Budget Proposal[17]

The budget proposal seeks $2.3 billion for BES RD&D activities, a 2.4 percent increase from FY 2021 enacted levels. Some highlights include:

- **A 13 percent increase in funding for Materials Sciences and Engineering.** Scattering and Instrumentation Science research would get a $11 million boost; Condensed Matter and Materials Physics research, $17 million; Materials Discovery, Design, and Synthesis, $16 million boost; and Energy Frontier Research Centers, $7 million.
- **Flat funding of $25 million for Established Program to Stimulate Competitive research (EPSCoR),** a program to advance research capabilities in states and territories with historically lower levels of federal research funding.
- **A 14 percent increase in funding for the Chemical Sciences, Geosciences and Biosciences subprogram.** Research in fundamental interactions would increase by $16 million, and photochemistry and biochemistry research by $24 million. Chemical transformation research would receive a $5 million boost.
- **A 6.8 percent cut to BES construction,** including reduced funding for upgrades at the Advanced Photon Source, the Spallation Neutron Source, and the Linac Coherent Light Source-II.

- **Flat funding for the Batteries and Energy Storage and the Fuels from Sunlight Energy Innovation Hubs.**

Further Reading

- Varun Sivaram et al., *Energizing America: A Roadmap to Launch a National Energy Innovation Mission* (ITIF and Columbia University SIPA Center on Global Energy Policy, 2020), http://www2.itif.org/2020-energizing-america.pdf.
- Colin Cunliff, "An Innovation Agenda for Deep Decarbonization: Bridging Gaps in the Federal Energy RD&D Portfolio" (ITIF, November 2018), http://www2.itif.org/2018-innovation-agenda-decarbonization.pdf.

Acknowledgments

The authors wish to thank David M. Hart for providing input to this report. Any errors or omissions are the authors' alone.

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ENDNOTES

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